PERSONAL CARE AND COSMETIC TECHNOLOGY

COSMETIC APPLICATIONS OF LASER AND LIGHT-BASED SYSTEMS

Edited by
Gurpreet S. Ahluwalia

William Andrew

COSMETIC APPLICATIONS OF LASER AND LIGHT-BASED SYSTEMS

PERSONAL CARE AND COSMETIC TECHNOLOGY

Series Editor: Meyer Rosen
President, Interactive Consulting, Inc., NY, USA

The aim of this book series is to disseminate the latest personal care and cosmetic technology developments with a particular emphasis on accessible and practical content. These books will appeal to scientists, engineers, technicians, business managers, and marketing personnel.

For more information about the book series and new book proposals please contact William Andrew at info@williamandrew.com.

http://www.williamandrew.com/PersonalCareCosmetic.php

COSMETIC APPLICATIONS OF LASER AND LIGHT-BASED SYSTEMS

Edited by
Gurpreet S. Ahluwalia

William Andrew
Norwich, NY, USA

ISBN: 978-0-8155-1572-2

Library of Congress Cataloging-in-Publication Data

Cosmetic applications of laser & light-based systems / edited by Gurpreet S. Ahluwalia.
p. ; cm. -- (Personal care and cosmetic technology)
Includes bibliographical references and index.
ISBN 978-0-8155-1572-2 (alk. paper)
1. Skin--Laser surgery. 2. Skin--Diseases--Phototherapy. 3. Hair--Diseases--Treatment. 4. Cosmetic delivery systems. 5. Surgery, Plastic. I. Ahluwalia, Gurpreet S. II. Title: Cosmetic applications of laser and light-based systems. III. Series.
[DNLM: 1. Cosmetic Techniques. 2. Laser Therapy--methods. 3. Hair--physiology. 4. Photochemotherapy--methods. 5. Skin Physiology. WR 650 C8327 2009]
RL120.L37C72 2009
617.4’770598--dc22
2008038597

Printed in the United States of America

This book is printed on acid-free paper.

10 9 8 7 6 5 4 3 2 1

Published by:
William Andrew Inc.
13 Eaton Avenue
Norwich, NY 13815
1-800-932-7045
www.williamandrew.com

ENVIRONMENTALLY FRIENDLY
This book has been printed digitally because this process does not use any plates, ink, chemicals, or press solutions that are harmful to the environment. The paper used in this book has a 30% recycled content.

To my mother and father, Surinder and Surjeet Ahluwalia for teaching me the virtues of life and providing unconditional love and support

To my wife Gail for her encouragement, patience and understanding

To my son Sean Preet and daughter Anjuli for their love and support

To my mentor David A. Cooney from National Cancer Institute, NIH who taught me the fundamentals of scientific investigation

Contents

Contributors

Gurpreet S. Ahluwalia PhD
The Gillette Company
A wholly owned subsidiary of The P&G Company
Needham, MA
USA

(Senior Director, Dermatology Clinical R&D, at Allergan, Inc., Irvine, CA, USA, as of November 2008)

Murad Alam MD
Northwestern University Feinberg School of Medicine
Associate Professor Dermatology and Otolaryngology, and Surgery
Chief, Section of Cutaneous and Aesthetic Surgery
Department of Dermatology
Northwestern University
Chicago, IL
USA

Macrene Alexiades-Armenakas MD, PhD
Assistant Clinical Professor
Department of Dermatology
Yale University School of Medicine

Director
Dermatology and Laser Surgery Private Practice
New York, NY
USA

Gregory B. Altshuler PhD
Vice President, Research and Development
Palomar Medical Technologies, Inc.
Burlington, MA
USA

Todd J. Banks PharmD, RPh
Regulatory Affairs Manager
The Procter and Gamble Company
Cincinnati, OH
USA

Natalia V. Botchkareva MD, PhD
The Gillette Company
A wholly owned subsidiary of The P&G Company
Needham, MA
USA

(At School of Life Sciences, The University of Bradford,
Bradford, UK, as of November 2008)

