could be white. The color of the earlobe usually is correlated with the color of eggs in laying hens. Chickens with red earlobes tend to lay brown eggs while those with white earlobes tend to lay white eggs (Morishita et al. 2021, p. 464). The ear lobe is covered by keratinized stratified squamous epithelium of five to six layers total thickness. These cells are two to three cuboidal cell layers and two to three flatted squamous superficial cells. The dermis forms a highly vascularized dense irregular connective tissue below the epithelium. Deeper, the dermis is less dense than the superficial layer with the presence of elastic fibers and large blood vessels. Resident macrophages (histiocytes) are present in addition to the regularly present fibroblast/fibrocyte. Elastic fibers and variable amount of connective tissue density were observed by the authors depending on the sectioned region of the ear lobe. The epithelial layer thickness of the ear lobe increases along the attachment side to the head. Herbst corpuscle close to the feather's follicle is small, while deeper corpuscles are larger.

1.2.3.4 External Ear Opening

The external ear canal opening of the chicken is caudal to the quadrate bone. Auricular glands are present on the ventral wall of the canal. These glands open into a duct and can be visualized under higher magnification (König et al. 2016, p. 243). Aural sebaceous glands around the external ear secrete a waxy substance (Menon and Salinukul 1989). Six classes of neutral lipids are identified by thin layer chromatography of the lipid materials extracted separately from the secretion as well as from the isolated whole glands present in the skin of the floor of the external ear canal of the domestic fowl (Dutta et al. 1997).

1.3 Feathers

Feathers are important structures and perform several functions during the bird lifetime including flight, thermoregulation, water repellent, communication, water transport, transfer of plant seeds, sound production, and brooding (incubation of eggs) (Lucas and Stettenheim 1972, pp. 257, 276).

1.3.1 Development

The somatopleure (ectoderm and somatic mesoderm) expansion and closure leads to the juxtaposition of the ventral pteryla. The embryonic proximal somatopleural mesoderm is destined to form a feather-forming dermis at two days of incubation (Fliniaux et al. 2004). Other researchers stated that early development of the feathers from pterylae start at day six of incubation of having a dermal pulp (sheath and basal layers) (Prum and Dyke 2003). Epidermal placode elongates forming a short bud with a tubular central dermal tissue. The epidermis forms the barb ridges and barbs of the first natal down. The pulp starts from the germ cells to produce the entire feather. Feathers are replaced/renewed throughout the entire life of the bird in a sequence of (continue for most species) events called molt. Feathers are entirely epidermal in origin and lined with epidermal cells which are anchored inside the dermis after passing through the epidermis and sometimes the hypodermis. Prum and Brush (2002) stated that a feather follicle differs from a hair follicle in that the follicular invagination is not merely a depression in the epidermis but a circular trough that encircles a persistent dermal papilla. Both primary and secondary feathers attach close to the periosteal layer of the bones.

1.3.2 Description of Feathers

Feathers are skin appendages like the glands of mammalian skin. They are tubular and widely variable in shape and chemical composition of the arrangement and numbers of keratinocytes (Prum and Dyke 2003) depending on their location and/or function. Morphologically, feathers are considered homologous of reptilian scales. However, in development, morphogenesis, gene structure, protein shape, sequence, filament formation and structure, feathers are different from scales (Brush 1996).

Researchers have noted the role of feathers in repelling parasites alone or in conjunction to earth elements. In a study conducted by Martin and Mullens (2012), they permitted chickens infested with lice to apply sand, litter, or kaolin (a fine clay) to their feathers for dusting. The use of kaolin resulted in significant reductions in lice populations, whereas dusting with sand or litter had little to no effect. Likewise, Vezzoli et al. (2015) reported that dusting with sand showed no impact on ectoparasitic mites.

1.3.3 Ptilosis and Pterylosis

Ptilosis refers to the complete set of feathers (plumage) associated with the feather's follicles, while pterylosis is the arrangement of feathers within certain tracts over the bird skin. On one plucked adult rooster (the authors prepared), different tracts including ventral and dorsal views were labeled (Figure 1.5A–C). The term pteria is a part of the bird skin where feathers grow, while apteria is the naked spaces between feathered skin, for example, on both sides of the chicken neck. Detailed feather tracts (pterylosis) of the chicken are described by Lucas and Stettenheim 1972, pp. 74–75).

