Techniques in Small Animal Wound Management

Edited by **Nicole J. Buote**

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Nicole J. Buote DVM, DACVS-SA
ACVS Founding Fellow Minimally Invasive Surgery (Soft Tissue)
Associate Professor
Department of Clinical Sciences
Small Animal Surgery Section
Soft Tissue Service
Cornell University School of Veterinary Medicine
Ithaca, NY, USA

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This textbook is dedicated to my family, whom I love the most and the best. Thank you for pushing me, for supporting me, and understanding me.

To my parents, Robert and Sharon, thank you for always urging me to think big and work hard. I have not and will not "settle."

Nathan, thank you for all your support during the creation of this book. I know it has been hard, and I couldn't have done it without you.

To my boys, William and Nicholas, thank you for all the hugs and support and for making me take a break occasionally. I hope you see the value in all this hard work. Love you best.

Contents

List of Contributors

Angela C. Banz, DVM, DACVS
VCA Northwest Veterinary Specialists
Clackamas, OR, USA

Cheryl Braswell, DACVECC, CHT-C, CVPP, CHPV
Spring City, TN, USA

Nicole J. Buote, DVM, DACVS-SA
ACVS Founding Fellow, Minimally Invasive Surgery (Soft Tissue)
Department of Clinical Sciences
Cornell University
Ithaca, NY, USA

Ryan P. Cavanaugh, DVM, DACVS-SA
ACVS Founding Fellow, Surgical Oncology
Associate Professor of Small Animal Surgery
Ross University School of Veterinary Medicine
St. Kitts, West Indies

Colin Chik, DVM
Department of Clinical Sciences
Cornell University
Ithaca, NY, USA

Kristin A. Coleman, DVM, MS, DACVS-SA
Gulf Coast Veterinary Specialists
Houston, TX, USA

James D. Crowley, BVSc
Small Animal Specialist Hospital
Sydney, Australia

Rebecca M. Harman, PhD
Department of Microbiology and Immunology
Baker Institute for Animal Health
Cornell University
Ithaca, NY, USA

Galina Hayes, BVSc, PhD, DACVECC, DACVS
Department of Clinical Sciences
Cornell University
Ithaca, NY, USA

Celine S. Kermanian, DVM
VCA West Los Angeles Animal Hospital
Los Angeles, CA, USA

M.S. Amarendhra Kumar, BVSc., MVSc., MS, PhD
Department of Medical Education
Tufts University Schools of Medicine and Dental Medicine
Boston, MA, USA

Daniel J. Lopez, DVM, DACVS-SA
Department of Clinical Sciences
Cornell University
Ithaca, NY, USA

Jill K. Luther, DVM, MS, DACVS-SA
Heartland Veterinary Surgery, LLC
Columbia, MO, USA

Brian Marchione, DVM, DACVO
Ocuvet Inc., Los Angeles, CA, USA

Megan Mickelson, DVM, DACVS-SA
ACVS Fellow of Surgical Oncology
College of Veterinary Medicine
University of Missouri
Columbia, MO, USA

Nathan Peterson, DVM, MS, DACVECC
Department of Clinical Sciences
Cornell University
Ithaca, NY, USA

Kathryn A. Pitt, DVM, MS, DACVS-SA
ACVS Fellow, Surgical Oncology
Wanderlust Veterinary Services
Academic and Private Practice Locum

Aarthi Rajesh, PhD
Department of Microbiology and Immunology
Baker Institute for Animal Health
Cornell University
Ithaca, NY, USA

Desiree D. Rosselli, DVM, DACVS-SA
VCA West Los Angeles Animal Hospital
Los Angeles, CA, USA

Bryden J. Stanley, BVMS, MANZCVS, MVetSc, MRCVS, Diplomate ACVS
Animal Surgical Center of Michigan
Flint, MI, USA

Julia P. Sumner, BVSc, DACVS-SA
Small Animal Specialist Hospital
Sydney, Australia

Gerlinde R. Van de Walle, DVM, PhD
Department of Microbiology and Immunology
Baker Institute for Animal Health
Cornell University
Ithaca, NY, USA

Foreword

It is with great pleasure that I write this foreword for the outstanding textbook, *Techniques in Small Animal Wound Management*, edited by Dr. Nicole J. Buote. I am acutely aware of the impact full-thickness wounding has on our small animal patients as well as how profoundly devastating and overwhelming it is for owners to be faced with the seemingly monumental task of restoring pain-free function to their much-loved family member. Our competence and confidence in effectively managing a challenging open wound play an essential role for the health and well-being of both patients and owners.

Wound management is both science and art, and as veterinarians, we are often faced with many complex issues, commonly requiring a multidisciplinary approach. Appropriate management of the wound and periwound until both are healthy is the first crucial step. Only then can clinicians choose the optimal reconstructive technique which is critical to successful healing. The choices we face at each step can at times appear too numerous and bewildering. The field is constantly evolving, requiring the unwavering commitment of wound care practitioners to maintaining an open mind, and researching newer therapies and modalities. Each wound is different, and each patient presents a unique set of challenges and complications. Every owner is different, and communication becomes a vital part of the journey. This remarkable compendium offers a comprehensive and insightful guide that will undoubtedly become a cornerstone in the education of veterinary students, veterinarians, and specialists alike, instilling knowledge and confidence. Dr. Buote, with her vision and dedication, has brought together a formidable assembly of experts who have collectively amassed and generously shared their knowledge.