Roy G. Geronemus MD
Director
Laser & Skin Surgery Center of New York
New York, NY
USA

David J. Goldberg MD, JD
Clinical Professor of Dermatology
Mount Sinai School of Medicine
New York, NY
USA

Director
Skin Laser & Surgery Specialists of New York and New Jersey
New York, NY
USA

Jillian Havey
Research fellow
Northwestern University Feinberg School of Medicine
Department of Dermatology
Northwestern University
Chicago, IL
USA

James Henry PhD
The Procter and Gamble Company
Cincinnati, OH
USA

Mary P. Lupo MD
Department of Dermatology
Tulane Medical School

Lupo Center for Aesthetic and General Dermatology
New Orleans, LA
USA

David H. McDaniel MD
Director
Laser Skin & Vein Center of Virginia
Virginia Beach, VA
USA

Cheri Millikin
The Procter and Gamble Company
Cincinnati, OH
USA

Serge Mordon PhD
Research Director
INSERM & Lille University Hospital
Lille
France

Michael Moretti
Editor/Publisher
Medical Insight, Inc.
Aliso Viejo, CA
USA

Vic A. Narurkar MD
Director and Founder
Bay Area Laser Institute
San Francisco, CA
USA

J. Frank Nash PhD
The Procter and Gamble Company
Cincinnati, OH
USA

Keyvan Nouri MD, FAAD
Professor of Dermatology and Otolaryngology
Director of Mohs Micrographic Surgery, Dermatologic and Laser Surgery Unit
Director of Surgical Training
Department of Dermatology & Cutaneous Surgery
University of Miami Miller School of Medicine
Miami, FL
USA

John E. Oblong PhD
The Procter and Gamble Company
Cincinnati, OH
USA

Rita V. Patel
Department of Dermatology
University of Miami
Miller School of Medicine
Miami, FL
USA

Valerie Anne Randall PhD
Professor
School of Life Sciences
The University of Bradford
Bradford
UK

Neil S. Sadick MD, FAAD
Clinical Professor of Dermatology
Weill Medical College of Cornell University
New York, NY
USA

Cosmetic, Laser and Dermatologic Surgery
New York, NY
USA

Douglas Shander PhD
The Gillette Company
A wholly owned subsidiary of The P&G Company
Needham, MA
USA

(At Trichoresearch, Gaithersburg, MD, USA, as of November 2008)

Anita Singh
Research Fellow
Department of Dermatology & Cutaneous Surgery
University of Miami
School of Medicine
Miami, FL
USA

David Sliney PhD
Consulting Medical Physicist
Fallston, MD
USA

Retired from US Army Center for Health Promotion
and Preventive Medicine
Aberdeen Proving Ground, MD
USA

Pete Styczynski PhD
The Procter and Gamble Company
Cincinnati, OH
USA

Valery V. Tuchin PhD
Institute of Optics and Biophotonics
Saratov State University
Saratov
Russia

Institute of Precise Mechanics and Control
Saratov
Russia

Voraphol Vejjabhinanta MD
Senior Clinical Research Fellow
Department of Dermatology & Cutaneous Surgery
University of Miami Miller School of Medicine
Miami, FL
USA

Clinical Instructor
Suphannahong Dermatology Institute
Bangkok
Thailand

Susan Walgrave MD
Zel Skin & Laser Specialists
Edina, MN
USA

Melea Ward
The Procter and Gamble Company
Cincinnati, OH
USA

Robert A. Weiss MD
Director
MD Laser Skin & Vein Institute, LLC
Hunt Valley, MD
USA

Dale Wiener
Palomar Medical Technologies, Inc.
Burlington, MA
USA

Paul Wiener
Palomar Medical Technologies, Inc.
Burlington, MA
USA

Brian Zelickson MD
Associate Professor of Dermatology
Department of Dermatology
University of Minnesota
Minneapolis, MN
USA

