Radiological Imaging in Nail Unit Disorders (Part I) - Modalities Used

Abstract
The nail unit is a unique skin appendage, capable of mounting only a limited number of reaction patterns to a variety of insults. This makes it difficult to diagnose many nail conditions based on clinical features alone. Thus, diagnostic modalities have an important role to play in nail disorders. Emphasis is placed on non-invasive diagnostic methods, of which, radiological imaging forms an important part; however, it is a field largely under-explored with very few studies and reports available in the literature. This could be due to the problems encountered in nail unit radiology including its small size, complex anatomy, requirement for special high-frequency probes to reliably evaluate superficial structures, and non-familiarity with nail unit radiological features even amongst trained radiologists. Nevertheless, it plays a useful role in diagnosing nail disorders (especially tumors), localizing the changes, exploring differential diagnoses, estimating prognosis, and planning management. This article is aimed at collating scientific data pertaining to various radiological modalities used in the diagnosis of nail diseases. The advantages and limitations of various imaging techniques used for evaluating the nail unit, including digital radiographs, high-frequency ultrasound, ultrasound doppler (USD), computed tomography (CT), and magnetic resonance imaging (MRI), are discussed in the first part. The second part will discuss the features of common and uncommon nail diseases.

Keywords: CT, digital X ray, MRI, USD, USG

Introduction
The nail unit is a functional utility, apart from carrying esthetic significance. Various infectious and non-infectious disorders affect the nail, and the common methods of evaluation include clinical examination, onychoscopy, direct microscopy, microbiological techniques, radiological examination, and histopathology.[1] Amongst these, least amount of literature is available regarding radiological examination of the nail, probably because of its small size and complex anatomy making it difficult to visualize; and the need for special probes due to its superficial location. Non-familiarity amongst both dermatologists and radiologists regarding nail unit features in health and disease is another impediment.

Presently, many radiological imaging techniques have been used in nail disease including radiography, ultrasonography (USG), ultrasound doppler (USD), computed tomography (CT), and magnetic resonance imaging (MRI).[2] However, their cost and availability varies, which needs to be kept in mind while ordering these modalities.[3] This narrative review aims to summarize the techniques, procedural nuances, advantages, and limitations of various radiological imaging modalities used for nail, so as to enable their better utilization. The second part of the review will detail the radiological features of individual nail disorders.

Methodology
A PubMed search pertaining to published articles using the keywords “radiology AND nail,” “radiodiagnosis AND nail”, “radiograph AND nail”, “CT AND nail”, “MRI AND nail”, “Ultrasonography AND nail” was done. The search yielded 6143, 10, 2494, 642, 615, and 6737 indexed English language articles, respectively. The articles pertaining to the “Nail Unit” in “dermatology” alone were shortlisted and abstracts were read. These were classified into reviews and clinical studies of various types. Detailed methodology, procedural details, and nature of imaging devices used, procedural nuances, advantages, and limitations were noted.

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advantages and disadvantages of these investigative techniques were collated and are summarized in a narrative fashion.

**Radiological techniques and features of nail unit**

Radiological techniques used in diagnosing various nail disorders, along with the features of a normal nail as visualized by them are summarized in Table 1.[2,4-8] [Figures 1a–d and 2a–c]. These include.

**Radiographs**

A conventional radiograph (digital x-ray) is one of the initial investigations for evaluating nail pathology, especially trauma or tumor. The recommended views are lateral [Figure 1a] and antero-posterior (AP) [Figure 3], which can help assess bony deformities of distal phalanx, suspected bony outgrowths, calcification, and gross bone invasion. Despite offering limited soft tissue evaluation, radiograph is probably the most often used nail unit radiological technique. High-resolution digital radiographs improve visualization markedly. Radiography is also recommended for suspected joint abnormalities, for example, osteoarthritis and psoriatic arthritis[9]; and differentiating enchondroma or osteoid osteoma wherein a calcified matrix of bone tumor is demonstrated. Calcification within soft tissue suggests phleboliths. For nail trauma, radiographs help evaluate phalangeal fracture, pathological or otherwise. However, radiographs suffer from poor sensitivity in evaluating bone invasion in subungual carcinoma even when the periosteum has been pathologically invaded; whereas, carcinoma microscopically limited to soft tissue, may show false radiographic evidence of bone invasion.[9] Radiographic nail findings are listed in Table 2.[2,9-11]

