Feng Xu · Tianjian Lu

Introduction to Skin Biothermomechanics and Thermal Pain

Science Press Beijing

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（皮肤热力学与皮肤热疼痛）

With 126 figures

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Preface

Advances in laser, microwave and similar technologies in medicine have led to recent developments of thermal treatments for disease and injury, involving skin tissue. In spite of the widespread use of thermal therapies in dermatology, they do not draw upon the detailed understanding of the biothermomechanical-neurophysiological behaviour, for none exists to date, even though each behavioural facet is somewhat established and understood. In view of this dilemma, a new research area emerges, which is the subject of this book: "Introduction to Skin Biothermomechanics and Thermal Pain". This area is highly interdisciplinary, involving the subjects of engineering, biology and neurophysiology. This book is focused on the introduction of this new research area. According to the schematic relationship between the areas involved, this book is divided into four parts: PART I. Skin bioheat transfer and thermal damage; PART II. Skin biomechanics; PART III. Skin biothermomechanics; PART IV. Skin thermal pain.

The book is multidisciplinary with a market across several subject areas and will be interesting to a wide range of readers from lab bench to clinics. The book is primarily planed as a textbook and reference book. It targets three segments of readers:

(1) Advanced students: this book primarily aimed at advanced graduate students in bioengineering, who have already some knowledge of engineering.

(2) Researchers: researchers may find this book a good reference, e.g. data base of different properties of skin tissue. Besides skin tissue, the methodology in this book can also be very useful for researchers on other biological tissues.

(3) Clinicians: the holistic methodology introduced in this book will be very helpful for clinicians to design, characterize and optimize strategies of delivering thermal therapies.