"*Techniques in Small Animal Wound Management*" is well-structured, beginning with a solid foundation in anatomical considerations, principles of wound healing, and factors influencing this intricate and fascinating progression. Understanding how a wound heals is essential, as it forms the bedrock upon which successful wound management strategies are built. Wound complications are, unfortunately, a reality, and this textbook equips readers with the knowledge and skills to recognize and address them appropriately – a necessary reminder for us to maintain adaptability and critical thinking. Wound terminology is nuanced, and this textbook clearly outlines how we classify wounds, how we describe wounds, and the language of wound closure. Effective communication among veterinary professionals is indispensable, and understanding the terminology is the bridge that connects us in our pursuit of excellence.

The journey through this book continues with a comprehensive exploration of the initial evaluation of the patient and the wound, emphasizing the all-important basic tenets of initial wound management, which are so critical for laying the groundwork for effective wound care. The book progresses to discussing a plethora of topical treatments, dressings, and bandages, providing insights into the latest advancements in wound care. The chapters on topical treatments and dressings, ranging from traditional to cutting-edge biologic and regenerative therapies, exemplify the evolving nature of wound management in veterinary medicine. These exciting newer therapies hold the promise of not only accelerating healing but also improving the overall quality of the repaired tissues.

The art of reconstructing wounds is an intricate endeavor full of decision-making, and the latter part of the textbook offers a solid guide to mastering variously shaped wounds, tension-relieving techniques, skin flaps, and free grafting. These skills are critical in the pursuit of a robust wound closure with excellent functional outcomes, and becoming familiar with such procedures greatly improves our competence. The inclusion of a chapter covering specific wound types, including several case studies, serves as a valuable tool, guiding readers through real-life scenarios and underscoring the unique nature of every wound and the necessity of individualized care.

Each wound, each patient, each owner, is a journey to be undertaken and a family story waiting to be told. It is our responsibility to guide that journey safely to the best possible outcome so that the story can be told well. Dr. Buote's *Techniques in Small Animal Wound Management* will facilitate veterinarians' ability to be successful in this responsibility. In closing, I extend my heartfelt gratitude to Dr. Nicole Buote and the contributors of this extraordinary textbook. Your dedication to the advancement of small animal wound management is evident on every page, and your commitment to spreading knowledge and improving care is inspiring.

8 October 2023 *Bryden J. Stanley, BVMS, MANZCVS, MVetSc, MRCVS, Diplomate ACVS*

Preface

Since the origin of medical practice, wound management has been critical to human and animal survival. Beginning with the Barber Surgeons of Henry V through the robotic surgeons of today, the treatment of wounds has captivated students, clinicians, and researchers. Whether you are a general practitioner, an emergency doctor, or a specialist, wounds will likely comprise a consistent part of your practice. The ability to assess and successfully treat wounds is therefore one of the most important skills you as a veterinarian can possess. The treatments available for wounds are as varied as their causes, and the complexity of their management is often challenging, leaving clinicians either elated or frustrated. These cases test a doctor's examination skills, clinical decision-making, and client communication. Clinicians of all experience levels require up-to-date information to ensure the best outcomes for their patients.

Even if wound management is a daily occurrence in your practice, the volume of new information published on a yearly basis can be overwhelming. There are already amazing resources on the biology of wounds and reconstruction techniques. We hope to complement these texts with the most current information in clinically relevant, easy-to-read sections. This textbook offers a depth of anatomy and physiology knowledge that is emphasized with clinical case examples and specific treatment recommendations in an effort to provide "something for everyone." Some information, such as the stages of wound healing, wound terminology, and initial evaluation, is a requirement for any text on wounds and can be found within; but we have added in-depth chapters on the anatomy of tissues most often affected by wounds and common complications that clinicians are likely to encounter to provide important clinical context. Many authors in this book are leaders in the field, publishing ground-breaking research on the treatments they discuss and providing insight from years of experience. On a specific note, this textbook includes 14 chapters on specific wound types, delivering detailed information about unique wound characteristics, treatment recommendations, and prognosis. While some chapters necessarily delve into advanced techniques (e.g. hyperbaric oxygen therapy, negative pressure wound therapy, stem cells, etc.), this text also includes hundreds of photographs and illustrations describing the basics of bandaging, drain placement, and the reconstructive techniques a recent graduate may need.

As wound treatments continue to evolve, so will this book, and we hope the online resources and videos add value for our readers. It is my intent to add updated references and product lists on a yearly basis to supplement the information contained in this textbook in between editions since wound management changes rapidly. I believe that giving back to the veterinary community is important; therefore, a portion of the proceeds from the sale of this book will be donated to the Association of Women Veterinary Surgeons (AWVS, www.awvs.org), an organization intent on supporting female surgeons and house officers to ensure they succeed and thrive. A textbook of this type is not produced solely by the editor, and I want to extend my deepest gratitude to every contributor for their tireless work as well as many of my colleagues at Cornell University who provided chapters, pictures, drawings, and encouragement. The time and energy spent to better prepare students, residents, and our colleagues is well worth it, and we hope this textbook helps you care for your patients and clients for years to come.

