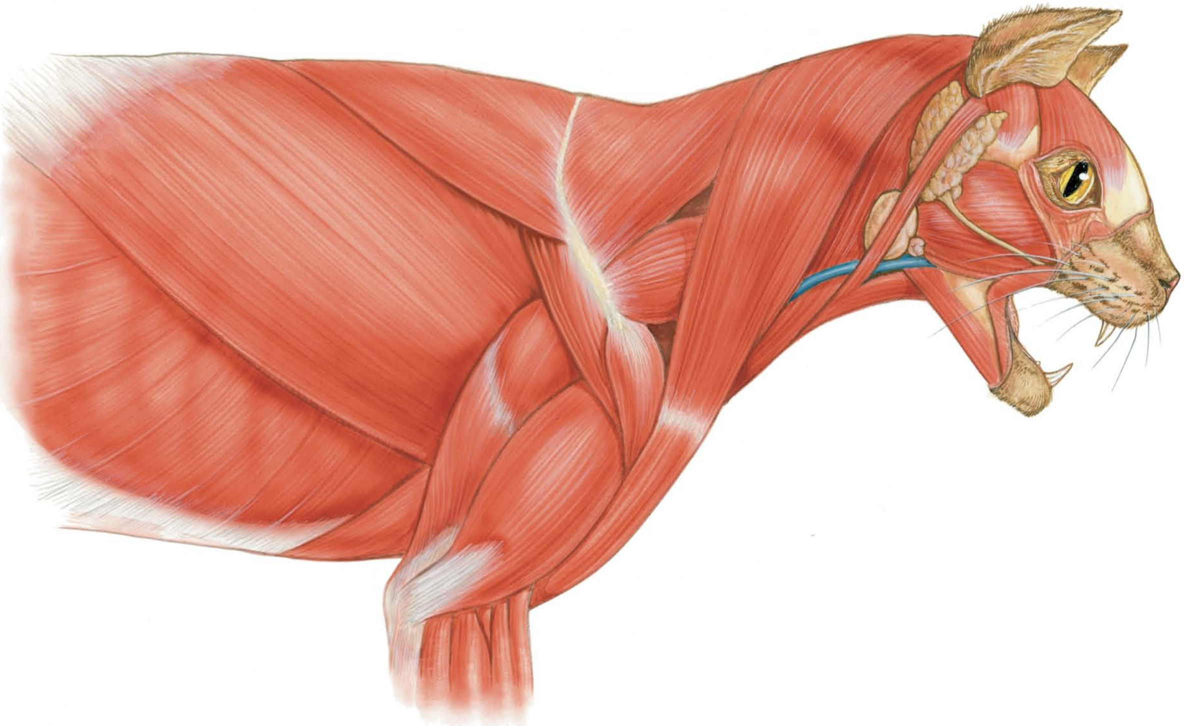
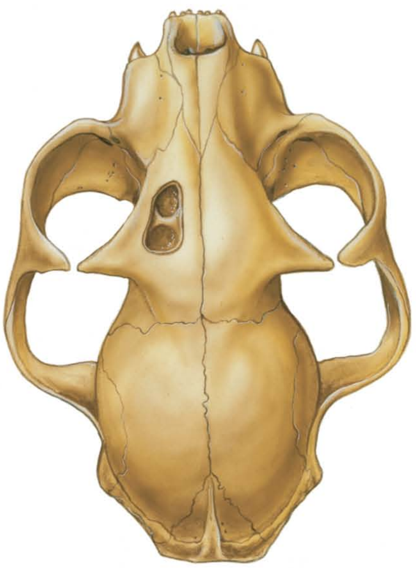
Atlas of Feline Anatomy

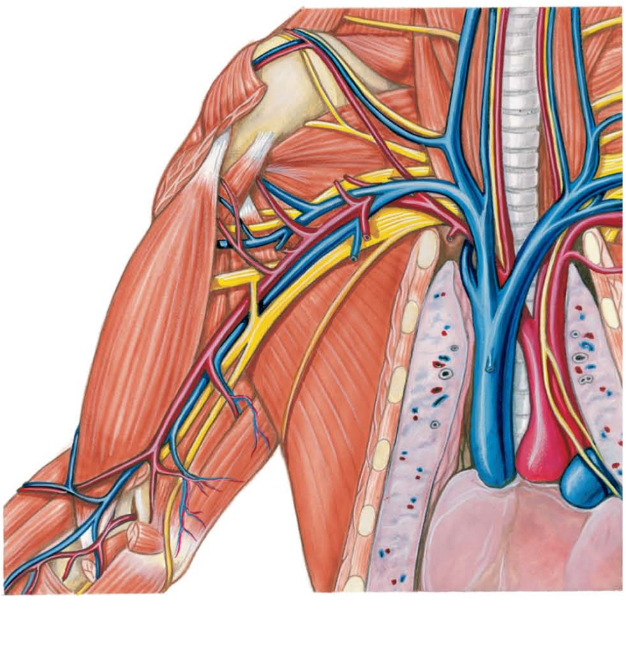
FOR VETERINARIANS

LOLA C. HUDSON
WILLIAM P. HAMILTON

SECOND EDITION







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Preface to the First Edition

"The cat is not a small dog" - unknown

This quotation succinctly states why we felt this book was needed. Although cats and dogs share many similarities as carnivores, they each have many unique characteristics. This uniqueness is important to veterinarians if we are to provide the best treatment to the animals in our care. The popularity of cats as pets has rapidly increased, but the pool of readily available information on veterinary medicine specific to cats has lagged behind. This is also true of scientific information on the anatomy of cats that is pertinent to clinical veterinary medicine. Certainly, anatomical information on felines is available if you know where to look. However, all too often, much of it uses archaic nomenclature, is inaccurate, or is tacked on as a paragraph at the end of a chapter or monograph on dogs. Even texts that state that they cover both dogs and cats do not consistently provide information on cats, so the reader is left wondering whether the material for the cat is the same as that for the dog, is unknown, or was just not included. Our frustration at not being able to find information or illustrations on cats led us to produce this atlas.

Most chapters in this text are not highly detailed; for example, the origin and insertion of every muscle in the feline body is not stated. We tried to place emphasis on those areas of anatomy that are frequently encountered in clinical medicine. Therefore, veterinary students may find this text more useful as an additional small animal anatomy text. Practitioners will find the illustrations useful in client education.

Readers will notice that the chapter on special senses is more detailed than other chapters. Because this information is quite difficult to find elsewhere in the literature, this greatly enhances the usefulness of this chapter.

The illustrations have been taken from original dissections, photographs, radiographs and are based on palpation by the authors or editors. We believe that they are accurate. However, should the reader find any inaccuracies in the illustrations or the text, we would appreciate notification for correction in future editions.

The nomenclature used is from *Nomina Anatomica Veterinaria* (with some rare exceptions) in order to bring feline anatomy in line with the terminology of current veterinary texts of other common domestic mammals.

This atlas, which was conceived of and proposed by William Hamilton and developed jointly with Lola Hudson, is a unique collaboration between medical illustrator and veterinary anatomist.

Lola C. Hudson
William P. Hamilton

Abbreviations

Throughout the text and figure legends, certain words are consistently abbreviated. In general, a single letter is used and denotes the singular form. Plurals are indicated by double letters. Other abbreviations or acronyms are defined with the first use in a chapter.

a., aa. artery, arteries

v., vv. vein, veins

n., nn. nerve, nerves

m., mm. muscle, muscles

ln., lln. lymph node, lymph nodes

Contents

Chapter 1

General Information and Physical Examination

Lola C. Hudson

Modified from the original chapter by Jacqueline Bird and Lola Hudson

General Information

The "house" cat was fully domesticated at least by 1600 BC, after domestication of the dog. While a cat skeleton from some 9500 years ago was discovered in Cyprus, this was believed to be during the period of domestication. Most authorities cite Egypt as a location for domestication but a more exact place is not known. It is believed that domestication coincided with the invention of grain silos, and that the human need for rodent control and the cat's need for a ready food source resulted in a mutually beneficial, but still aloof, relationship.

