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Anatomy & Function of the Nail

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Introduction

Despite their relatively small surface area, toenail problems and disease make up a significant proportion of a podiatrist's workload. Healthy nails provide a sense of wellbeing for the patient, as demonstrated by studies showing reduced quality of life in those suffering nail disease [1, 2]. Nail disorders may arise as a result of many factors including trauma, infection, systemic disease, and neoplastic disease. Careful assessment of the nails can give an indication of an individual's state of health. As a podiatrist, it is important to examine routinely all nails (including the fingernails), free of nail varnish and in good light to permit a thorough assessment. The use of a dermatoscope can provide additional detail to the assessment [3]. To understand the pathological mechanisms of many of the diseases affecting the nail requires a knowledge of nail anatomy and physiology. This article looks at the fundamentals of nail anatomy and physiology and introduces nail pathologies as observed in the clinic.

Nail Anatomy

The nail unit is labelled as one of the skin's appendages along with hair, sweat and sebaceous glands. It first begins to develop around the 9th week of gestation in the fingers as an infold of the developing epidermis, with the toenail following around a month later and development of the first nail plate begins around week 15 in utero [4] with continued growth to birth and beyond. The nail unit resides on the dorsal surface of each distal phalanx (SEE FIGURE 1). It is firmly secured in place by strong anchoring filaments and via attachments to surrounding ligaments and to the periosteum of the phalanx. These are located primarily between the base of the distal phalanx and the matrix (the posterior ligament), and at the distal tip of the phalanx and the lateral nail groove, located just under the free edge of the nail (the anterior ligament).

The primary function of the nail is to protect the underlying structures and distal phalanx, but in the fingernail, it aids dexterity and manipulation of small objects. The role of the toenail may be considered more vestigial in humans although it acts as a counter pressure to the soft volar tissues during standing and locomotion.

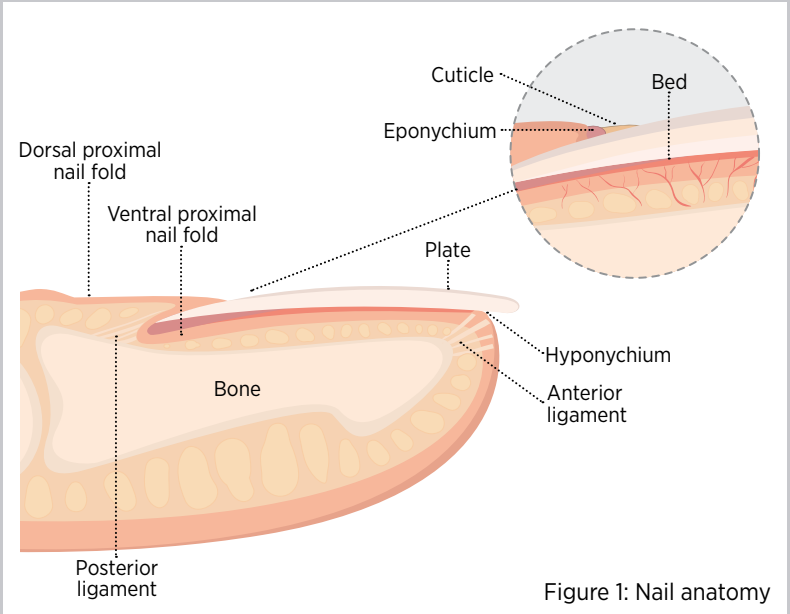

Figure 1: Nail anatomy

The Nail Plate

When examining the nail unit, the largest visible structure is the nail plate - a translucent convex sheet of hard keratin, overlying the nail bed (SEE FIGURE 2). Around a quarter of the nail plate is hidden at the proximal end under the cover of the proximal nail fold in the toes. Laterally, the nail plate shows slight convexity, allowing it to be secured in the lateral nail folds, or sulci. The nail plate is naturally translucent but appears light pink in colour, due to the underlying capillaries of the nail bed visible through the keratin sheet. Distally, the nail plate separates from the nail bed protruding at the hyponychium to form the free edge, which is naturally white in colour and its natural shape follows the contour of the lunula. Just proximal to this, at the point of separation, a deeper pink (in fair skin) or brown (in darker skin types) 1mm transverse band can be observed known as the onychodermal band (or sole horn) which is considered to be the area of particularly firm nail to nail bed attachment and thus