Feng Xu
Tianjian Lu
July 2010

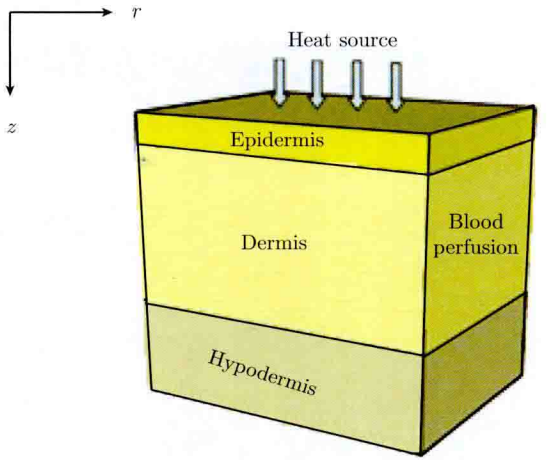


Figure 2.1 Structure of human skin

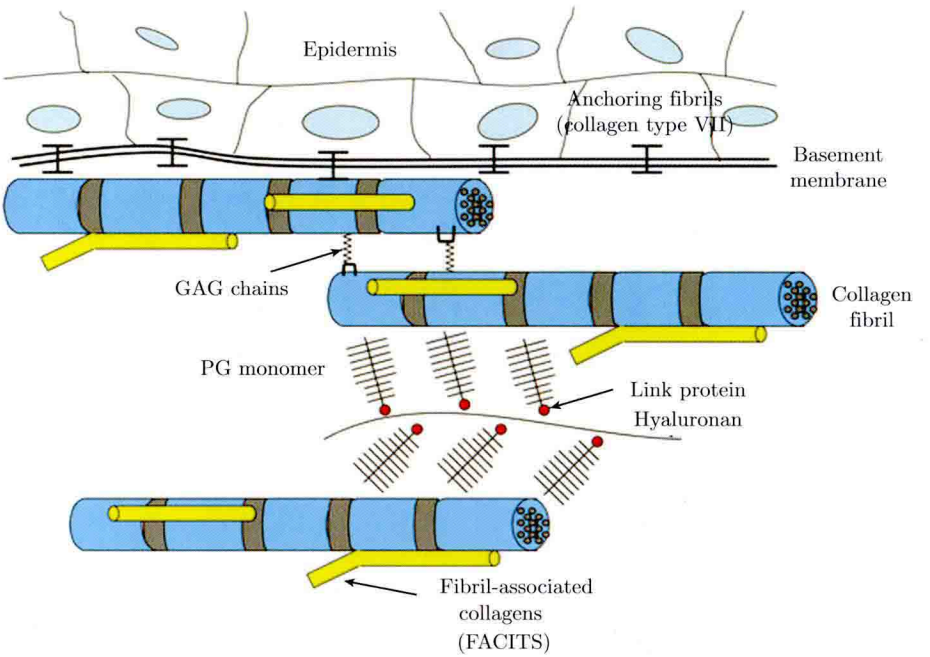


Figure 2.2 Macromolecular components of skin

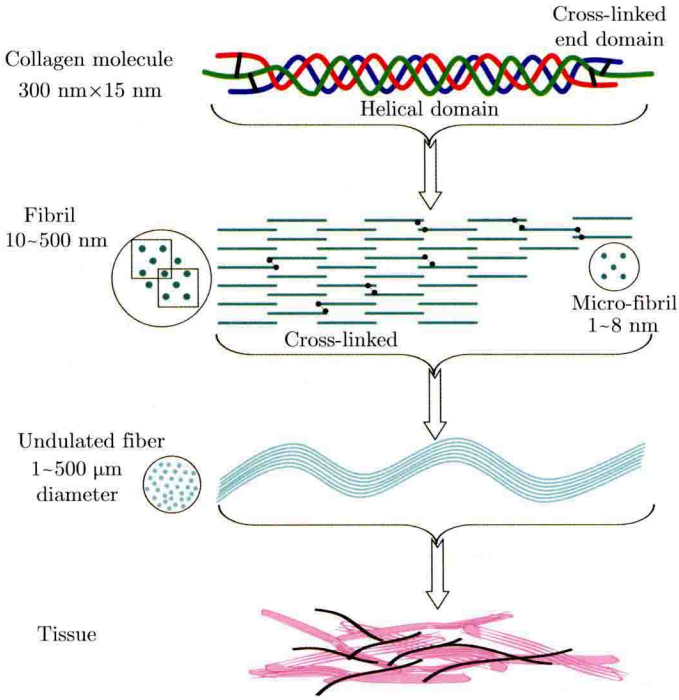


Figure 2.3 Molecular/fibrillar configuration of Type I collagen

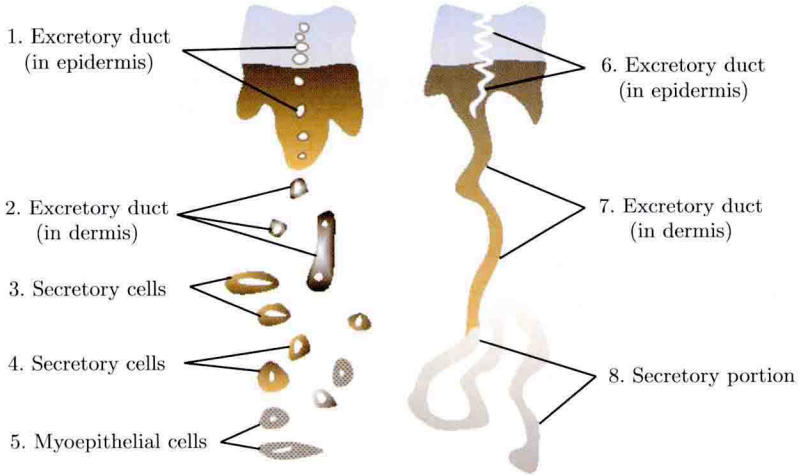


Figure 2.8 Sweat gland in skin

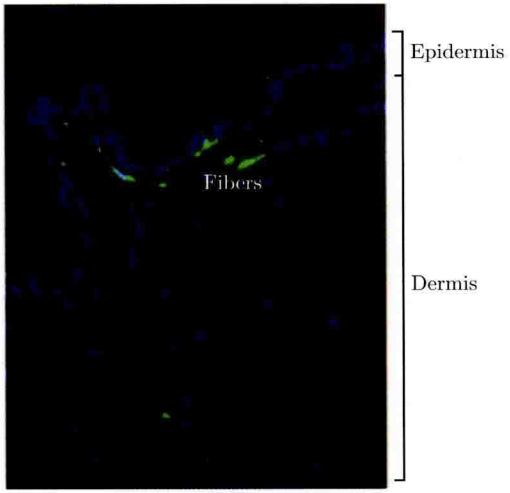


Figure 2.9 Histological section of free nerve endings in skin[28]
(by permission of Nature Publishing Group)