The cat was deified in ancient Egypt, being worshipped as Bastet, the goddess of fertility - both human and agricultural. This special esteem of cats resulted in attempts to prevent their export from Egypt, but eventually domestic cats appeared in other areas of the Mediterranean. The domesticated cat is now found throughout the populated world and over 35 breeds have been developed, although not all breeds are recognized by all groups. The Cat Fanciers Association currently recognizes 37 breeds. An abbreviated list of breeds (Table 1-1) is included in this chapter.

The domestic cat has the scientific name of *Felis catus* (*F. cattus*), but has also been identified under the name *Felis domesticus* (*F. domestica*), as the taxonomy underwent changes in 1996. Cats belong to the family Felidae, which includes the "big cats," to the order Carnivora, and to the class Mammalia. Overall, the cat shows less variation in body size and skull shape than is seen among dogs, which suggests that there is a more uniform genetic makeup in cats. Nevertheless, relatively long-faced cats (Siamese), short-faced cats (Persian) and medium-faced cats (domestic short hair) are found among the various recognized breeds.

TABLE 1-1
Abbreviated List of Recognized Feline Breeds in the United States

Abyssinian*	Cornish Rex*	Oriental*
American Shorthair*	Devon Rex*	Persian†
American Wirehair*	Egyptian Mau*	Ragdoll†
Balinese†	Exotic*	Russian Blue*
Birman†	Havana Brown*	Scottish Fold*
Bombay*	Japanese Bobtail*	Siamese*
British Shorthair*	Korat*	Somali†
Burmese*	Maine Coon†	Sphynx (hairless)
Charteux*	Manx*	Tonkinese*
Colorpoint Shorthair*	Ocicat*	Turkish Angora†

*= shorthair breed, †= longhair breed

The pet cat population in the United States has steadily increased over the last decade. The American Veterinary Medical Association reports that there are more cats than dogs in USA households as the companion animal. Such numbers have influenced the interest of the veterinary profession as seen by the increase in numbers of feline-related seminars at various local, regional, and national professional meetings. This interest has also lead to a boom in textbooks and monographs on feline medicine and surgery for the veterinary profession or inclusion of more feline-related material in "small animal" textbooks.

Physical Examination

A good, thorough physical examination takes only a few minutes to perform but reveals a wealth of information to the veterinarian. In order to be efficient, the routine examination is performed systematically, concentrating on the same things in the same order. The precise order is not important as long as it is done the same way each time. The procedure then becomes second nature and the likelihood of overlooking something is minimized. As many of the examination procedures are irritating to many cats, becoming practiced at a technique is important. A large portion of a physical examination is based on palpation. Which structures are palpable in a normal cat is dependent upon the body condition of the cat and the skill and experience of the veterinarian. The following is one method of performing the physical examination.

First, the cat is removed from its carrier. If it can move about without escaping, the cat is observed walking, noting the mentation, posture and gait for balance and control, as well as its general attitude. Once the cat is placed on an examination table, the hair coat is checked for indications of self-grooming, for areas of alopecia and for ectoparasites.

Next, the head becomes the focus. The dorsum of the skull is palpated while noting the health of the hair and skin. Both eyes are examined for size, shape, and position. The upper eyelid can be retracted to observe the sclera and conjunctiva for color. The presence of a normal tear film is noted by the glistening appearance of the cornea. Using the upper eyelid for protection, each orb is gently pressed to roughly compare intraocular pressure. (This step can be substituted with the use of ocular pressure measuring devices such as a Tonopen®.) During this procedure, the third eyelid may move into clear view and be assessed. The corneas, irides, and pupils are checked for smoothness, clarity, and symmetry. With a strong light source such as a transilluminator, the pupillary light reflex of each eye is assessed. The clarity and uniformity of the lens is evaluated. The fundus is examined taking care to visualize the retinal blood vessels, tapetum lucidum, non-tapetal areas and the optic disc. Both lateral and medial commissures are gently touched to observe the palpebral (blink) reflex, assessing cranial nerve V (sensory) and cranial nerve VII (motor) function. Care is taken not to stimulate the tactile hairs or induce a visual menace response instead of a palpebral reflex by using the tips of closed forceps brought over the head, caudal to rostral. A menace response is elicited by a small, quick hand movement toward each eye or an up and down motion in front of the eye while blocking the view of the other eye. Care is taken not to stimulate any tactile hairs with either the hand or by air movement.

The ears are assessed for normal upright position. The pinnae are examined on the concave and convex surfaces, and the canals are checked for abnormalities. An otoscopic examination of the external auditory canal and tympanic membrane is performed. The hairs inside the pinna are gently touched to elicit a twitch assessing cranial nerve VII motor function to auricular muscles.

The skin and hair coat of the nose are examined. The paranasal sinuses and recesses of the skull are assessed for sensitivity by pressing firmly dorsal to each eye, ventral to each eye, and on each side of the nose. Both nares are examined for symmetry and discharge. Gently touching just inside the nares with closed, blunt hemostats elicits a strong aversive reaction, assessing cranial nerve V sensory function.

The hair and skin of the lips are checked as well as the tactile hairs. The symmetry of the lips is noted. Lifting the lips allows examination of the gums, including color, and teeth. Capillary refill time can be ascertained by pressing the gum with a fingertip to blanch out the blood and observing how quickly the area turns pink again. Gently opening the mouth affords a quick assessment of the teeth, tongue, tonsils, palate, and of jaw tone (cranial nerve V). While the mouth is open, pressure on the intermandibular area will elevate the tongue for a better view of the sublingual region, which should be checked for foreign bodies (especially string). The breath of the cat is smelled for a foul odor indicating infection or a sour odor indicating uremia or ketoacidosis. Careful palpation of the intermandibular space under the jaw and the region ventral to the opening of the external auditory canal allows assessment of the salivary glands and lymph nodes. Generally, these structures are not identified as separate entities, but the abnormal enlargement of any of them may be obvious on palpation.

The hair and skin of the throat area is examined next. The trachea is palpated along its full length, and then firmly rubbed to test for an abnormal cough response. At the dorsolateral junction of larynx and trachea, the thyroid glands should be palpated. Lateral to the trachea, palpation is performed the length of each jugular furrow checking for lumps or signs of discomfort. Next the wings of the atlas are palpated along with the rest of the cervical vertebrae. The muscles of the neck are massaged. The head is moved dorsally, ventrally and to each side to check range of motion in the neck and the oculovestibular responses. The thoracic inlet is palpated for lumps or sensitivity.

The hair and skin of the thoracic region is assessed. The muscular and the bony prominences of the forelimbs are palpated. Continuing down the thoracic limbs, each joint is moved through its full range of motion. Each paw is placed on its dorsum for the cat to replace properly (proprioceptive positioning). The pads and claws of each paw are checked.

The ribs are palpated and the rib cage is pressed to assess compressibility. The pattern and rate of respiration are noted. The location of superficial cervical lymph nodes and axillary lymph nodes are checked, although again, only abnormally large lymph nodes may actually be readily palpated.

Auscultation of the heart is performed on both sides just caudal to the thoracic limb (see Chapter 4 also). The normal heart rate is 118 ± 11 beats per minute for a resting, relaxed cat. In a hospital environment where they are likely to be more anxious and stressed, cats may have a mean heart rate of 182 ± 20 beats per minute.

Each lung field is auscultated in the triangular area of the lateral thorax caudal to the forelimb (see Chapter 7 also) and in the axilla region cranial to the heart. The entire lung field is not completely accessible due to overlying limb and epaxial musculature. The trachea is also directly auscultated in the ventral neck. The respiratory rate is about 26 breaths per minute. Purring, which is unique to cats, occurs on both inspiration and expiration and can complicate pulmonary auscultation. (Sometimes, it can be very difficult to stop the cat's purring. Techniques that may stop purring include blowing on the cat's nose, gently tapping the cat's nose, and running water in a sink in the same room in which the cat is located.)

