THERMISTOR MEASUREMENT OF THE TEMPERATURE INCREASE DUE TO ABSORPTION OF DIAGNOSTIC ULTRASOUND

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Abstract: This article puts mind to metering a temperature's increases of a tissue due to absorption of a diagnostic ultrasound. As a metering method thermistors NR506 were used. Advantages and disadvantages of used metering method are discussed.

Introduction

During several decades, ultrasound has been used as a routine diagnostic and imaging modality in various clinical fields. Although its use has been generally considered as safe, there are still substantial concerns about possible bioeffects. There are three main types of bioeffect: cavitation, thermal heating and other mechanical interaction. One of the well-known effects of ultrasound is heating caused by ultrasonic absorption in tissues.

There has been a general trend towards increased output with the introduction of color flow imaging, more use of pulsed „spectral Doppler“ and higher demands on B-mode imaging. In response to these increases, recommendations for the safe use of ultrasound have been issued by several bodies. On the other hand, an overly conservative limitation of the output intensity of ultrasound devices may increase the risk of missing valuable diagnostic information. Therefore, there is a significant need for a reliable methodology to estimate the temperature increase induced by diagnostic ultrasound, so that its risk-free status can be maintained.

The absorption of ultrasound energy and self-heating of the probe causes heating in tissues. The tolerance of tissues to temperature elevation depends on the temperature rise and the type of tissue. The actual temperature rise will depend on the local specific heat capacity and time of exposure. It will also depend on the rate of temperature rise and distribution of heat in neighbouring tissues. Parameter of this case is known as the perfusion length [1], given by:

$$L = \sqrt{\frac{k}{\omega \cdot s_b}} \qquad (1)$$

where:
s_b is the specific heat capacity of blood,
k is the thermal conductivity of the tissue and
ω is the blood perfusion flow rate.

Thermal index (TI) is defined as the ratio of the total acoustic power to the acoustic power required to raise the tissue temperature 1 °C under determined assumptions. These assumptions include very simple beam shapes and tissue models [1]. The thermal index (TI) is intended to give a rough guide to the likely maximum temperature rise that might be produced after long exposure. Three forms of TI may be displayed, according to the application:

- TIS assumes that only soft tissue is insonated,
- TIB assumes bone is present at the depth where temporal intensity is greatest and
- TIC assumes bone is very close to the front face of the probe.

However, note that errors in calculating TI values, and the limitations of the simple models on which they are based, means that TI values can underestimate the temperature elevation by a factor of up to two.

As a direct measurement of the temperature distribution inside the human body is technically difficult and possibly unsafe, a measurements using biological models of a tissues becomes more suitable.

Bioeffects

The clinical effect of an exposure depends on the nature and degree of tissue injury. This can be assessed from biological effects studies. Several extensive reviews have been published regarding the adverse biological effects of ultrasonic heating based on animal studies, particularly in mammalian species [2]. With regard to adult tissues, the available literature suggests that tissue temperature elevations in the range of 8-10 °C, sustained for 1 to 2 minutes will cause tissue injury [3]. The reviews have also considered studies of teratogenic effects, usually on the developing brain, due to whole body heating of the embryo or fetus. The recommendations resulting from these reviews can be succinctly expressed as follows:

- a diagnostic ultrasound exposure that produces a maximum *in situ* temperature rise of no more than 1.5 °C above normal physiological levels

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(37 °C) may be used clinically without reservation on thermal grounds,

- a diagnostic ultrasound exposure that elevates embryonic and fetal *in situ* temperature above 41 °C (4 °C above normal temperature) for 5 minutes or more should be considered potentially hazardous,
- the risk of adverse effects is increased with the duration of exposure.

In addition, it has been reported that water immersion body heating of rats yielded the development of encephalocoeles in the rat fetuses in as little as 1 minute at a temperature elevation of 5 °C above normal physiological temperature [3].
For temperature elevations greater than 1.5 °C above normal physiological levels (37 °C), this information can be approximately matched to a functional form recommended by the NCRP. This yields an equation for combinations of temperature elevation and time which should be considered potentially hazardous:

$$t = 4^{5-\Delta T} \qquad (2)$$

where:
t is the time in minutes at the specified temperature and
ΔT is the temperature elevation above normal (37 °C).

Biological fantom

As a direct measurement of the temperature distribution inside the human body is technically difficult and possibly unsafe, a measurements using biological models of a tissues becomes more suitable.
Temperature changes were measured with biological fantom fabricated by Dansk Fantom service. Fantom's specification data are summarised in Table 1.