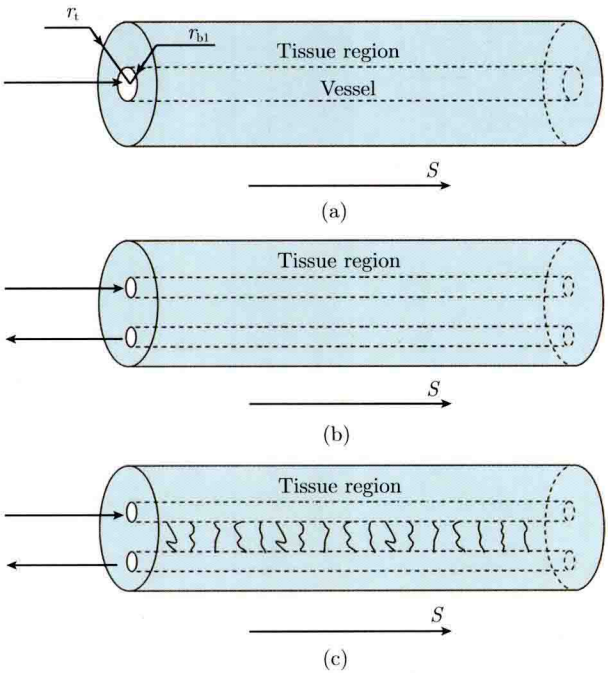


Figure 3.1 Vessel configurations of vascular models: (a) unidirectional vessel configuration; (b) countercurrent vessel configuration; (c) large/small/large vessel configuration

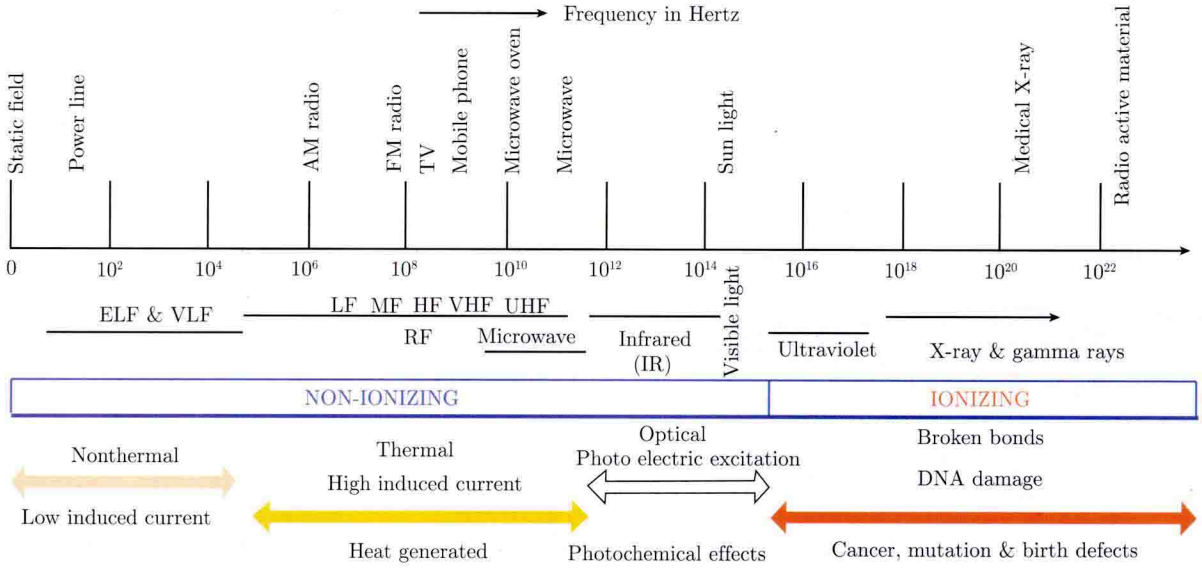


Figure 3.3 Electromagnetic spectrum[59] (by permission of the author)