Zel Skin & Laser Specialists
Edina, MN
USA

Preface

Though cosmetic science dates back nearly 4000 years, it is in the last two to four decades that the industry has made the most progress by coming up with high potency bioactive ingredients now part of cosmeceuticals, innovative topical drugs for beauty treatments, minimally invasive injectables such as Botox® Cosmetic and dermal fillers, and non-invasive, non-ablative laser and light-based systems for cosmetic dermatology. The laser and light-based systems are preferred by the consumer who demands more than what creams and topical drugs can deliver and thinks that injectables and surgery are a step too far. The cosmetic targets for these systems are diverse and include the removal of unwanted hair; the treatment of photodamaged and unevenly pigmented skin to improve tone, texture, and imperfections similar to what is achieved with aggressive peels and exfoliants; and the treatment of fine lines, wrinkles, and laxity to improve skin appearance and give it a rejuvenated look. The treatment of acne, vascular disorders, cellulite, pseudofolliculitis barbae (PFB), and the removal of tattoos and benign pigmented lesions are some additional conditions targeted by laser and light systems.

All laser and light-based systems for cosmetic dermatology are regulated by the FDA as medical devices. The FDA clears (not approves) these devices for marketing based on a determination of their substantial equivalence to a predicate marketed device under the Agency's 510(k) provisions. This has allowed for technology advancements to rapidly enter the marketplace without having to go through a lengthy regulatory approval process. This has resulted in the introduction of a large number of laser and light systems in the past two decades for a broad array of skin conditions. As good as these systems work in terms of their effectiveness and safety, there are certain limitations imposed by the physiological and biochemical makeup of their biological targets. Moreover, there are marked inter-individual differences between subjects in their response to the benefits and side effects of laser and light system treatments. Understanding the causes of this variability can go a long way toward individualizing treatment regimens and identifying synergistic combinations for providing desired benefits to the consumer.

The purpose of this book is to provide the research community a comprehensive review of the technology, from the basic biology of the involved target to the efficacy and safety that are specific to the device and the cosmetic dermatology indication. The text is organized into six parts and 25 total chapters. Each chapter is dedicated to a specific topic authored by experts in their field. Part 1 covers the technology fundamentals related to the physiology and biochemistry of skin and hair along with the biophysical principles of laser technology that are relevant to understanding specific light-tissue interactions. Part 2 covers available hair management options including various laser and light-based technologies and the laser effects on hair follicle biology at the molecular level. Available options for enhancing skin appearance, including microdermabrasion, cosmeceuticals, topical drugs, and combination treatments with a focus on various light-based systems are discussed in Part 3. Laser treatment of diverse skin conditions, including cellulite, acne, and PFB, and for wound healing, creating synergies with topical drugs, and the use of photodynamic therapy for enhanced cosmetic benefits are discussed in Parts 4 and 5. Part 6 is dedicated to the safety, including dermal and eye, and the regulatory aspects of gaining marketing clearance, of laser and light-based systems.

The next frontier in the quest for beautiful skin and youthful appearance is likely to be the combination of topical chemistry and medical devices. It is likely that the light-based devices being developed for the aesthetic home-use market will be complemented by cosmeceuticals and topical drug products to provide consumers with a complete beauty solution in the privacy of their homes.

I would like to thank all the contributors to this work, each of whom devoted their time and effort to reviewing the available literature, to sharing their personal experiences in cosmetic dermatology procedures, and to sharing their clinical and basic research findings.

Gurpreet S. Ahluwalia
Irvine, California
October 2008

PART 1
BASIC TECHNOLOGY AND TARGETS FOR LIGHT-BASED SYSTEMS

1

The Biology of Hair Growth

Valerie Anne Randall and Natalia V. Botchkareva

Centre of Skin Sciences, School of Life Sciences, University of Bradford, Bradford, UK

Gurpreet S. Ahluwalia (ed.), *Cosmetic Applications of Laser and Light-Based Systems*, 3–35,

