2 COMPARATIVE ANATOMY OF CHORDATES

INTEGUMENT AND INTEGUMENARY DERIVATIVES IN VERTEBRATES

Integument is the skin covering the body. It is one of the largest organs of the body, making up some of the 15% of the human body weight. It serves as a critical border between the organism and its environment. The integument is a composite organ having multifarious activities. It gives rise to several organs of the vertebrate bodies. The remarkable variety of skin structures and their roles makes it very difficult to summarise.

A. General structure of skin

The outermost surface is the epidermis. The epidermis lies on the **basement membrane** (basal lamina or reticular lamina) as a characteristic feature (Fig. 2.1). Below the basement membrane lies the **dermis**. The epidermis develops from ectoderm and dermis is derived from mesoderm and mesenchyme. There is a transitional subcutaneous layer of loose connective tissues and adipose tissues, called **hypodermis**, in between the integument and deep body musculature.

B. Embryonic origin of skin

At the end of neurulation in the embryo, the skin precursors are delineated. Single layered ectoderm proliferates to be multilayered epidermis. The deep layer of the epidermis, the **stratum basale (stratum germinativum)**, rests upon the basement membrane(Fig. 2.1). The cells of the stratum germi-nativum divide to form an outer layer called **periderm**. Additional skin layers are

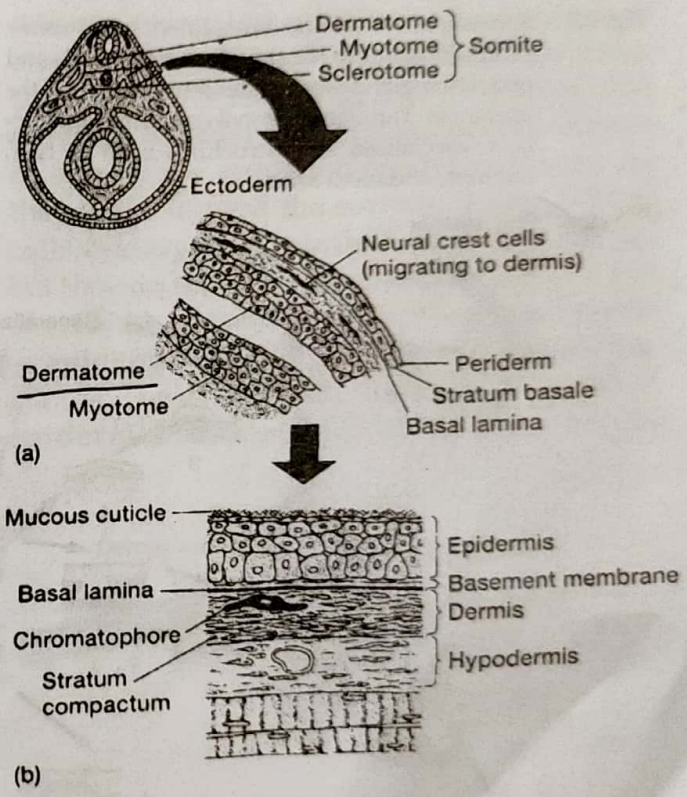


Fig. 2.1 : Embryonic development of the skin — (a) Cross-section of a vertebrate embryo. The ectoderm initially differentiates into a deep stratum basale, which replenishes the outer periderm. The dermatome settles under the epidermis to differentiate into the connective tissue layer of dermis. (b) The epidermis further differentiates into a stratified layer that often has a mucous coat or cuticle on the surface. Within the dermis, collagen forms distinctive layers that constitute the stratum compactum. The basement membrane lies between the epidermis and the dermis. Beneath the dermis and the deeper layer of musculature is the hypodermis, a collection of loose connective and adipose tissues

derived from these two layers with the advancement of development.

The dermis arises from several sources,

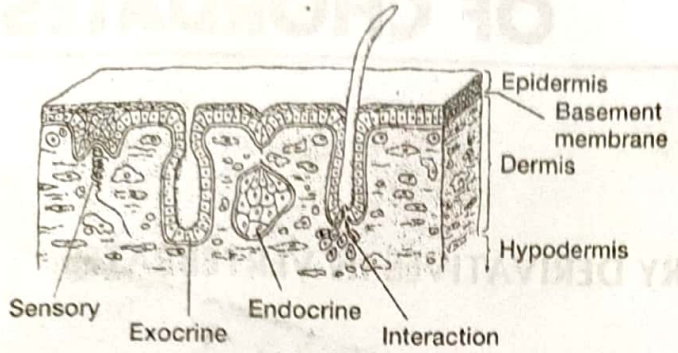


Fig. 2.2 : Specialisations of the integument — Sensory receptors reside in the skin. Exocrine glands and endocrine glands form from invaginations of the epidermis. Through a dermal-epidermal interaction, specialised skin structures such as hair, feathers, and teeth arise

principally from **dermatome**. The somites divide to form **sclerotome** medially and the **dermomyotome** laterally. *The sclerotome is the embryonic source of vertebrae and dermomyotome gives rise to myotomes.* The outer layer of the dermomyotome spreads out under the ectoderm as more or less distinct **dermatome** that differentiates into the connective tissue component of the dermis. Vascularisation and innervations are added, along with contributions from the neural crests. This simple structure of the integument gives rise to several ingredients and derivatives (Figs. 2.2 and 2.3).

C. Functions of skin

Skin is the boundary between animal and environment. It is well-known that animals