The hair and skin of the abdominal region is examined next. A flea comb is drawn through the hair coat, especially over the dorsal rump area checking for fleas, flea eggs, and flea dirt (feces).

In the abdomen, both kidneys are generally readily palpated caudal to the costal arch just ventral to the vertebrae, the right kidney being more cranial than the left. Usually, only the caudal pole of the right kidney can be palpated. The edge of the liver is normally detectable at the caudoventral limit of the costal arch. The full stomach is in the left cranial quadrant of the abdomen. The spleen may be palpable in the left, ventral abdomen cranial to the level of the umbilicus. The intestinal tract is palpated for smoothness, slipperiness, and size as loops of bowel pass between the fingers squeezing from dorsal to ventral abdomen. Frequently, feces can be detected in the descending colon. Abdominal masses in any location should be noted. The bladder is assessed in the caudal abdomen, checking for distention, wall thickness, and the presence of calculi. Palpation of the pregnant uterus is easiest at 21-25 days post breeding. The anus and external genitalia are examined for abnormalities.

Each hindlimb is palpated, as with the forelimb, moving all joints through full range, and assessing femoral pulses for rate and quality. The popliteal lymph nodes, located caudal to the stifle, are palpated for size and excess heat. Each paw is placed on its dorsum and the cat is allowed to replace it (proprioceptive positioning). The pads and claws of each paw are checked.

The vertebral column is palpated, pressing firmly between each dorsal spine. The tail should be stroked to detect abnormalities such as kinks. The ventral surface of the thorax and abdomen of the cat is felt giving particular attention to the sternum and xiphoid cartilage, mammary glands, and the superficial inguinal lymph nodes.

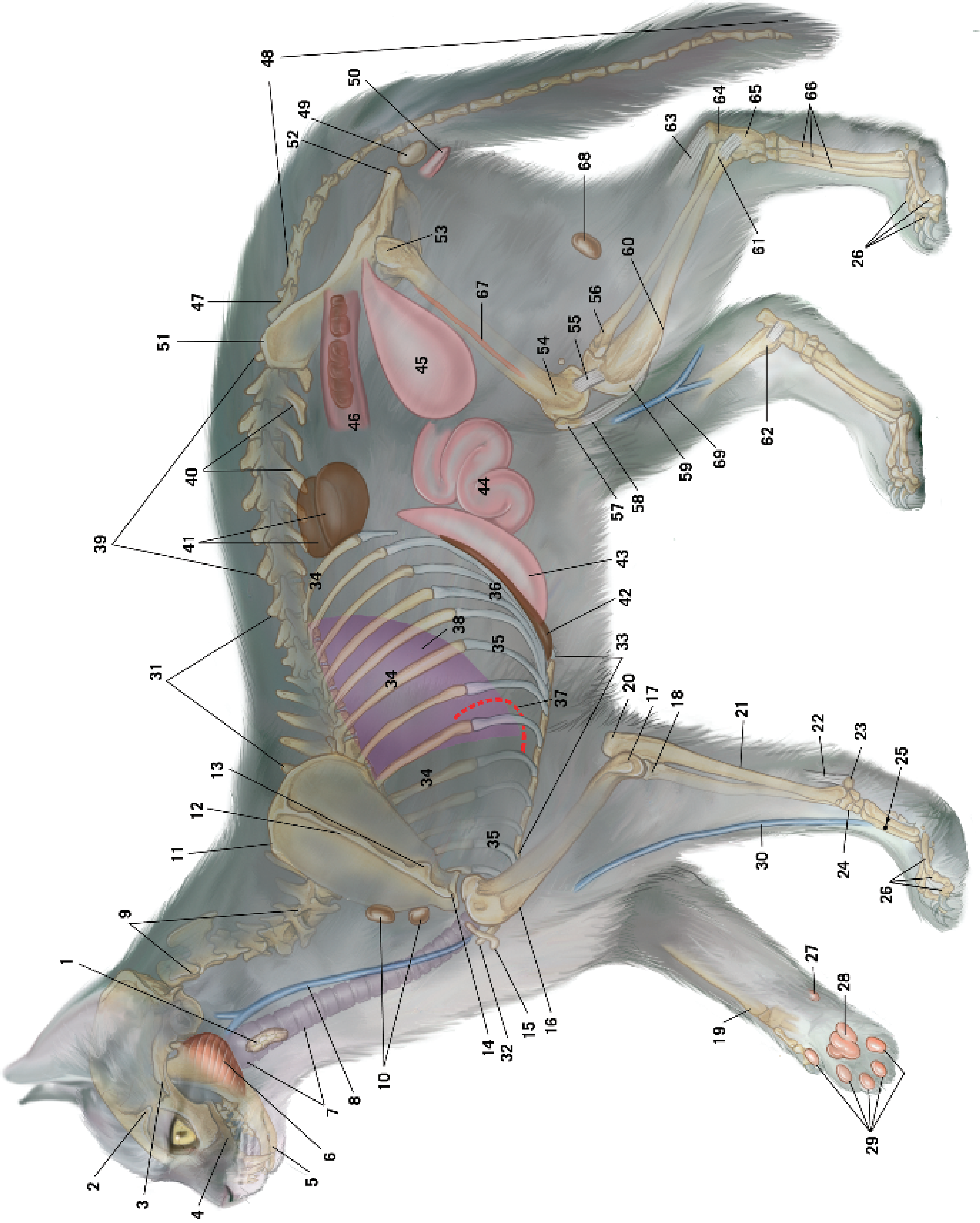
The cat's temperature should be taken. Normal body temperature in a healthy, relaxed cat is 38.5 ± 0.5°C (101.5 ± 1°F). Extreme agitation or excitement in a clinical setting may raise the temperature.

Sexual maturity of the female cat occurs in the first year, often at 6-7 months-of-age, in conjunction with the photoperiod. This relatively young age at puberty is a fact that surprises many neophyte cat owners. Queens are seasonally polyestrous from late winter to early autumn. The entire cycle is about 2 weeks long and the actual estrus (heat) lasts for an average of 7days. Coitus generally must occur for the queen to ovulate (induced ovulation) and pregnancy lasts for an average of 65 days. Abdominal palpation of pregnancy for number of kittens is best accomplished at 17-25 days of gestation and age of fetuses can be determined via serial plasma progesterone. Ultrasound after day 14 of gestation can also reliably determine pregnancy but numbers may

Plate 1-1

Major palpable structures of the normal cat, lateral view. In certain animals other structures such as individual muscles may also be identifiable. Some of labeled structures may not be identifiable in obese animals.

1 Thyroid gland
2 Frontal bone and its zygomatic process
3 Zygomatic arch
4 Maxilla
5 Mandible
6 Masseter m.
7 Larynx and trachea
8 External jugular v.
9 Cervical vertebrae
10 Superficial cervical l.n.
11 Dorsal border of scapula
12 Spine of scapula
13 Suprahamate process
14 Hamate process
15 Clavicle
16 Greater tubercle of humerus and its crest
17 Humeral condyle and lateral epicondyle
18 Proximal radius
19 Medial border of radius
20 Olecranon
21 Caudal border of ulna
22 Tendon of m. Flexor carpi ulnaris
23 Accessory carpal bone
24 Proximal and distal rows of carpal bones
25 Metacarpal bones II-V
26 Proximal, middle, and distal phalanges of digits II-V
27 Carpal pad
28 Metacarpal pad
29 Digital pads
30 Cephalic v.
31 Dorsal spines of thoracic vertebrae
32 Manubrium sterni
33 Sternum and xiphoid process
34 Ribs
35 Costal cartilages
36 Costal arch
37 Apex of heart (not palpable)
38 Auscultation triangle
39 Dorsal spines of lumbar vertebrae
40 Lateral epaxial muscles and transverse processes of lumbar vertebrae
41 Kidneys
42 Caudal border of liver
43 Stomach, when full
44 Loops of small intestine
45 Urinary bladder
46 Descending colon
47 Median crest of sacrum
48 Caudal vertebrae
49 Testis
50 Penis
51 Crest of ilium
52 Ischiatic tuberosity
53 Greater trochanter of femur
54 Lateral epicondyle of femur
55 Lateral collateral ligament of stifle joint
56 Fibula
57 Patella
58 Patellar ligament
59 Tibial tuberosity and crest
60 Cranial border of tibia
61 Lateral malleolus
62 Medial malleolus
63 Common calcanean tendon
64 Tuber calcanei
65 Tarsal bones
66 Metatarsal bones II-V
67 Femoral a. (On medial thigh)
68 Popliteal l.n.
69 medial saphenous v.



not be accurate. Radiography of the abdomen after day 45 can elicit more accurate numbers of kittens.

