

Jones [102] worked off of Farnworth's model to mathematically formulate heat and mass transport. The model includes the phenomenon of sweat secretion on the skin and assumes negligible moisture between fibers. The author was able to accurately calculate the vapor pressure and the rate of moisture accumulation at the skin.

Modeling for design

From the above review, it may be noted that the Pennes model could be considered a starting point to design and build a therapeutic system. In general, there are three engineering parameters to consider when designing such a system. The first parameter is the amount of local volumetric heat generation, the second parameter is the shape of the heating field, and the third parameter is the depth of penetration.

In order to create a detailed bioheat transfer analysis, a more sophisticated set of equations is needed. The two segment models return core and skin temperatures but no regional temperatures. The multi-segmented models are simple enough to be integrated to clothing models however input blood perfusion is taken as a constant. The finite element models are found to be the most accurate as they include further details of the human body anatomy, however the input blood perfusion is also taken as a constant.

A multi-segmented model could be used as a starting point for a nude young human adult. This model is proposed by Salloum et al. [103] and is designed to predict thermal and regulatory responses within human body segments and the environment. The model is based on the assumption that blood flow is the primary method of heat dissipation in the human body. To begin, the arterial system is divided into 128 segments representing the main and peripheral arteries. The blood going from the arteries to the capillaries is divided into blood flowing in the core and the skin. The blood entering a segment is divided into blood flow to the skin and blood flow to the next segment as shown in Figure 2. Olufsen et al. [104] modified the model proposed by Salloum et al. [103] by replacing the impedance of peripheral arteries with one calculated and assuming artery trees, which end with a minimum artery radius of 0.03 mm.

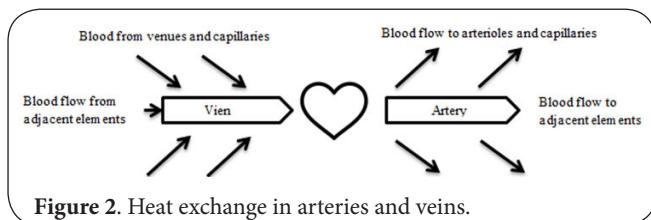


Figure 2. Heat exchange in arteries and veins.

Avolio [105] built another model that is used to determine the blood through all the different segments by modeling the flow resistance in each element. The input to the model is a standard cardiac ejection waveform. The segments are grouped into 15 body parts. Each of the body parts are con-

sidered to have a uniform temperature. The mathematical formulation is based on heat exchange through convection, conduction and perfusion in each of the body segment's four nodes; core, skin, artery and vein.

Based on appropriate modeling, authors are currently engaged in developing a controlled contrast therapy test bed that operates at a wide range of temperatures by using solid-state TEC technology. Although this technology is mostly used for cooling, it can also be used for both heating and cooling under controlled conditions, providing the comfort of avoiding the use of motors and liquids in the system. A multi-segmented human model with a proposed vest for contrast therapy is shown in Figure 3.

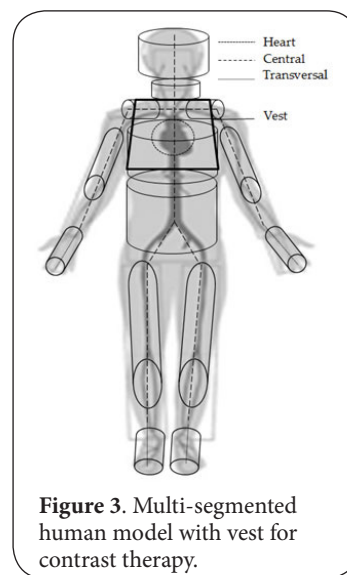


Figure 3. Multi-segmented human model with vest for contrast therapy.

The systemic blood circulation is subdivided into large and small vessels to investigate the temperature changes in subcutaneous and intramuscular tissue during a 30-minute cold- and hot-contrast therapy session.

Concluding remarks

HF is a staggering clinical and public health concern. It is, and will continue to be a substantial burden on health care systems and societies. In this article, research work on epidemiology, public health, and risk factors associated with HF have been reviewed. A rationale for the use of heat and/or cold as a treatment modality for HF was presented. Advancement in bioheat transfer modelling coupled with improvements in delivery techniques will have an impact in the design and analysis of a thermotherapy system (such as suits or vests) that deliver controlled heat and/or cold to the human body.

Conclusion

Thermotherapy in general and contrast therapy in particular are not yet fully developed modalities. There are still challenges in their routine clinical application, and there is still room for further improvements. However, the development of contrast

therapy is a viable example of an effective research and clinical program that is clearly important and from which physicians, physical therapists, engineers, and patients will benefit.





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