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REVIEW ARTICLE

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Imaging of the nail unit in psoriatic patients:A systematic scoping review of techniques and terminology

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Abstract

Background: The growing interest in the visualization of psoriatic nail unit changes has led to the discovery of an abundance of image characteristics across various modalities.

Objective: To identify techniques for non-invasive imaging of nail unit structures in psoriatic patients and review extracted image features to unify the diverse terminology.

Methods: For this systematic scoping review, we included studies available on PubMed and Embase, independently extracted image characteristics, and semantically grouped the identified features to suggest a preferred terminology for each technique.

Results: After screening 753 studies, 67 articles on the visualization of clinical and subclinical psoriatic changes in the nail plate, matrix, bed, folds and hyponychium were included. We identified 4 optical and 3 radiological imaging techniques for the assessment of surface (dermoscopy [$n = 16$], capillaroscopy [$n = 12$]), sub-surface (ultrasound imaging [$n = 36$], optical coherence tomography [$n = 4$], fluorescence optical imaging [$n = 3$]), and deep-seated psoriatic changes (magnetic resonance imaging [$n = 2$], positron emission tomography-computed tomography [$n = 1$]). By condensing 244 image feature descriptions into a glossary of 82 terms, overall redundancy was cut by 66.4% (37.5%–77.1%). More than 75% of these image features provide additional disease-relevant information that is not captured using conventional clinical assessment scales.

Conclusions: This review has identified, unified, and contextualized image features and related terminology for non-invasive imaging of the nail unit in patients with psoriatic conditions. The suggested glossary could facilitate the integrative use of

Abbreviations: 18-FDG, 18- Fluorodeoxyglucose; ACH, Acrodermatitis Continua of Hallopeau; CASPAR, Classification Criteria for Psoriatic Arthritis; CD-US, Colour Doppler Ultrasound; DIP, Distal Interphalangeal; D-OCT, Dynamic Optical Coherence Tomography; ERA, Early Rheumatoid Arthritis; FOI, Fluorescence Optical Imaging; mNAPSI, Modified Nail Psoriasis Severity Index; MRI, Magnetic Resonance Imaging; NAPPA, Nail Assessment in Psoriasis and Psoriatic Arthritis; NAPSI, Nail Psoriasis Severity Index; NAS, Nail Area Severity; N-NAIL, Nijmegen Nail Psoriasis Activity Index Tool; NVRI, Nailfold Vessel Resistance Index; OA, Osteoarthritis; OCT, Optical Coherence Tomography; OM, Onychomycosis; PD-US, Power Doppler Ultrasound; PET/CT, Positron Emission Tomography–Computed Tomography; PIP, Proximal Interphalangeal; PND, Psoriatic nail disease; PNSS, Psoriatic Nail Severity Score; PsA, Psoriatic arthritis; QoL, Quality of Life; RA, Rheumatoid arthritis; SNAPS, Severity of Nail Psoriasis Score; US, Ultrasound (Sonography).

non-invasive imaging techniques for the detailed examination of psoriatic nail unit structures in research and clinical practice.

KEYWORDS
imaging terminology, non-invasive imaging, psoriasis, psoriatic arthritis, psoriatic nail disease

1 | INTRODUCTION

Nail involvement among psoriatic patients is common, with reported prevalence rates of 10%–82% and an estimated lifetime incidence of >80%.[1] Psoriatic nail disease (PND) without skin involvement is present in 5%–10% of psoriatic patients, considered a prognostic factor for the development of psoriatic arthritis (PsA)[2] and disease severity in cutaneous psoriasis,[3] and associated with greater reduction in quality of life (QoL).[4] Diagnosis of and treatment recommendations for PND are mainly based on clinical evaluation, often involving one of several clinical scoring systems.[5] However, given that all currently available PND scoring systems are limited to visual inspection, clinical grading of the disease extent is based solely on symptoms listed in Table 1.

In case of clinically ambiguous presentation, non-invasive imaging techniques can visualize characteristic morphological features that can supplement clinical assessments to help avoid biopsies and tailor treatment plans.[6,7] Despite the growing clinical awareness of the nail unit's relevance for the management of psoriatic conditions and rising interest in the visualization of its clinically and subclinically affected subcomponents, a panoramic overview of available non-invasive techniques and a unified terminology for the description of psoriatic features are lacking.

In this systematic scoping review, we sought to map the existing evidence on non-invasive imaging modalities for assessment of various nail unit structures in patients with psoriatic disease (PD) and condense the existing vocabulary into a suggested glossary.

2 | MATERIAL AND METHODS

2.1 | Study registration

This systematic scoping review was registered in PROSPERO (Prospero ID CRD42020214736) and conducted following PRISMA guidelines (Supplementary Material 1).