Table 1: Fantom's specification data

Phantom no: 738, Bone Phantom

```
Date: 2004 November 23. Time: 9:54 Slice thickness: 3.01 cm +/-0.01cm
Sampling frequency: 100.00 Ms/sec +/-0.01% Temperature: 21.8 degree Celsius
+/-0.1 degree C

Sound speed measurement
frequency sound speed  +/- 2* SD
 3.0 MHz 1541.2 m/sec +     /- m/sec
 4.0 MHz 1542.0 m/sec +     /- m/sec
 5.0 MHz 1542.0 m/sec +     /- m/sec
 6.0 MHz 1542.0 m/sec +     /- m/sec
 7.0 MHz 1542.8 m/sec +     /- m/sec
 8.0 MHz 1542.8 m/sec +     /- m/sec
 9.0 MHz 1542.8 m/sec + /-  0.3 m/sec
 10. MHz 1542.8 m/sec + /- 0.3 m/sec
 11. MHz 1542.8 m/sec +     /- m/sec
 12. MHz 1542.8 m/sec +     /- m/sec
 13. MHz 1542.8 m/sec +     /- m/sec
 14. MHz 1542.8 m/sec +     /- m/sec
Measured mean     velocit 1542.6 m/sec
Calculated velocity at 23 degree Celsius: 1546 m/sec

Measurement of attenuation:
Density: 1055.0 Kg/m3 Impedance:
1.627 * 10E6 Kg/m2*sec Calculated
reflection loss: -0.02 dB
Frequency  attenuation                    +/-2*SD
 3.0  MHz, 1.51 dB/cm,  0.51 dB/cm*MHz +/-0.03
 4.0  MHz, 2.04 dB/cm,  0.51 dB/cm*MHz +/-0.02
 5.0  MHz, 2.46 dB/cm,  0.49 dB/cm*MHz +/-0.02
 6.0  MHz, 2.97 dB/cm,  0.49 dB/cm*MHz +/-0.02
 7.0  MHz, 3.45 dB/cm,  0.49 dB/cm*MHz +/-0.01
 8.0  MHz, 3.99 dB/cm,  0.50 dB/cm*MHz +/-0.01
 9.0  MHz, 4.47 dB/cm,  0.50 dB/cm*MHz +/-0.01
 10.  MHz, 5.02 dB/cm,  0.50 dB/cm*MHz +/-0.01
 11.  MHz, 5.66 dB/cm,  0.52 dB/cm*MHz +/-0.01
 12.  MHz, 6.21 dB/cm,  0.52 dB/cm*MHz +/-0.01
 13.  MHz, 6.79 dB/cm,  0.52 dB/cm*MHz +/-0.01
 14.  MHz, 7.35 dB/cm,  0.52 dB/cm*MHz +/-0.01
```

The lay-out, photo and CT scan of the fantom are presented by figure 1, 2 and 3.

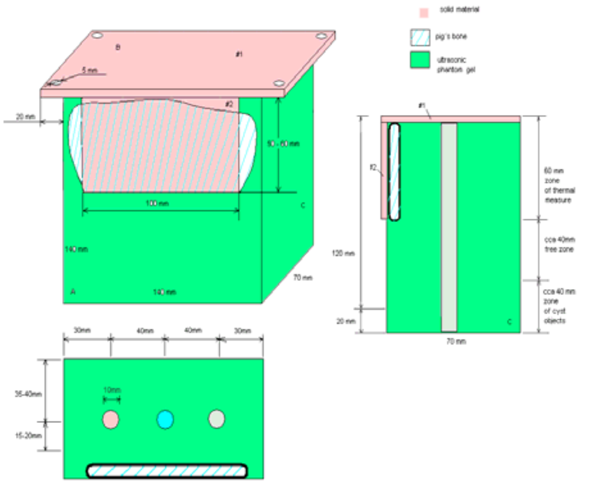

Figure 1: The lay-out of the fantom

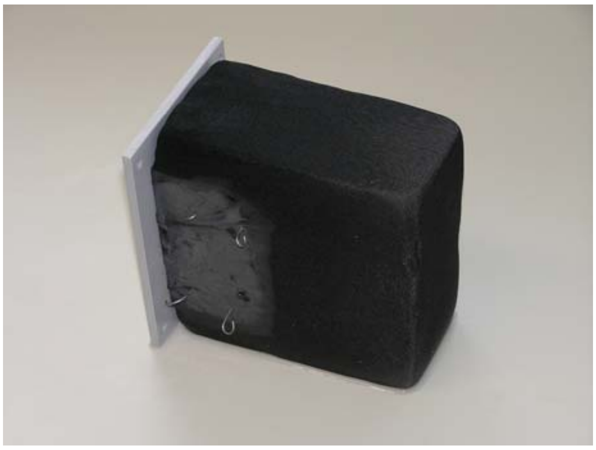

Figure 2: The picture of the real fantom

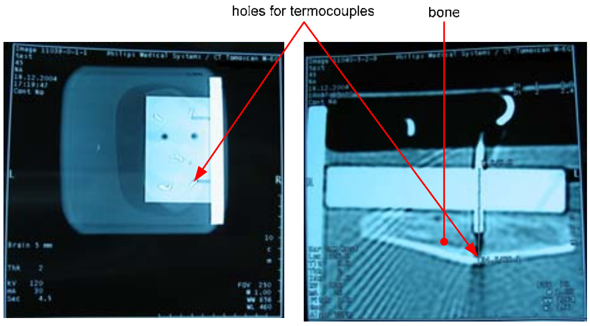

Figure 3: The CT scan of the real fantom

On the figures which are showed above, thera are visible drilled holes for the thermistors. Depht and hole diameter depend individually on dimensions of each thermistor and also depend on the placing depth of the bone which is situated inside of the fantom. Diameters of the holes range from 1.2mm to 2.1mm.

