INSULATION VERSUS COUNTER CURRENT HEAT SAVINGS

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INTRODUCTION

Our knowledge of the circulation pattern and the counter current phenomena and their effects on the heat budget of extremities is mainly descriptive and not very satisfactory. In literature heat savings by counter current exchange between parallel arteries and veins are reported ranging from 5 to 50% (1,2). However, only for the special case when many small arteries and veins in close contact (forming a rete) one was able to demonstrate qualitatively its importance. (3). Other researchers (4) paid more attention on the shift in venous return from cutaneous to deep lying vessels, increasing in this way the thermal insulation of the circulating blood. However, quantitative studies of those heat savings are not discussed.

The purpose of this study is to determine, by means of experimental data of heat loss and blood flow and a mathematical model of the circulation, the efficiency of the beat savings resulting from the thermal insulation and the counter current exchange of heat.

METHOD

This study of the heat savings in upper extremities of man is made by means of a mathematical model for the circulation (5). The model takes into account longitudinal as well as radial blood temperatures gradients and assumes that the vessel system *can* be approximated by one artery, a deep vein lying parallel and close to the artery, and a cutaneous vein. A valve at the end of the arterial branch regulates the relative amount q of the arterial blood flow **BF** through the cutaneous vein (q.BF) and the deep lying vein **([(1-q).BF].** The circulation model depends on four thermal parameters λ_i (i= 1, 2 ,3) and q. The thermal conduction parameters λ_i account for the heat transfers between: i=1 the deep or i=2 the cutaneous vessels respectively and i=3 between the deep lying vessels mutually.

The mathematical expression governing the relationship between heat loss H and blood flow **BF** is of the kind H= H(λ_i, q, AT, BF), in which AT is the temperature difference between the flowing arterial blood and the wet skin. The unknown parameters λ_i and q are obtained by fitting the model to experimental data of H and **BF,** obtained at ten different wet skin temperatures ranging from 7 to 40°C. It turned out that λ_1 was one order smaller compared to the corresponding λ_2, the latter being smaller but of the same order as λ_3. This (λ_3 large) lets suggest that the counter current exchange will play a dominant role in the conservation of heat.

The total heat conservation index E„ being the sum of the counter current savings of heat and the insulation heat savings, is found by looking to the difference between the real heat loss H(q) and the heat loss one would obtain if all venous blood should return through cutaneous veins or H(q=1). For this purpose we computed **E,** = $[H(q=1)-H(q)]/H(q=1)$ at different q-values **($0 \leq q \leq 1$)** and each time for a large range of blood flows. The E, value was normalized as the H-values are function (not linear) of **BF.** The individual heat savings E, by counter current exchange of heat between the counter flowing vessels is given **E,,** = $[H(\lambda_3=0)-H(q)]/H(q=1)$ and in the same way the impact of the insulation from venous shifting to deep lying vessels is obtained by E_{is} = $[H(q=1)-H(\lambda_3=0)]/H(q=1)$. The total saving E_t = $E_{cc} + E_{is}$.

RESULTS

The results show that the total heat conservation index E, depends on the rate of blood flow **BF** but most on the q-value or the amount of venous shifting. At constant flow (in the physiological range) *the* E, changes from 0.9 to 0 when q alters from 0 (no) to 1 (complete shifting). The E, value is at large and small q rather independent of the flow, but decreases by about 30% with increasing blood flow in the range from 3- to 20×10^{-4} $m^3/s.m^3$ tissue. The individual contributions **E,,** and E_{is} also depend on q and **BF. As** *can* be expected the efficiencies will increase with the amount of venous shifting. However, their importances change in a complementary way with the rate of blood flow. Although λ_3 is very large we find that E„ is important and the only contributor to E, when the rate of flow is very or negligibly small **(BF≈0).** However, from the moment that the flow becomes larger than 5×10^{-4} $m^3/s.m^3$ tissue its efficiency drops to less than 10%. On the other hand the efficiency of E_{is} is nil at the smallest flow values (BF≈0) but it becomes the main contributor in the physiological range of blood flows.

We computed also the heat savings E_t, E_{cc} and E_{is} for the experimental H, BF data obtained in the wet skin temperature range between 7-40°C. In Fig. 1 we can see that at the coldest skin temperature the total heat savings index E_t is large and about **70%.** This means that at the cold temperatures the heat loss was only 30% of the heat exchange one would obtain if all venous blood should return through cutaneous veins. We observe also that this important reduction is mainly produced by E_{is} or the better thermal insulation of the deep lying vessels. The impact of E_{cc} is small and maximal 15% at a wet skin temperature of 18°C when the arterial rate of blood flow was the smallest. At the warm skin temperatures, venous shifting decreases and rate of blood flow increases resulting in an E_t value of about **10%** or less. In this temperature range both E_{cc} and E_{is} efficiencies are comparable but small.

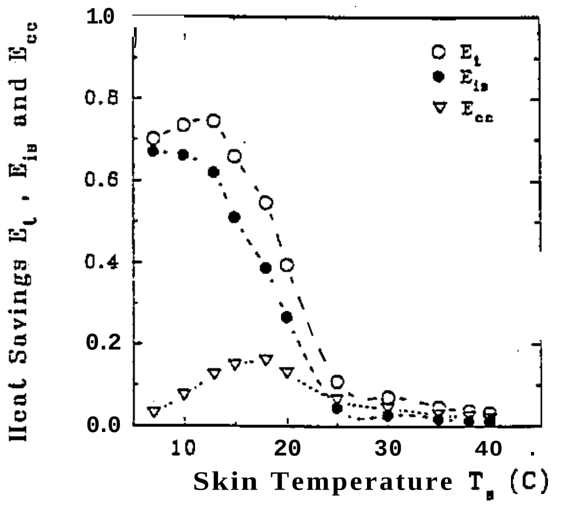

Fig. **1** Relative heat savings as a function of skin temperature.

CONCLUSION

The results show that the increase of the thermal insulation when the venous flow is shifted from cutaneous to deep vessels has the most important impact on the conservation of heat. This savings in energy reaches for the human hand a mean value of about **65%.** Concerning the savings by counter current heat transfer, we learn that the effectiveness is rather poor and depends strongly on the rate of blood flow. For the human upper limb, when the arterial blood flow is minimal we found a counter current efficiency of maximal 15%. Our results agree very good with the results obtained by Mitchell and Meyers (1), Aschoff (6), and Dawson and Weber (7).

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