- peak positive and peak negative acoustic pressure (p^+ and p^-)
- location of both of the peak acoustic pressures
- spatial-peak temporal-average derived intensity at the location of p^+
- acoustic pulse waveform at location of p^+
- beam widths parallel and perpendicular to the scan plane (if appropriate) at location of p^+
- nominal frequency
- ultrasonic transducer dimensions
- any control that adjusts the output power should be labelled and have a known accuracy
- pulse repetition frequency

(b) In addition, for Doppler and physiotherapy transducers:

- spatial-average temporal-average derived intensity
- total ultrasonic power

Various topics were discussed during the meeting but the main ones were 1) the relevance of various acoustic parameters to actual or conceivable bioeffects; 2) acoustical parameters that may be readily measured and specified; 3) possible implications of nonlinear propagation of ultrasound; 4) acoustical parameters for acoustic output labelling; and 5) reporting of acoustic output information in scientific publications. The group felt that there is a need for further work in at least the following two aspects of bioeffects of ultrasound: development of standard models to predict the initial rate of rise of temperature and the final temperature rise for different clinical applications of ultrasound, and establishment of new studies to determine cavitation thresholds *in vivo* for diagnostic ultrasound (i.e. high amplitude pulses with μs durations).

Meeting Delegates:

C. R. Hill (Chairman), D. R. Bacon, H. Boch, R. Blackwell, G. Cusick, F. A. Duck, G. R. ter Haar, H. Halliwell, J. H. Herbertz, S. Leeman, W. L. Nyborg, R. C. Preston, A. P. Sarvazyan, H. L. Stewart, T. A. Whittingham, A. R. Williams, J. Zagzebski

DISCUSSION

Discussion centered around the relevance of measuring p^+ or p^- and their relationship. In the absence of hard data as to which parameter is biologically more relevant (e.g. it could be argued that p^- related to the onset of cavitation and may be more appropriate), it was suggested that the value measured at p^+ be used as it was generally larger. Modern equipment with high output levels produces nonlinear effects which pose standardisation problems which need to be resolved to account for the different values obtained in water and tissue. Other complications which need to be addressed are the differences in the spatial position of p^+ and p^- and the variation of intensity integral with output (Duck and Staritt, 1985).

DOSAGE SPECIFICATIONS FOR ULTRASOUND EQUIPMENT

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Various types of dosage parameters have been suggested as relevant to certain types of biological effects. For example, the absorbed dose per unit volume and I^2t, where I is some form of intensity and t is the exposure duration, have been suggested as potentially important to the development of a dose concept for ultrasound. Yet, different mechanisms may suggest different dosage parameters. Given that an appropriate ultrasonic dosage parameter has not been identified and that the dosage will vary from patient to patient, with the same equipment, it makes sense at this time to specify only equipment output parameters. A set of output parameters should be specified which is complete enough to allow calculation of dose parameters that may be developed.

It has been common practice to discuss output levels in terms of intensity but there are individuals and groups that would prefer to specify acoustic pressure output. Arguments can be made for the appropriateness of each. It is clear that, independent of the parameter used, the output must be specified not only on a time averaged basis, but during the pulses. In addition to output parameters currently required by the AIUM Commendation Panel and the AIUM/NEMA Standard, the absolute acoustic pressure waveform should be made available for pulsed systems. More

study is necessary to determine if this should be measured at one or more locations, e.g. at the location of the peak positive pressure or at the location of the peak negative pressure if these are not the same. It is also clear that any attempt to calculate a dose in particular situations requires a knowledge of the time of exposure. The duration of exposure to any portion of the fetus, however, will always be impossible to accurately determine. Nevertheless, a passive equipment timer which is automatically activated when the transducer is active might provide a better estimate of exposure than is currently available.

Another serious problem associated with the determination of the output levels of diagnostic equipment is the difference in the nonlinear distortion of the waveform in tissues as opposed to water. The waveform measured in water will be severely distorted relative to the waveform in most solid tissues. It seems that new calibration procedures are desirable to yield a waveform which more closely represents that pertaining within the patient.

An increasing number of manufacturers are making output data available on a voluntary basis. It would appear that these data are of sufficient importance that all manufacturers should make their data available in a standard format, such as that used by the AIUM Manfacturer Commendation Panel.

It appears premature on the basis of our present understanding of the biological effects of ultrasound, to limit maximum equipment output levels.

SUMMARY

A dose has not been defined for pulsed ultrasound. I^2t should be investigated further as one possible dose parameter.

Exposure parameters can be determined. A complete set of equipment output parameters should be specified to allow calculation of dose parameters that may be developed.

In addition to output parameters currently required by the AIUM Commendation Panel and the AIUM/NEMA Standard, the absolute acoustic pressure waveform should be made available for pulsed systems. More study is necessary to determine if this should be measured at one or more locations, e.g. at the location of the peak positive pressure or at the location of the peak negative pressure if these are not the same.

On the basis of our present understanding of the biological effects of ultrasound it is not appropriate to limit maximum output levels.

DISCUSSION

Note was taken that in recent years the SPTP intensity of diagnostic equipment has increased from 30 W/cm^2 to over 1500 W/cm^2 due to more efficient transducers and the trend towards operating at higher frequencies with the consequent stronger focussing beams (Stewart *et al.*, 1985). This increase in exposure should be monitored although it was considered that nonlinearity may shortly limit such further increases. It was noted that the high output levels of the latest pulsed Doppler equipment could cause measurable temperature elevation.

Biological effects are more likely to occur at the spatial position where high acoustic pressures are present. Care is necessary to take into account the scanning motion in diagnostic examinations and emphasis should be placed on measuring single point exposure during the irradiation as well as total body exposure which is given by the total amount of energy used to undertake the ultrasonic examination. This will allow closer correlation with experimental studies in which the transducer is usually fixed in relation to the tissue target.

REFERENCES

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Stewart H. F., Leo F. P., Harris G. R. *et al.* (1985) Measurement of exposure levels from diagnostic ultrasound equipment in clinical use. Proc. 4th WFUMB Meeting. *Ultrasound in Med. & Biol.* (Suppl. 1), 478.