Legal Medicine 25 (2017) 23–28

Contents lists available at ScienceDirect

Legal Medicine

journal homepage: www.elsevier.com/locate/legalmed

Calibration and parameter variation using a finite element model for death time estimation: The influence of the substrate

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A R T I C L E I N F O

Article history:
Received 30 September 2016
Received in revised form 8 December 2016
Accepted 19 December 2016
Available online 21 December 2016

Keywords:
Death time estimation
Rectal temperature
Finite element simulation
Substrate

A B S T R A C T

The most established method for temperature based death time estimation is based on an empirical double exponential model. New physically based approaches using numerical simulation techniques are subject of current research. A major advantage of such models is the possibility to incorporate non-standard boundary conditions. The aim of this study was to investigate the influence of the substrate on the cooling rate of a body in the early postmortem phase. A finite element model was used for parameter variation in terms of different substrate materials. Simulation results showed a considerable influence of substrate material on the postmortem cooling rate of a body. From a thermodynamical point of view, comparability between measurements on a steel trolley and real cooling scenarios with common substrates like normal floors, asphalt or soil remains questionable. It could be shown that not only the type of substrate but also its composition can have a considerable influence on the postmortem body cooling rate.

1. Introduction

Death time estimation is of major importance for the reconstruction of homicide cases and for the verification of alibis given by alleged criminals. In forensic case work different methods can be applied for death time estimation in the early post mortem phase [1]. The interpretation of supravital reactions (e.g. electrical stimulation of skeletal muscles) and positive signs of death (rigor mortis, post-mortem lividity) as well as the reconstruction of the death time on the basis of the deep rectal temperature are approaches commonly applied in forensic routine. Each of theses methods can be accompanied by some inaccuracies concerning the resulting death time estimation. While ATP-consumptive processes prior to death mainly influence supravital reactions and rigor mortis, the cooling rate of a corpse show evident dependencies on environmental factors, clothing and stature. Nevertheless, due to the fact that humans are able to maintain a constant body core temperature of 37 °C under physiological conditions, temperature based methods should provide the most reliable death time estimates.

The most common temperature based death time estimation model was established by Henssge in 1979 [2] based on the work of Marshall and Hoare [3–5]. Following empirical model was developed and validated using results from experimental rectal temperature measurements:

$$T_H = \left((37,2 - T_e)\frac{p}{p - Z}e^{Z \cdot t} - (37,2 - T_e)\frac{Z}{p - Z}e^{p \cdot t}\right) + T_e$$

$$Z = 0,0284 - 1,2815 \cdot m^{-0.625}$$
$$p = 5 \cdot Z \quad 5\,^{\circ}\mathrm{C} \leqslant T_e \leqslant 23,2\,^{\circ}\mathrm{C}$$
$$p = 10 \cdot Z \;\; T_e \geqslant 23,3\,^{\circ}\mathrm{C}$$

The mass of the body is represented by m, T_e is the ambient temperature and T_H stands for the calculated rectal temperature. Different cooling conditions including environmental factors (wind, irradiation, etc.), the substrate the corpse is laying on and the clothing of the body can be incorporated by applying a so called corrective factor that is used for body mass scaling.

New physically based methods for the estimation of the time since death have been proposed in [6], den Hartog and Lotens [7] and Mall and Eisenmenger [8,9]. These authors used the finite element technique to generate thermodynamic models of the human body. Within finite element based models different boundary conditions can be incorporated by means of thermodynamic principles.

A potential influence of the substrate on the cooling rate of a body was described in Henssge et al. [10]. Following statements

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http://dx.doi.org/10.1016/j.legalmed.2016.12.007
1344-6223/

regarding the thermal properties of different substrates can be found: "Thermally neutral substrates are normal floors of rooms, dry soil, lawn, asphalt. In comparison, substrates which look more thermally insulating or heat-conducting should be additionally taken into account." Also the steel trolley covered by a blanket used in the experimental setup described in Henssge [2] is referred to as a thermally neutral substrate.

According to literature, there should not be any significant differences in the cooling rates measured in corpses resting on a steel trolley compared to bodies contacting for example normal floors or asphalt. Current literature lacks studies that deal with the influence of the substrate on the cooling rate of post mortem human subjects.

The aim of this study was to investigate the influence of the substrate on the cooling rate of a body in the early post-mortem phase. For that purpose an existing finite element model was calibrated on the basis of two experimental measurements performed under controlled conditions with unclothed corpses and normal body mass indices. Using this calibrated model, simulation models were generated with different common substrate materials.

