Journal of Special Topics

P1_7 Foetal Ultrasound Imaging Safety in Early Pregnancy

Roisin Boadle, Emma Wigfield, Amanjit Singh Dulay

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

November 20, 2009

Abstract

This article discusses the temperature increase of foetal soft tissue due to diagnostic ultrasound scans taken during the early stages of pregnancy. It is found that for standard foetal ultrasound frequencies of 3MHz-5MHz, cell development in the foetal tissue is only affected after scans lasting 600-1000s. Transducer motion is considered and it is demonstrated that the time a small piece of foetal tissue will be exposed to ultrasound heating for would not be this high. Therefore, it is concluded that there is no significant danger to the foetus due to ultrasound heating.

Introduction

Ultrasound (US) is commonly used to image the unborn foetus. Pulsed sound waves are applied to the body and the reflection of these waves at density boundaries allows an image of the internal structure to be built up- useful in diagnostic medicine. Despite it being considered one of the safest imaging techniques by medical practitioners [1], there are multiple scare stories on the internet warning expectant mothers that the use of US, particularly during early pregnancy, may harm the foetus [2]. An increase in tissue temperature can cause damage to cells, thus this article assesses the temperature rise in foetal tissue due to US scans and determines whether or not there is any danger to the foetus from this.

General Theory and Model

An US transducer emits pulses with a maximum time averaged (over the duration of one pulse) intensity I_0. As the waves travel through the tissue they are subject to attenuation (the intensity decreases with distance) due to absorption and scattering effects. Thus, from Fig. 1, $I_0 > I_1 > I_2$, where I_1 and I_2 are the US intensities at the positions indicated in the figure. The absorption of the US wave's intensity transfers energy to the tissue resulting in a heating effect. In this model, it is assumed that scattering is negligible so all attenuation results in tissue heating, this maximises the temperature increase.

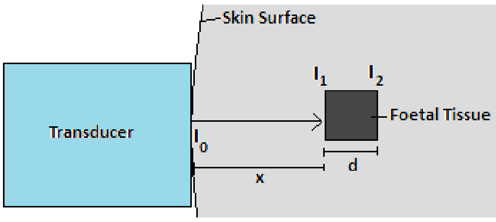


Fig 1. Model Setup

For US the rate of heating in the foetal soft tissue (Fig. 1) is given by, [3]

$$\frac{\Delta Q}{\Delta t} = 2\alpha d f I_1 \quad (1)$$

where ΔQ is the change in heat energy in the tissue (J), Δt is the scan time (s), α is the attenuation coefficient of tissue (dB/cm.MHz), d is the length shown in Fig. 1 (cm), f is the transducer frequency (MHz) and I_1 is the intensity of the wave (W/cm^2) at the position in Fig. 1. In order to relate the tissue heating to a temperature change, the change in heat energy (ΔQ in (1)) can be replaced by, [4]

$$\Delta Q = V C_{vol} \Delta T \quad (2)$$

where V is the volume of the foetal soft tissue being heated (cm^3), C_{vol} is the volumetric heat capacity of the tissue (J/cm^3.K) and ΔT is the temperature change. Substituting (2) into (1) gives

$$\Delta T = \frac{2\alpha d f I_1}{V C_{vol}} \Delta t \quad (3)$$

From the definition of a decibel (dB) [5] it can be shown that the intensity I_1 is

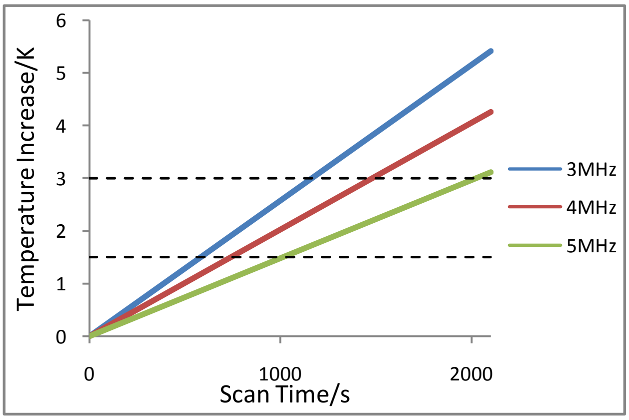
$$I_1 = I_0 10^{-\alpha f x / 10} \quad (4)$$

