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Modeling and Simulation of the Interstitial Medium Deformation Induced by the Needle Manipulation During Acupuncture

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Abstract. In this paper, we study the effects of inserted needle on the subcutaneous interstitial flow. A goal is to describe the physical stress affecting cells during acupuncture treatment. The model consists of the convective Brinkman equations to describe the flow through a fibrous medium. Numerical studies in FreeFem++ are performed to illustrate the acute physical stress developed by the implantation of a needle that triggers the physiological reactions of acupuncture. We emphasize the importance of numerical experiments for advancing in modeling in acupuncture.

AMS subject classifications: 76M10, 76S05, 76Z05, 92C50

Key words: Finite element method, FreeFem++, acupuncture, Brinkman model, interstitial fluid flow.

1 Introduction

Acupuncture is one of the oldest healing practices and alternative medicines. This minimally invasive procedure involves a penetration of skin with needles to stimulate specific points on the body, called acupoints, with the purpose of restoring balance in the flow of *qì* through meridians [1]. While this so-called traditional Chinese medicine has been

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recognized in 2010 on the Representative List of the Intangible Cultural Heritage of Humanity by UNESCO and was endorsed by the World Health Organization, there is a great demand to enlighten its underlying concepts such as *qì*, meridians, collaterals and acupoints. The absence of scientific background of acupuncture mechanisms certainly has motivated us to carry out modeling and numerical simulation of both macroscopic and microscopic aspects of the acupuncture process.

The classical technique involves inserting a hair-thin needle into acupoints. The needle is then manipulated to yield a local mechanical stress field through needle motions (lifting–thrusting cycle or rotation). After a short term of needle manipulation, the needle is retained until desired effects have been achieved. The mechanical interaction of needle with the skin and the subcutaneous tissue has been demonstrated [2]. This stimulation via mechanotransduction, that is activated by the stretch of mechanosensitive ion channels at the mastocyte surface, can lead to a cascade of biochemical reactions that drive acupuncture effects [3].

The same acupoint can be stimulated by acupressure, moxibustion, electroacupuncture [4], and, more recently, by laser acupuncture [5]. In the context of moxibustion, physical stimulation via the transfer of heat from burning moxa has been investigated [6–9]. Whatever the operation mode is, calcium entry in the mastocyte triggers degranulation and release of chemoattractants, neural stimulants, and endocrine substances. Such a process is sustained by the recruitment of mastocytes (chemotaxis). We have developed a model of chemotactic self-sustained response of mastocytes [10, 11]. The developed mathematical model constitutes a system of parabolic partial differential equations. Its simplest form describes the evolution of the density of mastocytes and the chemoattractant concentration subjected to a physical stress.

The present study is aimed at simulating the effects of an inserted needle on the interstitial flow. The reader is invited to read the accompanying paper [12] to get information on events occurring during the permanent regime, that is once the needle has been implanted and the stress field in the subcutaneous connective tissue is fully established.

This paper is organized in the following. Section 2 outlines the physiological mechanisms and the biological tissue involved during acupuncture treatment. Section 3 presents the mathematical modeling and the governing equations of flow in interstitium. The ALE finite element method is reviewed in Section 4. Numerical experiments are discussed in Section 5. In Section 6, concluding remarks are given.

2 Biological medium

2.1 Connective tissue

The skin consists of three layers of tissue known as the epidermis, dermis, and hypodermis lying above skeletal muscles. The hypodermis, a loose connective tissue, provides (1) structural and mechanical support, (2) transport of nutrients, metabolites, and waste