1984, *The British Journal of Radiology*, *57*, 257–258 MARCH 1984

Technical notes

Linear thermocouple arrays for *in vivo* observation of ultrasonic hyperthermia fields

By G. R. ter Haar and F. Dunn*

Physics Department, Institute of Cancer Research, Sutton, Surrey SM2 5PX

(*Received July 1983 and in revised form October 1983*)

Interest in localised hyperthermia for cancer therapy and other treatments continues to increase (10th L. H. Gray Conference, 1981). Ultrasound, operated in the low megahertz frequency region and at exposure intensities in the neighbourhood of 1 W/cm^2, has emerged as an accurate, easily managed way of producing elevated temperatures both superficially and at appreciable depths in human tissues and organs (Hunt, 1982). The ubiquitous thermocouple remains the most useful thermal detector in this field and, as it can be made very small in comparison with an acoustic wavelength (viz. about 1.5 mm at 1 MHz), may be employed without significantly altering the incident radiation field. We describe in this note the manufacture of thermocouple arrays useful for measuring temperature fields to appreciable depths in tissue in large mammalian subjects. The probe arrays we have used to date have involved up to five junctions, inserted to a depth of 4 cm in the thigh muscle of 300 kg pigs (ter Haar & Hopewell, 1982). The probes are recoverable and reusable and yield consistent, stable details of the elevated temperatures over treatment times extending to hours. Temperatures may be measured continuously during ultrasonic exposure. Details of the thermal field can be fed back to the ultrasonic power source, either manually or automatically, and used to maintain the desired, planned temperature elevation over the chosen tissue volume.

THERMOCOUPLE MANUFACTURE

Figure 1 illustrates the probe array and its assembly. Essentially, the array is constructed as a constantan bus-bar with electrically insulated copper offshoots at chosen intervals which are bent along the bus-bar to form a bayonet-like insertable unit. Commercially available wires 50 μm in diameter are used. The junctions are made using a low temperature solder cream (Multicore Solders Ltd., UK, Sn/Pb/Ag/Sb solder cream, melting point 179°C), which has the very important advantage of allowing the minimal quantity to be introduced using a needle-tip applicator. The solder cream contains flux, as well as solder, and thus the thermocouple elements need only be cleansed in the junction regions.

*Permanent address: Bioacoustics Research Laboratory, University of Illinois, 1406 West Green Street, Urbana, Illinois, USA 61801.

The arrangement, which has provided satisfactory outputs, as well as minimal construction problems, is an array of five junctions spaced 0.5–1.0 cm apart and is assembled on a thin metallic tray. The five copper wires (offshoots) are looped once around the constantan bus-bar, at each selected position, pulled taut and cut off, leaving a short tail, approximately 1–2 mm, remaining (the tail which facilitates the soldering is removed afterwards, thus avoiding pre-solder assembling difficulties). The end of the enamelled Cu wire has previously been stripped in order to allow electrical contact with the constantan wire. Small quantities of the solder cream (approximately 0.01 mm^3) are laid onto each junction, at the copper loop, using a fine needle-tipped applicator. Soldering can now be accomplished in a number of ways: (i) by insertion of the metallic tray and probe assembly into an oven heated to a temperature above that of the solder cream melting point, (ii) by bringing a cool flame near each junction in turn, or (iii) by heating the assembly on the metallic tray from below using a flame torch such as a Bunsen burner. (This last method has been adopted for routine array manufacture by the authors.) Because a low-temperature solder cream is used, the soldering procedure is short, taking only a few minutes and, depending on the method chosen, all junctions may be formed simultaneously.

The quality of the junction is determined by the DC electrical resistance measured at the terminals of the probe. Only a virtually zero resistance junction is acceptable, and thus the terminal resistance measured must be only that for the specific length of copper and

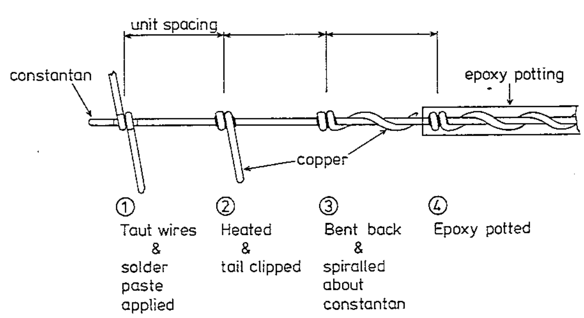

FIG. 1.

Montage of assembly details of linear thermocouple array.

constantan employed. As an example, for a thermocouple of 50 cm each of 0.001″ (0.025 mm) copper and constantan, a resistance of 125 ohms is expected due almost entirely to the constantan, and any measured resistance beyond this value is ascribed to the junction, and is therefore unacceptable.

An advantage of using the solder cream is that there is no need to clean after heating. The remaining copper "tail" can be removed using a field (dissecting) microscope. The copper wires are now bent back along the constantan bus and spiralled around it in a semi-taut fashion. Although not entirely necessary, the introduction of an epoxy-type material at this stage provides for a more rigid unit. This is accomplished by dipping and painting and working the resin into the spiralled stands. The bayonet portion of the unit is considered completed when the resin sets. The greatest diameter of the bayonet for a 5-junction array is typically 0.3–0.4 mm. The opposite end electrical connections, as desired, are now made.

Insertion into the specimen is accomplished by a method long utilised for such purposes (ter Haar & Hopewell, 1982) using a hypodermic syringe needle of sufficient size to contain the bayonet probe within its lumen. Thus, the array is inserted into the hypodermic needle, the complete ensemble inserted into the specimen and the needle withdrawn, leaving the probe in the desired position in the specimen. The array is then used in the conventional manner to yield the temperature–time history at each junction. When observations are complete, the bayonet is simply removed by retraction and, after minimal cleansing (and sterilisation) is ready for use again.

It is clear that two- and three-dimensional temperature field observations can be made by employing many such probes.

Acknowledgments

This work was supported by an MRC/CRC Joint Committee programme grant. F. Dunn's tenure at the ICR was supported by an American Cancer Society—Eleanor Roosevelt—International Cancer Fellowship, by a Fulbright Fellowship and by the University of Illinois.

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