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MEASUREMENT OF Ispta AND Isppa FROM REAL-TIME SCANNING MACHINES.

K.Martin

Medical Physics Dept. Newcastle General Hospital

INTRODUCTION

In assessing the likelihood of risk to patients from exposure to diagnostic ultrasound, it is necessary to make measurements of acoustic output parameters of scanning machines. Two relevant parameters to measure are the spatial peak pulse average intensity(Isppa) and the spatial peak temporal average intensity(Ispta).

The AIUM/NEMA standard [1] defines pulse average intensity as the pulse intensity integral divided by the pulse duration. Here, pulse duration is defined as 1.25 times the time interval between the points on the pulse waveform where the intensity integral has reached 0.1 and 0.9 of the total value. The AIUM/NEMA standard requires the maximum value of the pulse average intensity.

The spatial peak temporal average intensity is the maximum temporal average intensity anywhere in the acoustic field. If a small element hydrophone is placed in a stationary ultrasonic beam (e.g. from a B scan transducer or a real time probe in M-mode), it will generate the same pulse waveform on each pulse echo cycle. The spatial peak temporal average intensity is simply the time average of the largest pulse and both Ispta and Isppa will be measured near the focus of the beam.

A small element hydrophone placed in the acoustic field of a real time scanning machine receives a sequence of ultrasonic pulses of various amplitudes during each complete scan. The largest pulse amplitude is received as the beam axis crosses the hydrophone position. The maximum value of Isppa is the value for the largest pulse in the sequence at its spatial peak and is again located near the beam focus. The number of significant pulses in the sequence received by the hydrophone in the real time acoustic field depends upon the pulse repetition frequency, scan rate and the beam width. At the focal depth, where the beam width is a minimum, a relatively small number of high intensity pulses is received as the beam sweeps past the hydrophone. At other depths, where the beam width is greater, a larger number of lower intensity pulses is received often resulting in higher temoral average intensities than that at the focus.

Some examples of measurements of pulse average intensity(Ipa) and temporal average intensity(Ita) on real time scanning systems are shown, demonstrating that such differences in the locations of Isppa and Ispta are common.

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MEASUREMENT TECHNIQUES

The equipment and measurement techniques used have been described in detail elsewhere [2]. A PVDF bilaminar membrane hydrophone with 1mm active element was used to obtain the ultrasonic pulse waveforms. Ipa was measured by photographing the pulse waveform and digitizing using a graphics tablet and microcomputer. The value of Ipa was then calculated by the microcomputer.

Values of Ita were obtained by amplifying the hydrophone signal and applying it to an r.f.power meter with a thermocouple sensor which measures the time averaged electrical power in the waveform. The power is proportional to the temporal average acoustic intensity at the hydrophone. In all intensity calculations, it is assumed that the plane wave approximation holds and that intensity is proportional to the square of the excess acoustic pressure.

THE SINGLE ELEMENT TRANSDUCER

As described above, a hydrophone placed in a stationary ultrasonic beam receives the same pulse waveform on each pulse echo cycle and Isppa and Ispta are both located at the same point near the focus. Figure 1. shows a graph of Ipa and Ita against distance from the transducer for a single element transducer. Both parameters reach a maximum at approximately 7.5cm. Ipa is lower in proportion to Ita near the transducer owing to the increased pulse length in this region (Ipa = pulse intensity integral/ pulse length).

