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Multipoint Axial Thermometry for Death-time Estimation

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Abstract—Rectal thermometry, a form of single-point thermometry, is a standard method by which postmortem core temperature is measured for death-time estimation today. A recent study indicated that single-point thermometry measures the temperature of a central isotherm that exists at whichever body-depth is reached by the thermometer tip. The study demonstrated that postmortem central isotherms exist for extended periods inside the body as their radii gradually reduce during postmortem cooling. The temperature of a central isotherm, therefore, has low specificity for the number of minutes elapsed after death. In addition, the study demonstrated that a body's overall postmortem axial thermal profile continuously changed, beginning from the moment of death, throughout the cooling interval. A body's postmortem axial thermal profile therefore has high specificity for the number of minutes elapsed after death at the time it is measured. Finally, the study proposed the application of a body's postmortem axial profile for death-time estimation, to eliminate the uncertainty associated with single-point thermometry. This paper proposes multipoint axial thermometry (MAT) as a method of measuring a body's postmortem axial thermal profile for death-time estimation. A novel handheld MAT device prototype is proposed, and its application is demonstrated empirically and numerically.

Keywords — single-point thermometry, multipoint axial thermometry, MAT, death-time estimation, postmortem interval

I. INTRODUCTION

NUMERICAL analysis of postmortem axial heat transfer [1] demonstrated that the central isotherm that exists in life, which is generally referred to as the 'hot core', gradually reduces in diameter from the moment of death, while cooler circular isotherm rings successively develop on the skin and gradually propagate towards the body centre. The antemortem central isotherm (ACI) will therefore be recorded as being the postmortem temperature plateau (PMTP) when single-point-thermometry is used in the early stages after death. Even after the ACI disappears, it is replaced by a postmortem central isotherm (the isotherm ring that surrounds the ACI) whose initial diameter is substantial and gradually reduces over several hours. Central isotherms, as measured by single-point thermometry, are therefore not specific to the number of minutes lapsed after death. The overall thermal profile of the body, on the other hand, continuously evolves from the moment of death. Because postmortem axial heat transfer is characterised by continuous formation of successively cooler isotherm rings on the skin, whose diameters gradually reduce along with the ACI diameter, the overall axial thermal profile of a body is highly specific to the number of minutes lapsed after death at the time when it is measured. This specificity makes it ideal for death-time estimation compared to single-point thermometry, and its measurement and forensic application was first proposed by Mfolozi [1]. This paper proposes a novel handheld multipoint axial thermometry (MAT) device prototype for measuring the axial thermal profile of a body for death-time estimation. The paper demonstrates the procedure of MAT and the shape of a typical postmortem MAT profile.

II. MATERIALS

A. The Proposed MAT Device Prototype

The proposed MAT device needed to traverse the entire axial section of a body when inserted, ideally through the body's geometric centre, to enable thermometry of the central isotherm and all cooler concentric isotherms around it up to the skin. The author designed a T-shaped MAT device prototype consisting of a long vertical probe part and a short perpendicular handle part (Fig. 1). The probe consisted of a 350mm-long, 8.5mm wide printed circuit board on which sixty-four MAX30205 human body temperature sensors [2] were mounted 5mm apart. The sensors had a 0.0001°C temperature resolution. The printed circuit board was mounted onto the flat surface of a 325mm long, longitudinally-halved grade-316 stainless-steel rod of 5mm radius for mechanical support. The printed circuit board and stainless-steel rod were then inserted into a 350mm long clear Perspex tube whose inner radius was 5mm and outer radius 6mm. A 35mm long, arrow-shaped, grade-316 stainless-steel introducer having a pointed conical head and a cylindrical body of 5mm

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radius was fixed into one end of the Perspex tube with the pointed tip facing outward to facilitate skin perforation and insertion into the body. Two rubber gaskets of 4mm inner radius and 5mm outer radius were inserted between the introducer and Perspex tube to create a waterproof seal. The temperature sensors were numbered from the introducer end of the probe. Sensor 63 and sensor 64 were non-functional. The distance between the introducer tip and sensor 1 was 56.35mm (dead zone), the significance of which is discussed under the results section.

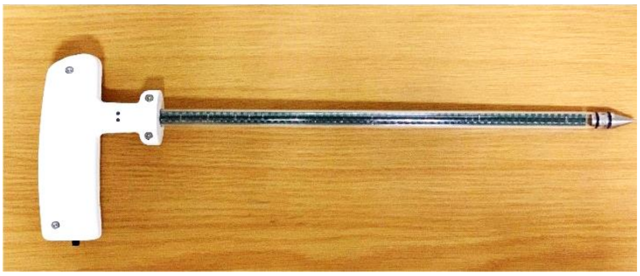

Fig. 1. The proposed MAT device prototype.