**Ultrasonography**

USG is an emerging, useful, and inexpensive radiological technique for nail evaluation, which avoids radiation exposure, while allowing separate evaluation of nail unit components based on their well-defined densities. Thickness, architecture, and vascularity of nail plate and bed can be evaluated based on their well-defined densities. Power doppler (PD) mode is utilized to study the vascularization of the nail unit. Thus, USG is useful for assessment of a range of infectious, noninfectious, and inflammatory nail disorders.[12] It has been used extensively for diagnosis, pre-surgical evaluation, choosing a biopsy site, and even surgical follow-up. However, unlike CT or MRI, it does not allow evaluation of bone medulla as sound waves do not pass through compact bone [Figures 1b and 2a]. For this, radiographs, CT scan, or MRI are better modalities.[7]

Nail USG requires appropriate higher frequency. While, lower frequencies like 7.5 MHz can visualize at >4 cm depth (useful for subcutaneous tissue and lymph nodes); increasing frequency (13.5–20 MHz) leads to a decline in depth of penetration (from 3 to 0.7 cm), making it useful for epidermis and dermis.[13] Even higher frequencies (50–100 MHz) penetrate to 0.3–0.015 cm, visualizing epidermal changes only.[14] Nail evaluation is
Table 1: Radiological features of the normal nail unit

| Nail unit component                  | Anatomical considerations                                                                 | Appearance on Radiographs                  | Appearance on USG                                      | Appearance on CT scan                  | Appearance on MRI                       |
|-------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------|-------------------------------------------------------|----------------------------------------|-----------------------------------------|
| Views used                          | Dorsal view                                                                                 | Lateral view                                | Longitudinal view                                      | Sagittal plane                         | Sagittal plane                          |
|                                     | Sagittal view                                                                               | AP view [Figures 1a, 3]                     | Transverse view [Figures 1b, 2a]                       | Axial plane                            | Axial plane                             |
|                                     | Sagittal view for complete understanding                                                    |                                             |                                                       | Coronal plane                          | Coronal plane                           |
|                                   |                                                                                             |                                             |                                                       |                                        |                                        |
| Nail plate                          | Keratinized structure                                                                       | Not described in literature. Findings are   | Composed of two parallel hyper-echoic bands, also     | Not described in literature. Findings   | Not described in literature. Findings   |
|                                     | Originates near middle third of the phalanx                                                  | usually non-specific.                       | known as the dorsal and ventral nail plate            | are usually non-specific.               | are usually non-specific.               |
|                                     |                                                                                             | Seen as faint linear radiodensity,         | These are separated by a hypoechoic space referred   | Not delineated from the non-specific    | Not delineated from the non-specific    |
|                                     |                                                                                             | appreciated in the lateral view           | to as the interplate space                            | soft tissue density in the expected     | soft tissue density in the expected     |
|                                     |                                                                                             |                                             | Nail matrix is a hyper-echoic structure               | location                               | location                               |
|                                     |                                                                                             |                                             |                                                       |                                        |                                        |
| Nail matrix                         | Located at the proximal end of the nail bed                                                | Not delineated separately from nonspecific | Seen as a hypo-echoic space between the ventral      | Not delineated separately from nonspecific | Appears as a homogenously hyper-intense |
| (germinal matrix) and underlying dermis | Largely covered by the double-layered proximal nail fold and the thin arising nail plate. | soft tissue density in the expected location  | nail plate and the dorsal cortex of the phalanx       | soft tissue density in the expected     | area with enhancement on gadolinium     |
|                                     |                                                                                             | on the lateral view                         | Low velocity arterial and venous blood vessels are    | location                               | injection.                              |
|                                     |                                                                                             |                                             | seen in this region, nearer to the bony margin.       |                                        |                                        |
| Nail bed (sterile matrix) and       | Located under the nail plate, extending up to the periosteum of the distal phalanx.        | Not delineated separately from nonspecific |                                                                 |                                        |                                        |
| underlying dermis                   | Distal continuation of germinal matrix.                                                     | soft tissue density in the expected location on the lateral view |                                                                 |                                        |                                        |
|                                     | Underlying nail bed dermis (papillary and reticular dermis) is 1-2 mm thick and rich in blood vessels, glomus bodies and innervations |                                             |                                                                 |                                        |                                        |
| Periungual tissue (nail folds)      | The nail plate is encased by the                                                            | Not delineated separately from             | Not delineated separately from                        | May not be delineated from              |                                        |
|                                     |                                                                                             | nail folds show same echogenicity as skin  | nonspecific soft tissue density in the expected       | nonspecific soft tissue density in the  |                                        |
|                                     |                                                                                             |                                              | location                                             | expected location                      |                                        |
|                                     |                                                                                             |                                              |                                                      |                                        |                                        |