Knowing what must be done does away with fear.
—Rosa Parks

Nicole J. Buote, DVM, DACVS-SA
ACVS Founding Fellow Minimally Invasive Surgery (Soft Tissue)
Associate Professor
Department of Clinical Sciences,
Small Animal Surgery Section,
Soft Tissue Service,
Cornell University School of Veterinary Medicine,
930 Campus Road,
Ithaca, NY 14853, USA
E-mail address: Njb235@cornell.edu

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/buote/wounds

The website includes:

- Videos that are supplementary to the script.

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The Skin

M.S. Amarendhra Kumar

Department of Medical Education, Tufts University Schools of Medicine and Dental Medicine, Boston, MA, USA

The **integument** comprises the skin and its appendages (referred to as the **adnexa**), including structures such as hair, glands, digital pads, and claws [1–3]. The adnexal structures are of epidermal origin; they are continuous with the epidermal layer of the skin, supported by the underlying connective tissue.

Skin: The **skin** (**cutis**) is one of the body's largest and most important organs, for it forms a protective layer against the external environment and plays a crucial role in homeostasis. It is composed of three layers [4], the epidermis, dermis, and hypodermis (or subcutis), all firmly attached to each other. Important differences between cats and dogs exist (Table 1.1) and effect the healing properties and treatment options available when managing injuries. Skin transmits various stimuli from the external environment to the central nervous system (CNS). The nerve fibers carrying these stimuli penetrate the tissues (muscles and fascia) underlying the hypodermis and travel to the CNS, often within the fascial planes that ultimately merge with the periosteum of the appendicular and axial skeletal elements (Figure 1.1). Fascial planes form distinct compartments for individual muscles in many regions of the body. The skin's vascular components travel by similar routes and are responsible for maintaining body temperature within physiologic limits and regulating systemic blood pressure.

Epidermis: The epidermis of the skin is avascular and serves as the outermost protective layer of the body (Figure 1.2). It minimizes trans-epidermal water loss, prevents invasion by infectious agents and other harmful substances, absorbs ultraviolet radiation by the melanocytes, and aids in Vitamin D biosynthesis. The basic structure of the epidermis is similar in all domesticated mammals with some minor regional and species differences. The thickness of the epidermis is inversely proportional to the density of the hair coat. In dogs and cats, since most of the skin surface is covered with hair, the epidermis is relatively thin. In the dog, the epidermis consists of two to three layers of living cells increasing to 10 layers [5–7] while in the cat, the epidermis is slightly thinner. The average time for epidermal turnover is 22 days in carnivores regardless of the thickness of the epidermis [8, 9]. Dermal papillae are small fingerlike extensions into the epidermis, surrounded by rete ridges of the epidermis. These two structures interlock with each other, anchoring the epidermis. Epidermal rete ridges are absent in most of the skin in carnivore skin due to the dense haircoat [10, 11]. The hair follicles extend into the dermis, firmly anchoring the epidermis. In sparsely haired regions such as the scrotum, inguinal, and axillary areas, the epidermis is slightly thicker and epidermal rete ridges may be observed. The term **glabrous skin** is applied to areas devoid of hairs, such as the nasal plane, lips, and genitals as well as parts of the limb extremities such as digital pads. These regions may have several layers of living keratinocytes, prominent basement membranes, and form epidermal rete ridges [10].

The epidermal layer rests upon a meshwork of extracellular fibers (**dermal–epidermal junction**) upon which the keratinocytes rest, called the **basement membrane** (or **basal lamina**), which is acellular and avascular (Figure 1.2). If the basement membrane is disrupted, as with a skin wound, other cells (such as activated fibroblasts and neutrophils) will pass through it from beneath to participate in healing processes, forming scars, extending capillary loops, and developing granulation beds. Otherwise, the basal lamina remains impassable. Beneath it is the dermis, the vascularized second layer of the skin.

Nonkeratinocytes: Several cell types are contained in these two major layers of the skin (the epidermis and dermis). The most common cells within the epidermis are **keratinocytes**, making up 85% of all epidermal cells. The nonkeratinocytes account for approximately 15% of the epidermis and include the melanocytes, tactile epithelioid cells (*Merkel cells*), and