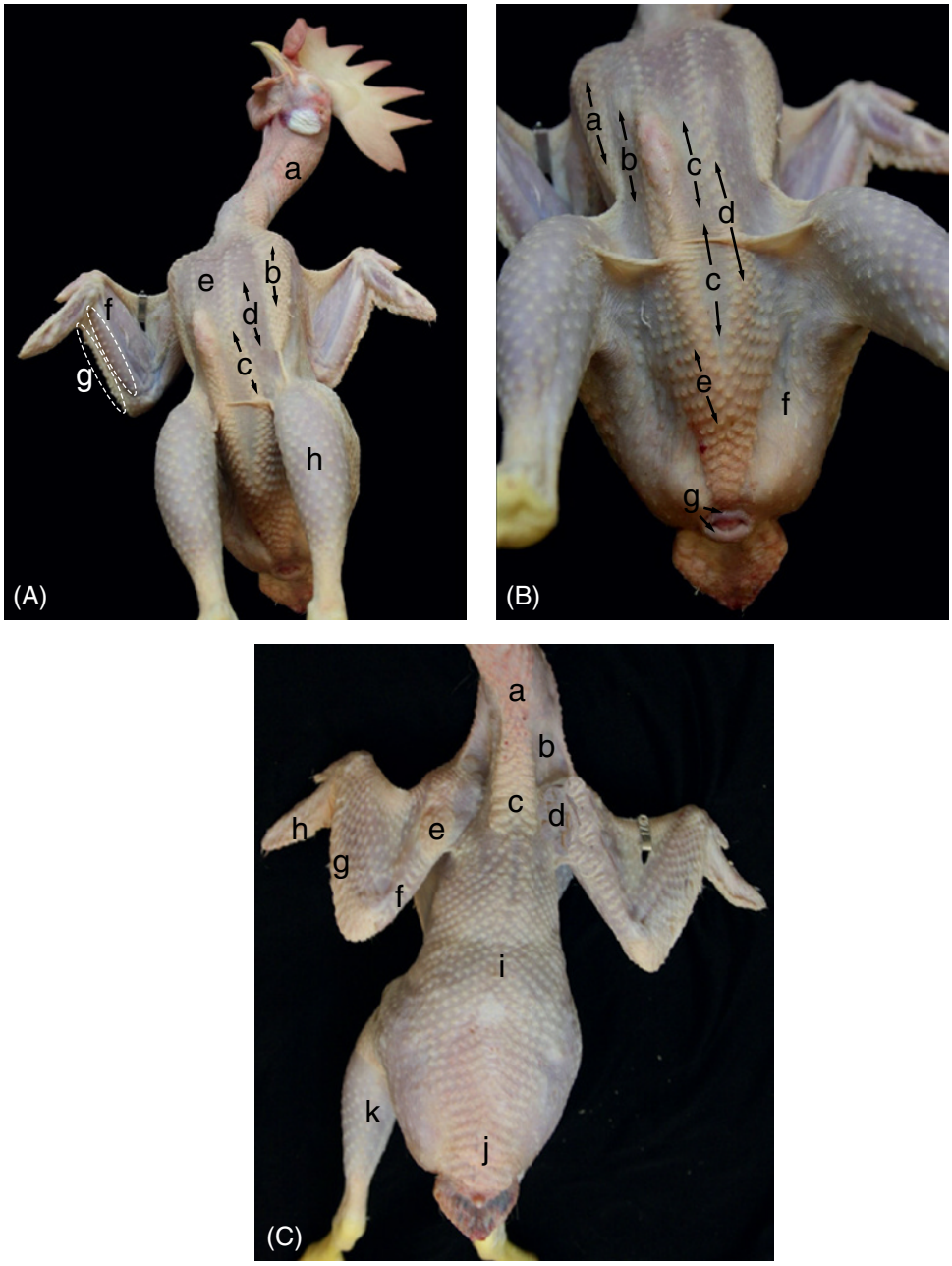

Figure 1.5 (A) Ventral view of a plucked adult rooster. (a) Lateral cervical tract, (b) pectoral tract, (c) sternal tract, (d) pectoral apterium, (e) sternal apterium, (f) secondary coverts, (g) secondary feathers, and (h) crural tract. (B) Ventral view of plucked adult male chicken. (a) Pectoral tract, (b) pectoral apterium, (c) sternal apterium, (d) sternal tract, (e) abdominal tract, (f) abdominal apterium, and (g) anal circulet. (C) Dorsal view of a plucked adult male chicken. (a) Dorsal cervical tract, (b) lateral cervical apterium, (c) interscapular tract, (d) scapular apterium, (e) humeral tract, (f) post humeral tract, (g) upper secondary feathers, (h) primary feathers, (i) dorsopelvic tract, (j) dorsal caudal tract, and (k) crural tract.

1.3.4 Feathers Color

Feathers can be of any color or mix of colors. However, color, structure, and shape may vary after molting. Melanin is a common pigment in chicken skin. Melanin is produced by melanocytes (a neural crest cell in origin). These cells are situated at the basement membrane of the skin and have pseudopodia to extend between the keratinocytes (all epidermal cells) of the epidermis. Through the process of transcellular movements, the melanosomes (melanin pigment within a single layer membrane) are phagocytosed by the keratinocytes (Sharlow et al. 2000). The second most common pigment is the carotenoid, a large group of

pigments produced by plants and other organisms. Once absorbed, carotenoids are transported in fat globules through the blood to the dermal feather pulp where they are selectively absorbed by the keratinocytes (Brush 1978). Red coloration comes from carotenoids, yellow from either carotenoid or melanin, while pink is a mixture of both red and yellow. If melanin pigments reach the epidermis in substantial amounts, these black pigments result in darkening the entire skin of the chicken, like in Silkie chickens. Green color comes from the lipochrome in the epidermis and melanin in the dermis. Other colors result from the combination of different pigments and physical properties of the feathers (Getty 1975, pp. 2071–2081).

1.3.5 Types of Feathers

1) Natal down feathers refer to the layer of early down feathers that cover the bird at a certain stage of early development. Birds can be classified as altricial or precocial. Chicken is a precocial bird that is covered with natal down after hatching. The hatchlings of altricial birds are almost naked. This divergence is thought to reflect environmental adaptation, but the molecular basis of the divergence is unclear (Chen et al. 2016).