1.1 Introduction

The hair follicle is a highly dynamic organ found only in mammals. Although frequently overlooked, the follicle is fascinating from many viewpoints. For cell and developmental biologists it has an almost unique ability in mammals to regenerate itself, recapitulating many embryonic steps en route [1,2]. For zoologists, it is a mammalian characteristic, significant for their evolutionary success and crucial for the survival of many mammals-loss of fur or faulty colouration leads to death from cold or predation. Human follicles also pose a unique paradox for endocrinologists as the same hormones, androgens, cause stimulation of hair growth in many areas, while simultaneously inhibiting scalp follicles causing balding [3,4]. In contrast, hair is often seen as rather irrelevant medically, as human hair loss is not life threatening. Nevertheless, hair is very important for most people [5]. Many men spend significant time shaving daily and vast amounts are spent on hair products; a ‘bad hair day’ is a common expression for days when everything goes wrong! This reflects the important role hair plays in human communication in both social and sexual contexts and explains why hair disorders such as hirsutism (excessive hair growth) or alopecia (hair loss/ balding) cause serious psychological distress [6].

Hair growth is co-ordinated by hormones, usually in parallel to changes in the individual’s age and stage of development or environmental alterations like day-length [7]. Hormones instruct the follicle to undergo appropriate changes so that during the next hair cycle, the new hair produced differs in colour and/or size. This chapter will review the functions of hair, its structure and the processes occurring during the hair growth cycle, the changes which can occur with the seasons, and the importance of the main regulator of human hair growth, the androgens. Throughout the chapter, the main emphasis will be on human hair growth.

1.2 The Functions of Hair

Mammalian skin produces hair everywhere except for the glabrous skin of the lips, palms, and soles. Although obvious in most mammals, human hair growth is so reduced with tiny, virtually colourless *vellus* hairs in many areas, that we are termed the “naked ape”. Externally hairs are thin, flexible tubes of dead, fully keratinised epithelial cells; they vary in colour, length, diameter, and cross-sectional shape. Inside the skin hairs are part of individual living hair follicles, cylindrical epithelial downgrowths into the dermis and subcutaneous fat, which enlarge at the base into the hair bulb surrounding the mesenchyme-derived dermal papilla (Fig. 1.1) [8].

In many mammals, hair’s important roles include insulation for thermoregulation, appropriate colour for camouflage [9], and a protective physical barrier, for example, from ultraviolet light. Follicles also specialise as neuroreceptors (e.g. whiskers) or for sexual communication like the lion’s mane [10]. Human hair’s main functions are protection and communication; it has virtually lost insulation and camouflage roles, although seasonal variation [11–13] and hair erection when cold indicate the evolutionary history. Children’s

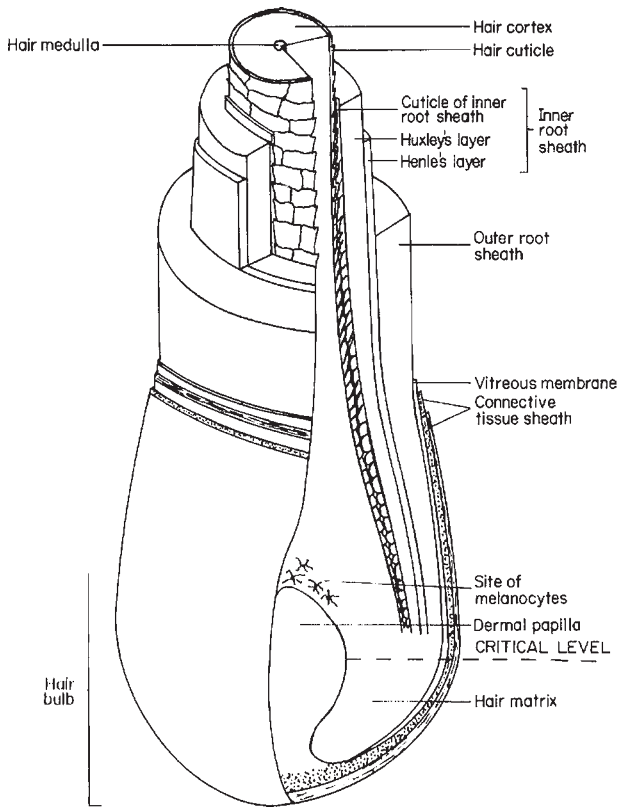

Figure 1.1 The hair follicle. The right-hand side of this diagram shows a section through the lower hair follicle while the left represents a three-dimensional view cut away to reveal the various layers. Drawing by Richard J. Dew. Reproduced from Randall [3].