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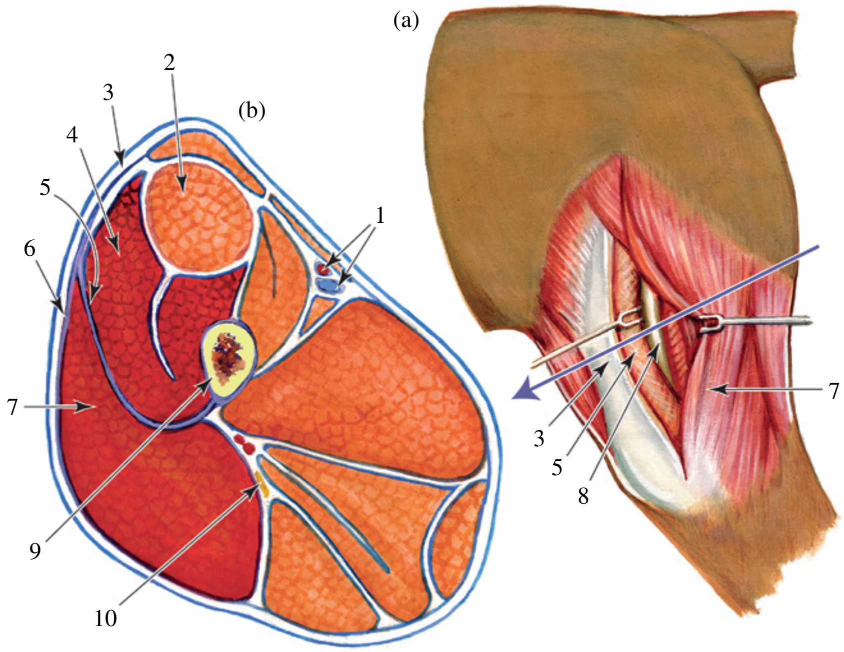

Figure 1.1 (a) Lateral approach to the shaft of the femur is shown. The fascia lata is split along the cranial margin of the biceps femoris m. (b) Cross-sectional view of left thigh. Note the location of nerves and blood vessels between the fascial planes. 1, Femoral artery and vein; 2, Rectus femoris m; 3, Fascia lata; 4, Vastus lateralis m; 5, Deeper lamina of fascia lata which runs between the vastus lateralis and biceps femoris muscles and reaches the shaft of the femur. The biceps femoris and vastus lateralis are therefore separated along this plane to reach the femur shaft; 6, Superficial lamina of fascia lata; 7, Biceps femoris; 8, Lateral shaft of femur; 9, Sciatic nerve.

intraepidermal macrophages (or *Langerhans* cells). **Melanocytes** are derived from neural crest cells. **Dendritic cells** (DCs) are a heterogeneous group of antigen-presenting leukocytes with a common origin that play an important role in the activation of the immune system. These cells have potent antigen-presenting capabilities with characteristic dendritic morphology. Three main cutaneus DC populations have been described: intraepidermal Langerhans cells (LCs), dermal myeloid DCs, and dermal plasmacytoid DCs (pDCs). The **intraepidermal macrophages** (***Langerhans cells***) are interspersed among the much more numerous keratinocytes (Figure 1.3) and act as antigen-presenting cells [13]. The LCs are one type of antigen-presenting DCs involved in cutaneus hypersensitivity reactions. They are capable of inducing

Table 1.1 Summary of skin differences between dogs and cats.

Item	Dog	Cat
Number of living epidermal cell layers	2–3 in most places, up to 10 layers in some places	Fewer layers of living epidermal cells
Merkel cell carcinoma	Relatively benign	Relatively aggressive
Melanocytes	More numerous	Fewer
Angiosomes (cutaneus perforating vessels)	Greater number of cutaneus perforating vessels in dermis/hypodermis	Fewer number of cutaneus perforating vessels in dermis/hypodermis
The density of tertiary and higher-order vessels	Higher density of tertiary and higher-order vessels	A lower density of tertiary and higher-order vessels
Hairs	Fewer secondary hairs (~9)	More secondary hairs (~12)
Wool (secondary) hairs	No medulla	Contains a medulla
Scrotal skin	Usually, sparse hair	Hairy
Facial sebaceous glands	Fewer on the face	More numerous on the face
Tail glands (modified sebaceous glands)	Located caudal to Ca 7 vertebra	Located at the baser of the tail
Dermis/hypodermis collagen production	May have a higher rate of collagen production	May have a lower rate of collagen synthesis ability
Wound repair	Rapid granulation tissue production	Delayed granulation tissue production

antiviral-specific immune responses *in vivo* [14]. The LCs survey the epithelium constantly for pathogens and migrate to the lymph nodes where they present microbial antigens to T-cells. This results in developing tolerance and maintaining tissue homeostasis [15]. Langerhans cells in the skin are continuously replenished from circulating bone marrow precursors [16, 17]. There is steady-state migration of LCs to skin-draining lymph nodes, perhaps to induce and maintain tolerance to cutaneus antigens. Their number in the epidermis is small compared to keratinocytes, and they are largely present in the upper stratum spinosum.

Tactile epithelioid cells (***Merkel* cells**) are in the stratum basale of hairless and hairy skin and are numerous in the nasal plane of carnivores. These cells, in association with sensory nerve endings, function as epidermal mechanoreceptors (Figure 1.3) that transmit tactile sensations (touch) through cutaneus nerves [18]. Merkel cells are neurosecretory cells thought to be derived from neural crest cells [19, 20]. However, recent studies in mice and humans indicate they may be derivatives of epidermal cells [21, 22]. They are slowly adapting cutaneus mechanoreceptors located in the basal layer of the epidermis. Merkel cell afferents are gentle touch receptors activated by steady skin indentation [21]. In humans, Merkel cell carcinoma is a rare cutaneus neuroendocrine carcinoma that is a highly malignant skin cancer most often associated with the presence of Merkel cell poliovirus genes (MCPyV) [22–24]. Originally thought to arise from Merkel cells, recent studies indicate in humans, the cancer cell origin is from primitive epidermal stem cells, early B-cells, or dermal fibroblasts [25–27]. In canine and feline Merkel cell carcinoma, MCPyV genes were not detected, indicating a different etiology for cancer [28]. In addition, Merkel cell carcinoma appears to be more benign in dogs but more aggressive in cats [29–31].