2) Blood feather is the one that is growing and or replacing the shed feather. The feather needs lots of nutrients to continue to grow and that is why blood filled the tubular portion of the feather which reflects the name. The blood vessels supplying this feather regress once the feather is fully developed.
3) Filoplume is a hair-like (filum-thread) that remains on the skin when all other feathers are removed. Filoplumes are present in all feather tracts of the body. There are usually more than two for each remix (flying feather) or rectrix (tail feather). They are associated with contour feathers and may be sensory or decorative in function.
4) Alular feathers are a specialized structure of the upper leading edge of a bird's wing that consists of a tuft of short flight feathers usually three in number attached to the movable first wing digit corresponding to the thumb to facilitates flight, landing, and maneuverability at slow speeds (Figure 1.6). By altering airflow, the alulae permit good maneuverability and control at low flying speeds which are crucial for takeoffs and landings (Linehan and Mohseni 2020).
5) Down feathers in adult birds are a layer of fine feathers under the main coat of the bird feathers.
6) Rictus is the soft tissue border of the mouth made of skin from the commissure angle forward into the proximal mandible and maxilla (Figure 1.2).

Figure 1.6 Rooster alular feathers (short flight feathers, usually three) normally attached to the movable first wing digit to facilitate flight, landing, and maneuverability at slow speeds.

7) Flying feathers include the primary, secondary, and tail feathers. The flying feathers consist of the shaft (rachis and calamus), barbs, and barbules.
8) Contour feathers are the predominant type of feathers, and they are larger in number compared to flying feathers. Length and shape of contour feathers varies from region to region (Lucas and Stettenheim 1972, p. 235).
9) Auricular feathers are modified contour feathers. They form several rows around the ear opening. They are of two types, rostral and caudal coverts that are arranged in a way to not hinder sound passage but prevent passage of insects and foreign materials (Getty 1975, pp. 2027 and 2082).
10) Bristles feathers in chicken are present only in the cilia of the eyelids (eyelashes).
11) Powder feathers are absent in chicken but present in pigeons.

