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RESEARCH ARTICLE

Evaluation of Heat Transfer in Acupuncture Needles: Convection and Conduction Approaches

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Abstract
Originating in ancient China, acupuncture using needles has been developed for thousands of years and has received attention for its reported medical remedies, such as pain relief and chronic disease treatment. Heat transfer through the needles, which might have effects on the biomechanism of acupuncture, providing a stimulus and regulating homeostasis, has never been studied. This article analyzes the significance of heat transfer through needles via convection and conduction, approached by means of computational analysis. The needle is a cylindrical body, and an axis symmetrical steady-state heat-transfer model that viscosity and static pressure was not applied. This article evaluates heat transfer via acupuncture needles by using five metal materials: silver, copper, brass, iron, and stainless steel. A silver needle of the type extensively applied in acupuncture can dissipate more than seven times as much heat as a stainless steel needle of the same type. Heat transfer through such a needle is significant, compared to natural body-energy consumption over a range of ambient temperatures. The mechanism by which heat flows in or out of the body through the needles may be crucial in the remedial efficacy of acupuncture.

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1. Introduction

Originating in ancient China, acupuncture has been developed for thousands of years and has received attention for its reported medical remedies, such as pain relief and chronic disease treatment [1]. The use of needles in medical therapy is a key component of traditional Chinese medicine (TCM) and is among the oldest healing practices in the world [2]. Jesuit missionaries returning to Europe in the 16th century termed this therapy acupuncture, from the Latin *acus* "needle" and *punctura* "pricking" [3]. In the rationale behind acupuncture, organs are considered energetic and bound to yin and yang forces, which manifest qi, which flows along meridians (pathways). Areas where qi comes close to the body's surface are acupuncture points [3]. TCM asserts that the therapeutic effects of acupuncture are achieved through the meridian system: imbalances in the flow of qi can be corrected by using skin-penetrating needles to dredge meridians, thus recovering health [4].

Studies of connective tissue structures show that acupuncture involves sensory-stimulating mechanisms [5—8]. From the viewpoint of physiology, intercellular chemical messengers within the interstitial fluid provide feedback stimulus to regulate homeostasis via chemical reactions, whose rates depend closely on temperature [9]. The stimulus from needles in acupuncture involves a change of temperature and heat transfer through tissue. Both ambient and body temperatures influence the effect of acupuncture [10]. This stimulus may result in the regulation of homeostasis. The effect of heat transfer on homeostasis has never been studied. This paper analyzes the significance of heat transfer through needles by means of convection and conduction.

2. Materials and methods

When an acupuncture needle is inserted into tissue, it can be regarded as a cylindrical heat-transferring medium, which involves the conduction and convection of heat. When using an acupuncture needle, an auxiliary heating treatment is frequently applied by moxibustion [11], which can transfer heat into tissue through the needle. Acupuncture needles are made of silver, copper, tinplate-galvanized iron, or stainless steel. Typically they are made of stainless steel and are usually disposable; reusable needles are sometimes used, although they must be sterilized between uses [12]. They vary in length between 13 mm and 130 mm. Short needles are used near the face and eyes, and long needles for fleshy areas. Needle diameters vary from 0.16 mm to 0.46 mm [13]. As a heat media, needles can either bring heat in or take heat out. This study deals with the heat that is taken out; any heat produced by friction from needle manipulating is neglected. The portion of the needle that is not inserted under the skin contacts the air, resulting in natural heat convection. Several studies have analyzed the natural convection of a vertical cylinder, comparable to the heat transfer of an acupuncture needle [14,15]. A physical model is presented in this study in Fig. 1, showing a cylindrical needle vertically inserted into tissue. The lower part of the needle is immersed in the tissue, and the temperature of its surface is expected to be the same temperature as the tissue. If there is a difference in temperature between the tissue and the air, heat conduction occurs within the needle. Because the upper part of the needle is exposed to the air, heat flows through the surface of the needle by natural convection.

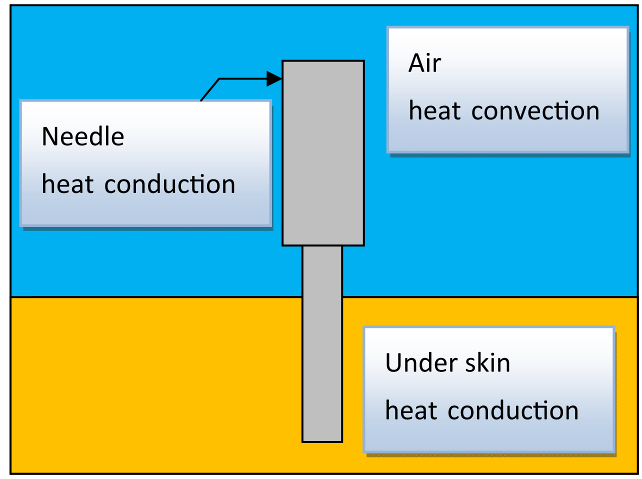

Figure 1 Physical model of needle heat transfer.

According to the model described above, without regard to viscosity and static pressure, the steady-state heat-transfer equation can be expressed as [14]:

$$\nabla \cdot (k \nabla T) = \rho c_p u \cdot \nabla T \quad (1)$$

where k is the thermal conductivity of the needle and tissue, T is the temperature, ρ is the density of the air, c_p is the specific heat capacity of the air, and **u** is flow velocity. This equation is solved by using numerical software COMSOL Multiphysics, Stockholm, Sweden. Silver, iron, copper, 70/30 brass, and 304 stainless steel are chosen to be the material of the analyzed needles, length and diameter of which are 70 mm and 0.3 mm, respectively. The top of each needle, with a length of 30 mm and a diameter of 1.2 mm, is for handling. There is 20 mm of the length of the needle in the tissue. Relative geometrical parameters, including dimensions of the needles, boundaries, and subdomains for analysis, are shown in Fig. 2. The boundaries and subdomains for analysis are based on axis-symmetrical calculation. There are five subdomains, from CO1 to CO5, defined as follows: CO1 is the handling part of the needle; CO2 is the thin upper part of the needle, exposed in the air; CO3 is the lower part of the needle, inserted in the tissue; CO4 is the surrounding air, involved in convective heat transfer; its height and width are 60 mm and 4.8 mm, respectively, with enough dimension that the temperature gradient converges to trivial; and CO5 is the tissue domain, which can be regarded as a heat-conductive regime, and convection is neglected [16]. The temperature gradient is not supposed to converge to trivial in this domain. The depth and width of CO5 are primarily set as 24.5 mm and 5 mm, respectively.

The boundary conditions along the axis of symmetry are set by thermal insulation. Those of subcutaneous boundaries are assumed to have a constant temperature the same as that of the tissue, 310 K. Those exposed to the air are

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