2.2 | Search strategy

We included original articles on non-invasive imaging of the nail unit (nail plate, nail matrix, nail bed, nail folds/eponychium and hyponychium) that contained the diagnosis of PD (i.e. cutaneous psoriasis, psoriatic arthritis and relevant subtypes). We excluded articles describing invasive *ex vivo* imaging (i.e. histopathological studies and investigations of nail clippings), literature reviews, consensus statements, editorials, guidelines, single case reports, conference abstracts, animal studies, protocols and articles published in languages other than English.

For our search strategy, the terms listed in Supplementary Material 2 were applied to PubMed and Embase. Relevant articles published between 1960 and 2020 underwent title and abstract screening, followed by a full-text review and inclusion by one author (VKO).

2.3 | Data collection and summary measures

Data were independently extracted by 3 authors (VKO, VDM and SB). Disagreements were resolved by consensus or a fourth author (MH) who acted as a referee. The following data points were collected from the included studies: diagnoses, comparator groups, image features, image acquisition, device specification, number of readers, imaging target site, and image evaluation.

Following a published approach on unifying terminology,[8] 2 content matter experts, a dermatologist with expertise in PND and optical imaging (VDM) and a musculoskeletal radiologist (SB), reviewed the terminology for each identified technique. By merging synonymous terms based on consensus among 3 authors (VKO, VDM and SB) to reduce redundancy, a glossary containing recommended terminology to cover all extracted image features was established. To assess the frequency of the glossary terms, the total number of articles and the relative number articles within each technique per term were calculated.

3 | RESULTS

A total of 753 articles were screened and 67 articles included, as depicted in the PRISMA flow diagram in Figure 1.[9-75] The number of articles per technique varied substantially, ranging from 36 for US to just one on PET/CT.

3.1 | Study characteristics

The included were published from 1960 to 2020 and conducted across 16 countries, including 37 (55.2%) in Europe, 10 (14.9%) in Middle East, 8 (11.9%) in Asia, 7 (10.4%) in the Americas and 6 (9.0%) in the UK. Funding was reported in 22 studies (32.8%), with the

TABLE 1 Overview of clinical features and their incorporation in physician-administered instruments used for the assessment of psoriatic nail disease

Origin	Clinical feature	NAPSI	mNAPSI	tNAPSI	NAPPA-Clin	N-NAIL	CASPAR[a]	Baran	Cannavó et al	SNAPS[b]	NAS
Bed	Oil drop/salmon patch dyschromia	x	x	x	x	x	–	–	x	–	x
Bed	Splinter haemorrhages	x	x	x	x	–	–	–	–	–	–
Bed	Subungual hyperkeratosis	x	x	x	x	x	x	x	x	x	x
Bed	Onycholysis	x	x	x	x	x	x	x	x	x	x
Matrix	Pitting	x	x	x	x	x	x	x	x	x	x
Matrix	Crumbling	x	x	x	x	x	–	–	x	x[c]	
Matrix	Red spots in lunula	x	x	x	x	–	–	–	–	–	–
Matrix	Leukonychia	x	x	x	x	–	–	–	–	–	–
Matrix	Beau lines	–	–	–	–	x	–	x	–	–	–

Abbreviations: CASPAR, Classification Criteria for Psoriatic Arthritis; mNAPSI, Modified Nail Psoriasis Severity IndexNAPPA, Nail Assessment in Psoriasis and Psoriatic Arthritis; NAPSI, Nail Psoriasis Severity Index; NAS, Nail Area Severity; N-NAIL, Nijmegen Nail Psoriasis Activity Index Tool; PNSS, Psoriatic Nail Severity Score; SNAPS, Severity of Nail Psoriasis Score.

[a]Diagnostic criteria for PsA.

[b]Also known as PNSS or Bath Nail Score.

[c]Specified as severe nail deformity/dystrophy.

majority receiving no funding (n = 9, 13.4%), full or partial funding from federal grants (n = 7, 10.4%), from industry (n = 7, 10.4%), from foundations (n = 6, 9.0%) or from universities (n = 3, 4.5%). Study results were published in dermatological (n = 32, 47.8%), rheumatological (n = 22, 32.8%), general medical (n = 6, 9.0%), radiological (n = 5, 7.5%) and other biomedical journals (n = 2, 3.0%).

In 48 (71.6%) out of 67 studies, either the entire study population or a subset showed clinical signs of nail psoriasis. Both cutaneous psoriasis (n = 52, 77.6%) and psoriatic arthritis (n = 47, 70,1%) were included in most studies. Early psoriatic arthritis (n = 3, 4.5%) and less common variants of psoriasis, such as isolated PND (n = 1, 1.5%) or pustular psoriasis/acrodermatitis continua (n = 2, 3.0%), have also been described. PND was graded in most studies, primarily using the Nail Psoriasis Severity Index (NAPSI), followed by the modified NAPSI (mNAPSI) and targeted NAPSI.