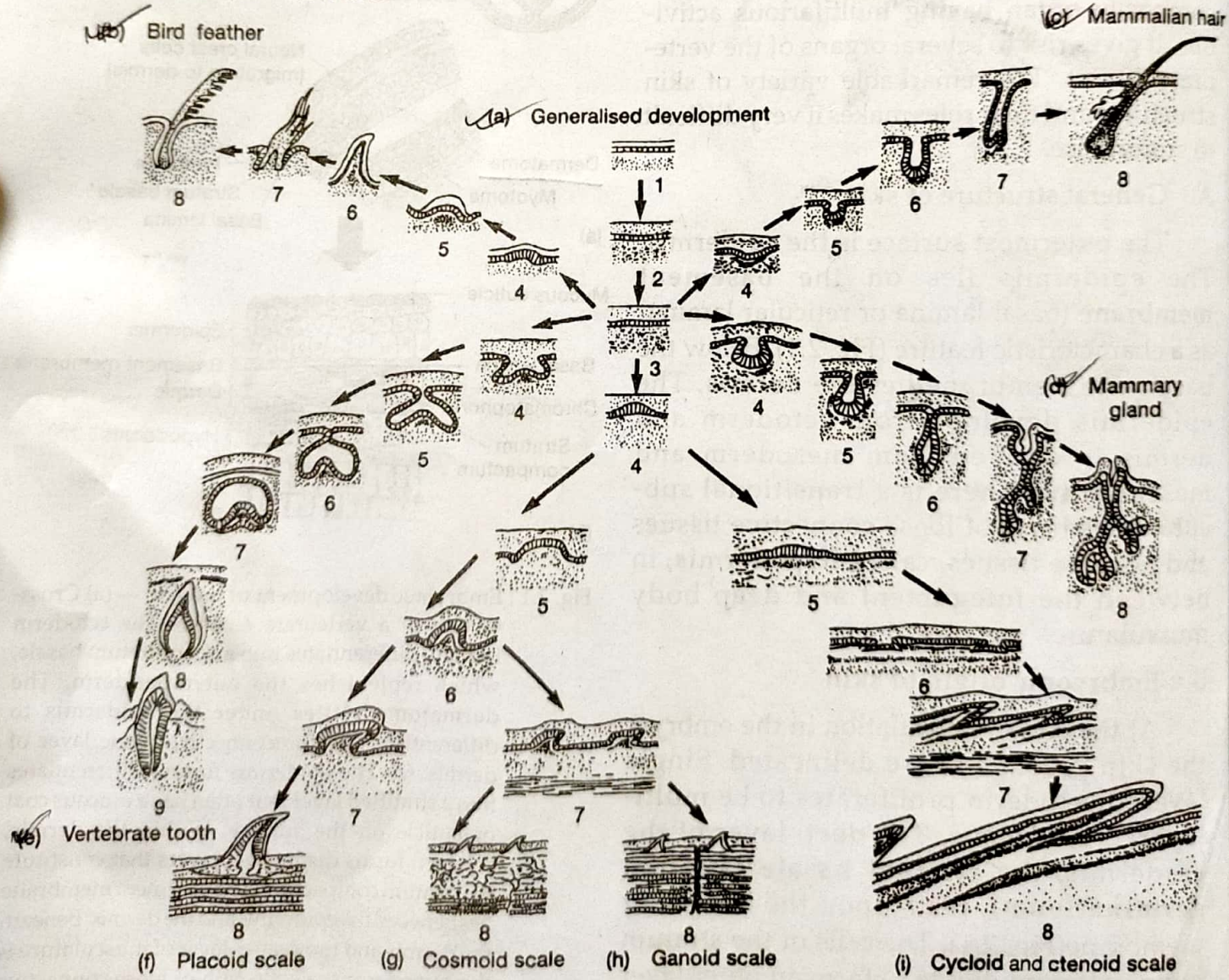


Fig. 2.3 : Skin derivatives — (a) Out of the simple arrangement of epidermis and dermis, with a basement membrane between them, a great variety of vertebrate integuments develop. Interaction of epidermis and dermis gives rise to feathers in birds (b), hair and mammary glands in mammals (c and d), teeth in vertebrates (e), placoid scales in chondrichthyes (f), and cosmoid, ganoid, cycloid and ctenoid scales in bony fishes (g–i)

encounter all possible type of atmospheric conditions. Therefore, it has to perform several activities to cope with the various situations. Some of the functions are :

- *Protection* — Horny and keratinous epidermis protect the animal from atmospheric problems. Some integumentary derivatives like horns, claws, antlers directly participate in the protection.
- *Temperature regulation* — Homoeothermic animals regulate their body temperature with the help of skin. They cool their body in summer by evaporation through skin and keeping their body hot by regulating evaporation.
- *Sensory* — Various receptors present in the skin convey different information to the brain for appropriate action, e.g., heat, cold, pain etc. Hair in most cases act as tactile receptor.
- *Excretion* — Some salts and metabolic end products are released through sweat.
- *Synthesis* — Vitamin D is synthesised from the UV light in the ergastarol of skin.
- *Secretion* — Sebum secreted from the sebaceous gland keeps the skin oily and prevents desiccation. Mammary gland secretes milk in mammals, poisonous gland secretes poison in toads.
- *Absorption* — Oily covering on the skin prevent easy absorption. However, fat-soluble vitamins can be absorbed through skin.
- *Osmoregulation* — Sweating, evaporation and diffusion through the skin tremendously help in osmoregulation.
- *pH balance* — Sweating, diffusion result in movement of salts to and from the body, causing change of pH of the body fluids.
- *Reservoir* — Considerable amount of fat, water, salt and glucose are stored in the dermis.
- *Gaseous exchange* — In some vertebrates wet skin helps in O_2 and CO_2 exchange, e.g. toads.
- *Indicator* — Changes in normal texture of the skin are good indicator of general health of the animal, e.g. vitamin deficiency, malnutrition, aging etc.

D. Different derivatives of the integument

The main components of the skin, i.e., epidermis and dermis, interact during embryonic development of animals to form different derivatives in the respective animal. Some of the derivatives are hair, feather, tooth, scale and mammary gland (Fig. 2.3).

E. Integument of fishes

In bony fishes, dermal scales do not actually pierce the epidermis, but they are so close to the surface they give the impression that the skin is hard (Fig. 2.4). The epidermal covering includes a basal layer of cells. Above this layer are stratified epidermal cells. As they move toward the surface, the epidermal cells undergo cytoplasmic transformations, but they do not become keratinised. Two types of cells are present in the epidermis of fishes — **epidermal cells** and specialised **unicellular glands**. The epidermal cells form the stratified epidermis. Unicellular glands are single,