Contd...
thus optimally done at 14–20 MHz with high-resolution linear array transducer,[15,16] providing a good balance between spatial resolution and penetration (60 mm).[17]

Nail USG can be performed in two and three dimensions, utilizing a variable frequency, sophisticated multi-channel machine. For examination, the finger or toe should be fully extended. Compression needs to be avoided when evaluating nail unit, as it can cause a false thinning and push superficial nodules outside the field of view. For this, copious amount of gel is applied over the entire nail unit and periungual area. A silicone, or gel pad can also be used between the nail and the transducer. The contralateral nail is generally used as a control for assessing thickness and echotexture. Sweeps are done in two perpendicular axes, longitudinal and transverse, using gray scale first and then color doppler with spectral curve analysis. Three-dimensional image reconstructions can be done using machine’s software. Gray scale evaluation assesses thickness and features of each component, while USD and PD help assess vascularity. PD helps to assess vascularity irrespective of velocity or flow direction, making it more sensitive. While doing PD study, care should be taken that the hands are not too hot or too cold, to be able to reliably assess inflammation. This can be ensured by placing the probe on the finger with a large amount of ultrasound gel or doing an examination under water.[19]

On USG, tumors or growths are visualized as focal hypoechoic lesions with demarcated or non-demarcated

| Table 2: Nail unit features visualized easily on a plain radiograph |
|----------------------------------------------------------|
| Clinical entity       | Radiological finding                                                                 |
|-----------------------|--------------------------------------------------------------------------------------|
| Subungual exostosis   | Bone growth arising over the distal phalanx of great toe commonly                    |
|                       | Usually appears as a well-circumscribed bony structure                               |
|                       | Lacks clear continuity with both the medullary cavity and cortex of the phalanx,     |
|                       | which can help in distinguishing it from osteochondroma                               |
| Hemangioma            | Phleboliths or rounded soft tissue calcifications can be present                     |
|                       | Other radiological findings include soft tissue swelling, benign periosteal reaction |
|                       | or remodeling if the lesion is present adjacent to bone                                |
| Subungual keratoacanthoma | A well-defined, cup-shaped lytic resorption in the distal phalanx                   |
| Subungual melanoma    | It may be due to pressure erosion because of the rapidly growing tumor               |
| Trauma                | Radiographs can demonstrate fracture of distal phalanx                                |
|                       | Especially recommended if there is a large subungual hematoma                        |