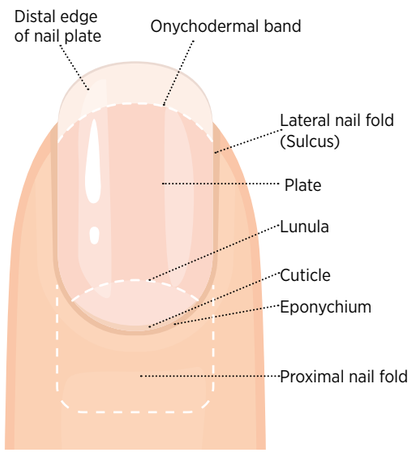

Figure 2: Gross nail anatomy (dorsal view)

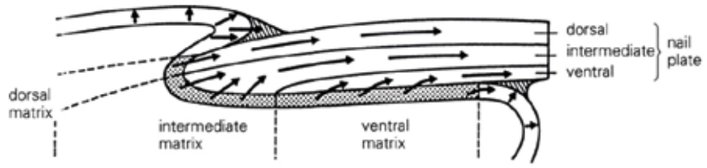

Figure 3: Nail matrix contributions to nail plate formation

a barrier to penetration from the external environment under the nail plate. Dorsally, the proximal nail fold is sealed from the outside environment by the cuticle (eponychium). The proximal nail fold covers the nail generating cells, known as the nail matrix. At the proximal end of the nail plate, the half-moon shape of the lunula can be seen, representing the most distal aspect of the nail matrix. The lunula is most commonly observed in the hallux and thumb, appearing paler than the adjacent nail bed.

The nail plate is hard, waterproof and relatively impermeable [5]. Studies have shown the nail to be a virtual barrier to both UV-A and UV-B light [6]. Structurally, the plate is a made up of three individual lamina of keratin, each layer being created from three different areas of the nail unit (SEE FIGURE 3). The dorsal aspect of the nail plate being derived from the dorsal matrix, the middle layer from the intermediate matrix and the ventral layer being contributed from the nail bed itself (sometimes termed the ventral matrix). However, the nail bed has little functional contribution to the nail integrity itself. Appreciation of the nail laminae can be helpful in determining the source of pathology. For example, alterations in the dorsal surface of the nail plate are palpable and visible, whereas intermediate nail disease is visible but not palpable.

CLINICAL APPLICATION: *Nail pitting is a common feature observed as small erosions in the top layer of the nail plate. Small numbers of pits may be of little relevance or indicative of any disease but when they occur in greater numbers, they may indicate skin disorders such as alopecia, eczema or psoriasis. In psoriasis, an increase in the epidermal transit time of keratinocytes in the skin and nail means that their nuclei are retained, and the cells are termed "parakeratotic". As the nail grows clear of the cuticle, these cells are softer and so fall out of the emerging nail plate leaving the characteristic pits observed in psoriasis.*

CLINICAL APPLICATION: *Nail degranulation (SEE FIGURE 4). Increasingly, the repetitive use of nail varnishes and lacquers on the nail can affect the keratin of the nail. Termed, nail degranulation, it is a recent phenomenon associated with the use of nail gels and lacquers. Regular application and re-application of harsh chemicals can cause surface changes to the toenails causing the top surface to dry out causing nail brittleness. Typically, the nail surface shows white areas of surface erosions. Treating nail degranulation generally requires the patient to thoroughly remove any residual varnish between applications and refrain from topical applications for a few months to help improve the appearance of the nail.*

The Proximal Nail fold (PNF)

The PNF is similar to the adjacent skin but lacks dermatoglyphics, hair and sweat glands. The most distal aspect is the cuticle (eponychium) which is projected onto the nail surface forming a watertight seal. This barrier is important as it prevents the ingress of infectious agents, irritants and allergens into the nail matrix.