The male cat should have testicles descending at the perinatal period and be palpable at 6-8 weeks of age. By 6 months of age, if both testes are not located within the scrotum at all times, the cat should be considered a cryptorchid. Generally, toms will also reach sexual maturity during the second half of their first year.

Kittens are born with hair but with eyes and ears still closed. These structures open and are functional at 3-15 days. Forced weaning can be safely done at 7 weeks-of-age, if the kittens can eat and drink from a dish. If the dam is allowed to wean the kittens, she may allow nursing for several months.

The life span of cats has increased with improvements in veterinary care and nutrition. It is no longer unusual to have feline patients that are in their late teens and even into the early twenties.

Table 1-2 shows the complete blood count (CBC) and common electrolyte and enzyme values for the cat as determined by Clinical Pathology Laboratory of the North Carolina State University Veterinary Teaching Hospital (used with permission).

TABLE 1-2
Feline Hematology and Clinical Chemistry Reference Ranges

Tests		Units	Feline	Tests		Units	Feline
A/G	A/G Ratio		0.6-1.5	pO_2V	PO_2, Venous	mm/hg	30-73
AGAP	Anion Gap		15-32	SDH	Sorbitol Dehydrogenase	IU/L	1.3-8.7
ALB	Albumin	g/dl	3.0-4.2	TCO_2V	TCO_2, Venous		16.3-23.3
ALP	Alkaline Phophatase	IU/L	14-50	TP	Total Protein	g/dl	5.8-8.2
ALT	Alanine Aminotransferase	IU/L	28-88	TRIG	Triglyceride	mg/dl	24-206
AMM	Ammonia	μmol/l	8-52	ALY	Atypical Lymph., Absolute	$10^3/\mu l$	0-0
AMY	Amylase	IU/L	580-1520	ALY%	Atypical Lymph %	%	0-0
AST	Aspartate Aminotransferase	IU/L	16-42	APTT	Activated Partail Thrombo	secs.	10.9-18.1
BAP	Bile Acids	μmol/l	5-18	BAND	Band, Absolute	$10^3/\mu l$	0-0.1
BAP2	Bile Acids, Post 2 Hour	μmol/l		BAND%	Band %	%	0-1.0
BEA	Base Excess, Arterial		-2.0-2.0	BASO	Basophil, Absolute	$10^3/\mu l$	0-0.3
BEV	Base Excess, Venous		-3.9-5.1	BASO%	Basophil %	%	0-3
BILIT	Bilirubin, Total	mg/dl	0.1-0.3	EOS	Eosinophil, Absolute	$10^3/\mu l$	0.1-2.3
BUN	Blood Urea Nitrogen	mg/dl	15-41	EOS%	Eosinophil %	%	1.0-22.0
CA	Calcium	mg/dl	9.3-11.5	FIB	Fibrinogen	mg/dl	50-300
CL	Chloride	mmol/l	113-122	HCT	Hematocrit		32.8-49.8
CHOL	Cholesterol	mg/dl	93-304	HGB	Hemoglobin		10.9-16
CK	Creatine Kinase	IU/L	72-481	LY	Lymphocyte, Absolute	$10^3/\mu l$	1.000-7.400
CREAT	Creatinine	mg/dl	1.0-2.1	LY%	Lymphocyte %		7.0-54
GLOB	Globulin	g/dl	2.4-4.9	MCH	Mean Corpuscular Hemoglobin	pg	13.0-17.7
GLU	Glucose	mg/dl	71-182	MCHC	Mean Corp. Hemo. Concentration	g/dl	31.1-34.0
HCO_3	HCO_3	mmol/l	14-23	MCV	Mean Corpuscular Volume	fl	40.7-53.8
K	Potassium	mmol/l	3.5-5.1	MON%	Monocyte %	%	0-5
LD	Lactate Dehydrogenase	IU/L	49-274	MONO	Monocyte, Absolute	$10^3/\mu l$	0-0.7
LI	Lipase	IU/L	10-64	MPV	Mean Platelet Volume	fl	8.8-21.3
MG	Magnesium	mg/dl	1.8-2.6	PCV	Packed Cell Volume	%	28-45
NA	Sodium	mmol/l	150-159	PLT	Platelet	$10^3/\mu l$	198-434
Na/K	Sodium / Potassium Ratio		30-43	PLTM	Platelet, Manual	$10^3/\mu l$	198-434
C-OSM	Osmolality, Calculated		305-322	PP	Plasma Protein	g/dl	6.5-8.4
pCO_2A	pCO_2, Arterial	mm/hg	23-36	PT	Prothrombin Time	secs.	11.2-15.3
pCO_2V	pCO_2, Venous	mm/hg	25-38	RBC	Red Blood Cell Count	$10^6/\mu l$	6.91-10.49
pHA	pH, Arterial		7.26-7.46	RLY	Reactive Lymph Absolute	$10^3/\mu l$	0-0.2
pHI	pH, Ionized		7.340-7.540	RLY%	Reactive Lymph %		0-2
PHV	pH, Venous		7.26-7.44	SEG	Segmented Neutrophil, ABS.	$10^3/\mu l$	1.6-15.6
PHOS	Phosphorus	mg/dl	2.5-5.5	SEG%	Segmented Neutrophil %		37-83
pO_2A	PO_2, Arterial	mm/hg	78-100	WBC	White Blood Cell Count	$10^3/\mu l$	4.25-14.3

Courtesy of the Clinical Pathology Laboratory at the North Carolina State University Veterinary Teaching Hosptial.

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Chapter 2

Integumentary System

Cherie M. Pucheu-Haston

Modified from the original chapter by Diane Bevier

The integument (skin) of the cat has unique properties with regards to coat color, skin pigmentation, inflammatory response, and specialized integumentary structures. As is the case for many other species, skin and haircoat condition is often an indicator of general health or internal disease. However, research specifically focusing on the feline integument is less extensive than for some other domestic species.

The skin functions as an enclosing barrier, preventing the loss of such substances as water, electrolytes, and macromolecules. In addition, it prevents entry of exogenous matter, including potentially injurious chemicals, foreign material, and microbiologic agents. The flexibility and elasticity of the skin allow free motion while still maintaining this protective barrier. This protection and immunoregulation are provided in the main by the keratinocytes (epitheliocytes), intraepidermal dendritic cells (Langerhans' cells), dermal dendritic cells and cutaneous lymphocytes. The skin also produces its own antimicrobial coating (which is transported to the surface in sebum and sweat) and even uses the normal surface bacterial and fungal flora to protect against invading pathogens.

The skin is the source of both hair and claws, which provide protection against ultraviolet light, thermal extremes and predators. These structures also facilitate hunting by allowing the cat to blend in with its environment and efficiently capture prey.

The skin also plays an important role in endogenous temperature regulation, as its extensive vasculature facilitates the conservation or dissipation of heat. It functions as a reservoir for electrolytes, water, vitamins, fat, carbohydrates, proteins, and other materials. The skin is a primary sense organ for touch, pressure, pain, itch, heat, and cold. Lastly, the skin can function as an excretory organ to rid the body of unwanted or excessive substances.

