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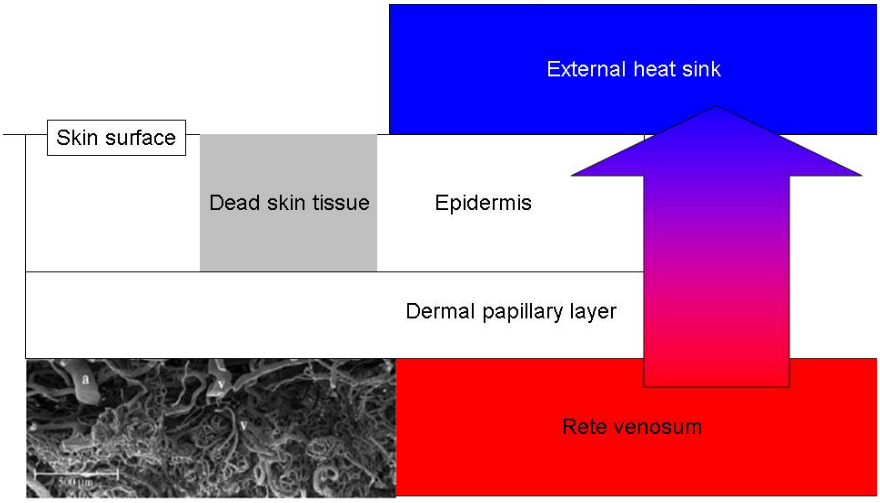
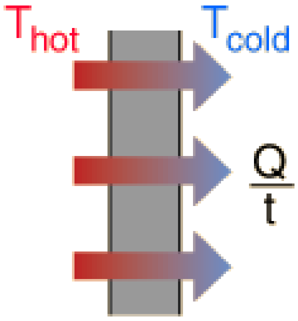
The Thermodynamics of Heat Exchange Across the Palmar Skin Surface

Heat transfer across the palmar skin surface model:



Rule # 1. Physiology cannot defy the laws of physics.



Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a material is at a higher temperature, then energy will be transferred through the material toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones. The rate at which the heat travels through the material is determined by the thermal conductivity of the material. For heat transfer between two plane surfaces (i.e., the skin surface and the walls of the rete venosum), the formula for calculating rate of conduction heat transfer is:

$$\frac{Q}{t} = \frac{\kappa A(T_{hot} - T_{cold})}{d}$$

Where:

Q/t = Heat transferred over time (t) in Watts

K = Thermal conductivity of the material in Watts/m°C

A = Surface area of the heat transfer portal in m^2

T = Temperatures of the sources and sinks in °C

d = Thickness of the barrier (skin) in m

To calculate the heat transfer capacity into or out of the blood in the rete venosum, (which can directly influence the general circulation), you must calculate the heat transfer across the wall separating the heat sink from the heat source. This would be the maximum capacity of the system in which sufficient blood is flowing through the rete venosum to maintain the wall temperature constant. With vasoconstriction, the whole thing falls apart and you get a cold hand as the $T_{hot} - T_{cold}$ approaches 0.

The thermal conductivity of tissue is 0.46 Watts/m°C.

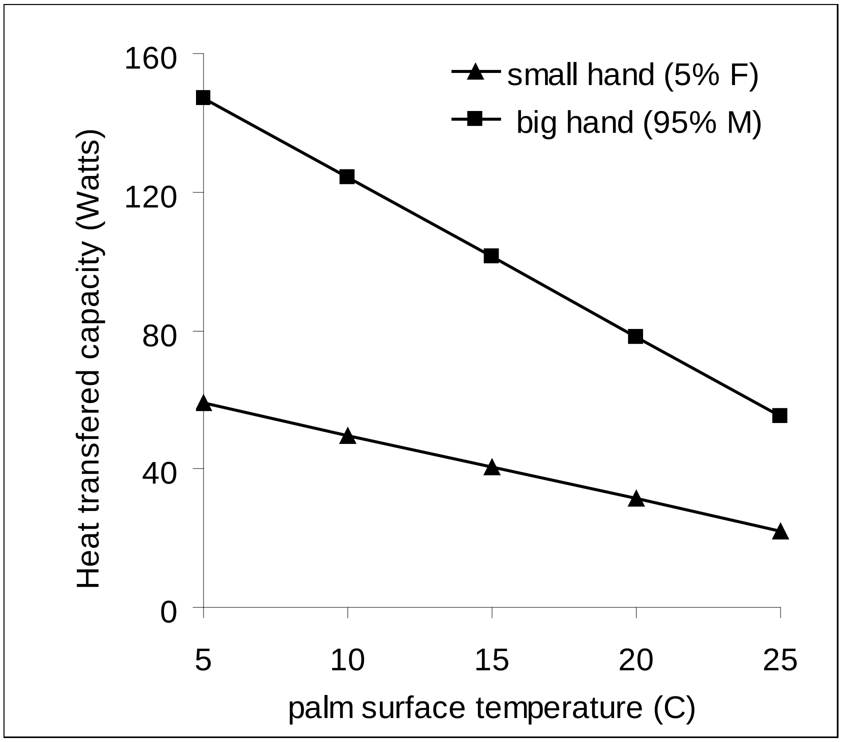
The surface areas depend on hand size, which scales pretty well with Body Surface Area (BSA) - palm skin area ≈ 0.5% BSA. BSA can be calculated from height and weight of an individual.

The 5 % female has a palm surface area of about 0.008 m^2 while a 95% male has a palm surface area of about 0.02 m^2.

When vasodilated, the temperature if the blood entering the rete venosum will approximate core temperature ≈ 37 °C.

The epidermis of the average palm (and sole) is 1.5 mm thick. The rete venosum are embedded in the dermal layer of the skin below the papillary layer. The thickness of the tissue wall between the skin surface and the rete venosum is ≈ 2 mm.

Given these parameters it is possible to calculate heat transfer capacity for any given skin surface temperature. In the figure below I have calculated the heat transfer capacity for across the palmar surface 5% females and 95% males at skin surface temperatures between 5°C and 25°C.



These calculations agree quite well with the heat transfer data we have determined empirically.

For maximum heat exchange the greatest possible thermal gradient achievable without compromising rete venosum blood flow must be maintained. The key for the external thermal load delivery component is to have close apposition and maximal surface contact with the palmar skin surface. Maintaining maximal blood flow through the underlying rete venosum is the second component of the challenge. The type of materials that make up the external heat exchange component are not particularly important. The temperature at the skin surface and the area of contact are the relevant parameters.