CLINICAL APPLICATION: *The importance of the biological seal around the nail unit is beautifully illustrated when it is breached within a digit. Paronychia (whitlow) is a condition defined as inflammation of the soft tissue around the nail, usually associated with a bacterial or fungal infection. Depending on the duration it can be termed acute or chronic (lasting several weeks). The condition typically occurs when there is break in the natural seal around the nail unit such as the cuticle or lateral nail folds, which allows ingress of pathogens or irritants. On the toes, the most common example is onychocryptosis, where penetration of the sulci by a sharp nail edge permits the introduction of bacteria leading to painful inflammation, hypergranulation and exudation. In the fingers, the typical cause of paronychia is nail biting, thumb sucking and frequent immersion of the hands in water which can lead to weakening of the cuticles. Retinoid drugs can also have a similar effect. Chronic paronychia in a nail leads to the loss of the natural cuticle.*

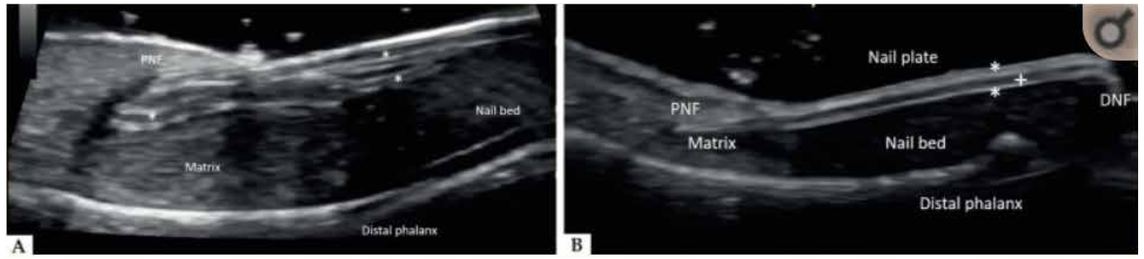

Figure 6: Ultrasound Image of retronychia (left) showing multiple nails (white dots) whilst normal nail (right). Reproduced under Creative commons licence [8]

Nail Assessment

Routine evaluation of the nails should be part of the skin assessment. Undertaken in good, preferably natural lighting, nails should be examined, free from any lacquer or varnish. As fingernails may show more subtle changes, it is important to include them in the patient examination. Visualisation of the nail unit can be enhanced using the dermatoscope. Application of ultrasound gel to the nail plate is the best coupling medium as it does not run unlike mineral oil (FIGURE 17). The dermatoscope should be "rolled" onto the nail plate to extrude any air bubbles and to enhance the image quality.

When any abnormality is encountered, the distribution of the affected nails should be considered. Local causes may affect just a few digits on one foot, whereas when multiple digits on both hands or feet are observed, a widespread or systemic condition should be considered. Photographs may be taken, ensuring that correct consent is taken, and appended to the patient's notes as a permanent record. Where a referral or second opinion is required, a letter should be drafted outlining the findings along with any clinical and dermatoscopic images to the patient's general practitioner. It is good practice also to send a copy of the letter to the patient for their reference.

Figure 17: Ultrasound gel is used on the nail plate prior to dermatoscopic examination

Figure 7: Longitudinal melanonychia in a fungal nail

CLINICAL APPLICATION *(SEE FIGURE 5): Sudden distal impact to the nail plate can cause a proximal detachment of the growing nail plate from the matrix, whilst remaining attached distally. Consequently, a second nail may develop within the matrix whilst the first nail is still in situ. As the new nail develops, the proximal nail fold becomes overcrowded, swollen and inflamed with bouts of pain. High frequency ultrasound can be helpful to confirm the presence of multiple nails within the matrix (SEE FIGURE 6). The condition is termed retronychia [9] and requires nail avulsion, without phenolisation, to remove all the nail plates and restore normal growth [7, 8]. The condition is commonly recurrent if the causative trauma is not eradicated – such as steel-capped footwear.*

The Nail Matrix

The cells of the nail matrix account for around 15 – 25% of the tissue below the nail plate. The area houses the dorsal and intermediate matrices which are responsible for generating the bulk of the nail plate. The far edge of the lunula marks the end of the nail matrix and it continues as the nail bed beyond. As in the normal epidermis of the skin, cells along the basal layer of the nail matrix divide to produce keratinocytes which differentiate, become anucleate, harden and die producing a hard keratin due to the abundance of sulphur, cysteine, glycine and tyrosine proteins, which contrasts with the small amounts in the softer keratin of the epidermis. Unlike the normal epidermis there is no granular layer evident in the PNF, but otherwise the two areas are comparable.