Hair Coat

Coat Types

The short-haired cat is the fundamental "wild" type and this coat type is dominant. The longest primary hairs of a long-haired cat may be three times as long as those of a short-haired cat. Three types of hairs have been described in the cat based on gross appearance: (1) primary or guard hairs (thickest, straight, taper evenly to fine tip) (2) awn secondary hairs (thinner, possess subapical swelling below hair tip) and (3) down secondary hairs (thinnest, evenly crimped or undulated). Primary and secondary or undercoat hairs are medullated in the cat. The adult cat does not possess "lanugo" (nonmedullated) hair. In the classic coat types, secondary hairs are more numerous than primary hairs (10:1 dorsally, 24:1 ventrally). The guard hairs of normal cats may vary as much as four to five times in diameter at a given location.

Both primary and most secondary hairs are relatively straight and fine in cats. However, several atypical hair coat types (such as the curly coat in the Devon Rex and Cornish Rex, and the wire-hair coat seen in the American Wirehair breed) have been perpetuated as breed characteristics.

Rex cat breeds are the result of several distinct mutations with a similar phenotype. The two best known Rex breeds are the Cornish Rex and the Devon Rex. Both have very short, wavy fur. The Cornish Rex appears to lack guard hairs completely, and has a very tight "wave" to the fur. In contrast, the Devon Rex has stunted guard hairs and less wavy fur. Despite their similar appearance the Cornish and Devon Rex breeds arise from two separate autosomal recessive mutations (Rex gene 1 and Rex gene 2, respectively). Even excellent specimens of both breeds tend to be very thinly furred on the head, ventral neck and chest, giving the appearance of pattern alopecia. Other Rex breeds include the Selkirk (plush curly hair, autosomal dominant mutation) and the LaPerm (long or short curly fur, autosomal dominant mutation). Closely related to the Rexes are the American Wirehair breed ("Wh" gene, autosomal dominant with incomplete penetrance) and the Sphynx breed ("hr" gene, recessive), which loses almost all of its fur by maturity.

Coat Distribution

Compared to most other domestic animal species, the cat's skin surface is almost completely covered in fur. The normal cat is thickly furred on all areas of the trunk, legs, neck and tail. Short but dense fur is present between the toes (both ventrally and dorsally), in the axillae, in the inguinal region, and throughout the perineal area (including the scrotum). Most of the head and face is also thickly furred, with the exception of the pinnae and the preauricular skin. These areas may be very thinly furred in even a long-coated cat, with skin easily visible through the sparse hairs.

Coat Growth

The hairs of the coat grow from follicles associated with the dermis. Hairs do not grow continuously, but rather in cycles. Each cycle consists of a growing phase (anagen) during which the follicle is actively producing hair, and a resting period (telogen) when the hair is retained in the follicle as a dead, or "club" hair that is subsequently lost. There is also a transitional period (catagen) between these two stages. Hair replacement in cats is asynchronously mosaic in pattern and predominantly responsive to photoperiod (although ambient temperature may play a contributory role). Cats in colder climates that spend significant periods outdoors will shed noticeably twice a year in the spring and fall. Normal indoor cats will shed all year long.

Hair follicle activity is maximal in the summer and minimal in the winter. In the summer, average hair growth is 289 $\mu g/cm^2$ skin/day (with approximately 70% of follicles in anagen at any time), while winter hair growth averages 62 $\mu g/cm^2$ skin/day. However, the average fur length is longer in the winter (30 mm for guard hairs and 15 mm for secondary hairs) compared to the summer (25 mm for guard hairs and 12 mm for secondary hairs). The average fur weight of a short haired cat is 19.9 g/kg, while the total yearly hair growth averages 32.7 g/kg.

Coat Colors

The heritability and variety of cat fur colors have long been a subject of fascination for cat fanciers and more recently, for geneticists as well. Careful breeding and observation have combined with modern genetic techniques to provide a detailed picture of the genetic landscape of feline coat color.

With few exceptions, the appearance of any given color and pattern is not a matter of simple "yes or no" genetic inheritance, but rather is the result of the interactions of multiple genes located on several different chromosomes. One of these exceptions is the completely white cat. The solid white ("W") phenotype is dominant over the phenotypes encoded by all other cat color genes. It is uncertain whether the W phenotype is the result of a separate gene, or if it is simply one allele of the gene that governs the presence of white spotting ("S"). Solid white cats with blue eyes are frequently deaf or hear poorly due to a variety of forms of cochlear degeneration.

The tabby gene ("T", chromosome B1) is associated with three striping patterns. The dominant Abyssinian allele ("Ta") codes for minimal striping, with darkly pigmented (eumelanin) hairs striping only the extremities, head and tail. The co-dominant Mackerel allele ("Tm") codes for the "typical" tabby striping pattern, with linear stripes of dark fur on the thorax as well as the head, tail and extremities. The recessive Blotched allele ("tb") codes for linear striping on the extremities, head and tail, but rounded, "blotchy" stripes on the thorax.

All cats carry one or more of the Tabby alleles, but expression of the striped tabby phenotype is dependent upon co-expression of dominant allele of the Agouti ("A") gene. This gene codes for agouti patterned fur-dark eumelanin bands at the base and tip of the hair, with a lighter pheomelanin band in the center. This light-colored pheomelanin banding is not seen if the cat is a homozygote for the recessive allele (the result of a two base-pair deletion of the ASIP gene), and thus the dark tabby stripes are not readily apparent.

Currently, the only known sex-linked cat color gene is the eumelanin-inactivating X-linked Orange ("O") gene. Female cats homozygous for the dominant O allele are orange in color, as are male cats carrying a copy of the dominant allele. Female heterozygotes (Oo) have areas of skin both with and without eumelanin inactivation and are tortoiseshell in appearance. They may be calico if one of the spotting gene alleles is also present.

TYR, the gene for tyrosinase, is located on chromosome D1. The dominant allele ("C") is seen in normally colored cats. Two sub-dominant alleles ("Cb" and "Cs") are associated with two distinct temperature sensitive mutations in the activity of tyrosinase and result in the Burmese and Siamese phenotypes, respectively. Cats homozygous for the third, recessive allele ("c" or "cc") are albino.

TYRP1, the gene for tyrosinase-related protein 1, is located on chromosome D4. This gene controls the "density" or darkness of eumelanin pigment. Cats carrying the dominant allele ("B") are black or have black stripes (if tabby). Cats carrying the sub-dominant allele ("b") are a chocolate brown, while cats carrying the recessive allele ("b1") are a cinnamon red.

Several other genes act as modifiers to the genes listed above. The dominant inhibitor of melanin gene ("I") inhibits pheomelanin, producing white hairs with eumelanin bands at the tips ("smoke" colored cats). The recessive allele of the melanophilin gene ("d") produces a diluted phenotype (black to blue-grey; orange to cream) by causing clumping of melanin within the hairs ("maltese dilution"). Finally, the spotted gene ("S") can produce a mostly white cat (homozygous dominant; "SS"), a cat with a white belly and/or mittens (heterozygous; "Ss"), or a cat with no white spots at all (homozygous recessive; "ss").

Tactile Hairs (whiskers)

Tactile hairs (vibrissae) are substantially thicker and longer than normal guard hairs. The tactile hair follicle is surrounded by a fibrous capsule and is richly supplied with a venous (blood) sinus. In the walls of the venous sinus are nerve endings responsive to movement of the tactile hair, which is amplified by wave action of the surrounding blood (tactile bodies). Most tactile hairs are found on the face, principally on the upper lip and around the eyes, though others are scattered on the lower lip, chin, and elsewhere on the head and carpus. They are named according to location, e.g., pili tactiles labiales maxillares. The tactile hairs of the carpal region are found on the caudal antebrachium and carpus.

The slightest movement of tactile hairs, even by air currents, stimulates the nerve endings and provides information on the cat's immediate surroundings. The attached arrector pili muscles move the tactile hairs and the hair can be "put on the alert" when required.