While most studies (n = 43, 64.2%) examined both a psoriatic and a control group, 24 studies (35.8%) lacked a comparator. The most common control group was healthy controls (n = 31, 46.3%), followed by (early) rheumatoid arthritis (n = 13, 19.4%), onychomycosis (n = 4, 6.0%), osteoarthritis (n = 3, 4.5%), lichen planus (n = 3, 4.5%) and undifferentiated arthritis (n = 3, 4.5%). Table 2 presents an overview of the psoriatic target groups and the control groups for each technique.

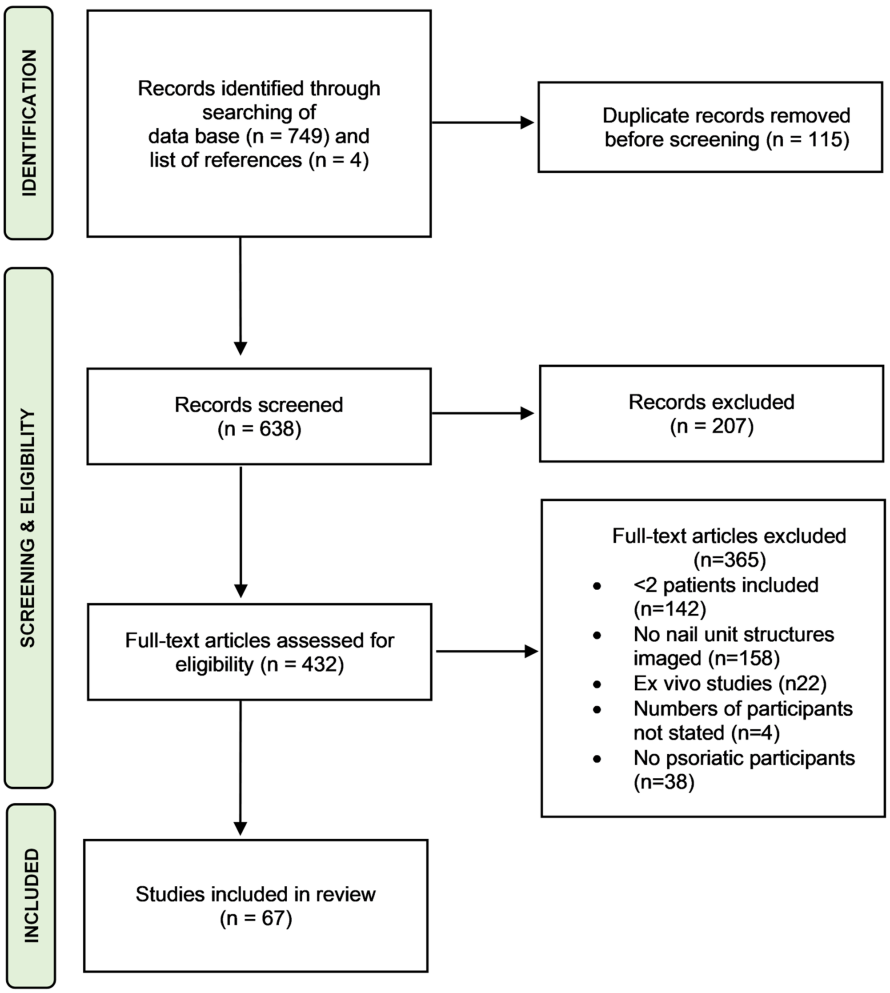
In 37 studies (55.2%), non-invasive imaging was used to identify markers to aid in the diagnostic process. Nine studies (13.4%) used imaging to define features that could supplement the clinical disease severity grading. In 8 studies (11.9%), the use of image features as markers for treatment response or surrogate endpoints was explored. Non-invasive imaging was also used to reveal features that can provide insight into the pathogenic processes in psoriatic diseases (n = 8, 11.9%) and to test its prognostic capabilities by identifying features predictive of disease progression (n = 6, 9.0%). In 10 studies (14.9%), the use of image characteristics was not further specified.

3.2 | Techniques and terminology

Four *optical* imaging techniques (dermoscopy, capillaroscopy, optical coherence tomography [OCT], fluorescence optical imaging [FOI]) and 3 *radiological* techniques (ultrasound imaging [US], magnetic resonance imaging [MRI] and positron emission tomography-computed tomography [PET/CT]) were identified. The publication trends of the 7 techniques were mapped in Figure 2.

A total of 244 different terms and expressions for the description of clinical and subclinical nail unit changes in different psoriatic disease groups were extracted (Supplementary Material 3). The number of included terms per technique ranged from 83 for dermoscopy to 2 for PET/CT. By semantically grouping all the extracted imaging terms, a glossary containing 82 unified terms was established to accurately describe the reported image characteristics. While 18 features correspond to items covered by conventional scoring systems (e.g. "*Pitting*," "*Onycholysis*", and "*Crumbling*"; Table 1), the remaining

FIGURE 1 PRISMA Flowchart



64 imaging features (78.1%) provide additional information beyond standardized clinical PND assessments, such as "*Loss of trilaminar appearance*", "*Nail matrix thickening*", and "*Dilated and dotted capillaries in the hyponychium*."