Within the nail matrix, melanocytes reside in the basal layer and stratum spinosum. Normally, the melanin produced is incorporated into the nail plate but is not visible. The presence of melanocytes may be protective against the risk of UV damage and subsequent malignancy. Langerhans cells and antigen presenting cells are also present within the matrix.

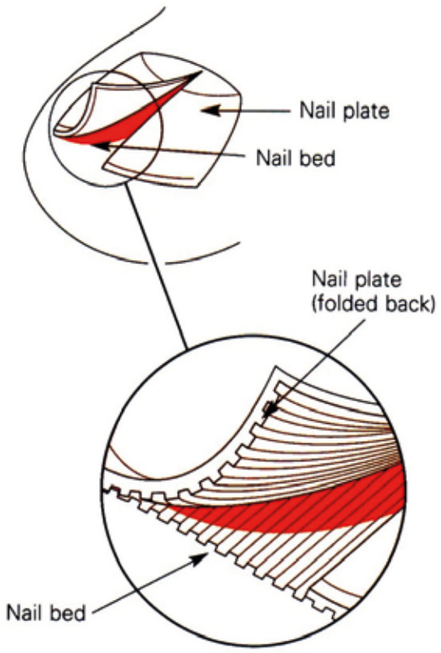

Figure 8: Nail bed arrangement with nail plate

CLINICAL APPLICATION: *Longitudinal melanonychia (SEE FIGURE 7) is characterised by a brown line running the full length of the nail plate from the matrix to the free edge. Melanin pigment is donated from active melanocytes in the matrix and is incorporated into the forming nail plate. In darker skin types, melanonychia may be a benign process, particularly in Afro-Caribbean individuals. Around 77% will have a melanonychia by the age of 20, and almost 100% by the age of 50 [4]. Longitudinal melanonychia is a more sinister sign in Caucasians and requires careful assessment. Other causes of melanonychia include trauma, exogenous pigments, endocrine disorders, drug therapies and naevi, located within the matrix.*

The Nail Bed

The nail bed is the continuation of the intermediate nail matrix distally, beyond the distal edge of the lunula. It accounts for 75% - 85% of the tissue beneath the nail plate. It adds an additional, but clinically insignificant amount of keratin to the emerging nail, sometimes termed as the "ventral matrix". The surface of the nail bed is not flat but has a tongue-in-groove arrangement running longitudinally along the nail plate, particularly at the distal aspect (SEE FIGURE 8). This serves to increase the degree of adhesion between the nail and nail bed by providing a greater surface area. Blood vessels close to the surface in this area run in a parallel fashion along the long axis of the grooves.

CLINICAL APPLICATION: *Splinter haemorrhages are 2-3mm plum-coloured lines, running longitudinally along the nail plate towards the free edge (SEE FIGURE 9). They are formed by blood haemorrhaging onto the nail bed and running within the subungual grooves before coagulating. They then grow out with the nail plate. Small numbers in a single digit are of little significance. The most common cause of splinter haemorrhages includes trauma, but they can also arise in eczematous and psoriatic nails and are seen occasionally in patients with endocarditis, hepatitis and cirrhosis.*

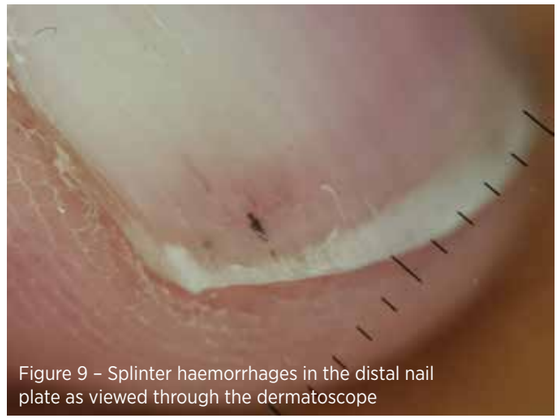

Figure 9 – Splinter haemorrhages in the distal nail plate as viewed through the dermatoscope

Figure 10 – Leukonychia occurring in the toenails

CLINICAL APPLICATION: *Changes in the colour of nail bed can give the illusion of changes in nail plate colour, owing to its natural translucency. Whitening of the nail bed (apparent leukonychia) can be seen in patients with renal disease and anaemia. True leukonychia refers to changes in the actual colour of the nail plate itself, occurring in the matrix and typically arises as a result of trauma and psoriasis affecting the nail (SEE FIGURE 10).*

The nail bed is naturally devoid of melanocytes and is anchored flat by vertical collagen fibres which run deep to the periosteum of the underlying distal phalanx. The epidermis in this area is just 2-3 cells thick but the dermis below contains a fine network of lymphatics, nerves and blood vessels but there is no subcutaneous fat in this area.