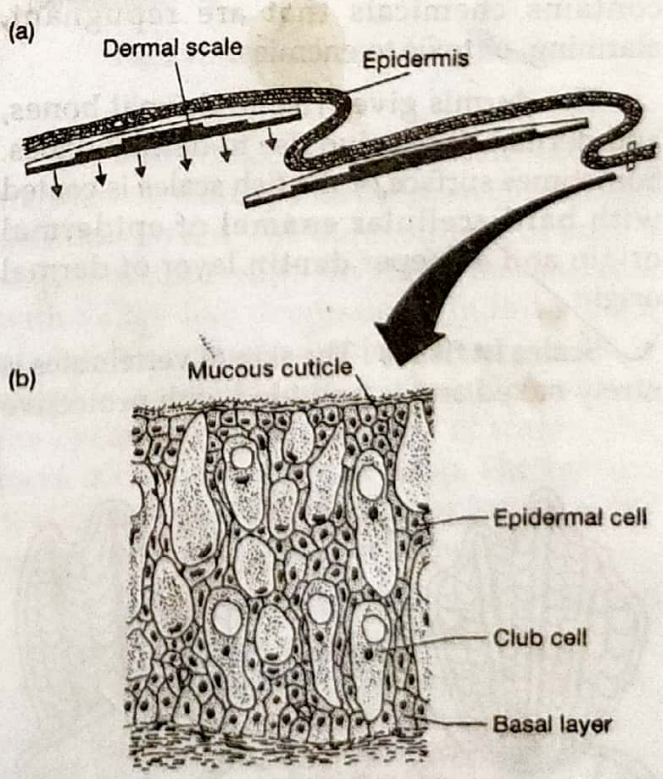


Fig. 2.4 : Skin of a bony fish (a) Arrangement of dermal scales within the skin of a teleost fish (arrows indicate direction of scale growth). (b) Enlargement of epidermis

Modification of scales — In sharks, teeth are modified placoid scales. In saw fishes 'saw' is modified placoid scales. In Terodon and Diodon the scales are transformed into protective spines. In *Acanthurus* the scales at the base of the tail transformed into sharp cutting blade. In basking shark the gill rackers are modified scales.

F. Integument of amphibians

Generally, the skin of frogs and salamanders includes two types of dermal glands — **mucus** and **poisonous** glands. They open to the surface through connecting ducts piercing the epidermis (Fig. 2.12). Numerous chromatophore cells are also present. In salamanders, the skin of the aquatic larvae includes a dermis of fibrous connective tissues, consisting of superficial loose tissue over a compact deep layer. Scattered **Leydig cells** of the epidermis secrete substances, which resist entry of bacteria or viruses. In terrestrial adults the Leydig cells are absent.

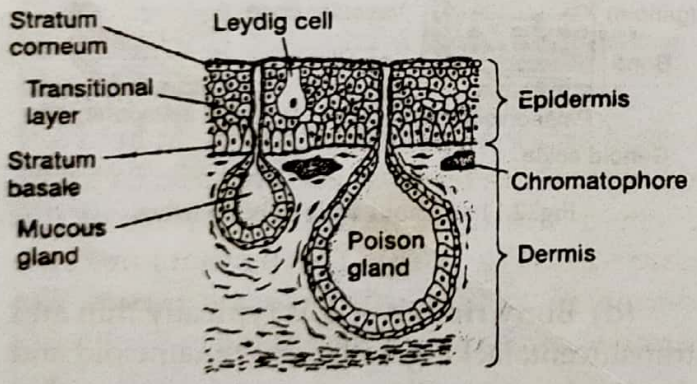


Fig. 2.12 : Diagrammatic view of amphibian skin showing mucous and poison glands that empty their secretions through short ducts to the surface of the epidermis

During breeding season **nuptial pads** may develop on the digits or limbs of male salamanders or frogs. Nuptial pads are raised calluses of cornified epidermis that help the male to hold the female during mating.

G. Integument of reptiles

Maximum keratinisation in the epidermis is the characteristic feature for the dry terrestrial atmosphere. Skin glands are very few in reptiles in comparison to amphibians. The epidermis is generally demarcated into three regions — *stratum basale*, *stratum granulosum* and *stratum corneum* (Fig. 2.13). The dermis is composed of fibrous connective tissue. Integumental glands are restricted to certain areas of the body of some reptiles. Many lizards possess rows of **femoral glands** along the underside of the hind limb in the thigh region. **Scent glands** are present in crocodiles and turtles. Most of the glands in reptiles are believed to be associated with reproductive behaviour.

Horny scales and plates in reptiles

The reptilian scale is a folding in the surface epidermis; thus it is **epidermal scale**. In the junction between adjacent scales there is a flexible **hinge** (Fig. 2.14). Large and plate-like scales of reptiles are called **scute**. Sometimes scales are modified into **crests, spines** or **horn** like processes. The rattles of the rattle

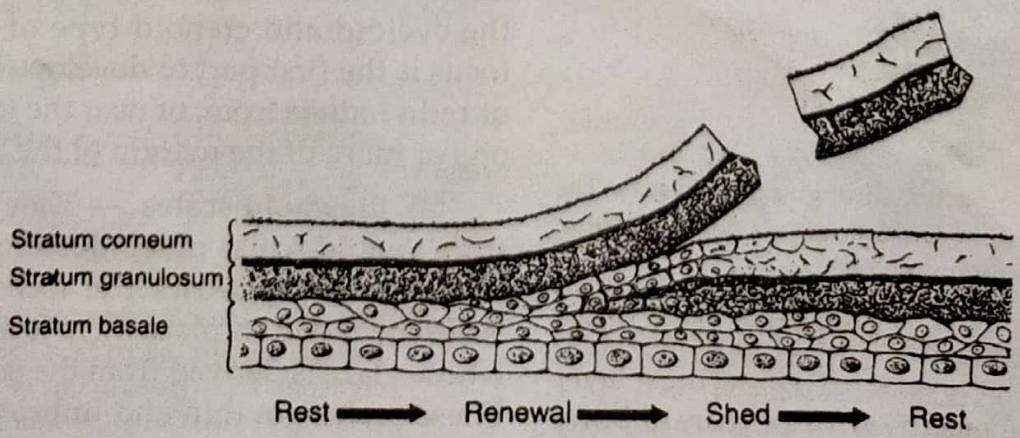


Fig. 2.13 : Reptile skin, showing process of skin shedding. Just before the old outer layer of epidermis is shed, the basal cells produce an inner epidermal generation. White blood cells collect in the splitting zone to promote separation of new from old outer epidermis

Table 2.1 : Difference between reptilian and fish scales

Fish scales	Reptilian scales
1. Built around bone of dermal origin.	1. Lacks the bony under-support or any significant structural contribution from the dermis.
2. It develops from the dermis and subsequently covered by different chemicals and minerals.	2. It is an epidermal surface folding.
3. The scales do not pierce the epidermis; instead, it remains covered under epidermis.	3. As the scales are epidermal, no question of piercing.

snakes are modified scales which are not shed off.