The extracted terms, categorized by imaging modalities, and our suggested glossary are listed in detail in Supplementary Material 3. A summary of the accessible anatomy and its relationship with psoriatic image features, as well as advantages and disadvantages of each technique, are presented in Figure 3.[76]

3.3 | Optical imaging modalities

Four different techniques were found in the literature, of which dermoscopy (n = 16) was the most commonly used one, followed by capillaroscopy (n = 12), OCT (n = 4), and FOI (n = 3).

3.3.1 | Dermoscopy

Dermoscopy, or onychoscopy in the context of nail imaging, refers to the examination of the skin and nails at high magnifications. This technique uses either polarized or non-polarized light and can be combined with different contact media such as ultrasound gel. Dermoscopy examinations are performed with handheld dermatoscopes commonly at 10× magnification, or with videodermatoscopes, which allow magnification of up to 200×; magnification of at least 40× is recommended for evaluating vascular structures. We found 16 articles on dermoscopy and extracted a total of 83 terms for the dermoscopic description of psoriatic changes of the proximal nail fold and periungual skin, the nail plate including lunula and upper nail bed, as well as the hyponychium. After reviewing and merging the identified terms, 28 dermoscopy features were entered into the glossary (66.3% reduction). The most commonly reported features were "*Onycholysis*" (articles n = 12), "*Splinter hemorrhages*" (n = 11), "*Irregular pitting*" (n = 10), and "*Erythematous linear band present abutting the onycholytic area*" (n = 10).

3.3.2 | Capillaroscopy

Capillaroscopy can evaluate small vessels in the nail folds at high magnification. It can reveal minute details of the vascular architecture and is commonly used in the differential diagnosis of rheumatological conditions. Twelve articles reported a total of 51 capillaroscopy terms describing the psoriatic changes

TABLE 2 Overview of the number of included optical and radiological imaging studies for each technique in psoriatic disease spectrum patients and various control groups

Clinical condition	Dermoscopy	Capillaroscopy	OCT	FOI	US	MRI	PET-CT	Total # of studies[a]
Psoriatic disease								
Psoriasis vulgaris	10	9	4		26	1	–	50
Pustular psoriasis	1	–	–	–	–	–	–	1
Acrodermatitis continua	1	–	–	–	–	–	–	1
Isolated nail psoriasis	1	–	–	–	–	–	–	1
Early psoriatic arthritis	2	–	–	–	1	–	–	3
Psoriatic arthritis	1	7	2	3	21	2	1	38
Non-psoriatic comparators								
Healthy	1	10	3	–	15	1	–	31
Rheumatoid arthritis (RA)	–	3	–	3	3	–	1	10
Onychomycosis (OM)	2	–	1	–	1	–	–	4
Osteoarthritis (OA)	–	–	–	1	1	1	–	3
Lichen planus	–	1	1	–	–	–	–	3
Early Rheumatoid Arthritis (ERA)	2	–	–	–	1	–	–	3
Undifferentiated Arthritis	–	–	–	2	–	–	–	3
Spondyloarthritis	–	–	–	2	–	–	–	2
Connective tissue disorder	1	–	–	1	–	–	–	2
Other	–	–	–	2	–	–	–	2
Glomus tumour	1	–	–	–	–	–	–	2
Trauma	2	–	–	–	–	–	–	2
Alopecia areata	1	–	–	–	–	–	–	2
Systemic sclerosis	–	1	–	–	–	–	–	1
Lupus	–	1	–	–	–	–	–	1
Scleroderma	–	1	–	–	–	–	–	1
Dermatomyositis	–	1	–	–	–	–	–	1
Eczema	–	–	–	–	1	–	–	1
Enchondroma	1	–	–	–	–	–	–	1
Subungual verruca	1	–	–	–	–	–	–	1
Longitudinal melanonychia	1	–	–	–	–	–	–	1
Darier disease	1	–	–	–	–	–	–	1
Onychophagia/nail tics	1	–	–	–	–	–	–	1
Digital mucoid cyst	1	–	–	–	–	–	–	1
Frictional pyogenic granuloma	1	–	–	–	–	–	–	1
Onychopapilloma	1	–	–	–	–	–	–	1
Onychomatricoma	1	–	–	–	–	–	–	1
Fibrokeratoma	1	–	–	–	–	–	–	1
Subungual hematoma	1	–	–	–	–	–	–	1
No control	9	2	1	–	12	–	–	24

[a]Number of studies investigating a particular disease across modalities; numbers are not additive as many studies have included multiple diseases.

of microvascular structures in the proximal nail fold were identified and merged into a total of 15 features (70.6% reduction). "*Tortuous capillaries*" (articles $n = 12$), "*Decreased capillary density (loops/mm)*" ($n = 5$), and "*Normal arterial limb, venous limb, and loop diameters of capillaries*" ($n = 5$) were the most frequently reported capillaroscopic features.