The handle part consisted of two symmetrical halves that were 3D printed with polyamide to create a housing consisting of a hilt. The halves were bolted together with two pairs of a bolt and nut. The housing contained a rechargeable Samsung ICR18650 Li-ion battery [3], a 32GB mini-SD card [4], a mini-USB charging port and a Raspberry Pi Zero [5]. The latter was a mini-processor that created a Wi-Fi hot-spot around the device to which a laptop, smartphone or tablet could be connected using a password. Body temperature sensors were linked to the Raspberry Pi Zero. The user could type the device's webpage address on any web-browser and real-time temperature measurements from the 62 sensors would be displayed. A feature on the webpage allowed recording of temperature measurements at 1-second intervals for a total of 180s per measurement-event. Thereafter, a comma-separated value file (.csv) was automatically created for each measurement event containing 11160 values (62 sensors x 180s), the times of their measurement, and the corresponding sensor-numbers. An icon pop-up menu would then be displayed to either download or email the .csv file. The device could store several .csv files at a time. A patent application is pending [6].

B. The Cooling Dummy

A cooling dummy that represented a recently-deceased human body in which MAT was to be undertaken using the MAT device prototype was built due to legal and logistical constraints that prohibited access to a human body. The cooling dummy is a human body surrogate used by several postmortem cooling studies [7] – [15]. A 771mm long cylindrical polyvinylchloride (PVC) punching bag having a 170mm radius was filled with 70L of a special gel solution consisting of 47.5% glycerol, 47.5% distilled water and 5% agar. The cooling dummy was allowed to cool and had a mass of 80.0kg (Fig. 2).

Fig. 2. The pre-heated Cooling Dummy vertically suspended and cooling outdoors in unforced convective conditions.

C. The 3D Computational Human Model

The 3D computational human model, thermal solver and computer hardware used for numerical demonstration of MAT were identical to those previously published [1], [16].

D. The Virtual MAT Device

The long shaft part of the MAT device prototype was used for numerical demonstration of MAT. It was computationally modelled in the thermal solver using the prototype's known dimensions and design features. Material properties assigned to its components are indicated in Table 1. The modelled virtual MAT device is indicated in Fig. 3.

Material	Density (kgm^{-3})	Thermal conductivity (W/m/K)	Specific Heat (J/kg/K)
316-grade stainless-steel	8000	16.3	500
Perspex	1051	0.2	1.8
Printed circuit board	2700	9	396
Rubber (gaskets)	1522	0.16	1050
Sensor-chip	2700	383	380

Table 1. Material properties applied to the virtual MAT device.

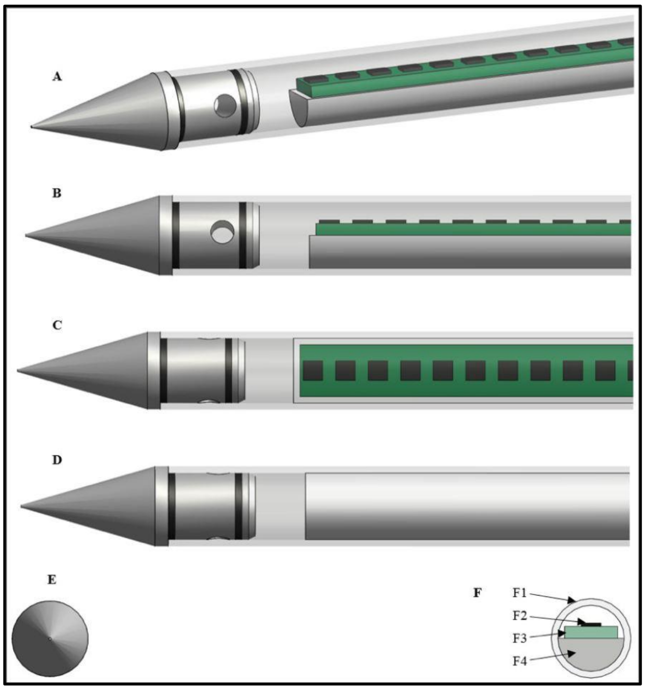

Fig. 3. The realistically modelled virtual MAT device prototype. A – F indicate oblique, lateral, superior, inferior, introducer-end and cross-sectional views, respectively. F1 – F4 indicate the clear Perspex tube, sensor chip, printed circuit board and the semi-circular stainless-steel rod, respectively.