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Termocouples were situated 0,2 mm and 0,4mm under bone's surface and total number of measured points was 3.

Thermistors

Each thermistor was placed inside of a glass tube and fixed by epoxy resin. The final thermistor probe is presented by figure 4.

Figure 4: The thermistor probe

As a sensing element for evaluationing temperature increase, termocouples NR506 were used. R/T characteristics of the termocouples are illustrated by figure 5.

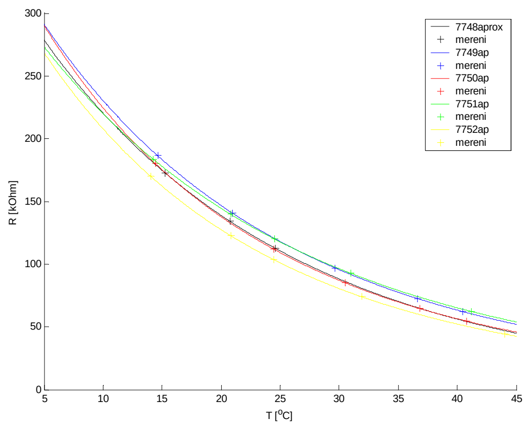

Figure 5: R/T characteristics of the termocouples

After calibration and linearization using Steinhart-Hart equation (see equation 3), termocouples were conected as illustrated by figure 6.

The Steinhart-Hart equation describes the resistance change of a semiconductor thermistor as related to its temperature. The equation is a 3rd-order log polynomial using three constants:

$$\frac{1}{T_k} = A + B \cdot (\ln R) + C \cdot (\ln R)^3 \qquad (3)$$

where:
A, B, C are constants determined through a calibration process,
R is the thermistor's resistance in Ohms and
T_k is the temperature in Kelvins.

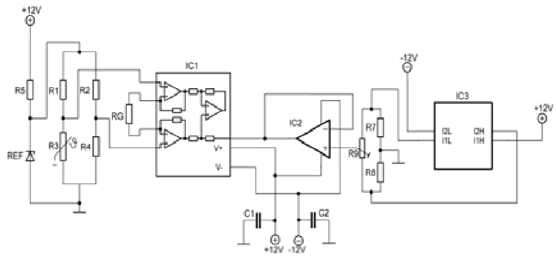

Figure 6: The scheme of a preamplifier

Output signal was measured by 34401A digital multimeter, 6.5 digit and measured values were transfered to PC for evaluation (figure 7).

Figure 7: 34401A digital multimeter

Ultrasound system

As a source of a ultrasound, SonoSite 180 Plus with microconvex broadband probe (C15/4-2) was used. Pulsed doppler was the operating mode of the ultrasound system. All measurements used water as a testing medium. Ultrasound system is presented by figure 8.

Figure 8: Ultrasound system

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Results

Total number of measured points was 3 and each point was measured 3 times. From these values arithmetics means were made. Result is ilustrated by figure 9.

During first 25 minutes fantom was be exposed to ultrasound energy from diagnostic system and after this time ultrasound system was be turn off. From measured values temperature increase of 0.4°C for first hole (0.2 mm under surface) and 0.15°C for second and third hole may be seen (0.4 mm under surface).

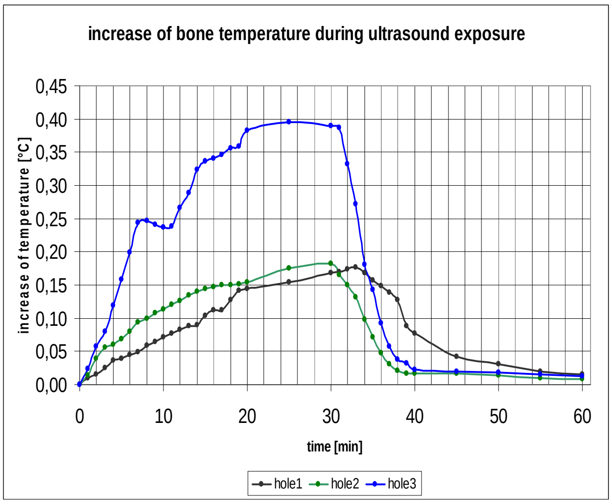

Figure 9: The measured values of a temperature changes during ultrasound exposure

There is a striking difference of a temperature increase between hole number 1 and two others. This difference is by reason of an unmatched thickness of the fantom's bone layer (see above).

Conclusions

Diagnostic ultrasound is safe but it seems logical to adopt a conservative approach giving the uncertainties in bioeffects data. The use of ultrasound for psychosocial or entertainment purposes should be discouraged, and like any other imaging examinations, there should be clinical indication for the examination. The benefit should outweigh any possible risks if there is a clear indication. In view of the wide margin of safety of diagnostic ultrasound, the benefit versus risk ratio is most favourable in comparison to other imaging modalities. All ultrasound examinations should be performed under the ALARA (as low as reasonably achievable) principle and all operators should be trained to operate their equipment accordingly.

References

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