hairs are mainly protective; eyebrows and eyelashes stop things entering the eyes, while scalp hair probably prevents sunlight, cold, and physical damage to the head and neck [14]. Scalp hair is also important in social communication. Abundant, good-quality hair signals good health, in contrast to sparse, brittle hair indicating starvation or disease [15]. Customs involving head hair spread across many cultures throughout history. Hair removal generally has strong depersonalising roles (e.g. head shaving of prisoners and Christian/Buddhist monks), while long uncut hair has positive connotations like Samson's strength in the Bible.

Other human hair is involved in sexual communication. Pubic and axillary hair development signals puberty in both sexes [16–18], and sexually mature men exhibit masculinity with visible beard, chest, and upper pubic diamond hair (Fig. 1.2). The beard's strong signal and its potential involvement in a display of threatening behaviour, like the lion's mane, [5,10,14] may explain its common removal in "Westernised" countries. This important communication role explains the serious psychological consequences and impact on quality of life seen in hair disorders like hirsutism, excessive male pattern hair growth in women, and hair loss, such as alopecia areata, an autoimmune disease affecting both sexes [19]. Common balding, androgenetic alopecia or male pattern hair loss [20], also causes negative effects, even among men who have never sought medical help [6]. Its high incidence in Caucasians and occurrence in other primates suggest a natural phenomenon, a secondary