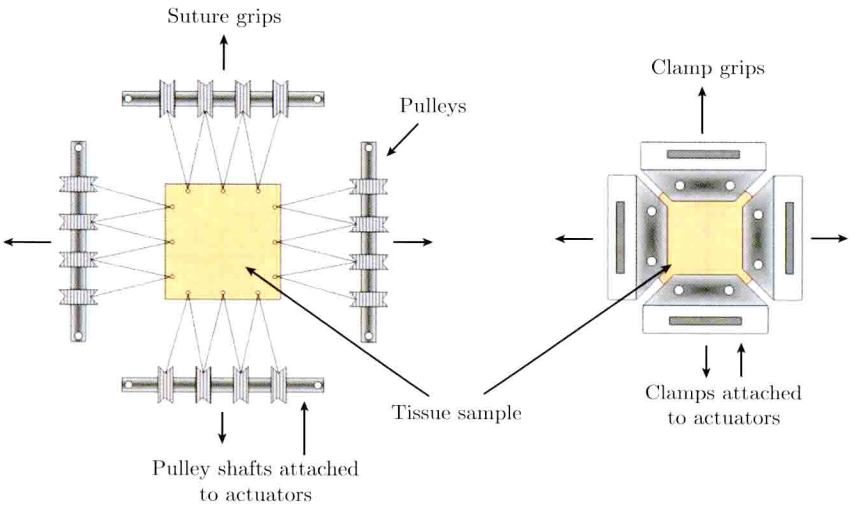


Figure 6.3 Different holding methods

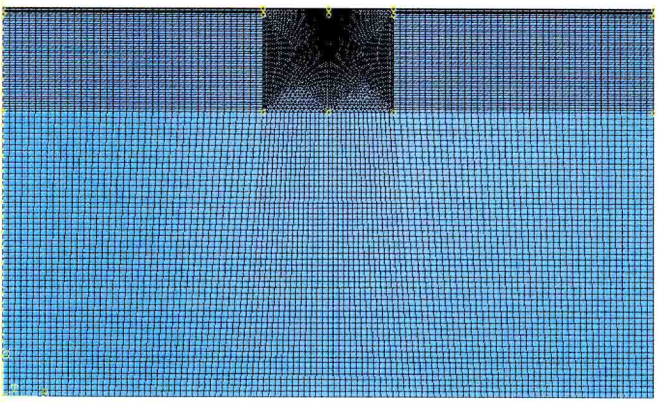


Figure 9.4 Mesh of the skin model in Figure 9.3 (by permission of Elsevier)

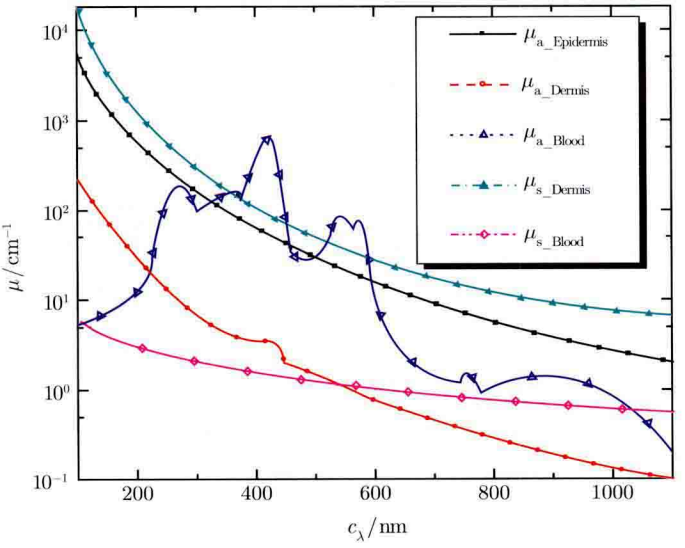


Figure 9.19 Optical properties of different skin layers (by permission of Elsevier)