Skin

Skin includes the epidermis, dermis, subcutis or hypodermis, the appendageal structures, vascular and nervous supply, and specialized glandular structures.

Pigmentation

In the cat, haired skin is only sparsely populated with melanocytes and melanin. Melanin is found mainly in the epidermis of the lip, pads, planum nasale, prepuce, scrotum, dorsal tail, pinnae, circumanal area, umbilical skin of the fetus and in the hair follicle bulbs. Dermal pigment and melanophages are rarely observed in normal cat skin, except for the scrotum.

Two body regions may develop pigmentation as they age. One is the sparsely haired preauricular/pinnal area. The other is the mucous membranes of the head. This pigmentation occurs most frequently in orange cats with the development of lentigo simplex. The condition often begins development at less than 1 year of age and progresses over time. Affected cats develop asymptomatic macular melanosis typically affecting the lips, gums, eyelids, and nose. Affected cats are at no apparent risk to develop other diseases, including melanoma.

Thickness and Surface of the Skin

The skin of the cat is quite pliable, especially over the neck and trunk. Skin over the dorsal neck and lumbar areas is normally slow to return to its original position when stretched and lifted. This must be kept in mind when attempting to assess hydration by skin tone.

The thickness of normal feline skin varies and decreases from dorsal to ventral regions on the trunk, and from proximal to distal regions on the limbs. The skin is thickest on the dorsal cervical, dorsal lumbar, and dorsal sacral regions; and thinnest on the scrotum and the lateral surfaces of the distal hindlimb, thigh, and distal forelimb. Maximal thickness (on the dorsal neck) has been recorded as 1.9-2 mm, while skin from the lateral thigh may be only 0.36-0.4 mm.

Microscopic, hairless, knob-like enlargements termed integumentary papillae or tylotrich pads are present in the haired skin of cats. These slow adapting mechanoreceptors are comprised of both epidermal and dermal components and are frequently closely associated with one or more hair follicles.

It has been suggested that the skin surface lipids of cats are mainly of epidermal origin (arising from the maturing corneocytes themselves) rather than of sebaceous gland origin. Feline skin surface lipids have been compared to human skin surface lipids. It was found that feline lipids are composed of more sterol esters, cholesterol, cholesterol esters and diester waxes and fewer triglycerides, monoglycerides, free fatty acids, monoester waxes and squaline than those of humans.

The pH of normal feline skin ranges from 5.6 to 7.4 (average about 6.5), which is somewhat less acidic than that of humans.

Microscopic Anatomy and Physiology

Embryology

Initially, the embryonic skin consists of a single layer of ectodermal cells over loosely arranged mesenchymal cells. In the 38-day-old fetus, the epidermis is about five cell layers thick without a stratum corneum and with a very cellular dermis. Aggregations of epidermal cells (the hair germs) project into the dermis at various intervals. These hair germs will form primary hair follicles. Sebaceous glands form as buds from the upper one-third of the developing hair follicle. Below this is another bulge that is the site for arrector pili muscle attachment. At 55 days gestation, the primary hair follicles contain well developed hairs, but secondary follicles may not have external hair shafts until after full term.

At the time of birth, the epidermis of the cat is about two cell layers thick and the dermis is packed with well developed primary hair follicles in anagen. A few days after birth the simple hair follicles are arranged in triads of a large central primary follicle bordered by two or three smaller follicles, which are producing secondary follicles. Subsequently, compound follicles are formed by buds produced from secondary follicles just below the level of the sebaceous glands.

Epidermis

The feline epidermis consists of four distinct layers in the areas of haired skin: the stratum corneum, stratum granulosum, stratum spinosum, and stratum basale. A fifth layer, the stratum lucidum, located between the stratum corneum and stratum granulosum, is present in the nonhaired areas of the pads and planum nasale. In general, the epidermis is thin consisting of two to three nucleated cell layers (about 12-45 μm). The thickest epidermis of the body is found on the pads and planum nasale (about 900 μm).

The epidermis of feline pads has a smooth surface, in contrast to the rough, papillated appearance of canine footpads. The pads and the planum nasale have prominent rete ridges (pegs). These rete ridges are not found in haired areas of normal feline skin.

The stratum corneum (horny layer) has a loose "basket weave" appearance on histopathological sections. This appearance is an artifact of fixation. The cells of this layer are flattened, anucleated, and eosinophilic when stained with hematoxylin and eosin. The thickness of this layer varies in areas of haired skin (3-20 μm), and the thickest layers are seen on the pads and planum nasale (15-35 μm).

Disease processes involving the stratum corneum usually cause increases in the thickness due to increased layers of keratinocytes. This increased thickness is termed hyperkeratosis, which may be subdivided into hyperkeratotic hyperkeratosis (in which keratinocyte nuclei are not retained) and parakeratotic hyperkeratosis (in which keratinocyte nuclei are retained, giving the hyperkeratotic layers a "stippled", somewhat basophilic appearance). The most common clinical syndromes causing hyperkeratosis include the scaling seen with dermatophyte invasion, infestation with surface feeding *Cheyletiella* sp. mites, and xerosis (dryness) of the skin (frequently seen in cats in the wintertime due to low-humidity indoor heating).

The stratum lucidum (clear layer) can be found in the pads and planum nasale, but not in haired skin. It consists of anuclear, homogeneous, hyaline-like material containing refractile droplets (eleidin). There are several layers of these translucent, poorly staining cells. Keratohyaline granules are not visible in these cells.

The stratum granulosum (granular layer) consists of flattened, basophilic, elliptical, or spindle shaped cells with shrunken nuclei and basophilic keratohyalin granules in the cytoplasm. This layer is usually one to two cells thick in haired skin areas except around hair follicle openings where it is often two to four cells thick. It is best developed in the pads and the planum nasale, where it may be 4 to 8 cells thick.

The stratum spinosum (prickle cell layer; spinous cell layer) consists of the daughter cells of the stratum basale. These are nucleated, lightly basophilic, and polyhedral to flattened cuboidal shaped cells. In haired skin this layer is one to two cells thick. The stratum spinosum becomes much thicker at the pads, planum nasale and at mucocutaneous junctions. The keratinocytes of the stratum spinosum are connected by intercellular bridges (desmosomes) that are more prominently visible in nonhaired skin. Ultrastructurally, keratinocytes are characterized by tonofilaments (keratin filaments) and desmosomes.

The stratum basale (basal layer) is a single row of columnar to cuboidal cells resting on the basement membrane zone that separates the epidermis from the dermis. There are three major cell types in this layer: the basal epitheliocytes, melanocytes and intraepithelial macrophages.

The basal epitheliocytes are actively reproducing, and their progeny push upward to replenish the more superficial layers of epidermal cells. The basal cells are nucleated and basophilic and range in shape from slightly flattened to cuboidal or columnar. Mitotic figures (representing actively dividing cells) may be present.

Melanocytes, which are rare in feline haired skin, are derived from neural crest. Melanocytes do not stain readily with hematoxylin and eosin and undergo artefactual cytoplasmic shrinkage during tissue processing. Therefore, they appear as "clear cells" in the stratum basale. Special staining procedures demonstrate their long cytoplasmic extensions (dendrites) that weave among the epitheliocytes. Where melanocytes are present, there is generally one melanocyte for every 10-20 basal cells. Melanocytes are responsible for production and transfer of melanin to a number of epitheliocytes, which together comprise the "epidermal melanin unit."

Intraepidermal macrophages (Langerhans cells) have a round cytoplasm with long dendrites extending between keratinocytes. Like melanocytes, these cells do not stain well with hematoxylin and eosin, and may appear as intercellular vacuoles or "clear cells". These cells are important antigen-capturing and –presenting cells, and increase in number in the face of active allergic inflammation. Immunohistochemical staining has demonstrated that these cells are recognized by antibodies specific for CD18, major histocompatibility class II (MHC II) molecules, CD4 and CD1a. Feline intraepithelial macrophages also possess intracellular structures analogous to human Birbeck's granules, in contrast to similar cells in the dog.