2. Methods

2.1. Finite element model

The finite element model presented and applied in this study was published in Mall and Eisenmenger [8,9]. For model generation and simulation a finite element analysis environment provided by MSC software was used (Marc and Mentat). Thirteen different types of tissues with the respective material properties were modelled to get a rough representation of the human anatomy. The substrate was modelled as a thin steel plate representing the trolley used in the experimental setup. The overall model consists of about 10,000 three-dimensional 8-node brick elements and 12,500 nodes. Convection and radiation are modelled as boundary conditions and the amount of heat transferred via conduction is determined by the material properties (conductivity) assigned to the elements. A detailed description of the model including a list of the material properties can be found in Mall and Eisenmenger [8,9].

Fig. 1 shows the model with different tissue compartments represented by gray scaled elements.

2.2. Calibration

The calibration of the finite element model was done on the basis of experimental measurement results. Several measurements with cadavers of newly deceased were performed by our working group between 2003 and 2006 under controlled conditions inside a climatic chamber [11]. The deep rectal temperature was captured every minute by a digital temperature sensor. In order to minimize additional influencing factors like clothing or adipose constitution two measurements with unclothed corpses, normal body mass indices and comparable body constitutions were chosen. Model validity in terms of post-mortem cooling was assessed for a node that corresponds to the experimental measuring point inside the rectum.

Prior to simulation, the model has been scaled to the height and weight given in Table 1 for case 1. By modifying the thickness of the subcutaneous fat layer of the torso, the model was modified so that the simulation results for case 1 matched the corresponding experimental temperature curves. In a second step, the modified model was "validated" by applying the boundary conditions of case 2. Due to similar constitution and similar ambient temperature the modified model should also match the experimental results for case 2.

2.3. Parameter variation

With the purpose to investigate the influence of the substrate on the cooling rate, different simulation models were generated including some common substrates and substrate compositions that can be found frequently in real world scenarios.

The thermal parameters for different materials were taken from building physics literature. Following substrates were modelled.

Table 2 contains the modelled substrates with the thermal properties used in the simulation. A typical construction (heated room beneath the floor) was modelled in case of the carpeted and the tiled floor, consisting of a layer representing the carpet or the tiles, a 5 cm thick layer of screed, a 3 cm layer of impact sound insulation (Polystyrene) and a 25 cm thick concrete layer. In order to determine the influence of the insulating layer on post mortem body cooling a simulation model was generated without the insulating layer. At the bottom side of the concrete layer radiation was defined representing the interface between the ceiling and the room beneath the floor. The pavement was modelled with

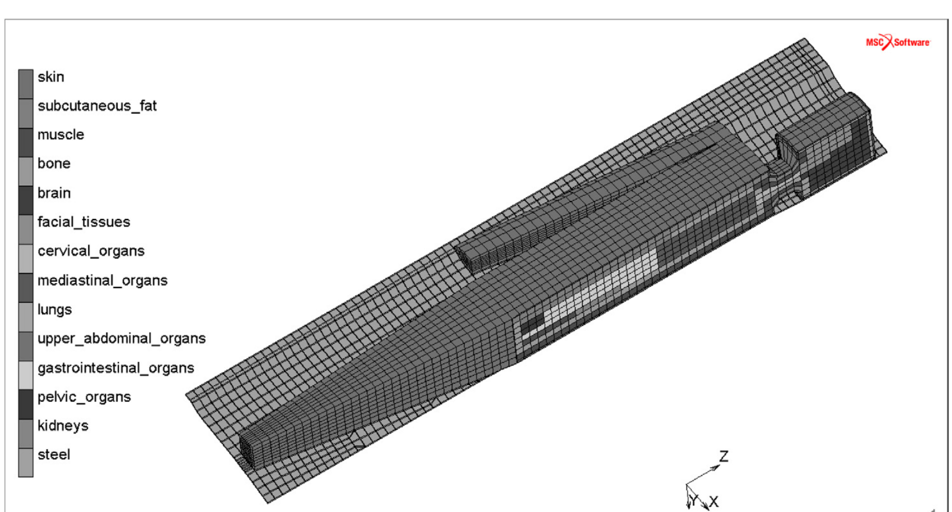

Fig. 1. Finite element model with different types of tissues (material properties).