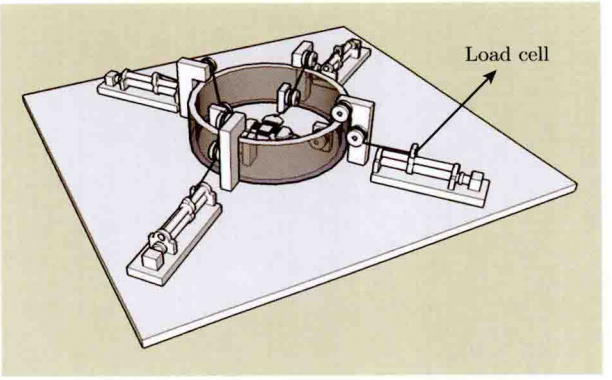


Figure 10.2 Loading subsystem of the hydrothermal tensile testing system: user-defined loading, such as isometric tension tests and isotonic tension tests, can be achieved through the pulley system

Figure 10.3 Practical implementation of Figure 10.1

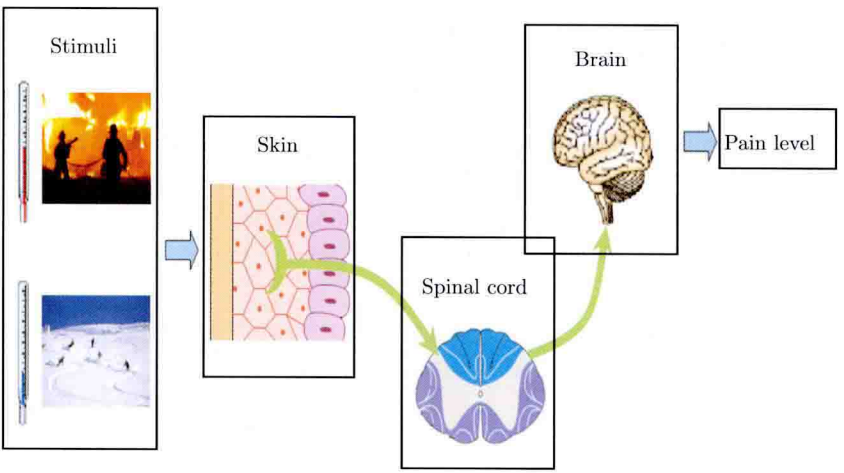


Figure 11.1 Skin thermal pain pathway: stimulus (hot/cold) → skin (the energy of thermal stimulus is converted into electrical energy via nerve impulses) → spinal cord & brain (the signals are transmitted to the dorsal horn of the spinal cord and brain, where they are modulated and perceived as pain sensation) (by permission of Elsevier)