1.3.6 Parts of Feather

Rachis: The rachis is the long solid portion of the feather shaft above the skin. The rachis carries the vanes composed of barbs connected by barbules in an interlacing pattern (Hodges 1974, p. 15) (Figure 1.7).

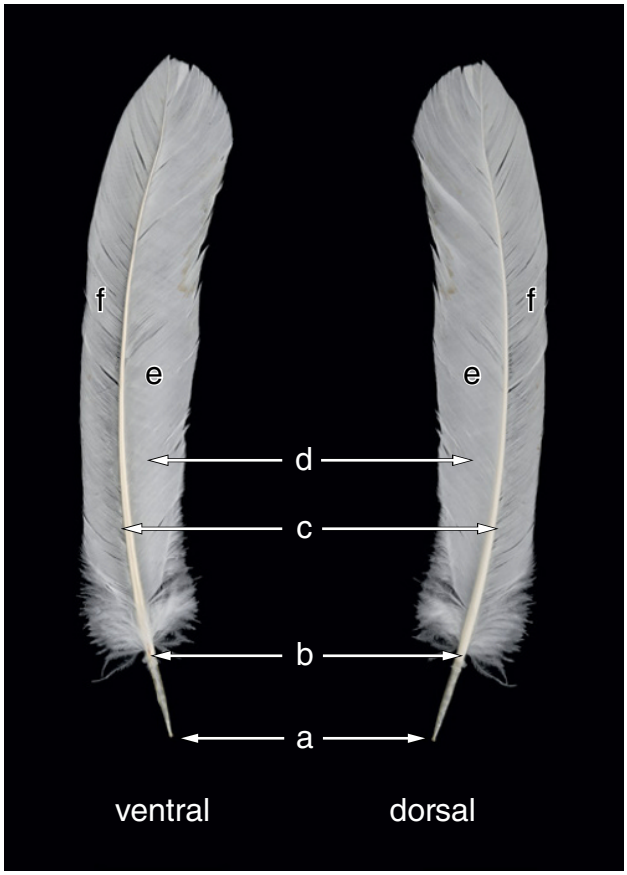

Figure 1.7 Adult feather from the tail. (a) Inferior umbilicus, (b) calamus (quill), (c) rachis, and (d) barbs. If this was a primary feather from the wing, (e) it would be considered posterior barbs and (f) anterior barbs.

Calamus (quill): The calamus is the hollow inner portion of the feather shaft that lacks barbs and attaches to the skin. The calamus is the bare portion of the feather and partly lies within the feather follicle (Lucas and Stettenheim 1972, p. 235). It is the tubular structure of the feather composed of non-pigmented stratified squamous epithelium and has transverse partitions within the cavity. It is separated from the rachis by the superior umbilicus opening.

Umbilicus: Inferior (distal) umbilicus contains the dermal papilla at the end of the feather inside the dermis while the superior (proximal) umbilicus always presents at the neck of the follicle where the dermal papilla projects into it.

Barb (ramus Pl. rami): *The barb is an* individual rigid strand of feather material (keratin), extending laterally from the rachis to form the vane.

Barbule: The barbule is a lateral branch of a feather barb composed of two rows proximal and distal. The distally directed barbules have hooks that interlock with the proximal rows.

1.3.7 Microscopic Description of Feather

Fully developed feathers have a single cell layer of low cuboidal germinal cells with large spherical nuclei. Flattened and compacted cells are present above the germinal layer toward the feather lamina. Below the epidermal layer is a thin basement membrane (Lucas and Stettenheim 1972, p. 358). The dermis underneath the feather is dense and twice as thick as the epidermal layers. It is composed of collagen fibers with a few elastic fibers along with blood vessels and lymphatic vessels.

1.3.8 Types of Flying Feathers

Flying feathers (remiges) are divided in primary, secondary, and tertiary feathers. The tail feathers (rectrices) share general common structures in respect to the calamus and rachis. The primaries are usually 10 in number in chicken and curved inward, while the secondaries are 17–18 (Getty 1975, p. 2076) which are more curved inward compared to primaries. The numbers and shapes of tail feathers (rectrices) vary among breeds and between male and female.