The basement membrane zone is the physiochemical interface between the epidermis and dermis. The basement membrane zone is thin and indistinct on stained sections in areas of haired skin. The zone is important not only in anchoring the epidermis and the dermis, but also plays important roles with regards to barrier function, epidermal nutrition, wound healing and maintaining tissue architecture. This layer is primarily of epidermal origin.

Dermis (Corium)

Because the cat has no rete ridges and dermal papillae in areas of haired skin, there is no clear division between the more superficial (papillary) and deep (reticular) dermis. The dermis is composed of collagen, elastic and reticular fibers, interstitial ground substance, nervous tissue, blood vessels, lymphatics, arrector pili muscles, and various cellular elements.

The superficial dermis is composed of fine, eosinophilic collagen fibers that are mostly parallel to the epidermis and interlace near the dermo-epidermal junction, as well as a network of fine elastic fibers. The collagen fibers have great tensile strength, and are larger than the elastic fibers. They account for the majority of dermal fibers and comprise most of the dermal extracellular matrix. Elastic fibers are composed of fine branches and single fibers that possess great elasticity and account for only a small portion of the dermal extracellular matrix.

The deep dermis consists of dense, irregularly arranged collagen fibers that are about three times larger than those of the superficial dermis. These fibers parallel the skin surface and also encircle hair follicles. Elastic fibers of the deep dermis are thicker and less numerous than those of the superficial dermis. In general, collagenous bundles are smaller and more loosely arranged in areas of skin with particularly high flexibility (such as the interscapular region).

The normal feline dermis contains fibroblasts, mast cells, occasional mononuclear leukocytes (including $CD4^+$ T cells) and, rarely, neutrophils or eosinophils. Cats with dermatitis may have increased numbers of intraepithelial macrophages / dendritic cells, mast cells and eosinophils (as well as $CD4^+$ and $CD8^+$ T cells) in the dermis, and often in the epidermis as well.

The ground (interstitial) substance of the dermis is a mucoid gel-sol of fibroblast origin composed of proteoglycans, dermatan sulfate, and chondroitin sulfates. This provides support and nutrients for the dermal appendageal structures including the hair follicles, sebaceous glands, apocrine, and eccrine sweat glands, arrector pili muscles and the dermal vasculature and nerves. Small amounts of mucin (a granular to stringy appearing substance which stains blue with hematoxylin and eosin) are often seen in normal feline skin, especially around appendages and blood vessels.

Subcutis

The subcutis (hypodermis) is composed of thick bands of collagen fibers and abundant, smaller elastic fibers that interweave and enclose fatty adipose tissue. Inflammation of the subcutaneous fat can occur in cats on diets of red tuna fish, other fish diets, various canned foods and excessive amounts of cod liver oil. The etiology of this syndrome involves deficiency of vitamin E and its antioxidant property. This disorder is termed pansteatitis or yellow fat disease and causes painful subcutaneous nodules. Other causes of subcuticular inflammation (panniculitis) include infections with bacteria, actinomycetes, fungi or mycobacteria, injection of foreign substances, trauma, pancreatitis and vascular inflammation.

Hair Follicles

A hair follicle is the hair and the immediate surrounding structures. There are five major portions to the feline hair follicle: the dermal hair papilla, the hair matrix, the hair, the inner epithelial root sheath and the outer epithelial root sheath, which is an extension of the epidermis. The cells of the hair matrix give rise to the hair shaft and the inner root sheath.

The hair follicle generates a cone-shaped epidermal hair bulb that defines the limit of the dermal papilla. The dermal papilla may induce growth and regulate differentiation within the hair matrix.

The hair shaft is divided into medulla, cortex, and cuticle. The medulla is the innermost region of the hair and is composed of a cord of longitudinal rows of cuboidal cells, or cells flattened from proximal to distal regions. The cells are solid near the hair root, but the rest of the medulla contains air and glycogen vacuoles. The cortex is the middle layer of the hair. It consists of completely cornified, spindle-shaped cells, whose long axis is parallel to the hair shaft. These cells contain the pigment that gives the hair its color. The cuticle, the outermost layer of the hair, is formed by flat, cornified, anuclear cells, arranged like slate tiles on a roof, the free edge of each cell facing the free end of the hair. In the cat, the profile of the hair shaft is distinctly serrated. Secondary hairs have a narrower medulla and a more prominent cuticle than do primary hairs.

Secondary hairs are arranged in clusters of two, three, four, and five groups around a large, central, primary hair. Each peripheral group of hairs usually contains three smaller primary hairs, surrounded by 6 to 12 secondary hairs. Twelve to 20 hairs may emerge from a common opening. Central primary hairs may have their own sebaceous glands, apocrine sweat glands, and arrector pili muscles, while smaller primary hairs and secondary hairs usually share common glands and arrector pili muscles.

Sebaceous Glands

Sebaceous glands are holocrine glands producing sebum and show a characteristic simple alveolar structure. Two or three glandular units empty via ducts into the upper portion of the hair follicle around which they are clustered. Sebaceous lobules are bordered by a basement membrane zone, upon which sits a single layer of deeply basophilic basal cells ("reserve" cells). These cells become progressively more lipidized and eventually disintegrate to form sebum toward the center of the lobule. Sebaceous glands in most haired skin average 20-75 μm in diameter, but glands as large as 700 μm may be seen on the lips and the dorsal surface of the tail.

Sebum is an oily secretion that keeps the skin soft and pliable and gives the hair shafts their glossy sheen. During periods of illness or malnutrition, the haircoat may become dull and dry as a result of inadequate sebaceous secretions. In contrast, hyperactivity of these glands or abnormal secretions may result in or complicate the pathologic conditions of feline acne and stud tail.

The sebaceous glands of the lips and face are numerous and larger than in other regions. Other areas of increased numbers of these glands in feline skin include the chin, which has oval clusters of glands (submental organ), dorsal aspect of the tail (supracaudal organ, preen gland), and the scrotum. Sebaceous glands are not found in pads or the planum nasale.

Apocrine Sweat Glands

Apocrine sweat glands are coiled or saccular, and are distributed throughout all haired skin. These glands range from 15-35 μm in diameter and consist of a single row of flattened to columnar epithelial (secretory) cells and a layer of fusiform myoepithelial cells. The glands are located deep to the sebaceous glands but open through a duct into the canal of the hair follicle superficial to the sebaceous duct opening. Apocrine glands are not present in pads or planum nasale. They are largest and most numerous near mucocutaneous junctions, in interdigital spaces, and over the dorsal neck, and rump. Large (45-110 μm) saccular apocrine glands may be found on the dorsal tail in the supracaudal organ. Hyperfunction of these glands and the associated large sebaceous glands may result in the buildup of waxy, greasy debris ("stud tail").

Eccrine Sweat Glands

Eccrine sweat glands are small, tightly coiled merocrine glands which found only in the pads. They consist of a layer of cuboidal to columnar epithelial cells and a layer of fusiform myoepithelial cells. The excretory duct opens directly to the pad surface. These glands have both adrenergic and cholinergic innervation. They may secrete when the cat is hot or frightened, and may play a role in scent marking.

Feline eccrine sweat is hypertonic, alkaline in pH, and contains high concentrations of sodium, potassium and chloride.

Arrector Pili Muscles

Arrector pili muscles are smooth muscle, and contain intracellular and extracellular vacuoles. Each originates in the superficial dermis and inserts on a bulge of the central, primary hair follicle. These muscles are smaller in diameter than the central primary hair follicle with which they are associated. They are present in all haired skin areas, being most highly developed in the dorsal lumbar, sacral and tail regions. Contraction of this muscle is involuntary and may be stimulated by a low ambient temperature. This results in erection of the hair from its normally oblique posture; when this happens to hairs en masse, the thickened pile traps more air and improves the insulation of the body. A similar effect occurs in the "flight or fight" reaction mediated by the sympathetic nervous system; the pronounced response by the hairs of the neck and back raises the "hackles" that give an animal a threatening appearance. Contraction of these muscles also helps express the sebaceous glands.

