Review Article

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

Chander Grover, Shikha Bansal[1], Ameeta Varma[2], Deepak Jakhar[3]

Department of Dermatology and STD, University College of Medical Sciences and Guru Teg Bahadur Hospital, New Delhi, India, [1]Department of Dermatology and Venereology, Vardhman Mahavir Medical College and Safdarjung Hospital, Delhi, India, [2]Consultant Radiologist, St Clair MRI Centre, Port of Spain, Trinidad, [3]Consultant Dermatologist, Dermosphere Clinic, New Delhi, India

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 has 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, details of structures visualized,

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Address for correspondence:
Prof. Chander Grover, Department of Dermatology and STD, UCMS and GTB Hospital, Dilshad Garden, Delhi - 110 091, India.
E-mail: chandergroverkubba76@gmail.com

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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[2]; 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]

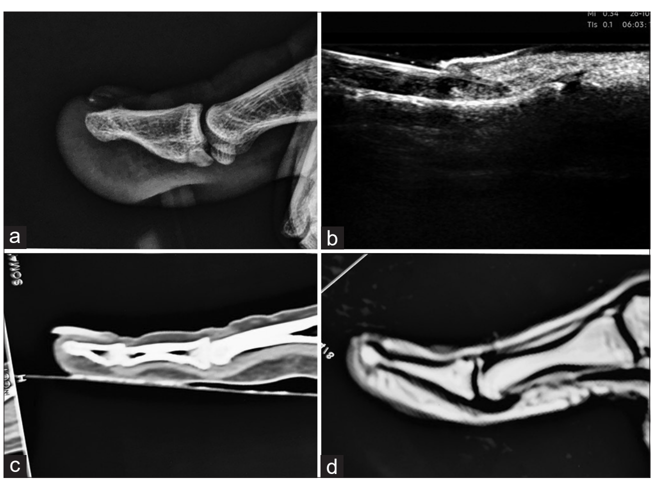

Figure 1: (a–d) Imaging of the nail unit in the sagittal section as seen on various imaging modalities. (a) Lateral view of digital x-ray. (b) Longitudinal view image of ultrasound of the nail unit showing ventral and dorsal aspects as bilaminar hyper-echoic parallel bands with a hypoechoic space between them called as interplate space. The hypo-echoic subungual space represents the nail bed and the nail matrix lies at the proximal end of the nail bed. The smooth surface of the dorsal cortex of the distal phalanx is also seen. (c) Sagittal section from a CT scan image of the normal nail. (d) Sagittal T1-weighted MRI image showing the nail unit anatomy. Images have been rotated to demonstrate comparative anatomy

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

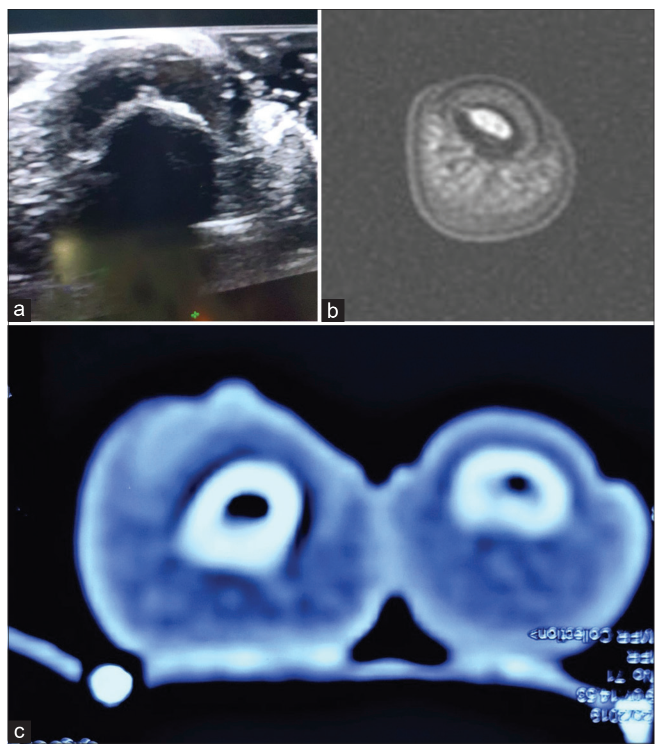

Figure 2: (a–c) Imaging of the nail unit in the transverse/axial section as seen on various imaging modalities. (a) Transverse view image of ultrasound of the nail unit showing the margins of the skin, nail bed, and underlying bone cortex. Smooth superficial and deep margins of the nail plate can be seen. The underlying nail bed is homogeneously hypoechoic. (b) Axial T1-weighted MRI image of a digit. (c) Axial sections from a CT scan image of a nail. Images have been rotated to demonstrate comparative anatomy