1.3.8.1 Primary Remiges and Their Coverts (also Known as Cover Feathers)

The primary feathers are 10, stiff, pointed at the end and more symmetrical than rectrices. They start at the wrist as number 1 and end distally as number 10 at the edge of the wing. After feathers attach to the underside of the feather, usually at the level of the superior umbilicus. Coverts are present for both primary and secondary feathers (Figures 1.7 and 1.8).

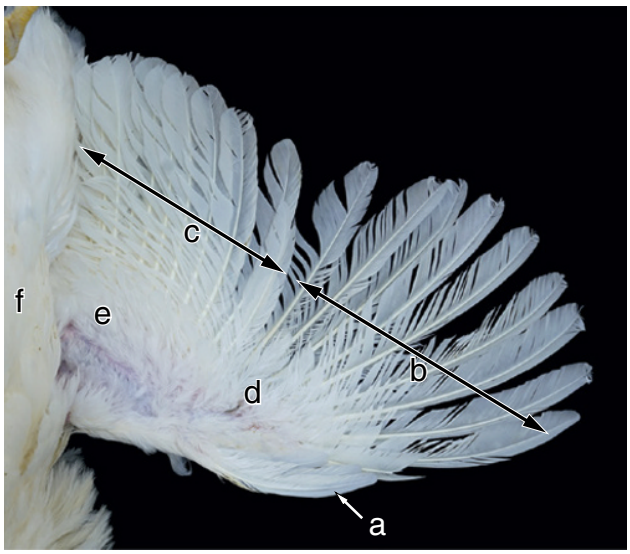

Figure 1.8 Wing feathers of a chicken. (a) Alulae, (b) primary feathers, (c) secondary feathers, (d) ventral covert for primary feathers, (e) ventral covert for secondary feathers, and (f) body contour feathers.

1.3.8.2 Secondary Remiges and Their Coverts

Secondary feathers in chicken are 17–18. The first 12 feathers are larger and stiffer compared with the last 6. Secondary covert feathers are arranged as upper major and upper median. They result in the formation of a distinct band (wing bar) (Getty 1975, pp. 2070 and 2077) (Figures 1.8 and 1.9A and B).

1.3.8.3 Rectrices and Their Coverts

Rectrices are sickle feathers surrounded by less curved tail feathers that vary between the rooster and the hen. It is stated that one through seven or eight rectrices implanted along the lateral margins of the tail. The bases of the tail feathers are attached to the pygostyle bone and covered by several rows of upper and under the tail coverts (major, median, and minor) (Getty 1975, p. 2076).

1.3.8.4 Contour Feathers

Contour feathers are the largest and the predominant type of feathers. The length and shape of contour feathers vary from region to region. Contour feather regions include the neck, thoracic, abdominal, pelvic limb, vent, and external ear opening. They have calamus and rachis plus inferior and superior umbilicus like flying feathers (Lucas and Stettenheim 1972, p. 253). Contour feathers consist of a well-developed shaft, a vane, and an afterfeather. The remige coverts (wing flight feathers), the rectrice coverts (tail flight feathers), and the general feathers of the body, neck, and limbs are all contour feathers. Replacement of contour feathers (molting) requires a longer period which may extend into three months (Nickel et al. 1977, p. 163) (Figure 1.10).

1.4 Lamellar Corpuscles

Large and small Herbst corpuscles were observed close to the feather and close to the skin surface (Figure 1.11). Each corpuscle is presented with an axis cylinder in the central part and is surrounded by outer and inner lamellae of concentric layers of connective tissue fibers. Reticular fibers were seen around blood vessels and in between adipose tissue (Bharathi et al. 2018). A small Herbst corpuscle serves as mechanoreceptor and registers slight movement which is present close to the filoplume, while a larger size corpuscle close to the calamus registers deep pain (Lucas and Stettenheim 1972, p. 276). Smooth muscles attach outside of the follicle by an elastic tendon in all feathers except in the filoplumes (Getty 1975, p. 2082).