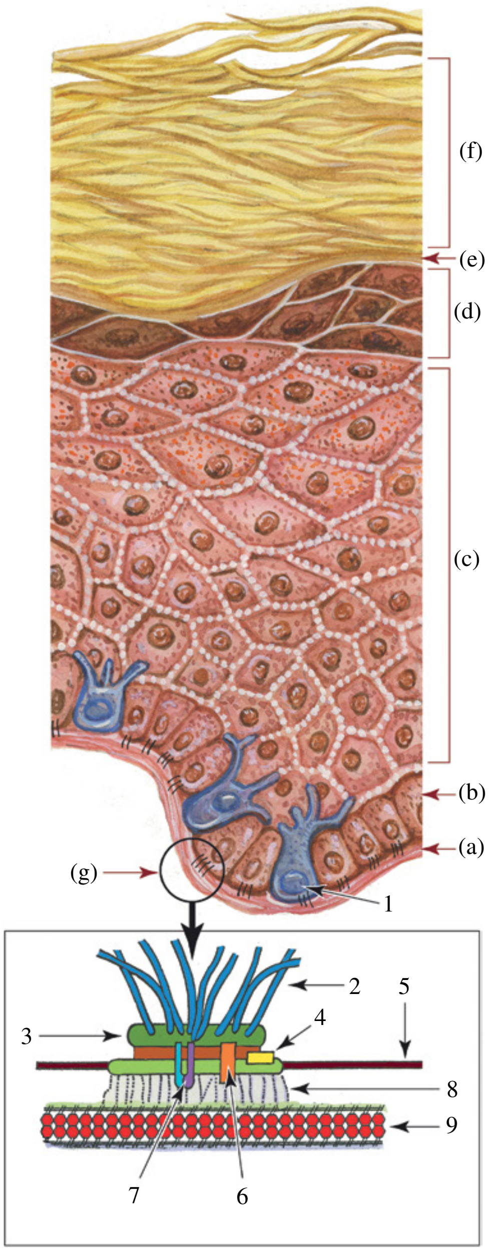

Figure 1.2 Layers of epidermis. (a) Basement membrane. (b) Stratum basale. (c) Stratum spinosum. (d) Stratum granulosum. (e) Stratum lucidum. (f) Stratum corneum. (g) Cells of stratum basale are anchored to the basement membrane by hemidesmosomes. 1, Melanocyte; 2, Keratin filaments (tonofilaments); 3, Plate; 4, Bullous pemphigoid antigen-1; 5, Plasma membrane; 6, Bullous pemphigoid antigen-2; 7, Integrin; 8, Anchoring filaments; 9, Basal lamina.

Cutaneus Immune Barrier

Skin, as an immunologic organ, is present at the critical junction between the host and the environment. The most important function is to guard against potentially damaging agents such as microbes, toxins, and radiation. This is effectively accomplished by the presence of anatomical, biochemical, and immunologic barriers. The anatomical barrier consists of the tight cell-to-cell junctions and associated skeletal proteins of the stratum corneum. This barrier is enhanced by sebaceous gland secretions. Biochemical barriers include hydrolytic enzymes, acids, lipids, and antimicrobial proteins. The immunologic barrier is composed of cellular and humoral constituents of the immune system. Within this barrier exist cooperative arms of innate and adaptive immunity [32]. The **innate immune system** is a primitive defense mechanism comprised immune cells such as macrophages, neutrophils, and LCs, and their associated inflammatory mediators such as cytokines and chemokines. To mount a defensive reaction against the invading pathogen, the innate immune system must discriminate between "self" and "non-self." Several molecules exist in pathogens absent in the host, collectively known as pathogen-associated molecular patterns (PAMPs). Innate immune cells use pattern recognition receptors (PRRs) such as toll-like receptors (TLRs), and peptidoglycan receptors (PGNs) to identify PAMPs in pathogens. Identification of pathogens triggers a cascade of inflammatory reactions including the secretion of cytokines and chemokines. These mediators further enhance the offensive assault on pathogens. Some of