III. METHODS

A. *Empiric demonstration of MAT*

The cooling dummy was pre-heated to 37°C in an incubator and, upon its removal, tied by its suspension belts to the legs of a metal trolley used to transport it. A small blanket was placed between the metal trolley and the cooling dummy during transportation, for insulation. The trolley was then placed outdoors and tilted vertically to freely suspend the cooling dummy in open air. The MAT device was first calibrated in ice-water at 0°C. After suspension of the cooling dummy in free-air, the MAT device was inserted into the cooling dummy, arbitrarily 3hrs 46 min after removal from the incubator, normal to its long axis through the PVC at a height of 360mm. The MAT device was fully inserted until the handle hilt rested on the cooling dummy PVC. Sensor 61 was at the level of the PVC, sensor 62 was outside the body and the stainless-steel tip of the introducer had perforated the opposite side of the cooling dummy PVC and protruded by 4mm. The MAT device was linked to a laptop via its Wi-Fi and the date and time were synchronised. The MAT device temperature was allowed to equilibrate with the cooling dummy temperature before MAT was undertaken.

B. *Numerical demonstration of MAT*

Numerical demonstration of MAT consisted of three sequential computational simulation steps. Step 1 numerically approximated the antemortem axial temperature distribution of the 3D human computational human model as previously described [16]. The Step 1 simulation solution formed the *initial condition* for the Step 2 simulation, which simulated postmortem cooling over a 5-hour period as previously described [1]. The Step 2 simulation solution formed the initial condition for the Step 3 simulation, at the beginning of which the virtual MAT device was computationally inserted into the right thigh of the 3D human computational model. Step 3 simulation settings were identical to those of Step 2. The initial temperature of the MAT device was identical to the air temperature setting used in the Step 2 simulation. The length of the Step 3 simulation was adjusted to allow thermal equilibration of the virtual MAT device with the 3D computational human model. Temperature attained by individual virtual MAT sensors at the end of Step 3 constituted the MAT profile of the 3D human computational human model as measured by the virtual MAT device.

IV. RESULTS

A. *Empiric demonstration of MAT*

The MAT device required 50 minutes to thermally equilibrate with the cooling dummy. Thus, the overall cooling interval at which the MAT profile was obtained was therefore 4hrs32mins. The plotted MAT profile curve was parabolic as indicated in Fig. 4. Data from sensor 62 and sensor 61 were omitted because these sensors were not inside the cooling dummy gel. Data from sensor 64 and sensor 63 were unavailable, as stated before. These missing data, together with dead-zone, resulted in the parabolic profile missing a part on the left-hand side of curve. However, the parabolic shape indicated symmetrical distribution of isotherms around a central point, consistent with observations previously made by Mfolozi [1]. The highest temperature of 37.5°C was recorded by sensors 24 to 28 that were anatomically at the centre of the cooling dummy. This 37.5°C isotherm thus had a 20mm diameter consistent with the ACI as it was about to disappear. In other words, 37.5°C was likely the PMTP temperature that would have been measured by single-point thermometry for the preceding 4hrs 32mins.

B. Numerical demonstration of MAT

The virtual MAT device probe was far longer than the diameter of the 3D computational human model right thigh, therefore virtual sensors measured temperature along the entire diameter of the 3D computational human model's right thigh. This was the ideal manner of performing MAT. The MAT profile curve plotted from the virtual sensors also indicated a parabolic shape consistent with symmetrical temperature distribution highest at the centre (28°C) of the thigh and lowest on skin. (See Fig. 5). Both the numerical and empiric MAT curves indicated a parabolic shape, confirming presence of symmetrical distribution of isotherms around a central point.