| Table 1: Contd... |
|-------------------|
| Nail unit component | Anatomical considerations | Appearance on Radiographs | Appearance on USG | Appearance on CT scan | Appearance on MRI |
|-------------------|
| proximal nail fold (eponychium), lateral nail fold (perionychium) and distal nail fold (hyponychium). | nonspecific soft tissue density in the expected location | elsewhere (except palms and soles) | nonspecific soft tissue density in the expected location | nonspecific soft tissue density in the expected location |
| Phalanx           | Located inferior to nail bed | Bony shadow | Bony margin of the distal phalanx appears as a continuous hyper-echoic line corresponding to the bony cortex. | Seen as a bony density | Sagittal images depict inter-phalanageal joint accurately. Insertion of extensor tendon onto the base of distal phalanx; articular cartilage and palmar plate can be seen |
|                  |                               | Contours visualized in AP, lateral and oblique views | Distal inter-phalanageal (DIP) joint is seen as an anechoic space that has fluid and cartilage. |                             | |

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borders. Depth, area, and demarcation from surrounding structures can be identified. Doppler evaluation helps to pickup intra or peritumoral flow signals. Low-resistance pulsatile flow suggests malignant and metastatic potential. Limitations of USG include need for special training and skill [Table 3]. It also lacks sensitivity for highly localized, in-situ lesions <0.1 mm in size, or pigmented lesions.

USG is also uniquely placed with respect to joint examination. It can reliably assess the distal interphalangeal joint including the insertion of the extensor apparatus and the joint capsule. This is especially useful in cases with suspected psoriatic arthritis with nail changes. Swelling arising from the joint capsule causes compression of the nail matrix, producing secondary changes in the nail plate. Most frequently encountered is the mucoid pseudocyst, and USG helps to confirm a joint origin of this cyst.

**Computed tomography**

Use of CT in nail unit is limited due to poor soft tissue resolution; it is useful when bone involvement is suspected, for example, in nail tumors with bony erosion, or soft tissue calcification. CT can be evaluated in coronal, sagittal, and axial views [Figure 4a–c]. Contrast enhancement aids delineation of vascularity as hypo or hyper-vascular lesions. Specific contrast agents can help create variable enhancement patterns based on differences in vascularization or interstitial tissue network. Advanced techniques like helical acquisition, that offers high quality and 3-D imaging of distal phalanx, have improved the scope of CT scan in nail unit. Though there is radiation exposure, it is considered insignificant at the level of fingertip.

**Magnetic resonance imaging**

MRI is largely considered as the radiological technique of choice for the nail unit. It is indicated when USG provides limited information, or when more information is needed regarding specific tumor patterns. It allows detection of growths, and evaluation of their relationship with adjacent structures; hence, helping preoperative planning. It can characterize tissues with different histopathological features. Nevertheless, USG scores over MRI in being cheaper, faster, more accessible, and permitting repeated, dynamic, and comparative examination.

MRI of fingernails is done with patient in prone and hand first position. In case of toenails, MRI is done with patient in supine and feet first position. MRI of normal nail unit may not accurately distinguish between the components of nail unit. Nail plate shows as a single, homogenous hypo-intense structure. Like CT, MRI also generates coronal, sagittal, and axial views [Figure 5a–c]. Axial slices help evaluate the nail from proximal to distal end, demonstrating tendons, lateral ligaments, inter-phalangeal joint, proximal nail fold, nail matrix underneath, nail bed, and lateral nail folds. Sagittal slices assess the entire length of nail unit in one frame. Coronal slices are not very helpful. The two basic MRI images are T1-weighted (highlights fat tissue) and T2-weighted (highlights fat and water) images. While T1-weighted image shows morphological, anatomical, and structural details, T2-weighted image helps in tissue...
### Table 3: Advantages and limitations of various radiological techniques