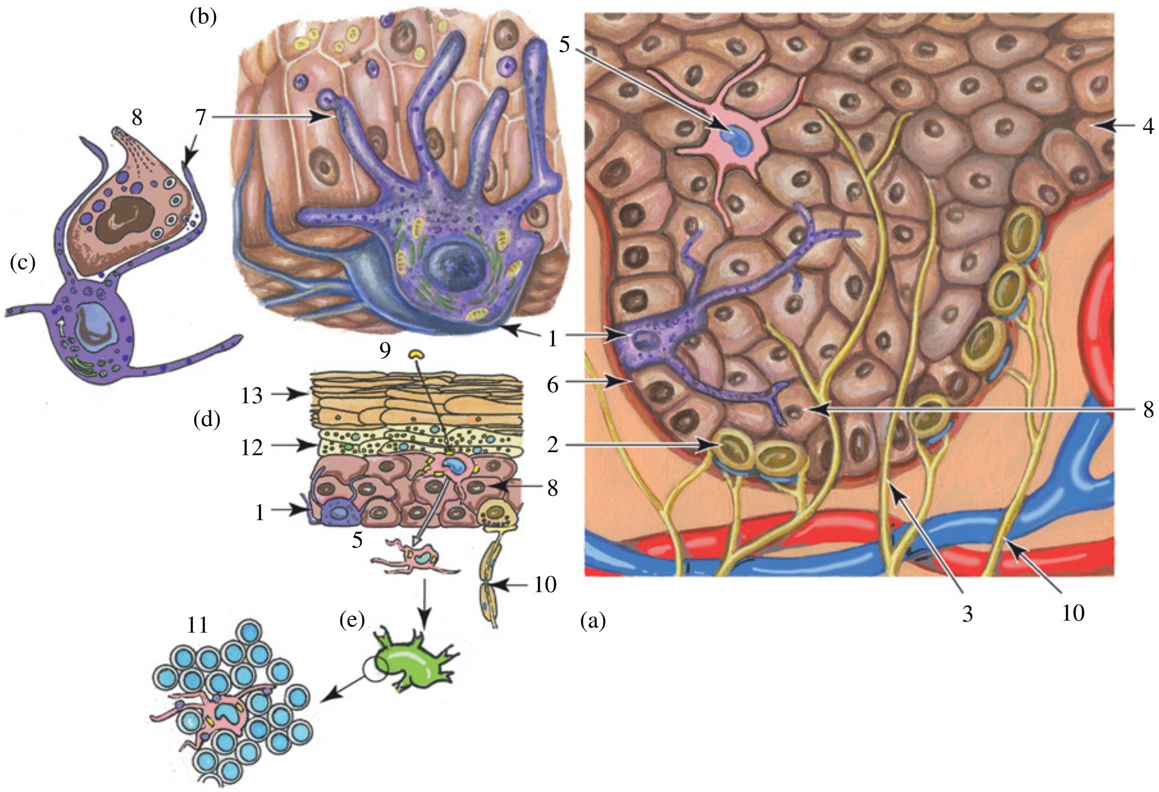

Figure 1.3 Keratinocytes and nonkeratinocytes of the epidermis. (a) Epidermis showing a melanocyte (1), Langerhans cell (5) and keratinocytes (8). (b) A melanocyte shown in-situ with its dendritic processes. (c) An isolated melanocyte shown transferring melanosomes along its cytoplasmic processes to an adjacent keratinocyte. (d) A Langerhans cell ingests an antigen by phagocytosis. It will then migrate from the epidermis to local lymph nodes; (e) Once the Langerhans cells reach a lymph node and transform into dendritic cells, they stimulate T lymphocytes. 1, Melanocyte; 2, Tactile epithelioid (*Merkel*) cells are mechanoreceptors derived from the neural crest. They are shown with their sensory nerve endings exhibiting a broad nerve plate (*Merkel* cell-neurite complex or the tactile hair disc, shown in blue); 3, Unmyelinated nerve fibers that penetrate the epidermis. These nerve endings mainly detect temperature and pain sensations; 4, Stratum basale; 5, A Langerhans cell, which belongs to the immune system. It detects foreign antigens and presents them to T-lymphocytes; 6, Basement membrane; 7, Cytoplasmic processes of a melanocyte; 8, A keratinocyte adjacent to a melanocyte receiving melanosomes; 9, Antigens that penetrate the epidermis are detected by the Langerhans cells; 10, A sensory nerve fiber terminating on a Merkel cell; 11, T-lymphocytes activated by Langerhans cell in the lymph node; 12, Stratum granulosum; 13, Stratum corneum. *Source:* Concept Adapted from Kierszenbaum [12].

the primary players such as lymphocytes and DCs mediate and augment **adaptive immunity** (humoral immunity), which is more evolved and allows immunologic memory.

Melanocytes (Figure 1.3): Melanocytes are derived from the neural crest and are present mainly in the epidermal stratum germinativum and in hair follicles. **Melanophores** (Chromatophores) are found in lower vertebrates (fishes and amphibians) and differ from melanocytes in how they transfer melanin pigment to adjacent areas. Unlike melanocytes which can produce only **eumelanin** (brown/black) or **pheomelanin** (red/yellow), melanophores can synthesize several pigments [33, 34]. Melanophores are also derived from the neural crest and their main function is pigment aggregation in the center of the cell or dispersion throughout the cytoplasm, allowing the animal to effect color changes important for camouflage and social interactions. In mammals, melanocytes transfer **melanosomes** to adjacent keratinocytes of the basal layer via dendritic processes, protecting deeper layers of the skin from ultraviolet radiation (which is particularly damaging to cells during mitosis). Although melanocytes maintain close contact with keratinocytes via dendritic processes, they have a slower turnover rate than keratinocytes. In the dog, on average, one melanocyte exists for every 10–20 keratinocytes, while in the cat, there are fewer melanocytes [35]. The melanocytes, unlike the keratinocytes, are a stable population of cells living many years without undergoing cell division, while keratinocytes divide actively and live only a few days. If melanocytes decide to divide, the consequences are usually serious due to the development of malignant tumors [36].