1.5 Molting

Molting involves two phenomena, shedding of feathers (ecdysis) and growth of new feathers (endysis) (Lucas and Stettenheim 1972, p. 197; Watson 1963). The process starts after hatching by replacing the natal feathers with real feathers. Once all the feathers are fully developed, the first real molting starts. Both pituitary and thyroid glands play a significant role in the physiological molting

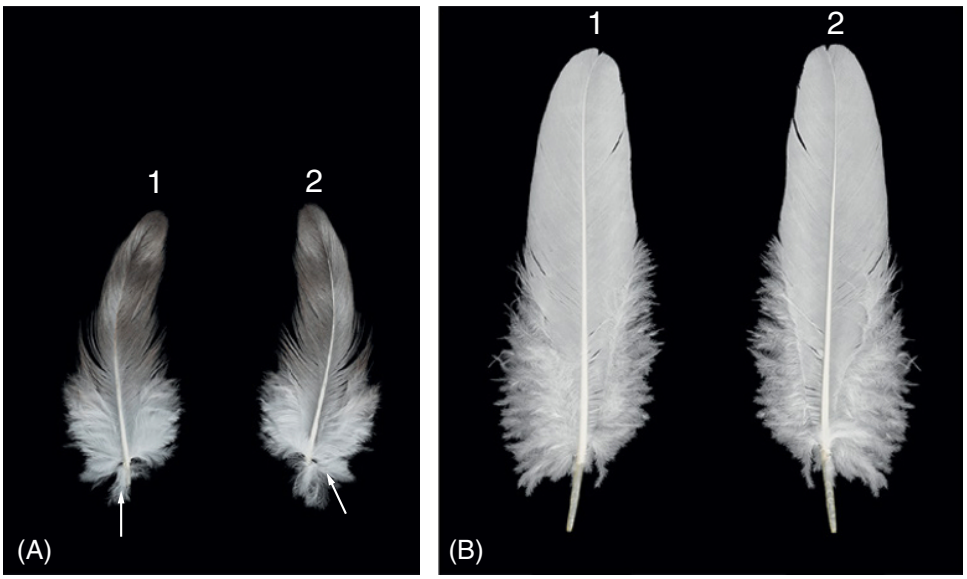

Figure 1.9 Relative size of feathers. (A) Primary feather covert from dorsal surface of the wing. Arrows indicate after feather. (B) Secondary feather covert from dorsal surface of the wing. (1) Dorsal surface of the feather and (2) ventral surface of the feather.