The Hyponychium

The hyponychium is the epithelial area located under the free edge of the nail plate. Its proximal boundary is the onychodermal band and distally it merges with the normal skin of the pulp of the digit at the distal groove. The area is effectively a crevice which can act as a reservoir for microbes (see clinical application below).

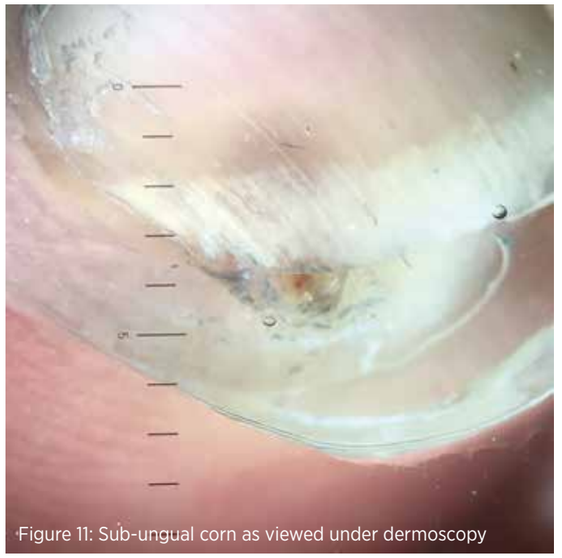

Figure 11: Sub-ungual corn as viewed under dermoscopy

CLINICAL APPLICATION: *Onychomycosis typically follows tinea pedis. The dermatophytes spread from the plantar surface onto the volar surfaces of the toes and up under the nail, onto the nail bed [10]. This can take many months or years. This subungual invasion is the most common route for fungal infection in the foot by dermatophytes and is referred to as Distal Lateral Subungual Onychomycosis (DLSO). Toenail invasion typically occurs in nails that have suffered physical trauma hence it is most commonly observed in the first, second and fifth toenails. Damage to the nail plate causes disruption of the onychodermal band – the distal, natural seal of the nail permitting entry of dermatophytes onto the nail bed to initiate infection.*

CLINICAL APPLICATION: *When pain is elicited from pressure applied distally to the nail, a sub-ungual corn should be suspected. Corns are most common on the skin, but can arise in the distal nail bed under the nail plate itself as a dark spot which yields slightly under pressure eliciting the pain. Typically, they occur in patients in their sixth and seventh decade in the midline of the toe [11]. Nail resection and enucleation of the corn is normally curative although recurrence is possible (SEE FIGURE 11).*

Neuro-vascular supply to the nail unit

The nail unit of both the toes and fingers has a rich blood supply being served from four digital arteries (two dorsal and two plantar, either side) arising from the plantar arch and arcuate artery on the dorsum of the foot. The main supply runs from the ventral surface serving the pulp of the digit before looping upward and serving the dorsal structures of the nail bed. Connecting branches supply the extensor tendon insertion and matrix area through the superficial arcade (dorsal nail fold arch), whilst two sub-ungual arcades (proximal and distal) serve the nail bed. There are numerous anastomoses ensuring a good supply of blood even if one area is compromised or the pulp of a digit is compressed from weight bearing, for example. The nerves run a similar course accompanying the arteries to serve the nail bed, pulp and matrix (SEE FIGURE 12).

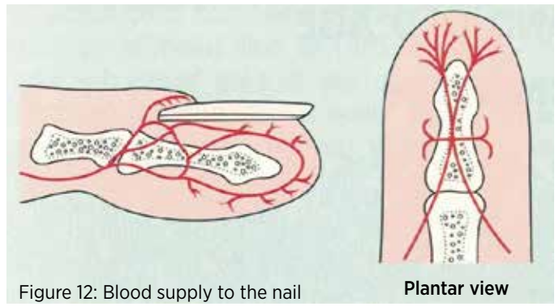

Figure 12: Blood supply to the nail

Figure 13: Nail fold capillaries visible through the dermatoscope

Blood vessels in the nail bed are very densely concentrated giving rise to the natural pink colouration. Glomus bodies are specialist encapsulated neuro-vascular structures containing muscle fibres particularly abundant in the fingers and toes (90-500 per cm2). Each glomus body is supplied with blood through an arteriole and connects directly to a venule, surrounded by smooth muscle fibres. Glomus bodies are able to contract acting as a "peripheral heart". They are important for maintaining blood flow in response to changes in the ambient temperature directing blood away from the surface of the epidermis in low temperatures by constriction whilst maximising blood flow when temperatures are high.