In many reptiles dermal bone is present, known as **gastralia** e.g. crocodiles, *Sphenodon*. These are collection of bones in the abdominal area. Sometimes dermal bones support the epidermis, they are known as **osteoderms**. Plates of dermal bone located under the epidermal scales, i.e. osteoderms, are found in crocodilians, some lizards, etc. Some bones of the turtle shell are probably modified osteoderms.

Moulting or ecdysis — It is a process of shedding off epidermal cornified layer of the skin at regular intervals. As moulting begins, the stratum basale, which has given rise to the strata granulosum and corneum, duplicates the deeper layers of granulosum and corneum, pushing up under the older layers (Fig. 2.13). White blood cells invade the stratum intermedium, a temporary layer between old and new skin. These WBCs are thought to promote the separation and loss of the old superficial layer of the skin. This process is clearly influenced by the anterior pituitary and thyroid gland activity.

H. Integument of birds

The epidermis comprises of the stratum basale and the stratum corneum. In between them there is a transitional layer of cells transformed into the keratinised surface of the corneum (Fig. 2.15). The feathers are epidermal in origin. Birds have few glands, like **uropygeal gland** and **salt gland**.

The dermis, especially near the feather follicles, is richly supplied with blood vessels. During brooding season, the dermis in the

Fig. 2.14 : Epidermal scales of Reptile skin. Extent of projection and overlap of epidermal scales varies among reptiles and even along the body of the same individual. Snake body scales (top) and tubercular scales of many lizards (bottom) are illustrated. Between scales is a thinned area of epidermis, a "hinge" allowing skin flexibility

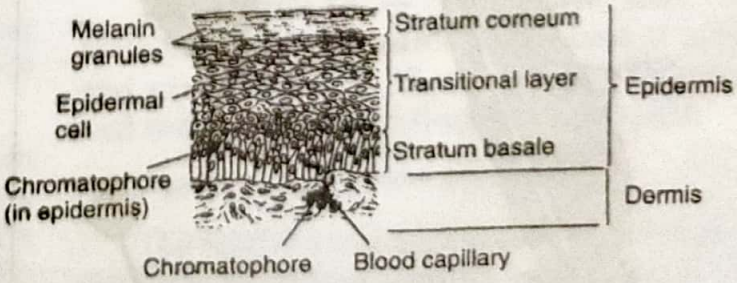


Fig. 2.15 : Section of a bird skin showing the stratum basale and the keratinized surface layer; the stratum corneum. Cells moving out of the basal layer spend time first in the transitional layer before reaching the surface. This middle transitional layer is equivalent to the spinosum and granulosum layer of mammals

breast of some birds become heavily vascularised, forming a **brood patch** in which warm blood can come into close association with the incubated eggs.

Exoskeleton of Birds

In most of the members of the phylum Chordata the integument is soft and contains no hard skeletal parts, but many members have bony elements, derived from the dermis, present in the skin. Dermal scales of integumentary origin provide a protective armour, and are present in most fishes, in a few amphibians, in crocodilians, and in turtles. The term ***dermal skeleton*** is used in referring such structures and their derivatives. Sometimes the dermal skeleton is called the ***exoskeleton***, but this term is more properly applied to the skeleton of invertebrates. In birds, what we are referring as exoskeleton, are the derivatives of epidermis of the integument.

Feather of Birds

Structure of a typical feather

A typical feather consists of several structural peculiarities. The **seapus** or **stem** is a stiff axial rod, running the whole length of the feather (Fig. 2.16). The stem has several zones along its length. The **calamus** is the tubular semi-transparent proximal portion, the base of which is inserted into the skin. At the terminal point of the calamus, there is a small aperture called the *inferior umbilicus*. At the opposite end of the *inferior umbilicus* of calamus, there is another pore, called *superior umbilicus*. The distal part of the stem is solid rod like structure, called **rachis** or **shaft**. It is a tapering, flexible, elastic rod, square in transverse section. It has a ventral longitudinal groove called **umbilical groove**.

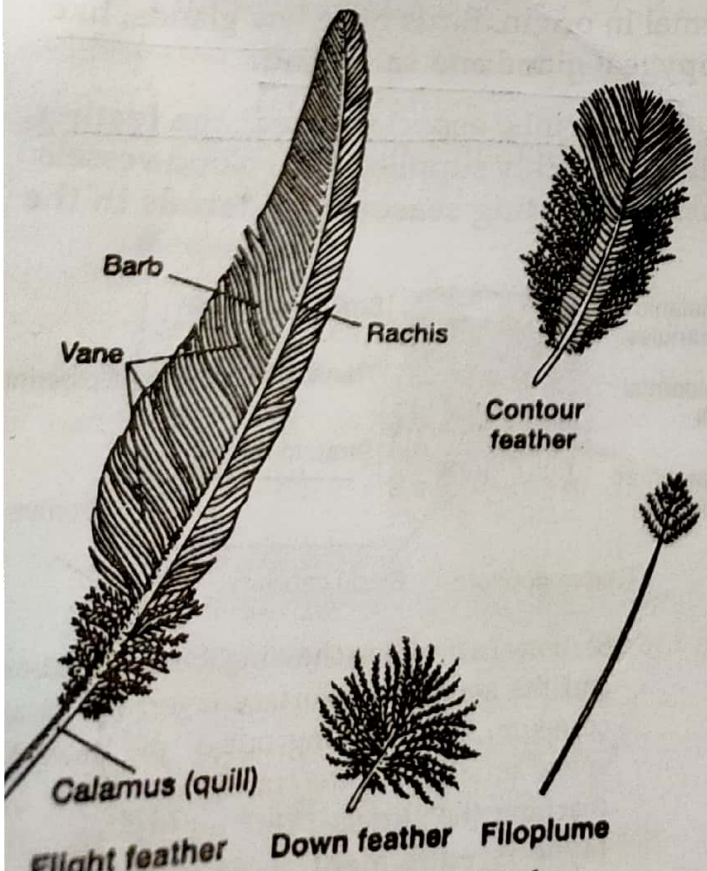
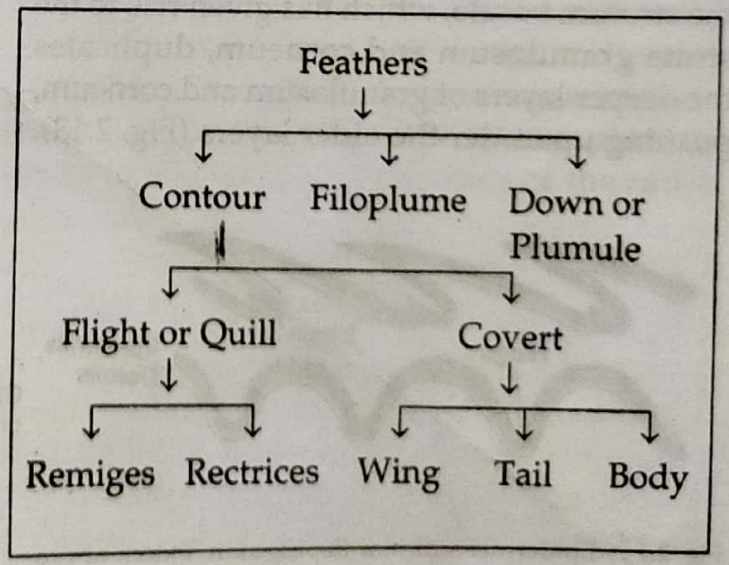