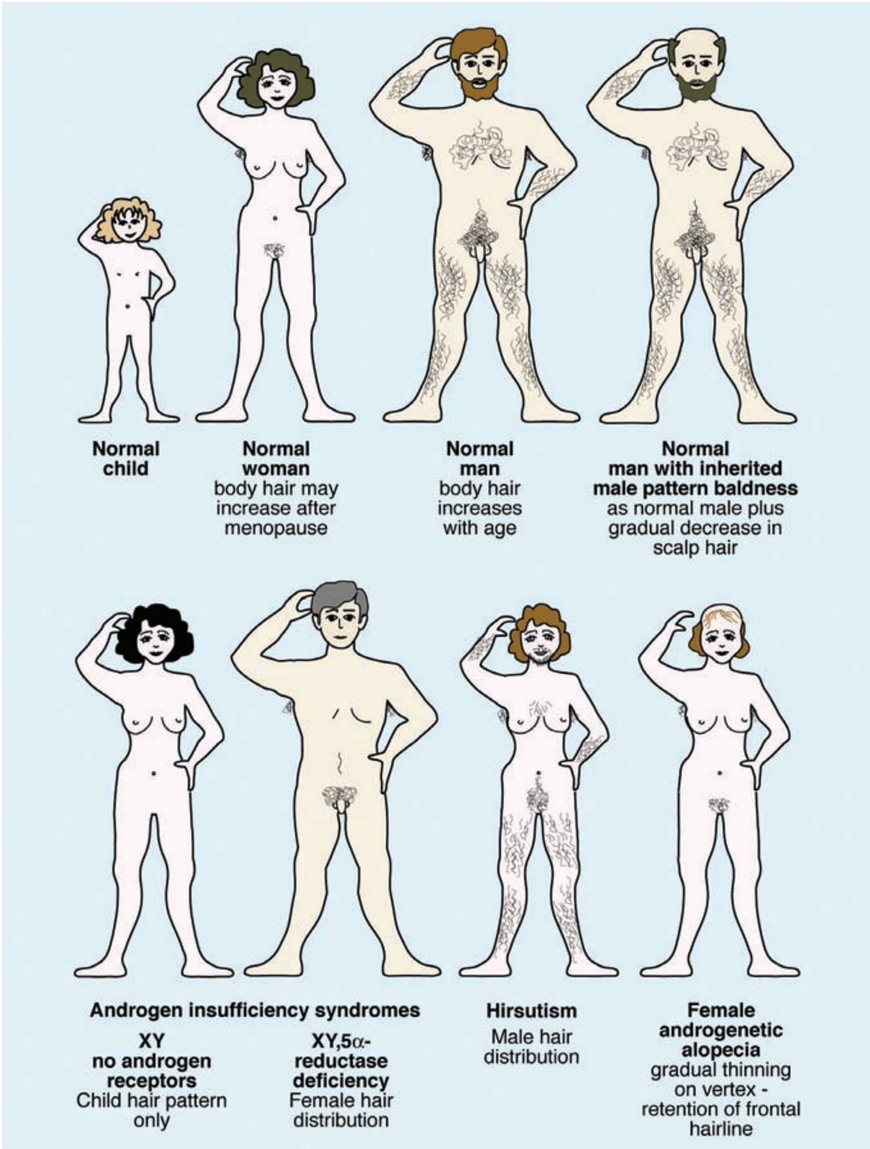

Figure 1.2 Human hair distribution under differing endocrine conditions. Normal patterns of human hair growth are shown in the upper panel. Visible (i.e. terminal) hair with protective functions normally develops in children on the scalp, eyelashes, and eyebrows. Once puberty occurs, further terminal hair develops on the axilla and pubis in both sexes and on the face, chest, limbs, and often back in men. In people with the appropriate genetic tendency, androgens may also stimulate hair loss from the scalp in a patterned manner causing androgenetic alopecia. The various androgen insufficiency syndromes (lower panel) demonstrate that none of this occurs without functional androgen receptors and that only axillary and female pattern of lower pubic triangle hairs are formed in the absence of 5α-reductase type-2. Male pattern hair growth (hirsutism) occurs in women with abnormalities of plasma androgens or from idiopathic causes and women may also develop a different form of hair loss, female androgenetic alopecia. Reproduced from Randall [221].

sexual characteristic, rather than a disorder. Marked balding would identify the older male leader, like the silver-backed gorilla or the senior stag's largest antlers. Other suggestions include advantages in fighting, as flushed bald skin would look aggressive or offer less hair for opponents to pull [14]. If any of these were evolutionary pressures to develop balding, the lower incidence among Africans [21] suggests that any possible advantages were outweighed by hair's important protection from the tropical sun. Whatever the origin, looking older is not beneficial in the industrialised world's current youth-orientated culture.

1.3 Hair Follicle Anatomy

The hair follicle can be divided into three anatomical compartments: the infundibulum, isthmus, and the inferior segment. The upper follicle is permanent, whereas the lower follicle, the inferior segment, regenerates with each hair follicle cycle. The infundibulum extends from the skin surface to the sebaceous duct. The isthmus, the permanent middle portion, extends from the duct of sebaceous gland to the exertion of arrector pilli muscle. The inferior segment consists of the suprabulbar area and the hair bulb. The hair bulb consists of extensively proliferating keratinocytes and pigment-producing melanocytes of the hair matrix that surround the pear-shaped dermal papilla, which contains specialised fibroblast-type cells embedded in an extracellular matrix and separated from the keratinocytes by a basement membrane [22]. The hair matrix keratinocytes move upwards and differentiate into the hair shaft, as well as into the inner root sheath; the melanocytes transfer pigment into the developing hair keratinocytes to give the hair its colour. The epithelial portion of the hair follicle is separated from the surrounding dermis by the *perifollicular connective tissue* or *dermal sheath*. This consists of an inner basement membrane called the hyaline or glassy membrane and an outer connective tissue sheath. The major compartments of the hair follicle from the innermost to the outermost include the hair shaft, the inner root sheath, the outer root sheath, and the connective tissue sheath (Fig. 1.1).