Pigmentation

Melanocyte and melanosome activities are largely regulated by the pituitary hormone, alpha-melanocyte-stimulating hormone [37, 38] (α-**MSH**, also called **intermedin**). In some mammalian species (rat, rabbit, ox, etc.), the pars intermedia of the pituitary is well-defined and contains large amounts of α-MSH, but in other mammals (and birds) it is practically vestigial, and so α-MSH is thought to originate from the adenohypophysis. In the carnivores, the pars intermedia secretes α-MSH. Alpha-MSH shares an amino acid sequence with another pituitary hormone, adrenocorticotrophic hormone (**ACTH**). The adrenocorticotrophic hormone is composed of 39 amino acids, of which the first 13 represent α-MSH. Because of the common amino acid sequence of these two hormones, hyperpigmentation has been described in some animals with pituitary-dependent hyperadrenocorticism [39], and in others with Addison's-like disease where ACTH levels are increased.

Coat Color and Temperature: The color gene, the dominant C gene, codes for the enzyme tyrosinase (TYR), which is involved in the first step of melanin pigment production. Mutations in the TYR gene result in temperature-sensitive pigment production, producing *Burmese* and *Siamese* colors. Mutation of the TYR gene is also associated with the inhibition of fur pigmentation when temperatures rise above a certain level. When Siamese and Himalayan kittens are born, they are uniformly white due to the reasonably constant temperature of the intrauterine environment. Soon after birth, cooler segments of the body, mainly the extremities, begin to develop pigmentation. In older Siamese cats, the fur darkens as the entire body becomes slightly cooler, due to age-related reductions in cutaneus blood flow. Removal of fur in these cats' results in darker pigmentation of exposed growing hair due to a decrease in surface temperature. For this reason, unnecessary clipping of hair should be avoided in show cats of these breeds.

Alpha-MSH (and ACTH) cause melanosome dispersion, and thus skin darkening, while melatonin (from the pineal gland) and catecholamines cause melanosome concentration (and thus skin pallor). The term **melanoderma** is used to refer to increased melanin pigmentation of the skin, whereas the term **leukoderma** (Vitiligo) refers to a loss of this pigmentation [40]. Autoimmune dermatoses affecting melanocytes result in vitiligo in humans. Dogs and cats are also susceptible to this condition [41]. In dogs and cats, depigmentation mainly affects the face, including eyelashes, nasal planum, oral cavity, ears, and muzzle, but also noticed on footpads, scrotum, nails/claws. White coat color in cats is associated with blue (occasionally orange) eyes, and these animals sometimes exhibit a genetic predisposition to deafness. Calico coat color is sex-linked in cats [42] and is associated with females with XX chromosomes, or males with an extra X chromosome (Klinefelter's Syndrome, with XXY).

The **dermal–epidermal junction**: The dermal–epidermal junction is known as the **basement membrane zone** (Figure 1.2) consisting of the **basement membrane**. The basement membrane has a gate-keeping function controlling the bi-directional traffic of cells and bioactive molecules [43]. The basement membrane region is crucial to stabilizing epidermal attachment to the dermis, and it also acts as a barrier and filter zone. However, nutrients and water can freely diffuse through the basement membrane zone from the dermal side of the skin toward the epidermis. Although the terms "**basal lamina**" and "basement membrane" are used interchangeably, the term basal lamina is usually employed with electron microscopic descriptions, while the term "basement membrane" is generally used with light microscopy. The basement membrane zone is continuous along the entirety of the dermal–epidermal junction and the dermal intersection between hair follicles and skin glands. Based upon electron microscopic studies of this junction, two components of the basal lamina have been described, the **lamina lucida** (40 nm electron-lucent zone, mainly containing the glycoprotein laminin) and the **lamina densa** (50 nm electron-dense zone, composed mainly of collagen). The basement membrane core structural components include collagen IV, laminins, nidogens, and heparin sulfate proteoglycans [44]. The mechanical stability of the basement membrane depends largely on collagen IV scaffold [45]. The stratum basale cells of the epidermis are anchored to the basement membrane zone and dermis through specialized attachments called **hemidesmosomes** (so named because of their appearance as half-desmosomes, Figure 1.2). The outer layer of the hemidesmosomes interfaces with the plasma membrane while its inner layer interfaces with intermediate filaments. Anchoring filaments from hemidesmosome span across the lamina lucida to join lamina densa [46]. This junction is also often associated with numerous disease processes. Protein components such **bullous pemphigoid antigen** is a component of hemidesmosomes [47]. Bullous pemphigoid (BP) is an autoimmune disease in both humans and in animals, associated with antibody formation against the bullous pemphigoid antigen [48–50]. Transient cells also pass through the basement membrane, such as neoplastic cells in certain cancers, neutrophils, and other leukocytes during inflammation. Apparently, invading cells secrete proteolytic enzymes to dissolve the basement membrane [51, 52].