Fig. 2.16 : Feather types of birds

The **vexillum** or **vane** is the flattened portion of the feather, attached along the sides of the rachis. It is made up of **barbs** and **barbules**. The barbs are series of narrow elastic lamina, attached by their base along the two sides of the rachis. The barbules are much smaller processes which form fringe along the sides of the barbs, bearing **hooklets**. These hooklets binds with the hooklets of other barbs and so give the feather a consistent structure.

Varieties of feather : According to the shape and distribution on the body the feathers are divided into three major types. Various types of feathers are tabulated in the following chart :



A. Contour feather

These feathers determine the shape of the body of a bird, as they cover the body in a

definite way. The barbules are well-developed and interlocked with others. These are of two types :

1. **Flight or Quill feathers** — Flight feathers constitute the major locomotor surfaces. These are the large feathers of wing and tail. Accordingly they are defined differently — (a) Remiges or wing quill, and (b) Rectrices or tail quill.

(a) **Remiges or wing quill** — The feather of the wings is called as remiges. This has the inner half of the vane much broader than the outer half (Fig. 2.16). The narrow half of each feather overlaps the broad half of the one anterior to it. The effect of this is to allow air passage between the feathers in the down-stroke.

The number of remiges is about twenty-three. The remiges are divided into two groups, on the basis of the limb bones on which it is attached. The **primary quills** are attached on the **manus**. In pigeon, they are eleven in number, of which six are attached to the metacarpals (**meta-carpal quills**), one **ad-digital** is attached to the phalanx of the post axial digit, two **mid-digital** attached to the middle proximal phalanx of the middle digit, and two **pre-digital**, one of which is small, attached to the distal phalanx of the middle digit. The **secondary quills** are attached to the ulna. They are twelve in number.

(b) **Rectrices or tail quill** — These are present on tail. These feathers have two haves of the vane about equal in size. These are twelve in wild rock pigeon, but may be more in domestic breed. These feathers are distributed in a half-circle along the tail.

2. **Covert feather** — These are medium sized feathers covering the whole body. These are similar in appearance to the flight feathers but smaller in size. According to their distribution they are divided into three types :

(a) **Wing covert** — These are covering the wings. Upper coverers are called **upper wing coverts** and lower coverers are called **lower wing coverts.**

(b) **Tail covert** — There are **upper** and **lower tail coverts** covering the upper and lower part of the tail.

(c) **Body covert** — Except wings and tail these feathers cover other parts of the body. They give the body a smooth outline.

B. **Filoplumes**

These are minute rudimentary feathers left in the skin after the bird has been plucked. Each consists of a hair like long stem, with a very rudimentary vane at its apex and few barbs devoid of interlocking barbules (Fig. 2.16).

C. **Down feather or Plumule**

These are generally short, soft and woolly feathers, covering the body of young newly hatched birds (Fig, 2.16). They have short calamus. Bunch of long, soft barbs are at the tip of the calamus. There are no hooks on the barbules. Usually they are not present in an adult bird.

D. **Other feathers**

(a) **Powder down feather** — These are down feathers, which do not mature after development. Instead, these are broken down to powdery materials. Their definite function is not known. It is believed that they maintain the texture of the feathers as talcum powder.

(b) **Rectal bristle** — These are modified filoplumes. They have small calamus and rachis with rudimentary barbs. Generally found at the base of beak of flycatcher and goatsucker.

(c) **Vibrissae** — These are hair-like feathers. Generally present at the base of beaks and around the eyes. These are tactile receptors and well developed in the nocturnal birds.

Arrangement of feathers on the body

The feathers of a bird are distributed over the body in certain definite areas (Fig. 2.17). The distribution of feather is called **pterylosis**. The area where feathers are arranged, is called **pterylae**, the intervening tracts where feathers are not present, is called **apteria**. Only filoplumes are present in the apteria.

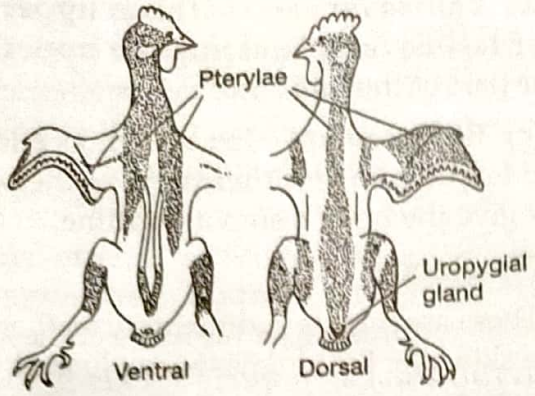


Fig. 2.17 : Pterylosis in bird

Development of feather

Feather develops during embryonic period from **feather follicle**. Feather follicles are invaginations of the epidermis that dip into the underlying dermis (Fig. 2.18). The root of the follicle in association with the dermal pulp cavity begins to form the feather. The feather itself grows outward in a sheathed case. Within the sheath, the central axis is divided into a distal rachis and a proximal calamus.