1.3.1 The Hair Shaft

The hair shaft consists of the medulla, cortex. Immediately above the matrix cells, hair shaft cells begin to express specific hair shaft keratins in the prekeratogenous zone [23]. The medulla is a central part of larger hairs, such as beard hairs, and a specific keratin expressed in this layer of cells can be controlled by androgens [24]. The cortex is composed of longitudinally arranged fibres. The hair shaft cuticle covers the hair, and its integrity and properties have a great impact on the appearance of the hair. It is formed by a layer of scales that interlock with opposing scales of the inner root sheath, which allows the hair shaft and the inner root sheath to move upwards together.

1.3.2 The Inner Root Sheath

The inner root sheath consists of four layers: the cuticle, Huxley's layer, Henle's layer, and the companion layer. The cells of the inner root sheath cuticle partially overlap with the cuticle cells of the hair shaft, anchoring the hair shaft tightly to the follicle. Inner root sheath cells produce keratins 1/10 and trichohyalin that serve as an intracellular “cement” giving strength to the inner root sheath to support and mould the growing hair shaft, as well as guide its upward movement. The transcription factor GATA-3 is critical for inner root sheath differentiation and lineage. Mice lacking this gene fail to form an inner root sheath [25]. The inner root sheath separates the hair shaft from the outer root sheath, which forms the external concentric layer of epithelial cells in the hair follicle.

1.3.3 The Outer Root Sheath

The outer root sheath contains a heterogeneous cell population including keratinocytes expressing keratins 5 and 14, keratinocyte and melanocyte stem cell progeny migrating downward to the hair matrix, and differentiating melanocytes [26–29]. Between the insertion of the arrector pili muscle and duct of the sebaceous gland the outer root sheath forms a distinct bulge, which has been identified as a reservoir of multipotent stem cells [30]. These cells are biochemically distinct and can be identified by long-term retention of BrdU or by immunodetection of cytokeratins 15 and 19, CD 34 (in mice), and CD 200 (in humans) [31–34]. In addition, these cells are characterised by their low proliferative rate and their capacity for giving rise to several different cell types including epidermal keratinocytes, sebaceous gland cells, and the various different types of epithelial cells of the lower follicle [35]. This area also contains melanocyte stem cells [36]. Moreover, recently nestin, the neural stem cell marker protein, was also shown to be expressed in the bulge area of the hair follicle. Nestin-positive stem cells isolated from this area could differentiate into neurons, glia, smooth muscle cells, and melanocytes in vitro. Experiments in mice confirmed that nestin-expressing hair follicle stem cells can differentiate into blood vessels and neural tissue after transplantation to the subcutis of nude mice [37]. These experiments suggest that hair-follicle bulge-area stem cells may provide an accessible source of undifferentiated multipotent stem cells for therapeutic applications [37].

1.3.4 The Dermal Papilla

The hair bulb encloses the follicular dermal papilla, which comprises a group of mesenchyme-derived cells, the dermal papilla cells, mucopolysaccharide-rich stroma, nerve fibres, and a single capillary loop. The follicular papilla is believed to be one of the most important drivers to instruct the hair follicle to grow and form a particularly sized and pigmented hair shaft. Several experiments have shown that the dermal papilla has powerful inductive properties. Dermal papilla cells transplanted into non-hair-bearing epidermis are able to induce the formation of new hair follicles [38,39]. The dermal papilla is an essential source of paracrine factors critical for hair growth and melanogenesis; it is believed to be the interpreter of circulating signals such as hormones to the follicle (discussed in Section 1.7). Specific examples of factors produced by the dermal papilla that influence hair growth include noggin, which exerts a hair growth-inducing effect by antagonising bone morphogenetic protein (BMP) signalling and activation of the BMP receptor IA expressed in the follicular epithelium [40]. Keratinocyte growth factor (KGF) is also produced by the anagen dermal papilla, and its receptor, FGFR2, is found predominantly in the matrix keratinocytes. The activation of this pathway by injections of KGF into nude mice induces hair