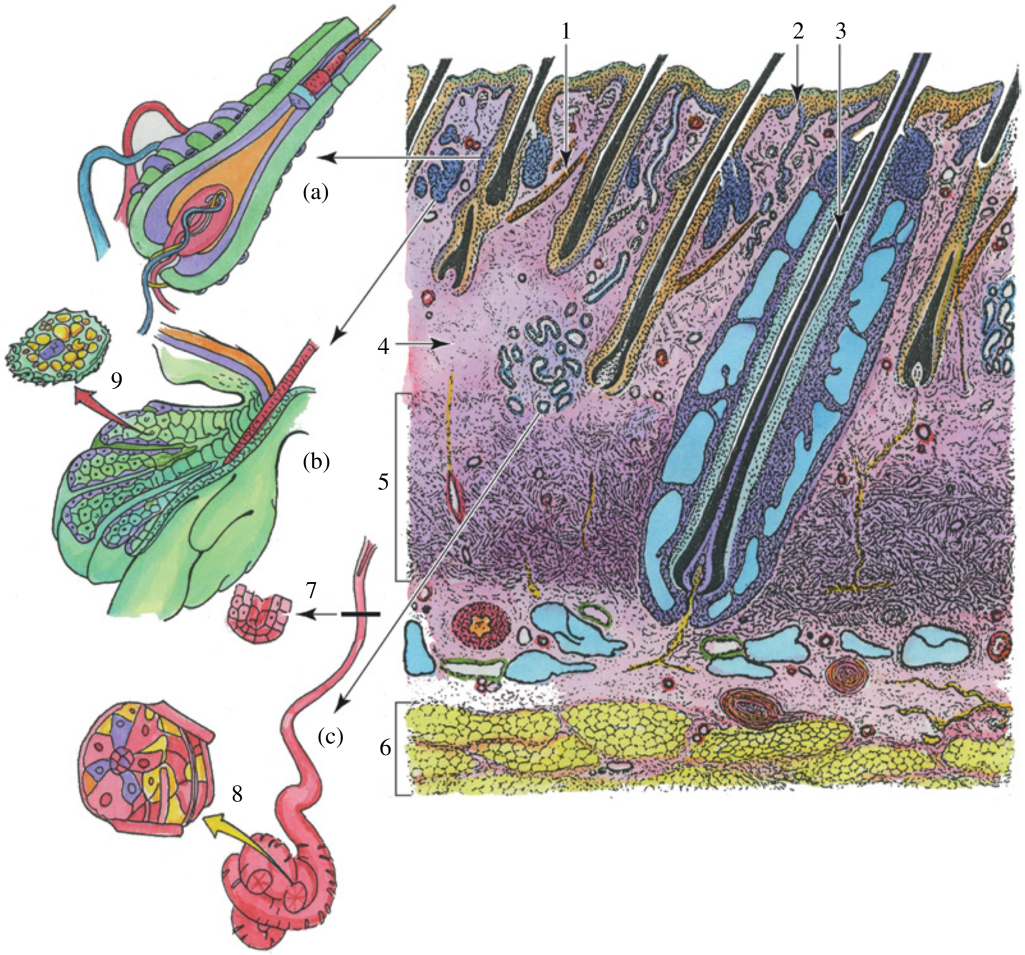

Figure 1.4 Schematic diagram of skin showing hairs and associated structures. (a) Simple hair follicle. (b) Sebaceous gland. (c) An eccrine sweat gland. 1, Arrector pili m; 2, Papillary layer of the dermis; 3, Sinus hair; 4, Dermis; 5, Reticular layer of the dermis; 6, Hypodermis with fat cells; 7, Cross sectional view of a sweat gland excretory duct; 8, Schematic view of the secretory portion of a sweat gland; 9, A sebaceous gland cell. *Source:* Adapted from Konig [53].

Other Structures: Among the epidermal adnexa of the skin are other structures such as hair follicles and sweat and sebaceous glands (Figure 1.4), all of which leave the confines of the epithelial layer and penetrate, some quite deeply, into the dermis [1–3]. Hair follicles are important not only for generating the hairs that insulate the body; but also, for serving as reservoirs for various stem cell populations, including keratinocyte precursors. The follicular bulb regions of the epidermal external root sheaths of some primary hair shafts (Figure 1.9) are associated with smooth muscles (*arrector pili* mm). These structures penetrate the deep dermal region, sometimes even to the hypodermis (Figure 1.5), and are distally attached to fibers in the superficial region of the dermis. These muscles raise the hairs to trap air and insulate the animal when its core body temperature falls.

Skin thickness varies widely in different regions of the body, with mean skin thickness in dogs varying from 0.5 to 5.0 mm and 0.4 to 2 mm in cats [5, 54, 55], depending on a variety of physiological variables including breed, anatomical region of the body, sex, age, and degree of skin hydration [56]. A report indicates a significant negative correlation between age and skin thickness in dogs [55]. The breed of the dog also influences skin thickness, Labrador retrievers exhibited thicker skin than other breeds [55]. The skin is extremely thick in areas prone to abrasions (e.g., footpads), yet thin in other regions (e.g., the flank). The stratum corneum is highly cornified where the skin is subjected to mechanical damage, as in the digital pads. Thick and thin skins are differentiated primarily based on the relative thickness of the stratum corneum, the outermost of the five layers of the epidermis. Hyperadrenocorticism results in thinning of the skin as a physical sign exposed to glucocorticoids [57].