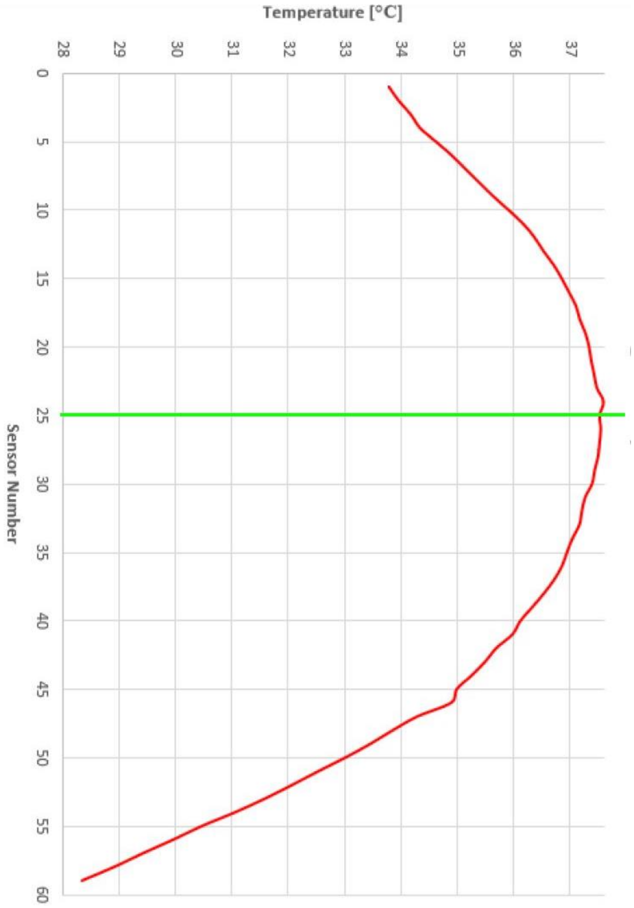

Fig. 4. The MAT profile curve of the Cooling Dummy obtained 4hrs32mins after 'death'. The green line is the centre-line of the dummy.

V. DISCUSSION

The MAT device prototype was designed to measure as much of the postmortem axial thermal profile of a body as possible. The style of a liner 1-dimensional probe was the most practical choice. The ideal MAT device design was one with a single continuous temperature sensor able to measure a smooth axial thermal profile without the interruptions created by spaces between sensors. Technical limitations with temperature sensor size prohibited fabrication of the ideal MAT device. The 50 minutes required by the MAT device to thermally equilibrate with the cooling dummy was attributed to the material properties and physical dimensions of the Perspex tube, stainless-steel rod and possibly the printed circuit board. Thickness of the printed circuit board was a consequence of the number of temperature sensors on it. The 50 minutes was not of major concern for purposes of this study because the MAT device was only a concept demonstrator whose design characteristics were likely to be revised in the future, to ideally reduce this interval. It was important to appreciate that the thermal equilibration interval occurred during postmortem cooling so that in casework death-time estimation, the thermal equilibration period is considered as such.

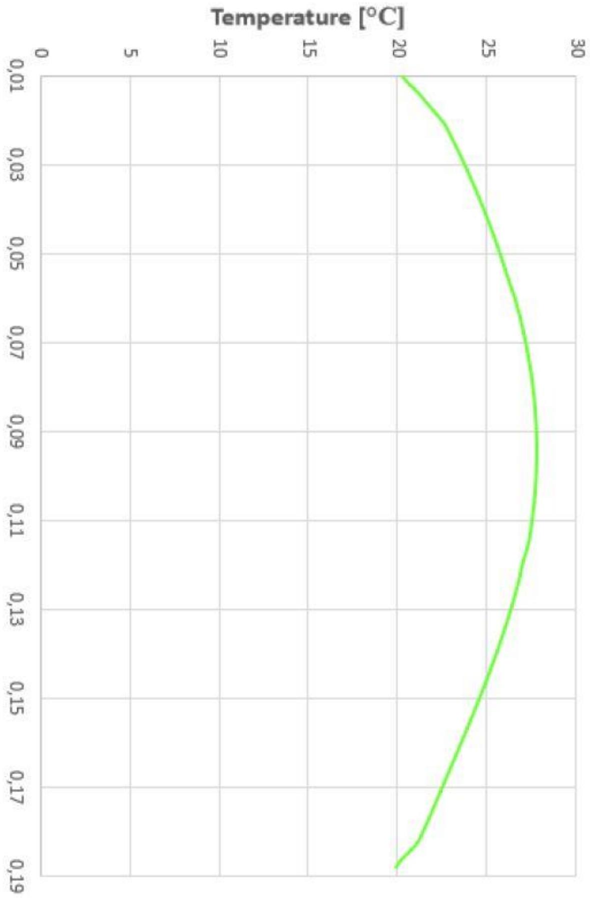

Fig. 5. The MAT profile curve measured by the virtual MAT device in the 3D computational human model.

Postmortem cooling of a body, whether in the physical or computational world, occurs on the skin and therefore axial MAT profiles from both demonstrations were expected to be parabolic. It became obvious from the empiric demonstration that the ideal length of a MAT device is one that is more than the diameter of the body region where MAT is to be undertaken, to avoid obtaining asymmetrical parabolic MAT curves. The length discrepancy was not an issue in the numerical demonstration. Insertion of a MAT device perpendicular to the skin and to the long axis of the body segment where MAT is performed, with the device aimed towards that body segment's axial centre, was deemed the ideal MAT technique for casework death-time estimation.

VI. CONCLUSIONS

This paper demonstrates that thermometry of postmortem axial thermal profile of a body, as first proposed for death-time estimation [1], is possible using suitable instrumentation such as the now proposed MAT device prototype. The MAT procedures demonstrated in this paper detected both the central isotherm and all other isotherms that existed in the body. More precise MAT procedures for death-time estimation requires special considerations that are the subject of further research.

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