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 Sagittal view for complete understanding	Lateral view AP view [Figures 1a, 3]	Longitudinal view Transverse view [Figures 1b, 2a]	Sagittal plane Axial plane Coronal plane [Figures 1c, 2c, 4a-c]	Sagittal plane Axial plane Coronal plane [Figures 1d, 2b, 5a-c]
Nail plate	Keratinized structure Originates near middle third of the phalanx	Not described in literature. Findings are usually non-specific. Seen as faint linear radiodensity, appreciated in the lateral view	Composed of two parallel hyper-echoic bands, also known as the dorsal and ventral nail plate These are separated by a hypoechoic space referred to as the interplate space	Not described in literature. Findings are usually non-specific. Not delineated from the non-specific soft tissue density in the expected location	Nail plate in full length is visualized on sagittal images. It appears as highly organized, homogenously hypo-intense structure
Nail matrix (germinal matrix) and underlying dermis	Located at the proximal end of the nail bed Largely covered by the double-layered proximal nail fold and the thin arising nail plate.	Not delineated separately from nonspecific soft tissue density in the expected location on the lateral view	Nail matrix is a hyper-echoic structure	Not delineated separately from nonspecific soft tissue density in the expected location	Appears as a homogenously hyper-intense area with enhancement on gadolinium injection. Underlying dermis appears as a hypo-intense structure with scattered foci of hyper-intensity Lamellar tendons encasing the matrix appear as hypo-intense bands. Lunula (distal matrix) is seen as an oval shaped area of high signal intensity on T2 weighted sagittal images
Nail bed (sterile matrix) and underlying dermis	Located under the nail plate, extending up to the periosteum of the distal phalanx. Distal continuation of germinal matrix. Underlying nail bed dermis (papillary and reticular dermis) is 1-2 mm thick and rich in blood vessels, glomus bodies and innervations	Not delineated separately from nonspecific soft tissue density in the expected location on the lateral view	Seen as a hypo-echoic space between the ventral nail plate and the dorsal cortex of the phalanx Low velocity arterial and venous blood vessels are seen in this region, nearer to the bony margin.	Not delineated separately from nonspecific soft tissue density in the expected location	May not be delineated from nonspecific soft tissue density in the expected location
Periungual tissue (nail folds)	The nail plate is encased by the	Not delineated separately from	Nail folds show same echogenicity as skin	Not delineated separately from	May not be delineated from

Contd...

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) The dermis is visualized as hyper-echoic band mainly due to the presence of collagen. Subcutaneous tissue appears as hypo-echoic band due to presence of fat lobules.	nonspecific soft tissue density in the expected location	nonspecific soft tissue density in the expected location
Phalanx	Located inferior to nail bed	Bony shadow Contours visualized in AP, lateral and oblique views	Bony margin of the distal phalanx appears as a continuous hyper-echoic line corresponding to the bony cortex. Distal inter-phalanageal (DIP) joint is seen as an anechogenic space that has fluid and cartilage.	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

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 It may be due to pressure erosion because of the rapidly growing tumor
Subungual melanoma	Non-specific soft tissue swelling and, sometimes, bony erosion may be seen
Trauma	Radiographs can demonstrate fracture of distal phalanx Especially recommended if there is a large subungual hematoma

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.[18]

On USG, tumors or growths are visualized as focal hypoechoic lesions with demarcated or non-demarcated borders. Depth, area, and demarcation from surrounding structures can be identified. Doppler evaluation helps to pickup intra or peritumoral flow signals.[9] 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.[17]

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.[18] 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.[19] 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.[20] 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.[18]

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.[21] 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

Figure 3: Nail unit radiograph AP view

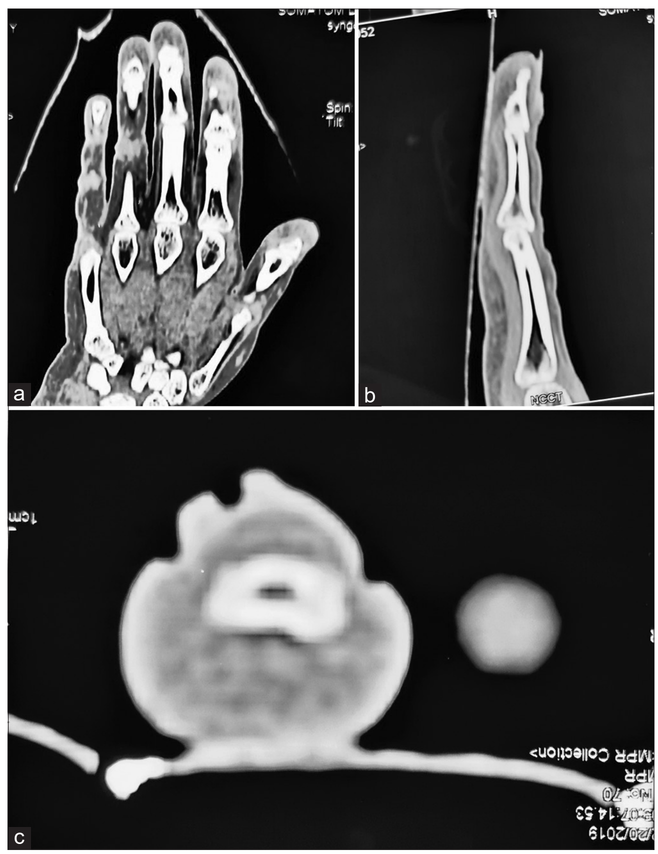

Figure 4: (a–c) Nail unit non-contrast CT (NCCT) images in (a) coronal section, (b) sagittal section, and (c) axial section. Images have been rotated to demonstrate comparative anatomy