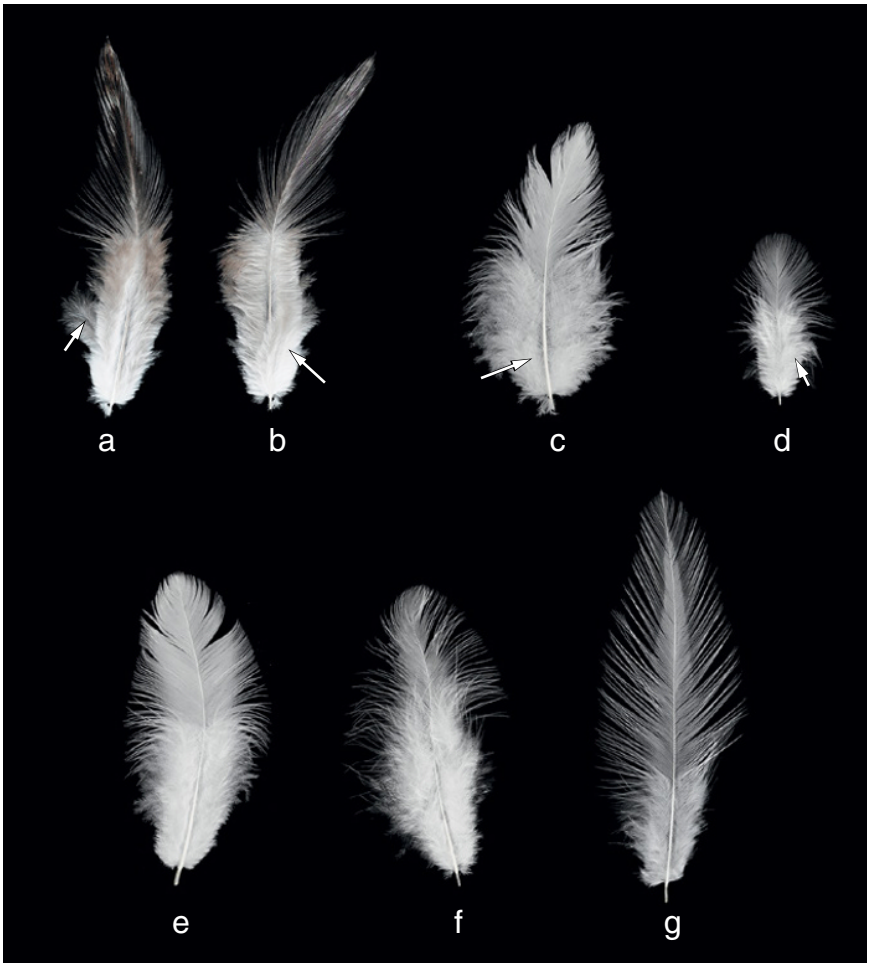

Figure 1.10 Relative size of contour feathers with after feathers (arrows) from different regions. (a and b) Colored feathers from the back, dorsal and ventral views, respectively, (c) dorsal chest region, (d) thigh region, (e) cranial abdomen, (f) caudal abdomen, and (g) neck.

process (Nickel et al. 1977, p. 162; Dyce et al. 2010, p. 789). Adult bird yearly molting usually happens at the end of summer or the beginning of the fall, lasting approximately for two months. For the primary feathers, molting starts from inside outward, while for the secondary feathers, it is the opposite. Filoplume molts along with its associated feather. Increased need for protein and other nutrients is essential for adequate feather molting. This is followed by a high metabolic rate and expenditure of energy. Diverse factors affect molting and timing like diet, environmental conditions, reproduction, season, temperature, humidity, lighting conditions, hormonal influences, species, and gender. Discrepancies of any of the listed factors often result in a partial molt or incomplete feather formation, which may even be manifested as a change in feather color (Perry 1987, pp. 40–50; Spearman and Hardy 1985, pp. 1–56). After completion of the feather development, there is always a quiescent papilla still at the base of the follicle. This papilla will always be ready to grow once the feather is shed or removed (Nickel et al. 1977, p. 163).

1.5.1 Induction of Molting by Food Deprivation

The commercial egg industry uses feed deprivation to induce molt because it is easy and gives the best results. Regardless of the results, feed deprivation and the stresses implied on the hens raise lots of concerns regarding animal welfare. At early stage of feed deprivation, hens have been seen to manifest temporarily increase levels of alertness, activity, and aggressive behavior during the first 48 hours. Alternative induced molting method has been sought to reduce animal welfare concerns. For example, the method that involves alteration of feeding regimen and cause at least some body weight loss (Webster 2003).

1.5.2 Feather Picking

Feather picking is common among chicken as well as other species of birds. Picking is usually around the tail, vent, or sometimes head. There are many reasons for feather picking in chicken, among them are overcrowded coop/housing, stresses of any kind, lack of proteins (reported to be rare by