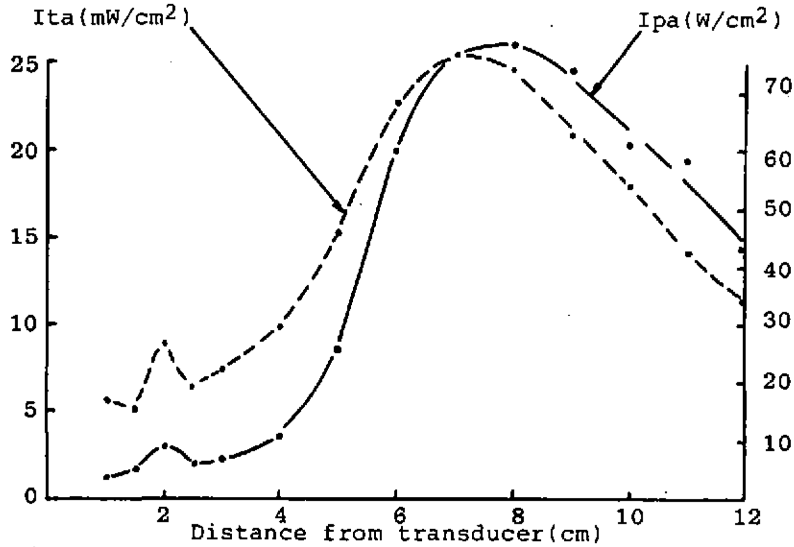

Figure 1. Ita and Ipa vs. distance from a single element transducer.

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LINEAR ARRAY

Figure 2. shows an example of Ipa and Ita plotted against distance from the probe for a linear array (Hitachi EUB24F). Ipa is a maximum at 6cm showing that the beam is focussed at this depth but the maximum temporal average intensity is measured at 2.5cm from the probe

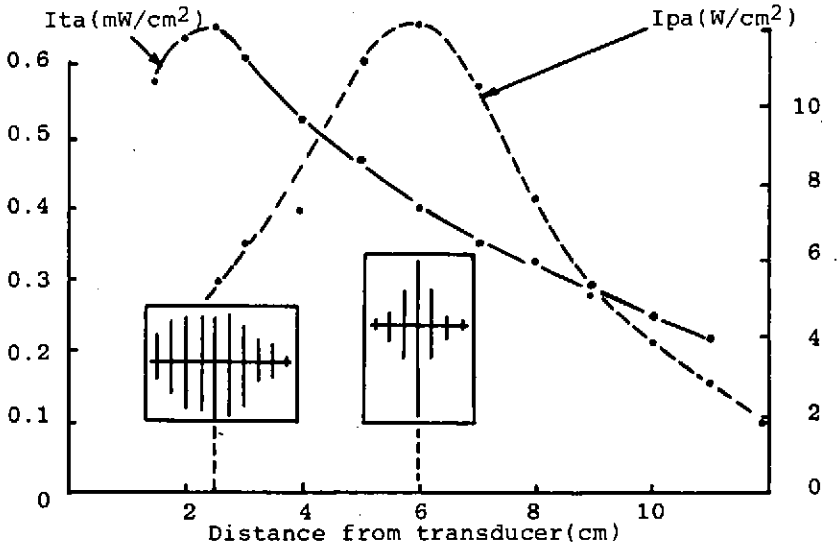

Figure 2. Ita and Ipa vs. distance from a linear array transducer

The sequence of pulses received on successive pulse echo cycles as the beam sweeps past the hydrophone is also illustrated in figure 2 for depths of 2.5cm and 6cm. At 6cm, few pulses are received as the focal zone passes the hydrophone but this sequence contains the pulse which yields the maximum pulse average intensity. This particular pulse will make a large contribution to the temporal average intensity at this point (the intensity is derived from the square of this voltage waveform). At 2.5cm, pulse average intensities are lower than Isppa but as the beam is wider, a larger number of pulses is received. These combine to give a temporal average intensity which exceeds the value at 6cm.

This arrangement of the locations of Ispta and Isppa does not occur in all linear array systems. The location of Ispta is dependent on the electronic aperture and focussing characteristics of the beam in the scan plane and the mechanical aperture and focussing provided across the scan plane.

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MECHANICAL SECTOR SCANNER

Figure 3 is an example of Ita and Ipa plotted against distance from the probe for a mechanical sector scanner. The probe contains a 2.25MHz, 19mm diameter transducer with a fixed focus at 11cm. As expected, Isppa is located at a depth corresponding approximately to the focal distance of the transducer. Ita shows no large variations in magnitude in the first 10cm of the field. The number of pulses received per scan at 2cm is much greater than the number received at the focal depth.