where I_0 is as previously defined, f is in MHz and x in cm. Substituting (4) into (3), the relationship between the temperature increase and the duration of the scan is

$$\Delta T = \frac{2\alpha d f I_0 10^{-\alpha f x/10}}{V C_{vol}} \Delta t \quad (5)$$

Foetal Tissue Results and Discussion

In foetal US scans, $I_o \approx 10 mW/cm^2$ and $3MHz < f < 5MHz$ [6]. During early pregnancy, US scans usually require the expectant mother to have a full bladder, giving an attenuation coefficient of α = 0.89 dB/cm.MHz and x = 2.6cm [3]. Graph 1 shows a plot of ΔT against Δt, using V=1cm^3, d=1cm and C_{vol} for tissue is approximated as 4.18 J/cm^3.K [3].



Graph 1: The increase in tissue temperature with scan time

Foetal soft tissue is more sensitive to temperature increases than most other tissues in the adult body. An increase of 1.5K can slow cell development and 3K can cause cell death [7]. Graph 1 indicates these temperatures with dashed lines. It is clear that a higher frequency increases the safe scan time, this is due to the frequency dependence of α: the intensity I_1 calculated using (4) is greater for lower frequency US waves than their higher frequency counterparts. However, even at 3MHz the scan does not start to affect the foetus until after 600s (10mins). The above calculations assumed that the transducer remains motionless throughout the scan. In reality it would be swept across the skin to reveal different views of the foetus. For example, assuming a slow sweep speed of ~2mm/s, the 1cm piece of tissue used here would only experience heating for 5s, increasing the temperature by 0.007K (5MHz)- 0.013K (3MHz). When focussing on one spot, hand shake and patient breathing or foetus movement would mean that the transducer remains in motion relative to the foetus, albeit at a slower speed. Thus, it is unlikely that a foetus would ever be subjected to entirely stationary scans lasting up to 600s.

This model is a worst case scenario as it has assumed that there is no heat dissipation within the foetal soft tissue; in reality, heat is lost from the tissue being heated into the surrounding tissues and blood stream. This dissipation would increase the safe scan duration by removing some of the heat transferred to the tissue by the US, decreasing the temperature rise. On the other hand, the tissue surrounding the foetus would be heated by absorption of the US energy; whether this temperature increase is enough to significantly change the safe scan times found here would require further study and discussion of the heat dissipation within this surrounding tissue.

Conclusion

The calculations in this paper show that for a perfectly stationary scan, the temperature rise in foetal tissue due to an US scan only starts to affect cell development for scans of between 600s (3MHz) and 1000s (5MHz). However, other considerations such as heat dissipation and transducer motion would act to decrease the temperature increase thus lengthening the safe scan time. In conclusion, this article finds that tissue heating due to US scans during early pregnancy is not significant enough to cause concern.

References

[1] http://www.ohioswallow.com/extras/ 0821417088_chapter_03.pdf p.52

[2] http://www.greenhealthwatch.com/news stories/newslatest/latest0701/ultrasound-hurt.html

[3] W.D O'Brien Jr, Progress in Biophysics and Molecular Biology **93** 2007 pp.212-255

[4] http://www.ac.wwu.edu/~vawter/Physics Net/Topics/Thermal/HeatCapacities.html

[5] http://www.phys.unsw.edu.au/jw/dB.html

[6] C Sohn, H-J Voigt, K Vetter, *Doppler ultrasound in gynaecology and obstetrics*, George Thieme Verlag (2004) pp.21-22

[7] H. Laburn, A. Faurie, D. Mitchell, J Therm Biol **28** 2003 pp. 107-116