Functions of feather

Feathers are insulating the body of birds from heat. Flight feathers are highly modified for efficient flying through the air. Some times colour of the feather match efficiently with the ambient colours concealing the bird both from predator and prey. In some birds sexual dimorphism is clearly visible from the feathers. Feathers help in sexual behaviour in some birds, e.g. tail feather of peacock.

Beaks of birds

A hard keratin layer covers the upper and lower jaws of birds. These covered jaws are called beaks. The coverings of the upper and lower beaks are known as **maxillary** and **mandibular rhamphotheca,** respectively. These rhamphotheca

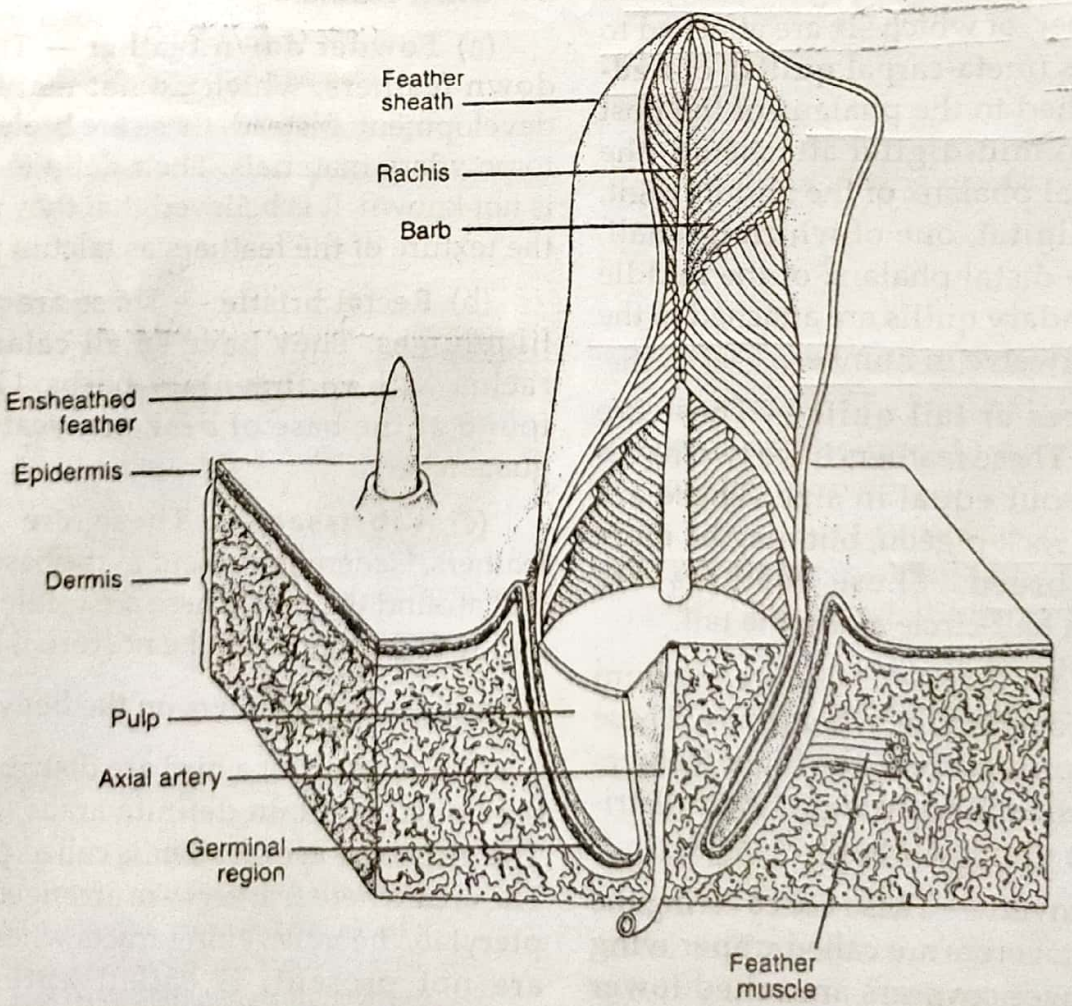


Fig. 2.18 : Growth of a feather follicle. The feather forms within a sheath, which like the feather, is a keratinised derivative of the epidermis

are actually modified skin. Beaks act for food collection, nest building, protection and maintenance of feathers by polishing with the secretions of uropygeal gland. There are varieties of modified beaks found in nature; this is supposed to be due to different types of food habits. Nature of beak is an important taxonomic criterion in birds.

Scales of birds

Epidermal scales are confined to the shank and the feet of birds (Fig. 2.19). In some birds scales are found at the base of the beak. These scales are arranged in an overlapping fashion. In some species males possess horny scaly covering over the bony projections of tarso-metatarsus, this is called **spur**.

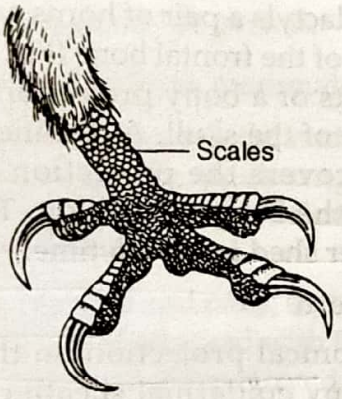


Fig. 2.19 : Epidermal scales are present on the feet and legs of birds

Claws of birds

Claws are situated at the open end of the digits of the foot (Fig. 2.19). These are composed of hard keratin and are modified scales. A claw has a dorsal plate called **unguis** and a ventral plate called **subunguis**. Claws are used mainly for grasping food and in **perching mechanism**. In addition it is used for self-defence and aggression.

I Integument in mammals

Epidermis is divided into five layers; from outside these are as follows (Fig. 2.20) :

(i) *Stratum corneum* — This is the outermost keratin layer. Cell boundary is indistinguishable and nucleus is absent. This layer is thick in the palm and sole and thin in the lips. Hair developed from this layer.

(ii) *Stratum lucidum* — This is the second layer from the outside. It is a thin layer. Cells are devoid of nucleus and cell membrane is inconspicuous. The cells of this layer possess **eleidin** which gives rise to keratin.