In the case of a sector scanning system, it is more likely that Ispta will be located closer to the probe than in the linear array. As well as the beam width effects discussed in the previous section, the line density in sector scanning systems increases as the probe is approached. Also, due to the finite diameter of the transducer, points very close to the probe may receive exposure on every pulse echo cycle in the complete sector scan resulting in a large temporal average intensity. Figure 3 suggests that in the case illustrated, Ita continues to increase towards the probe beyond the range of measurements. In this region however, the plane wave approximation may not be valid and such calculations of intensity are less reliable.

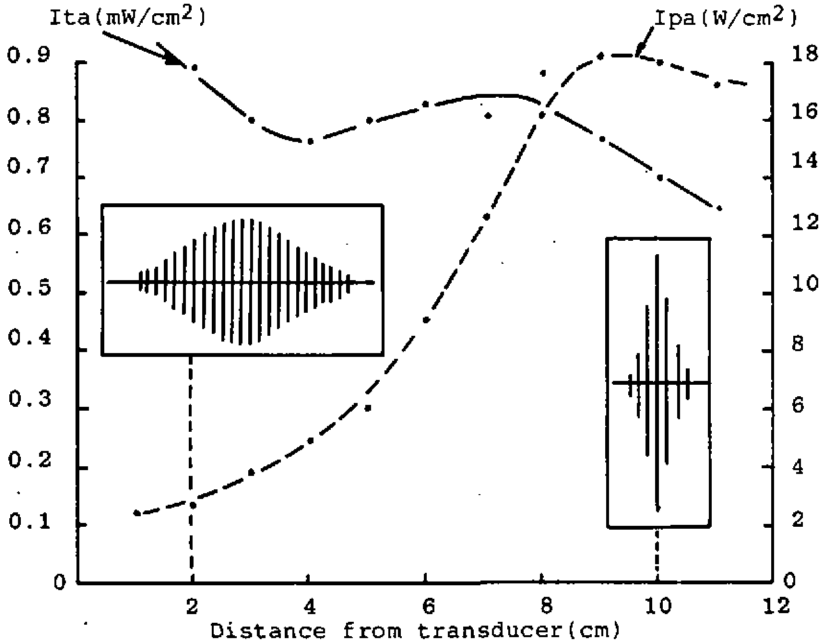

Figure 3. Ita and Ipa vs. distance from a mechanical sector scanner transducer

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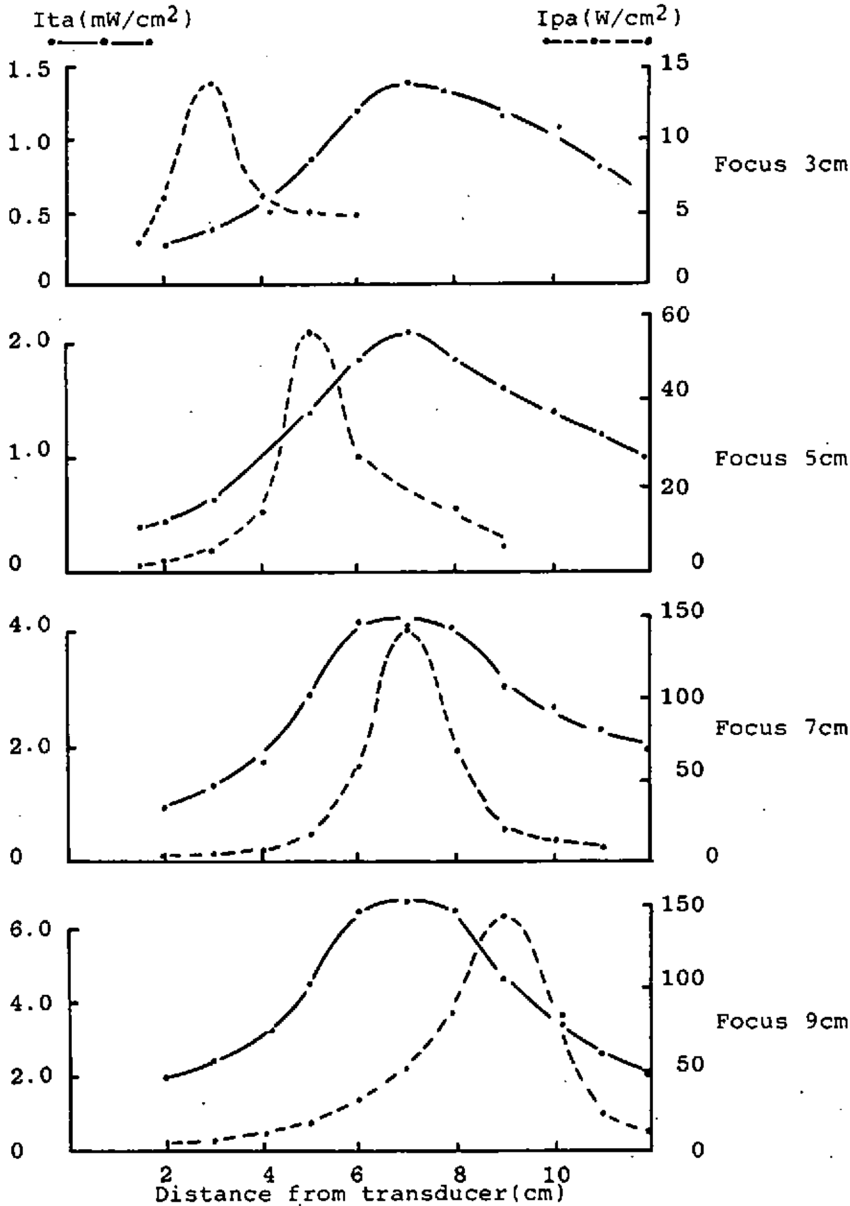