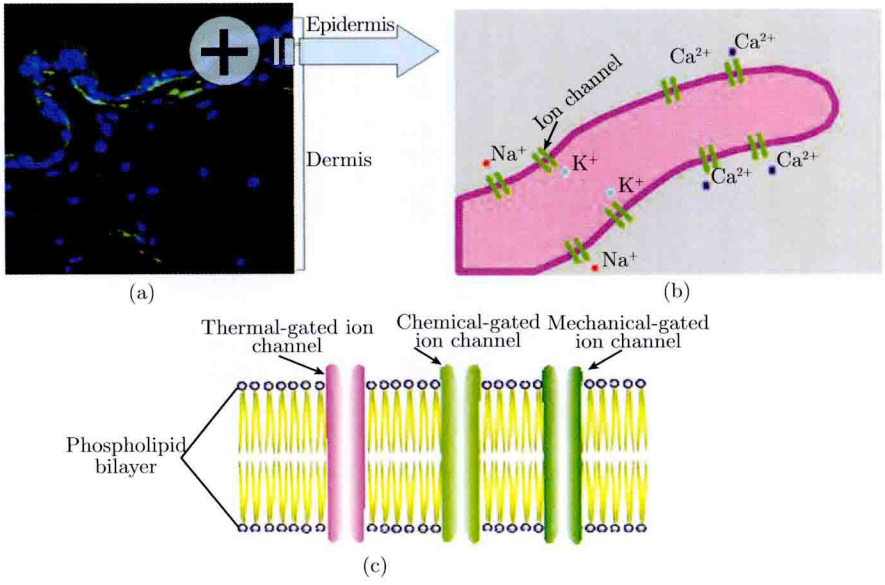
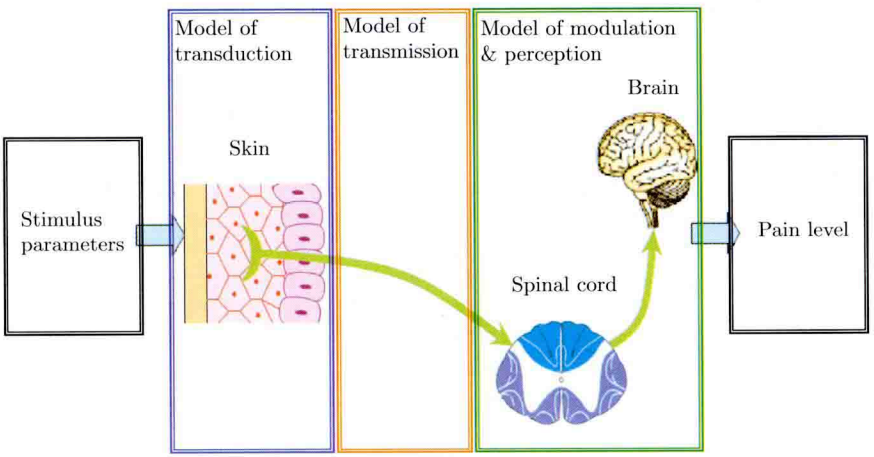


Figure 11.4 Schematic of nociceptor transduction: if the thermal stimulus surpasses the thermal threshold of nociceptors [points in (a)[51]], the heat current will be induced due to the opening of the corresponding ion channels in (b), and the action potential is triggered; the thermal stress and thermal-damage-induced release of some chemical mediators may also open corresponding mechanically- and chemically-gated channels in (c) if it is larger than the mechanical threshold (by permission of Nature Publishing Group)



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Contents

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Introduction

1.1 Introduction

All biological bodies live in a thermal environment with no exception of human body, where skin is the interface with protecting function. It is the largest single organ of the body and plays a variety of important roles including sensory, thermoregulation and host defense etc. Among these roles, the most important one is the thermoregulation: skin functions thermally as a heat generator, absorber, transmitter, radiator, conductor and vaporizer. This thermoregulation function makes the skin an important barrier for the human body to various outside conditions. However, in extreme environment, people may feel uncomfortable or even pain due to extreme hot or cold. Obviously, skin fails in protecting the human body when the temperature is out of normal physiological range. Furthermore, in medicine, various thermal therapeutic methods have been used widely to cure disease/injury involving skin tissue, where the objective is to induce thermal injury precisely within skin tissue but without affecting the surrounding healthy tissue.

Then, questions come up. Why do human beings feel uncomfortable/pain in extreme thermal environment? What is happening in human body in extreme thermal environment? How to protect human body in extreme thermal environment? These questions have been addressed in this book.

1.2 Skin Biothermomechanics and Thermal Pain

1.2.1 What is skin thermomechanics and thermal pain?

Skin biothermomechanics and thermal pain is the study of the bio-thermal-mechanical-neurophysiological behaviors of skin tissue under different thermomechanical loadings.

1.2.2 Specialities of the problem

1) Thermal behaviour in skin tissue

Thermal behavior, or heat transfer, in skin is mainly a heat conduction process coupled to complicated physiological processes, including blood circu-