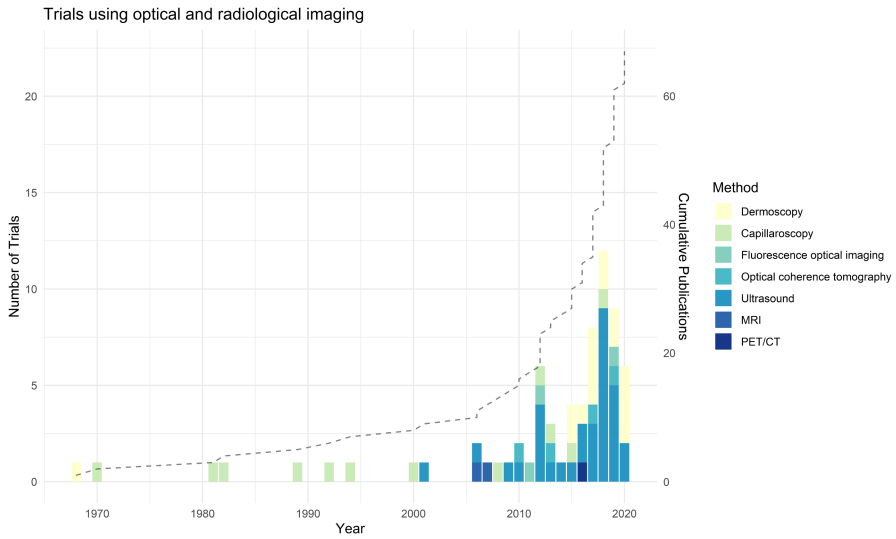


FIGURE 2 Trends in imaging of the psoriatic nail unit over time

3.3.3 | Optical coherence tomography (OCT)

Optical coherence tomography measures back-scattered light to capture two-dimensional and three-dimensional high-resolution images. In addition to conventional assessment of near-surface components of the nail unit, the vascular morphology of the nail folds can be visualized by dynamic optical coherence tomography (D-OCT). We extracted 24 structural and dynamic OCT terms from 4 articles describing morphological and morphometric changes of the nail plate, nail bed and the nail fold, and merged them into 15 image characteristics (37.5% reduction). The most commonly reported features included "*Pitting*" (articles $n = 4$), "*Wavy, irregular, and rough nail plate surface*" ($n = 4$), "*Nail plate thickening*" ($n = 3$), and "*Leukonychia*" ($n = 3$).

3.3.4 | Fluorescence optical imaging (FOI)

Fluorescence optical imaging is a non-ionizing fluorescence-based technique that can visualize microcirculation using intravenously applied indocyanine green dye. After the application of the tracer dye, decks of more than 300 images can be captured of both hands simultaneously. Three articles described the use of FOI using nine different terms for various patterns of dye wash-out and related fluorescence intensity that could be merged into 3 (66.7% reduction): "*Triangular, slightly arcuate enhancement from nail bed into distal interphalangeal joint*" (articles $n = 2$), "*Different pattern of nail perfusion (hot, blue, or green nail)*" ($n = 1$), and "*Different phase of enhancement in fingertips (early, intermediate, or late)*" ($n = 1$).

3.4 | Radiological imaging modalities

Of the 3 techniques were identified, US was the most frequently used ($n = 36$), followed by MRI ($n = 2$) and PET/CT ($n = 1$).

3.4.1 | Ultrasound imaging (US)

US uses high-frequency sound waves to produce images of structures. Colour Doppler US and the more sensitive Power Doppler US can visualize the speed and direction of blood flow through the vessel. With 36 articles, US was the most commonly used technique for assessment of the psoriatic nail unit. A total of 61 sonographic terms for the description of the nail plate, nail bed, the proximal nail fold and the distal interphalangeal joint were extracted and subsequently reduced to 14 US characteristics (77.1% reduction)."*Loss of trilaminar appearance*" (articles $n = 20$), "*Nail plate thickening*" ($n = 19$), "*Increased power Doppler signal (blood flow) in nail bed*" ($n = 18$), and "*Nail bed thickening*" ($n = 18$) were the most frequently reported features in our glossary.

3.4.2 | Magnetic resonance imaging (MRI)

Magnetic resonance imaging is a radiological non-ionizing imaging technique used to form pictures of the anatomy and the physiological and pathological processes of the entire body. MRI scanners use settings of pulse sequences and magnetic field gradients to generate images for specific clinical indications. Gadolinium, a commonly used contrast agent, can provide additional information such as increased vascularization and signs of inflammation. We found 2 articles on the use of MRI, with and without contrast agents, for the evaluation of the nail plate and bed, the distal interphalangeal joint, as well as the surrounding soft tissue. The 14 identified terms could be merged into 6 features (57.1% reduction). The most commonly found MRI features include "*Extra-articular inflammatory reaction extending to the nail bed*" (articles $n = 3$), "*Inflammatory reaction involving the nail bed*" ($n = 2$), "*Soft tissue Gadolinium enhancement*" ($n = 2$), and "*Nail plate thickening*" ($n = 2$).