(iii) *Stratum granulosum* — Third layer from the outside and is composed of three to five cell layers. The cells contain **keratohyaline granules**, responsible for the name of the layer.

(iv) *Stratum spinosum* — This is fourth layer from the outside. It is much thicker than the others. The cells of this layer bear several spiny structures emerging out from the membrane. So these are called **prickle cells**. These spines attach with the spines of the adjacent cells.

(v) *Stratum basale* — This is the fifth and last layer of the epidermis. The cells of this layer are columnar and continuously dividing mitotically to replace upper layers.

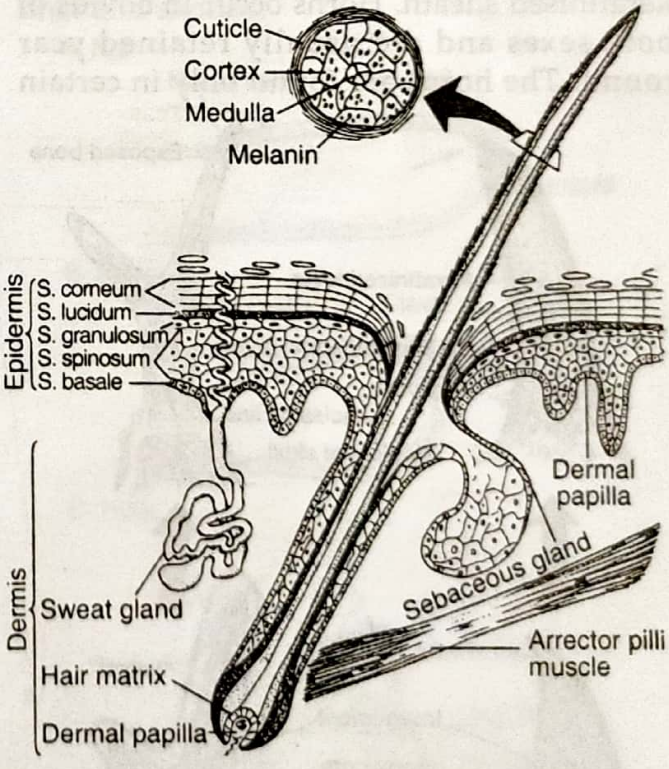


Fig. 2.20 : Mammalian skin. The epidermis is differentiated into distinct layers. The dermis gives out dermal papillae that give the overlying epidermis an undulating appearance. Sweat glands, hair follicles, and sensory receptors lie within the dermis. Notice that the sweat ducts pass through the overlying epidermis to release their watery secretions on the surface of the skin (S. = Stratum)

Cytoplasmic extensions from the basal cells reach the cells of dermis.

(vi) *Stratum malpighii* — This layer is not the part of epidermis. But present in-between epidermis and dermis. This layer possesses branched cells called **melanocytes.**

Dermis or Cutis vera is composed of collagenous and elastic fibres. Upper layer of dermis is well-organised **papillary layer,** which maintains connection with the melanocytes and prickle cells. Inner layer of dermis is loose connective tissue with fat deposition. **Fibroblast** cells of the dermis produce fibrous tissue and reticulo-endothelial system. Some of the cells possess melanin pigment and are called **melanophore.** Dermis contains sweat, ceruminus, and sebaceous glands.

Horns in mammals

Horns appear as outgrowths of the skull beneath the integument, which forms a keratinised sheath. Horns occur in bovids of both sexes and are usually retained year round. The horns are found only in certain members of the order Artiodactyla and in *Rhinceros* of the order Perissodactyla. According to structure and mode of formation, three types of horns are found in mammals [Fig. 2.21A].

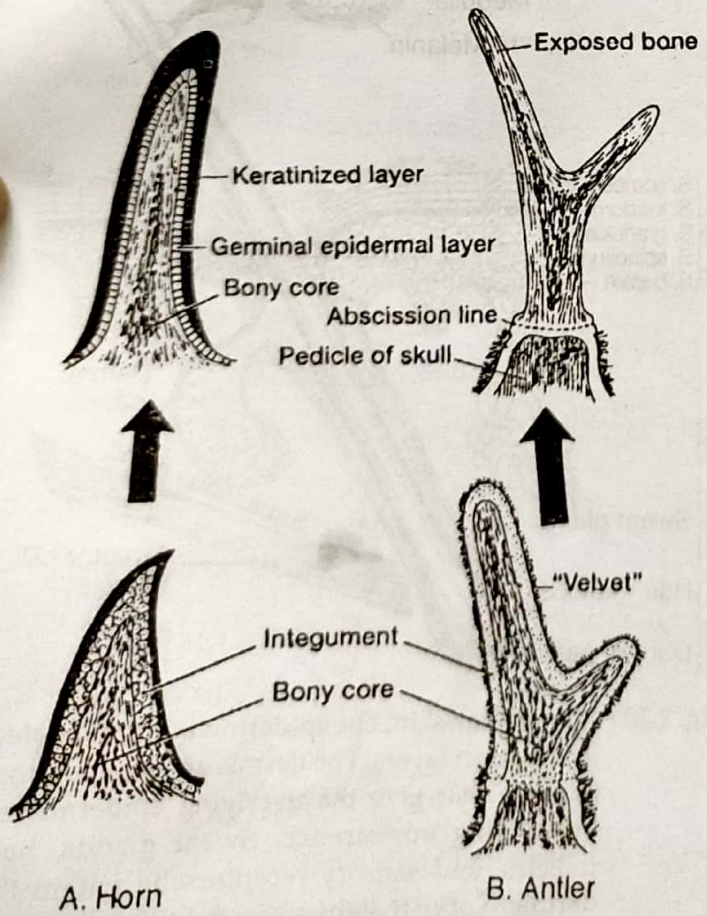


Fig. 2.21 : A. Horns and B. Antlers. Showing early and developed stages

1. **Keratin fibre horn**

In case of *Rhinoceros* a hard conical structure is present on the front of the nasal region of the skull. It is composed of a cluster of bony fibres. The fibres are fused together by a mass of hard and keratinised cells growing from the epidermis. Each fibre resembles a very thick hair and emerges from a dermal papilla. The fibres are, however, not true hair as their bases lack follicles.