Senile changes of the Feline Integument

Certain histologic changes are often encountered in the skin of normal cats that have reached approximately nine or ten years of age. Variable degrees of hyperkeratosis and follicular keratosis are common. Granular, fragmented collagen fibers may be seen. Follicles and sebaceous glands may become atrophic. Sebaceous glands may look vacuolated. Occasional arrector pili muscles may appear fragmented, more vacuolated, and eosinophilic than normal.

Blood Vessels

Blood vessels to the dermis are arranged in three distinct intercommunicating plexi of arteries and veins: the deep (subcutaneous), middle (cutaneous) and superficial (subpapillary) plexi. Simple cutaneous arteries emerge from the fascial planes between underlying muscle masses to supply the deep plexus primarily. Mixed cutaneous arteries supply the muscle mass and eventually terminate in the deep plexus.

The deep plexus is found at the interface of the dermis and subcutis. Branches from this plexus descend into the subcutis, and ascend to supply the lower portion of the hair follicle and the apocrine sweat glands. These vessels continue their ascent to feed the middle plexus that lies at the level of the sebaceous glands. Branches from the middle plexus supply the arrector pili muscles, the middle portions of the hair follicles, sebaceous glands and supply ascending branches to feed the superficial plexus. Capillary loops emanate from the superficial plexus and are arranged parallel to the skin surface. These vessels supply the epidermis and superficial portions of the hair follicles.

Lymphatic Vessels

Lymphatic vessels are infrequently seen in routine histologic preparations of normal cat skin. They arise from capillary networks, which lie in the superficial dermis and surround the adnexae. These vessels drain into a subcutaneous lymphatic plexus. In edematous or inflamed skin, lymphatic vessels may occasionally be seen as distended, thin walled vessels which are usually lined by a single row of elongated cells.

Nerves

The nerves to the skin are a mixture of motor and sensory nerve fibers. In addition to the important function of sensory perception (touch, heat, cold, pressure, pain and itch), the dermal nerves promote survival and proper functioning of the epidermis ("trophic influences"). Postganglionic neurons of the sympathetic nervous system innervate the smooth muscle walls of the cutaneous blood vessels, the arrector pili muscles, and the myoepithelial cells associated with the sweat glands. The majority of the nerves to the epidermis and dermis are sensory neurons. On the basis of the properties of afferent units, sensory activity in skin can be subdivided into mechanoreceptors, thermoreceptors, and nocioceptors.

Mechanoreceptors in feline hairy skin have been classified as: (1) "rapidly adapting mechanoreceptors" (Pacinian corpuscle, hair follicle receptors), (2) "slowly adapting mechanoreceptors" (tylotrich pad, Ruffini endings), (3) tactile hairs, and (4) nonmyelinated mechanoreceptors.

Nocioceptors are involved in itch and pain perception. Nociceptors are supplied by A δ fibers (myelinated) and C fibers (nonmyelinated). Proteolytic enzymes, substance P, and vasoactive intestinal peptide have all been demonstrated in the skin of the cat. All are known to be mediators of pruritus in other species.

Plate 2-1

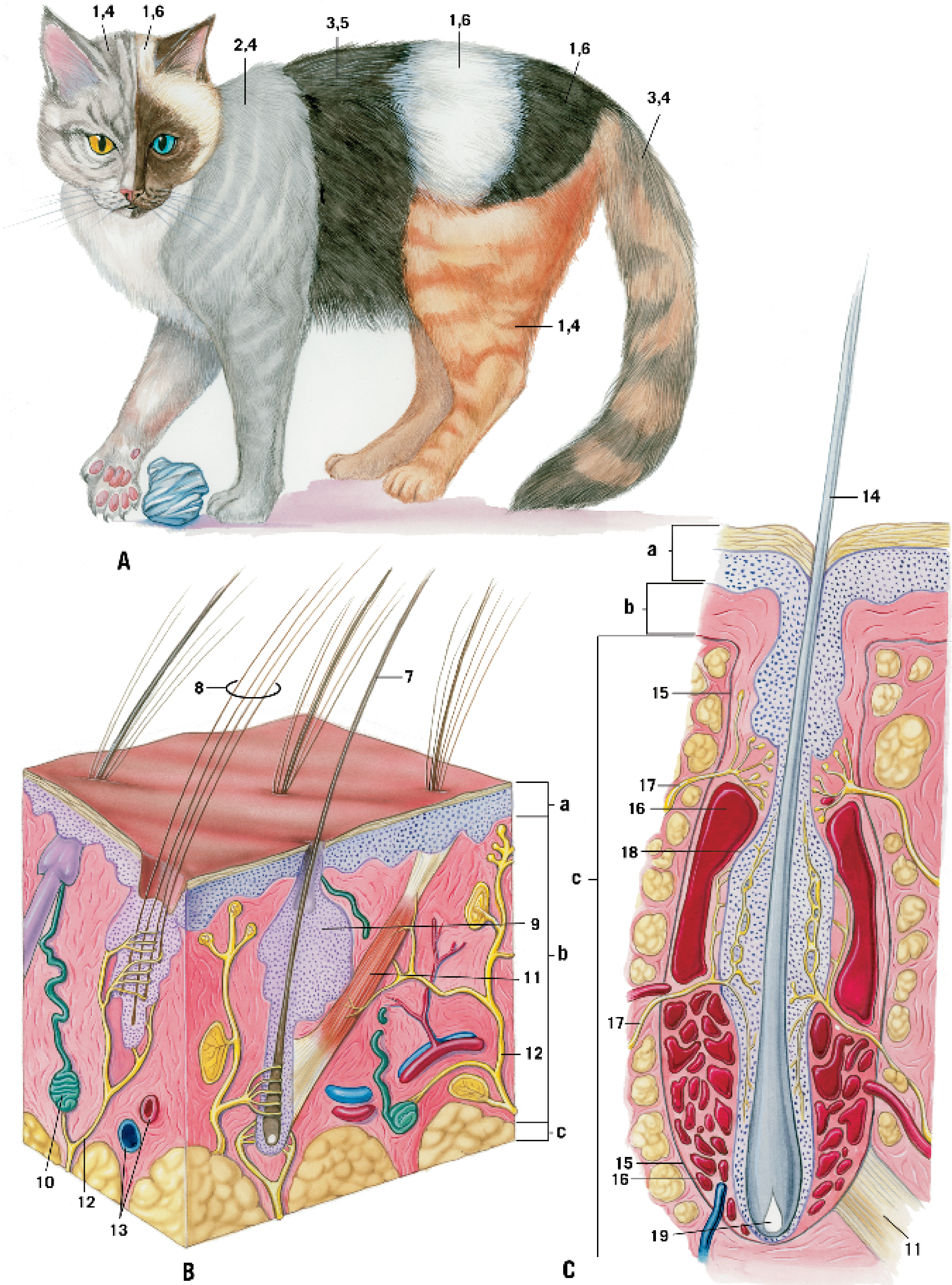
Figure A Particolored cat showing several coat types and coat colors
Figure B Schematic illustrations of histological layers of integument
Figure C Schematic illustration of tactile hair.

1-3 Coat Types
- **1** Short hair coat
- **2** Rex (curly) coat
- **3** Long hair coat

4-6 Coat Color Pattern
- **4** Mackerel (tabby)
- **5** Abyssinian
- **6** Self colored

- **a** Epidermis
- **b** Dermis
- **c** Subcutis
- **7** Primary hair
- **8** Secondary hairs
- **9** Area of sebaceous gland
- **10** Apocrine sweat gland

- **11** M. Arrector pili
- **12** Nerve fiber
- **13** Cutaneous vessels
- **14** Tactile hair
- **15** Fibrous capsule
- **16** Venous sinus
- **17** Sensory nerve fibers
- **18** External root sheath
- **19** Hair papilla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