Nail fold Capillaries

The superficial capillaries of the nail fold may be easily visualised using a dermatoscope (SEE FIGURE 13). The capillaries being in a longitudinal flat hairpin arrangement looping close to the base of the cuticle with a high density particularly in the toes [12]. Inflammatory disorders such as scleroderma, dermatomyositis and mixed connective tissue disease can manifest as changes to these highly ordered vessels demonstrating changes to the vessel structures [13].

Nail Constituents & Dynamics

Much like the skin, many clinicians view the nail unit as an inert structure but it is an area of significant kinetic and biochemical activity. The nail plate is constructed of lamellar layers of tightly packed keratin and contains large amounts of protein (78%), a small amount of water (18%) and very little lipid (<5%). The nail plate is constructed from a combination of hard (80%) and soft (20%) keratins with additional intermediate filaments high in sulphur, tyrosine and glycine. The disulphide bonds are thought to contribute largely to nail hardness by acting as glue that holds the keratin fibres together, thereby creating the nail plate's tensile strength in combination with hydration [14]. Drying of the nail typically leads to nail brittleness, whilst excessive hydration softens the nail plate. Soaking the nails in water causes a temporary breakdown in the covalent disulphide bonds, which leads to uncoiling of the hard keratin structure and softening of the nail plate. Mineral constituents include zinc, magnesium, iron, sodium, copper and calcium. They are all found in small quantities and are unlikely to contribute to the hardness of the nail. Studies have shown nails are harder in males than females [15].

CLINICAL APPLICATION: *Joseph Beau (1846) first observed and reported transverse ridges occurring in the nail plate following serious systemic infections. This observation subsequently became known as Beau's lines. They arise due to cessation of nail growth. Typically, after nail growth resumes, they emerge and become visible in the fingernail plates around four weeks after the event. In the toenails, typically only the hallux is affected. They are characterized by forward pointing, wedge-shaped indentations in the nail plate of variable depth and obliquity. The obliquity of the indentation reflects the rate of onset and its severity [16]. Prolonged disease can lead to growth cessation and nail shedding from a proximal direction (onychomadesis). Common causes are listed below in Table 1.*

TABLE 1 : Causes of Beau's lines

Common	Rare
Fever (infectious diseases) Post-natal Trauma Chronic paronychia Chronic eczema Local inflammation	Drugs Syphilis Hand, Foot & Mouth Disease Zinc Deficiency Hypoparathyroidism

Figure 14: Koilonychia of the 1st nail in an infant (normal development)

Unlike hair, but akin to epidermis, the nail grows continuously throughout one's life. Measurement of nail growth is usually taken as a simple longitudinal elongation, but does not truly reflect nail growth as it fails to capture increase in thickness [17]. Fingernails grow at a rate of 3mm per month, whilst toenails grow at half of that rate (1mm per month). Complete regeneration of a fingernail can take 4-6 months whilst a toenail can take up to a year or more. Typically, the peak rate of nail growth is in the second decade before showing a slow decline of 0.5% per year after the age of 25 [18]. Research has shown that nails with onychomycosis have a reduced growth rate compared with controls [19]. Throughout life there are subtle changes in the form of the nail plate. In infancy, the nail plate is generally very thin, consequently it is subject to koilonychia - this is temporary in the vast majority of cases with the plate returning to normal shape as it thickens (SEE FIGURE 14).

There are a number of known factors which affect the rate of nail growth and these are summarised in Table 2 (below).

Table 2: Factors affecting the rate of nail growth [18, 20, 21].