| Technique | Advantages | Limitations |
|-----------|------------|-------------|
| **Radiographs** | Low cost | Does not reveal soft tissue abnormalities |
| | Easily available | Radiation exposure |
| | Fast interpretation | May not be able to visualize minute changes due to poor resolution |
| | Least training required | |
| | Assesses bony structure reliably | |
| **USG** (High frequency USG with Doppler studies) | Low cost | Highly operator dependent |
| | Ready availability even in emergency setting | Steep learning curve |
| | Portable | Requires appropriate training |
| | No radiation exposure | Lack of sensitivity for lesions <1 mm in size |
| | No contraindications | Cannot measure very superficial lesions (<0.1 mm in depth) |
| | Less time consuming | Cannot differentiate pigmented lesions or flattened lesions |
| | Easy to evaluate multiple nails | Can be hampered by artifacts |
| | Allows precise measurements | High-frequency probes required for nail evaluation |
| | High frequency USG provides good spatial resolution with depth of penetration up to 60 mm | May overestimate lesion thickness as compared to histopathology, due to surrounding inflammation |
| | Allows real-time evaluation | Underestimation of thickness is possible for ulcerated lesions or compressible lesions |
| | Clear depiction of trilaminar nail structure | |
| | Gray scale mode combined with doppler | |
| | USG reveals characteristic tissue densities along with vascularity | |
| | USG guided procedures can be done | |
| | Varying echogenicity gives characteristic sonographic appearance to benign tumors, pseudo-tumors, psoriasis, cysts and vascular lesions. | |
| | Can be used for suspected foreign body | |
| **CT Scan** | Reliable evaluation of bony structures | Radiation exposure, even though it is less for digital tip evaluation |
| | Contrast enhancement helps to visualize vascular and inflammatory changes | High cost |
| | Enhanced resolution of images | Resolution of tissue planes is not as good as MRI |
| | Less time consuming | Requires skill and training for interpretation of images |
| **MRI** | Accurate anatomic definition and differentiation of nail tumors | Limited availability |
| | Signal characteristics can indicate tumor pathology giving a more specific diagnosis | May not be available in emergency settings |
| | Can provide information about histological type of glomus tumor | Cannot be freely used for a suspected foreign body, which may be magnetic |
| | Considered investigation of choice for nail unit, especially the soft tissue components | High cost |
| | | Resolution limited to lesions >3 mm |
| | | Requires skill and training for interpretation of images |
| | | Subject to motion artifact |
| | | Inferior to CT in detecting acute hemorrhage, or bony injury |
| | | Time consuming, prolonged acquisition time for many images |
| | | Many contraindications to be kept in mind regarding implanted devices including metallic devices, pacemakers, electronic |

Contd...
Continuous advancements make MRI more and more useful for accurate and detailed nail analysis. Gadolinium enhancement shows nail matrix as a homogenously hyper-intense area, while dermis appears hypo-intense with interspersed hyper-intense foci. Micro-coils for finger imaging help study even minute details of nail unit. High-resolution MRI delivers higher signal-to-noise ratio (SNR), thus allowing acquisition of data with higher spatial resolution.[23]

The radiological investigation of choice for assessing various tissue components of the nail unit are summarized in Table 4.

**Conclusions**

Radiological imaging is an important adjunct diagnostic modality for evaluating nail disorders. The non-invasive nature and easy availability of most of the techniques are a distinct advantage. Overall, radiographs and CT help in evaluating calcification and bone structures while high-resolution MRI and USG with color doppler are particularly useful in locating and characterizing nail plate and/or soft tissue aberrations. USG (with high-frequency transducer) and USD help in effective tissue characterization. MR imaging helps to resolve equivocal USG findings by providing more accurate information about location of lesion and specific signal characteristics, which guide towards pathology. When used judiciously and in expert hands, much information can be gleaned from radiological techniques, adding immense value to nail diagnosis.

**Author contributions**

Chander Grover and Shikha Bansal have equally contributed to the design and writing of the manuscript and are accountable for all aspects of the work. Ameeta Varma and Deepak Jakhar offered critical comments and
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Conflicts of interest
There are no conflicts of interest.

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