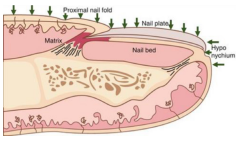
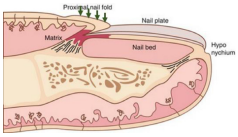
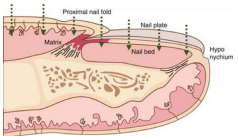
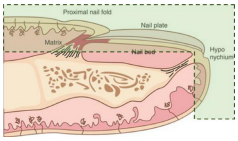
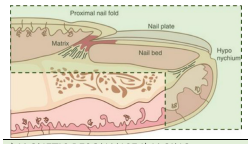
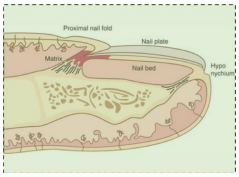
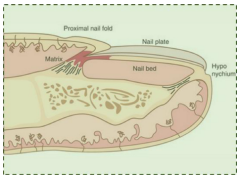
Accessible anatomy	Nail bed	Nail matrix	Surrounding skin	Pros & Cons
DERMOSCOPY				
	• Onycholysis • Erythematous linear band present abutting the onycholytic area • White streaks • Hemorrhagic spots • Splinter hemorrhages • Translucent yellowish-orange discoloration in the nail bed • Pustules • Scaling • Subungual hyperkeratosis • Dilated and dotted capillaries in nail bed • Dilated capillaries arranged parallel over the onychodermal band of the nail plate and surrounded by a prominent halo	• Nail plate thickening • Crumbling • Irregular pitting • Leukonychia • Longitudinal ridging • Lamellar splitting • Transverse grooves • Onychomadesis • Trachyonychia • Red spot in the lunula • Fuzzy lunula	• Hypertrophic cuticle • Periungual scaling • Pseudo-fiber sign • Dilated and dotted capillaries in proximal nail fold over a reddish/pinkish background • Dilated and dotted capillaries in lateral nail folds • Dilated and dotted capillaries in hyponychium	+ Low cost, fast acquisition, versatile, and requires little training - No information on deeper-lying structures, limited field of view, and challenging lens apposition depending on nail convexity
CAPILLAROSCOPY				
	--	--	• Normal capillary density (loops/mm) • Increased capillary density (loops/mm) • Decreased capillary density (loops/mm) • Normal arterial limb, venous limb, and loop diameters of capillaries • Decreased arterial limb, venous limb, and loop diameters of capillaries • Normal capillary loop amplitude • Reduced capillary loop amplitude • Elongated capillary length • Shortened capillary length • Subpapillary plexus visibility • Hemorrhages • Sluggish blood flow • Avascular areas • Tortuous capillaries • Coiled capillaries	+ High magnification of vessel morphology, fast acquisition, and requires little training - Only information on nail folds, not compatible with psoriatic plaques, requires contact medium
FLUORESCENCE OPTICAL IMAGING				
	• Triangular, slightly arcuate enhancement from nail bed into distal interphalangeal joint • Different phase of enhancement in fingertips (early, intermediate, or late) • Different pattern of nail perfusion (hot, blue, or green nail)	--	• Triangular, slightly arcuate enhancement from nail bed into distal interphalangeal joint • Different phase of enhancement in fingertips (early, intermediate, or late) • Different pattern of nail perfusion (hot, blue, or green nail)	+ Captures multiple fingers simultaneously, provides functional information - Low resolution, requires fluorescent tracer injection, not tested on feet
OPTICAL COHERENCE TOMOGRAPHY				
	• Onycholysis • Subungual hyperkeratosis • Abnormalities of the deep nail bed	• Nail plate thickening • Loss of trilaminar appearance • Wavy, irregular, and rough nail plate surface • Superficial fissuring of the nail plate • Pitting • Leukonychia • Hyperreflective spots in the nail plate	• Ragged skin surface of the proximal nail fold • Steep skin-nail angle • Epidermal thickening of the proximal nail fold • Dilated vessels in a haphazard orientation in proximal nail fold (en-face view) • Increased density of blood vessels extending superficially in proximal nail fold (cross-sectional view)	+ Fast acquisition, very high resolution, no coupling medium, functional information using D-OCT - Sensitive to motion artifacts, low penetration depth with limited information on deeper-lying structures
US IMAGING (SONOGRAPHY)				
	• Nail bed thickening Increased power Doppler signal in nail bed • Extra-articular inflammatory reaction extending to the nail bed	• Nail plate thickening • Loss of trilaminar appearance • Wavy and irregular nail plate surface • Pitting • Hyperechoic deposits in the ventral plate • Elastogram value • Nail matrix thickening • Increased power Doppler signal in nail matrix	• Epidermal thickening of the proximal nail fold • Increased power Doppler signal (blood flow) in proximal nail fold • Nailfold vessel resistance index	+ Fast acquisition, functional information using Power/Color-Doppler, information on joint and enthesis - Requires contact medium and appropriate probe
MAGNETIC RESONANCE IMAGING				
	• Inflammatory reaction involving the nail bed • Subungual Gadolinium enhancement	• Nail plate thickening • Surface irregularity	• Soft tissue Gadolinium enhancement	+ High resolution, visualization of deep-seated changes including bone alterations - High cost, restricted accessibility, slow acquisition, may require gadolinium injection
POSITRON EMISSION TOMOGRAPHY/COMPUTED TOMOGRAPHY				
	• Elevated 18F-FDG uptake at the nail bed due to inflammation	--	--	+ High resolution, functional information on inflammation - High cost, restricted accessibility, radiation exposure