2. **Hollow horn**

In artiodactyls a pair of horns are present, one on each of the frontal bone (Fig. 2.21). The horn consists of a bony projection from the frontal bone of the skull. A cornified layer of epidermis covers the projection. A cavity enters into the bony projection. The horny layer is never shed in the lifetime.

3. **Prong horn**

It is a conical projection on the frontal bone. A horny epidermal sheath covers the projection. The sheath usually bears prong. This unique type of horn is found in antelope, *Antelocopra americana* of Western America (Fig. 2.22).

Antlers in mammals

These are mesodermal derivatives. In natural condition these are hard bony structures develop on the frontal bone of the skull. Antlers appear as outgrowths of the skull beneath the overlying integument, which is referred to as "velvet" because of its appearance. This overlying velvet dries and falls away, leaving the bony antlers. Antlers are restricted to members of the deer family and, except for caribou (reindeer), they are present only in males. Antlers are sheded and replaced annually [Fig. 2.21B and 2.22]. A mature antler has many branches, e.g. males of some deer, both male and female of giraffe and caribou possess antlers. In giraffe the skin

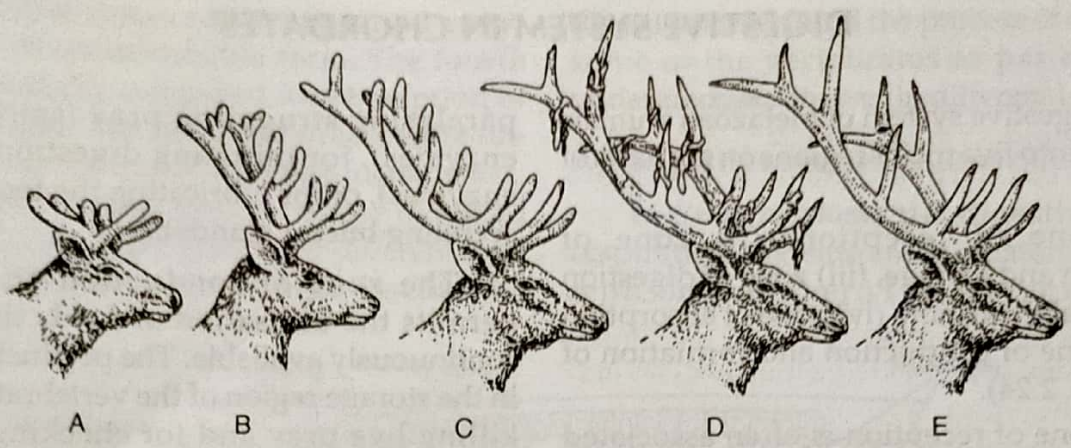


Fig. 2.22 : Annual growth of elk antlers. A, B. New antlers begin to grow in April. C. By May, antlers are nearly fully formed even though they are still covered by the living integument (velvet). D. By late summer, the velvet has begun to dry and peel off. E. Fully formed bony antlers are in place

covering of the antlers never shaded; it remains throughout life period.

Hoof, claw and nails in mammals

In ungulate mammals the end of the digits remains covered by thick unguis, called hoof. Sub-unguis is present below the unguis (Fig. 2.23).

In case of claws and nails, sub-unguis plate is rudimentary and attached with the pad of the digit. The unguis is sharp curved needle- like. The members of the feline group can withdraw their claws within the paws. In nail the unguis is broad and flat, sub-unguis is rudimentary and remains at the base of the nail.

Hair in mammals

Hair are slender keratinous filaments. Root is the base of a hair, the remaining length constitute shaft. The outer surface of the shaft forms a scaly cuticle. Beneath this, is the hair cortex, and at its core is the hair medulla (Fig. 2.20).

The hair shaft is produced in the epidermal **hair follicle** and projects above the surface of the skin. The surface of the epidermis dips down into the dermis to form the hair follicle. At its expanded base, the follicle receives a small tuft of the dermis, the **hair papilla**. The **arrector pilli** muscle, a thin band of smooth muscle anchored in the dermis, is attached to the follicle and makes the hair stand erect in response to cold, fear or anger.

Thick covering of hair is **fur** or **pelage**, generally composed of guard hair and underfur. The larger, coarse hair, called **guard hair**, are the most apparent on the outer surface of the fur. The **underfur** is situated beneath the guard hair and is usually much finer and shorter.

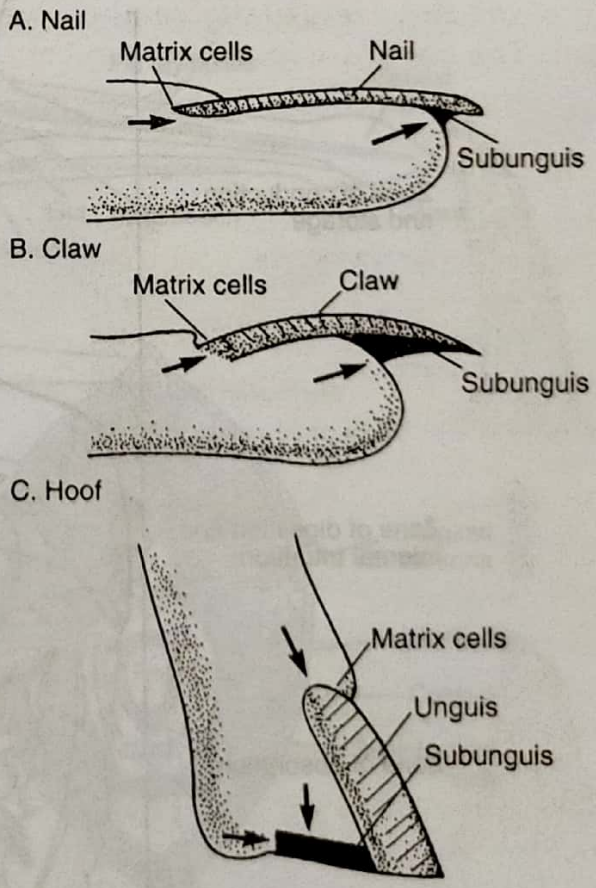


Fig. 2.23 : Epidermal derivatives — A. The nail, B. Claw, C. Hoof. In all the cases the plate of cornified epithelium growing outward (arrows) from proliferating matrix cells at its base and from the subunguis.