Tissue Substitutes, Phantoms and Computational Modelling in Medical Ultrasound

ICRU Report 61 - A New Publication

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As part of its on-going initiative to stimulate the improvement and development of tissue substitutes, phantoms and computational modelling in medical practice, the International Commission on Radiation Units and Measurements has just published a new Report devoted to this specialty in medical ultrasound [1]. A discussion of the Report by Fairhead appeared in the June, 1998 issue of ICRU NEWS [2].

The Commission Sponsors were I. Isherwood, J. R. Mallard and A. Wambersie. The Report Committee comprised D. R. White, (chairman), F. A. Duck, A. C. Fairhead, L. N. Rothenberg, A. Shaw, J. A. Zagzebski and M. Zankl. A. J. Coleman and R. V. Griffith were consultants to the Committee.

The Report reviews the use of tissue substitutes, phantoms and computational body models representing human tissues in medical ultrasound. Specifications are given of those quantities that are considered important to the maintenance and development of reliable physical measurements. Although tissue substitutes, phantoms and body models are used for investigating all applications of medical ultrasound, only those used to assess image quality, Doppler-equipment performance and temperature rise are considered in the Report.

No attempt has been made to include every tissue substitute, phantom or body model used in medical ultrasound. Those selected for inclusion are representative of those in common and restricted use.

It is important to note that the inclusion in the Report of a phantom or tissue substitute available commercially does not in any way constitute an endorsement of that product.

The text is divided into five parts. Part One (content shown below) provides background material. In the first Section, the scope of the Report is discussed, together with an outline of the applications of medical ultrasound.

Section 2 presents definitions and specifications for acoustic and thermal quantities. For example, any material used to simulate a particular body tissue with respect to a set of physical characteristics is called a tissue substitute [ICRU Reports 44 (ICRU, 1989) and 48 (ICRU, 1992)] [3, 4]. Physical quantities such as speed of sound, acoustic impedance...
and attenuation coefficient are usually considered in medical ultrasound. If the thermal properties of the tissue substitute are important, then thermal conductivity, thermal diffusivity and specific heat capacity may need to be considered. A phantom is a structure that contains one or more regions of tissue substitute.

Section 3 briefly discusses the physical aspects of the propagation of ultrasound in body tissue.

Section 4 covers the relevant physical properties of both healthy and abnormal body tissues. Twelve body tissues and two average soft tissues have been selected for inclusion in the Report: Body tissues - adipose tissue, blood (whole), brain, breast, cortical bone, eye-lens, eye-vitreous, kidney, liver, muscle-cardiac, muscle-skeletal, skin. Average compositions - average soft tissue (non-fatty), average soft tissue (fatty).

For purposes of standardisation and intercomparison, there are many cases when it would be beneficial to have a set of internationally recognized, ultrasound-related physical characteristics for different types of body tissue. These would act as 'standard' values and could be the first step on the way to an Ultrasound Reference Man. Such a 'standard' set does not exist and it is beyond the scope of the Report to propose one. However, acoustic and thermal physical data are presented which appear to be 'representative' of ten different types of body tissue.

Part Two is devoted to tissue substitutes. The major part of Section 5 deals with the ultrasound-related requirements for tissue substitutes, considering materials for imaging, Doppler flow and thermal measurements. A short discussion on other requirements, such as, homogeneity, stability, toxicity and machining properties is also included. An historical review of tissue substitutes, together with the acoustic and thermal properties of some commonly used materials, concludes this part.

Phantoms are considered in Part Three. Section 7 discusses ultrasound-related requirements for imaging phantoms, Doppler phantoms and thermal phantoms. Other requirements, such as, homogeneity, stability mechanical properties, thermal properties and safety, are also identified. Section 8 gives details of phantoms used in diagnostic and therapeutic procedures.

Part Four (Section 9) is devoted to computational modelling. The discussion outlines the theoretical aspects of the ultrasonic field, body models, propagation models and modelling of biophysical effects. Particular emphasis is given to thermal predictions.

A summary, together with recommendations for tissue substitutes, phantoms and computational modelling is given in Part Five.

The Report ends with six Appendices (below). Acoustic and thermal properties of twelve body tissues and sixteen tissue substitutes are tabulated in Appendix A. The physical quantities given are as follows: Acoustic properties - speed of sound, temperature coefficient of speed of sound, mass density, characteristic acoustic impedance, amplitude
attenuation coefficient, amplitude absorption coefficient, backscattering coefficient, non-linearity coefficient. Thermal properties - specific heat capacity, thermal conductivity, thermal diffusivity.

Appendices B and C give specifications of 43 selected phantoms and nine body models. Four representative specification sheets from the Report are reproduced at the end of this paper.

Some basic formulae used in computational modelling of thermal heating are tabulated in Appendix D.

Appendix E outlines production methods for water-based gel tissue substitutes and phantoms.

Appendix F presents a glossary of 36 principal terms used in the Report.

Appendix G is a short Bibliography (Acoustic Theory) of 25 publications on *The Ultrasound Field (Linear and Non-linear)* and 11 publications on *Cavitation Modelling*.

Some 280 cited references are listed in the Report.

ICRU Report 61 is aimed at those clinicians, scientists, engineers and other professional groups that use, support and develop medical ultrasound techniques. These techniques are now used very widely throughout healthcare. At one extreme, simple scanning methods are employed increasingly in primary healthcare, while at the other extreme complex systems are used in specialist areas, such as cardiology and vascular surgery.

The publication is a continuation of a series of Reports dealing with tissue substitutes and phantoms. A following Report will deal with phantoms in MRI.

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