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Cutaneous Microcirculation and Tissue Oxygenation

The cutaneous microcirculation has a unique anatomical arrangement that accommodates different and sometimes conflicting functions - the supply of nutrients, clearance of waste products and control of heat exchange. This paper concerns with the transport of oxygen to tissues of the papillary layer of the dermis and the epidermis. This is the region between the sub-papillary plexus and the surface of the skin.

The first part of the talk is on in vivo measurements of oxygen partial pressure (pO_2) in dermal papillae of healthy human subjects using oxygen-sensitive micro-electrodes (tip diameter $\sim 5\mu m$) that were developed in house. When the skin is covered with paraffin oil, pO_2 increases with depth from values close to zero at the surface to about $40 - 50 mmHg$ close to the sub-papillary plexus. The gradient appears to be steepest through the outer $30\mu m$ that corresponds to the epidermis. When microvascular blood flow in the immediate vicinity of the tissue is occluded, pO_2 falls exponentially to a value $10 - 20 mmHg$ below its pre-existing value. From this, it would appear that the oxygen supply to the epidermis is vulnerable to very local reductions in perfusion. Our observation that pO_2 increases with depth would be predicted if all oxygen is delivered to the papillary dermis and epidermis from the sub-papillary plexus. Under physiological conditions, however, oxygen can enter the outermost layers of the skin from the atmosphere to meet the needs of the epidermis.

The second part of the talk is on theoretical modelling. A 3-dimensional multilayered model based on the anatomical arrangement of upper layers of the skin has been developed, which includes the stratum corneum, the germinal layer, dermal papilla, papillary loop, and subpapillary plexus. Parameters, such as oxygen diffusivity, solubility, and consumption rate, took different values in different layers, reflecting heterogeneity in tissue properties. Transport of oxygen in the blood and in tissues was considered under different flow rates and skin surface boundary conditions. pO_2 distribution was calculated using values for parameters based on measurements. The model revealed a number of results:

1. Diffusion of oxygen from the air into the skin accounted for approximately 10% of the oxygen consumption in superficial layers of the skin under normal skin conditions. This supply of O_2 , however, was restric-

ted to superficial regions of the epidermis, due to the low O_2 diffusivity and solubility in the stratum corneum, and high oxygen consumption in the germinal layer.

2. Papillary loops served for rapid delivery of the oxygen to the germinal layer, where intensive oxygen consumption existed. Changes in the blood flow rate there affected the pO_2 distribution in the dermal papilla.
3. Subpapillary plexus was the main source of the oxygen supply to the superficial layers of the skin, and accounted for approximately two-thirds of the total oxygen supply there under normal skin surface and blood flow conditions.
4. There were regions in the epidermis, where tissue pO_2 was below or very close to the critical oxygen partial pressure. Cells in these regions were either inactive or under constant threat of oxygen starvation when fluctuations in blood circulation occurred.

The study demonstrates the need of close interaction between experimental and theoretical studies in biomedical engineering.