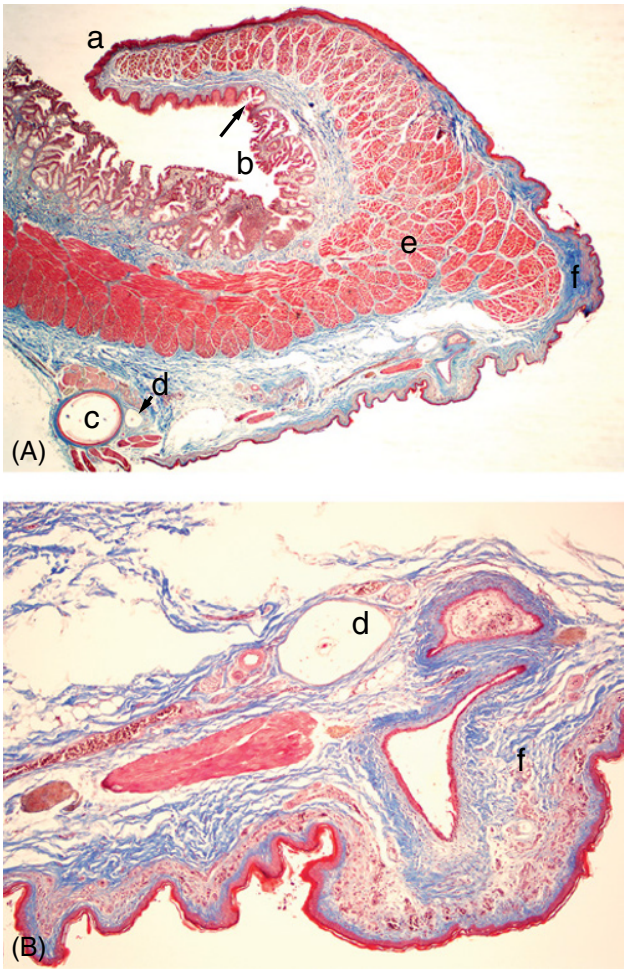

Figure 1.11 (A and B) Adult rooster vent showing the transition of the epithelium (arrow) from stratified squamous (a) to simple columnar epithelium inside the proctodeal cavity (b). Notice the presence of a feather follicle close to the skin (c) accompanied by Herbst corpuscle (d) and another Herbst corpuscle in the deeper dermis (d), vent skeletal muscle (e), and dermis (f).

Calder and Albright (2021)), excessive light, mineral deficiency, and parasitic infestation. Exposed areas of the skin encourage other chickens to pick. For the treatment of feather picking, one should consider the causative agent or its reason to eliminate first. This is followed by improving diet and paint window with red paints because chicken will go for the red exposed skin regions to pick. Individual experiences by the authors are the use of green alfaalfa hunged within the chicken housing to keep the chicken away from picking other chickens especially during the time of molting.

1.6 Debeaking

Debeaking (removal of one third of the beak) at one-day-old chicks is a widespread practice which showed no effect on body weight or mortality up to eight weeks of age (Lonsdale et al. 1957). Though positive results obtained from debeaking to stop cannibalism, stop feather picking, and decrease mortality, negative behaviors were reported (Cunningham 1992). The beak has nerve ending receptors and these are sensitive to pain (nociceptors). Trimming of the beak results in increased excitation of these nerve endings. Debeaking reported a decrease in activities for a brief period after the operation. Cunningham (1992) also reported that it is impossible to assess the degree of pain after debeaking, but the procedure can be considered painless. These comments were mentioned in response to the welfare activists who would like the breeders to stop debeaking because of the temporary pain the chicken exposed to during the operation and after it.

1.7 Eyelids Including Third Eyelid

Please see Chapter 9, Sense Organs (vision).

1.8 Vent

The vent is ellipsoidal in shape and consists of two labii, dorsal and ventral, which communicate with each other at the left and right commissures. The outer skin layers close to the labii are thin and consist of two to three layers of lightly keratinized stratified squamous epithelium. The stratified squamous epithelium becomes thinner at the junction with the simple columnar cloacal epithelium (Figure 1.12). The lamina propria and tunica submucosa are fused together due to the absence of lamina muscularis mucosa. This combined layer is called propria submucosa (Eurell and Frappier 2006, p. 172). The layer is filled with loose connective tissue, macrophages, lymphocytes, plasma cells, and fibroblasts. Coiled tubular glands line the most dorsal and middle part of the vent wall. They secrete mucus for lubrication and may play a role in certain species reproduction by helping to maintain favorable environment for the sperms. It is reported that the vent glands aid in extending the survivability of sperms (Dana et al. 2010). Two thick skeletal muscles surround the vent, inner circular and outer longitudinal. These muscle bundles are clearly surrounded by connective tissue of endomysium, perimysium, and epimysium. Individual myofiber surrounded by endomysium which are mostly reticular fibers, while the other two are mostly collagen fibers where perimysium surrounds a bundle of myofibers, while the epimysium surrounds the entire muscle. Bundles of small arteries, arterioles, and their accompanied veins and venules scattered within the connective tissue. Lamellated