Table 3: Advantages and limitations of various radiological techniques

	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	Low cost	Highly operator dependent
(High frequency USG with Doppler studies)	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	
	Easy to evaluate multiple nails	Cannot differentiate pigmentary lesions or flattened lesions
	Allows precise measurements	Can be hampered by artifacts
	High frequency USG provides good spatial resolution with depth of penetration up to 60 mm	High-frequency probes required for nail evaluation
	Allows real-time evaluation	May overestimate lesion thickness as compared to histopathology, due to surrounding inflammation
	Clear depiction of trilaminar nail structure	
	Gray scale mode combined with doppler USG reveals characteristic tissue densities along with vascularity	Underestimation of thickness is possible for ulcerated lesions or compressible lesions
	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
		May not be available in emergency settings
	Signal characteristics can indicate tumor pathology giving a more specific diagnosis	Cannot be freely used for a suspected foreign body, which may be magnetic
	Can provide information about histological type of glomus tumor	High cost
	Considered investigation of choice for nail unit, especially the soft tissue components	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

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Table 3: Contd...

Advantages	Limitations
	devices, aneurysm clips, magnetizable materials, cochlear implants, and some artificial heart valves
	Pregnancy (relative contraindication)
	Contraindicated in patients with severe agitation or claustrophobia

Table 4: Radiological investigation of choice for evaluating specific tissue component of the nail unit

Specific tissue component of the nail unit	Radiological investigation of choice
Bone (distal phalanx)	Radiography
Tendons and ligaments	MRI
Blood vessels	USD and Magnetic Resonance Angiography
Nail plate	USG
Nail matrix	MRI
Nail bed	USG
Nail folds	USG

MRI: magnetic resonance imaging; USD: ultrasound doppler; USG: ultrasonography

characterization. The limitations of MRI are summarized in Table 3 and include a prolonged image acquisition time.

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.[22]

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.

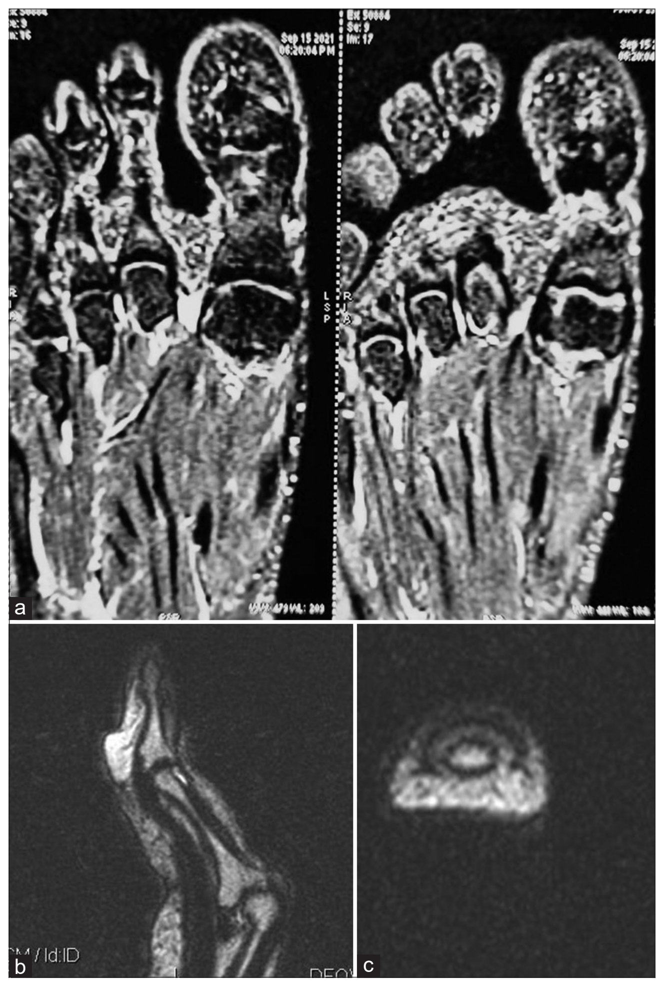

Figure 5: (a–c) Nail unit serial MRI images in (a) coronal section, (b) sagittal section, and (c) axial section

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 did corrections to the draft. All authors are responsible for ensuring accuracy and integrity of the manuscript.

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Conflicts of interest

There are no conflicts of interest.

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