FIGURE 3 Overview of accessible anatomy, image features, and expert opinion of optical and radiological modalities for imaging of the nail unit in psoriatic patients

3.4.3 | Positron-emission tomography-computed tomography(PET/CT)

PET/CT scanners combine positron emission tomography (PET) and x-ray computed tomography (CT) to acquire images from both devices in the same session. PET scans rely on the use of small amounts of radioactive materials, the most common radiotracer being F-18 fluorodeoxyglucose (FDG), a molecule similar to glucose. Sites of inflammation can be detected using PET scans, as these commonly exhibit increased FDG-activity, and subsequently anatomically associated using the high-resolution CT scan. We identified one article on the use of PET/CT and extracted 2 terms describing enhanced tracer uptake and related inflammation that could be merged into 1 (50% reduction), namely "Elevated 18F-FDG uptake at the nail bed due to inflammation."

3.5 | Method comparison

Among the 82 image features, 12 could be assessed by two or more techniques. The overlap between image characteristics is covers "*Pitting*" (dermoscopy, OCT, US), "*Onycholysis*" (dermoscopy, OCT), "*Nail plate thickening*" (dermoscopy, OCT, US, MRI), "*Subungual hyperkeratosis*" (dermoscopy, OCT), "Leukonychia" (dermoscopy, OCT), "*Dilated capillaries in the proximal nail fold*" (dermoscopy, OCT), "*Increased capillary density*" (capillaroscopy, OCT), "*Irregular nail plate surface*" (OCT, US, MRI), "*Hyperreflective/echoic spots in the nail plate*" (OCT, US), "*Epidermal thickening of the proximal nail fold*" (OCT, US), "*Loss of trilaminar appearance*" (OCT, US) and "*Extra-articular inflammatory reaction involving extending to the nail bed*" (US, MRI).

Heterogeneity was found in the characterization of the shape of capillaries in patients with PD. In contrast to OCT and dermoscopy investigations describing *enlarged* capillaries, 42% of capillaroscopy studies reported a *reduced* capillary diameter. Concerning capillaroscopic capillary density, "*Decreased capillary density*" was reported more frequently than "*Increased capillary density*." Figure 3 compares the various techniques and their respective image features, highlighting the differences in accessible anatomy. While optical techniques have been used to visualize surface (dermoscopy, capillaroscopy) and near-surface (OCT, FOI) nail unit structures (e.g. the nail folds and their capillary network), the application of radiological techniques has been focused on the assessment of shallow subsurface (US) and deeper-lying structures (MRI, PET/CT) including extra-articular inflammatory reactions extending to the nail bed.

3.6 | Bias sources and limitations

Substantial methodological variation was found in the image acquisition and analysis, summarized in the overview of included studies in Supplementary Material 4. The level of experience in acquiring and interpreting images has not been reported consistently. The majority of the studies ($n = 27$) stated the same author conducted both image acquisition and interpretation, while 25 studies did not specify who collected or assessed the data. In the remaining studies, image evaluation was carried out by either 2 ($n = 11$), 3 ($n = 2$), 4 ($n = 1$) or 5 ($n = 1$) authors. Most studies have focused on imaging of only a subset of nails, excluded toenails, lacked a clinical disease severity stratification of imaging features, or reported morphological features only per patient without a per-nail analysis. Consequently, there is a gap of knowledge regarding the association of image features and anatomical variation, the prevalence of image features in toenails, quantitation of subjectively evaluated pathological changes, and the utility of imaging in subclinical psoriasis.