Slower	Faster
Physiologic	
Females	**Males**
Toes 1st and 5th digits Winter Night Lactation	Fingers 3rd digit Summer Day Handedness Increased ambient temperatures
Pathologic	
Severe infections Prolonged illness Cancer therapies Nerve injuries Ischaemia Hypothyroidism Malnutrition Congestive Heart Failure Smoking Psoriasis Erythroderma Hyperthyroidism Pregnancy Biting Repeated, minor trauma	
No known effects on nail growth: Diet supplements, steroids, stress, height, weight or skin colour.	

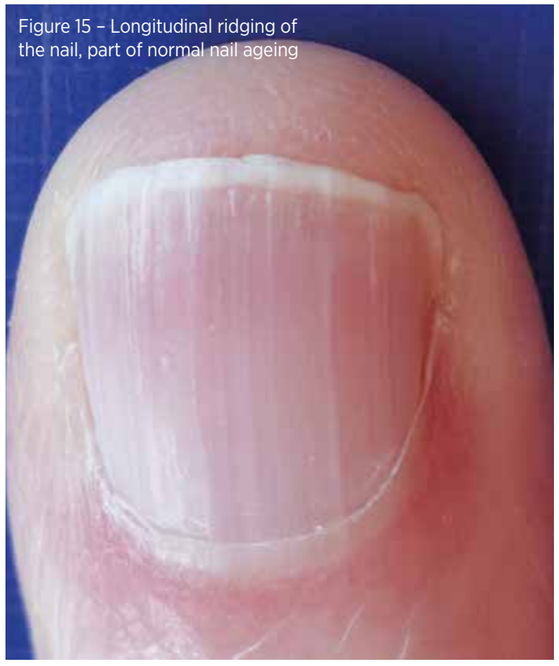

Figure 15 – Longitudinal ridging of the nail, part of normal nail ageing

Nails in older age

As we age, the rate of nail growth declines – between the 3rd and 9th decades it reduces by around 38% [18] and structurally the nail plate becomes more pale, dull and whitened or opaque. Colour changes in the nail may mean it appears more white, yellow or grey. The lunula may become decreased in size or even absent. Longitudinal ridges become more of a feature (SEE FIGURE 15). Moreover, nail pathology becomes more common in old age due to a range of factors including:

- Reduced peripheral circulation and arterial disease
- Fungal infections
- Accumulated trauma / faulty biomechanics
- Trauma
- Effects of inappropriate footwear
- Neoplasia / tumours
- Systemic disease

Typically, with ageing, the fingernails become more brittle whilst toenails become more thickened.

CLINICAL APPLICATION: *Older patients with serious systemic disease may develop a type of apparent leukonychia (whitening of the nail bed) which gives the appearance of opacification of nearly the entire nail, obliteration of the lunula, and a narrow band of normal, pink nail bed at the distal border [22]. The condition is known as Terry's nail (SEE FIGURE 16). The condition, although appearing in healthy older individuals, can be associated with cardiac, renal and hepatic failure as well as diabetes. Around 25% of hospital inpatients may show the nail change [23]. The cause is unknown, but it is thought to occur due to a reduction in nail bed vascularity as a result of connective tissue overgrowth.*

Figure 16 – Terrys nails (whitening of nail bed [A] with distal red band [B]) Reproduced under creative commons licence [23]

Table 3: Glossary of nail anatomy

Term	Definition
Nail unit	The entire anatomical area encompassing the nail plate and associated structures.
Nail plate	The sheet of hard keratin produced from the matrix.
Lateral nail folds	The skin folds at the edge of the nail bed which help to secure the nail plate onto the nail bed.
Hyponychium	The space located under the free edge of the nail plate, at the tip of the digit.
Eponychium	The skin that projects forward onto the nail plate, effectively sealing off the proximal nail fold from the external environment.
Cuticle	The most distal projection of the eponychium consisting of dead, keratinised epidermal cells.
Proximal nail fold	The infold of epidermis, at the base of the nail, that houses the nail producing cells.
Nail matrix	The cells responsible for the production of the hard keratin of the nail.
Nail bed	The majority of the skin visible under the nail plate from the distal edge of the lunula to the hyponychium.
Lunula	The crescent shape frequently visible at the base of the nail which represents the most distal aspect of the nail matrix.

Summary

Careful examination of all twenty nails can be helpful as part of the general patient assessment. Understanding of nail anatomy and physiology can be helpful to the clinician to recognise both local and systemic disorders. ■

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