Figure 4. Ita and Ipa vs. distance from a variable focus array.

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VARIABLE TRANSMIT FOCUS ARRAY

Figure 4 shows the variations of Ita and Ipa with distance from the transducer for a linear array with variable electronic focussing on transmit. Four sets of measurements are pesented with the focussing set to depths ranging from 3cm to 9cm.

The two most prominent features of these graphs are firstly that the location of Isppa follows the focal depth very closely and secondly that the relative variation of Ita with distance from the transducer is very similar for all four focal depths, Ispta occurring at a depth of approximately 7cm in each case.

The changes in the magnitude of Ispta and Isppa with focal depth are also of interest. Ispta increases with focal depth over the range investigated whereas Isppa increases with focal depth to a maximum at 7cm and 9cm. It is likely that this parameter decreases at greater focal depths.

Such a variation in the magnitude of Ispta with focal depth is expected from the changes in the aperture used. When the focus is set to 3cm, the aperture is relatively small. To achieve effective focussing at 7cm and 9cm, the aperture must be increased. If the level of transducer excitation is maintained, this results in increased transmitted power. Indeed, in clinical use, if the depth of interest is 9cm rather than 3cm then increased transmitted power is desirable to compensate for the extra attenuation in the intervening tissue. In variable focus systems, the maximum Ispta is typically achieved with the focus set to maximum depth.

CONCLUSIONS

It is clear from the measurements presented here that in real time systems Ispta and Isppa are commonly located at different distances from the transducer. If temporal average intensity is calculated on the assumption that the spatial peak is located at the point of maximum acoustic pressure, then a significant underestimate of Ispta may be obtained.

In assessing the possibility of risk to the patient from exposure to diagnostic ultrasound it is necessary to estimate, from measurements made in water, the intensity levels which might exist in human tissue. Normally, spatial peak pulse average intensities will be reduced by attenuation in tissue between the transducer and the beam focus. This may not be true for temporal average intensities however, particularly in the case of mechanical sector scanners where Ispta is likely to be located very close to the transducer. Here the value of Ispta which is produced in tissue could be very similar to the value measured in water.

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REFERENCES

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[2] K.Martin, "Portable equipment and techniques for measurement of ultrasonic power and intensity." To be published in Proceedings of IPSM meeting "Physics in Medical Ultrasound", Durham University, 1985, IPSM conference report series.