M. M. Osman
Graduate Assistant.

E. M. Afify
Professor of Mechanical Engineering.

North Carolina State University,
Raleigh, N.C. 27650

Thermal Modeling of the Normal Woman's Breast

A comprehensive thermal model of the normal woman's breast is presented. The model is developed taking into consideration metabolic heat production, tissue perfusion with capillary blood, arterial and venous blood thermal interaction and change of arterial blood temperature with position. A series of computer programs are written using a 3-dimensional finite-element technique to evaluate the surface temperature distribution of the breast. Comparison between the results obtained for the model and those from thermograms of a woman's breast are in good agreement.

Introduction

Among the various biophysical methods that have been developed in the diagnosis of breast cancer, there are thermography and X-ray mammography. Thermography has great appeal due to its nondestructive nature while X-ray mammography might be destructive due to the possible carcinogenic effect of X-radiation at diagnostic levels. It is the objective of this investigation to study the surface temperature distribution of the normal woman's breast as a first step towards modeling the temperature patterns of malignant breast. The results of this study will shed light on the factors which influence the temperature patterns of the normal woman's breast in thermography.

Heat transfer through subcutaneous tissue, modeled as heat-generating, porous material, has been investigated by Nevins and Darwish [1]. They have considered heat transfer by conduction, and also by convection, due to the flow of blood through the simulated porous structures of the head and limbs. Assuming a symmetrical distribution of blood flow, they have calculated the temperature distribution in the head. One of the earliest mathematical models of tissue heat transfer was that of Burton [2]. He reported that the laws of heat conduction through solid materials are adequate to describe the actual flow of the heat in biological tissues. He considered that heat was conducted along paths perpendicular to the body surface. The coefficient of thermal conductivity was variable, depending on the blood flow near the skin. Wissler [3] defined a mathematical model with one-dimensional, radial heat flow. He divided the human body into six cylinders, representing the head, trunk, and the four limbs. Each was considered as a homogeneous cylinder of tissues which generated heat uniformly and was supplied with blood at constant arterial temperature. Keller and Seiler [4] developed a one-dimensional steady-state continuum model for heat transfer through the tissue of peripheral regions in man, taking into consideration the effects of tissue conduction, convection by blood flow, vascular heat exchange, and tissue metabolism. Haberman, et al. [5] simulated the effect of metabolic heating by thermal sources, and solved the one-dimensional energy equation into consideration heat conduction and blood perfusion to predict the skin temperature during thermography. Their analytical model demonstrated the relative influences of room temperature, heat transfer coefficient, blood perfusion rate, tissue thermal conductivity, and metabolic heat generation rates on skin temperature.

From the above survey, it is noted that the 3-dimensional surface temperature distribution of normal woman's breast, to the authors' knowledge, has not yet been considered. It is the objective of this paper to develop a thermal model of the normal woman's breast taking into consideration the effects of metabolic heat production, tissue perfusion with capillary blood, arterial and venous blood thermal interaction and change of arterial blood temperature with position.

Physiology of the Breast

To develop a representative model of the breast, the physiology of the breast is presented.

The woman's breast is composed of four essential spherical layers representing skin, fat, muscle, and core (connecting tissue), shown in Fig. 1(*a*). In the middle area of skin layer there is a very highly perfused area, the areola. In the middle of areola is the nipple.

The pattern of blood circulation in the breast can be divided into two main parts (Figs. 1(*b, c*)):

1 The arterial supply: mainly dependent on subclavian and axillary arteries. The gland is nearly entirely supplied by branches originating from the half-deep arterial tree. From the periglandular arterial tree originate: (*i*) superficial branches directed towards the skin, particularly in the aerolar and periareolar region; (*ii*) half-deep branches supplying the retro-glandular structures.

2 The venous drainage utilizes the following routes: (*i*) the half-deep route according to a course and a drainage which corresponds to the main preglandular arterial branches; (*ii*) the superficial route, originating from the peri-areolar ring and running in the skin layer, where it forms a tree much richer than the arterial one [6].

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