The reporting frequency of the extracted imaging features was presented "per study", which has limited clinical relevance without a "per patient" and "per nail" analysis. The lacking reporting standards and imaging protocols for optical and radiological imaging of the nail unit in psoriatic patients represent a bias that complicates a meta-analytic study comparison. Due to this substantial heterogeneity in anatomical imaging target sites, diversity in psoriatic disease severity, and analytical reporting standards, a quantitative analysis may have produced inappropriate and potentially misleading results. To prevent errors in the interpretation of this systematic review, a meta-analysis was not conducted.

4 | DISCUSSION

By scoping the literature for evidence on non-invasive visualization of nail unit structures in psoriatic patients, we have identified 4 optical and 3 radiological imaging techniques. After systematically reviewing the reported image features, we condensed the 244 extracted terms into an overarching glossary for all relevant modalities. By outlining the accessible anatomy for each technique and cutting the number of imaging terms by 66.4%, this review represents a first step in addressing the obstacles to more widespread use of optical and radiological imaging in the context of PD.

4.1 | Clinical relevance of non-invasive imaging

Dermoscopy is a convenient diagnostic technique that allows better visualization of abnormalities in the nail plate and bed. Dermoscopic findings depend on the portion of the nail that is clinically affected, and the use of polarized or non-polarized light.[77,78] The latter is preferably used with a transparent gel as a coupling medium in order to fill the space between the convex surfaces of the nail plate and the plane dermoscopy lens. Dry dermoscopy permits better visualization of the alteration of the nail plate surface, which are typical of nail matrix involvement, while the use of ultrasound gel is recommended for the examination of patients affected by nail bed psoriasis as well as abnormalities in the periungual vascular network. When examined with at least 40-fold magnification, vascular abnormalities appear dilated, irregularly distributed, long and tortuous capillaries similar to capillaroscopy. At lower magnifications with handheld dermatoscopes, these vessels are visible as regular red dots. Capillary density is positively correlated with the disease severity and response to treatment.[22] Dermoscopic detection of the characteristically dilated hyponychial capillaries typical of nail psoriasis at hyponychium can help confirm the diagnosis in patients with unspecific symptoms, for example simple onycholysis or mild nail bed hyperkeratosis.[22,78] Nail fold dermoscopy is useful for evaluating the severity of psoriasis as it can visualize the degree of microvascular changes, visible as capillaries with both morphometric and morphological abnormalities.[16] Nail plate thickening, crumbling, transverse grooves, splinter haemorrhages, translucent yellowish-orange discoloration visible through the transparent nail plate and erythematous linear band present abutting the onycholytic area are considered markers of PND activity.[79] The main limitation of dermoscopy is its operator dependency; nail dermoscopy may result in lower diagnostic accuracy than naked-eye examination

when performed by clinicians with limited experience and training in the interpretation of nail dermoscopy.[78]

Structural microvascular abnormalities in the proximal nail fold, where capillaries run parallel rather than perpendicular to the skin surface, can be visualized non-invasively using capillaroscopy.[33,80] Examination of the proximal nail fold can help assess the severity of psoriasis as it reflects the extent of microvascular changes, such as changes in capillary density. Periungual psoriatic plaques can, however, obstruct the visibility of the nail fold capillaries, making this technique less suited to examining patients with active psoriasis in the eponychium. Reports on capillaroscopically assessed vessel diameter and density are, however, conflicting and raise concerns regarding its reliability to assess psoriatic microvascular abnormalities in the nail folds.[27,33,80] Further, high-magnification dermatoscopes have shown to be portable and more affordable alternative to traditional nailfold capillaroscopy for the detection of vascular changes in connective tissue disease.[81] Despite efforts to automate the analysis of the capillary network,[82] capillaroscopy requires practical training and a broad knowledge of rheumatological conditions to be able to use it for diagnostic purposes in patients with psoriatic arthritis or isolated nail psoriasis.

US, in particular the high-frequency ultrasound (HFUS) which has a higher spatial resolution but lower penetration depth than conventional US, provides structural and functional information below the surface and at greater detail than dermoscopy.[83] US allows evaluation of nail abnormalities, in particular thickness of the nail matrix, loss of trilaminar appearance, and vascularization of the skin, which are significantly associated with nail psoriasis.[84] US has shown to be a sensitive imaging method and useful tool for the assessment of involvement at intra- and extra-articular level in PsA patients.[85] These inflammatory changes can become more pronounced and extend over a considerable territory, including the articulation (presence of synovial fluid and/or synovial hypertrophy), the entheses (an early feature seen in PsA) and the extra-capsular tissues as well as the nail bed.[84] US can also reveal an increased abnormal vascularization, an expression of inflammation, both in the nail bed and in the extra- and intra-articular compartments.[86] Accurate and reliable interpretation of US images requires extensive experience and should only be performed by radiologists or healthcare professionals with relevant training.

OCT provides the clinician with grey-scale images of tissue microarchitecture without the need for a coupling medium.[87] Moreover, the speckle-based D-OCT detects particle movement such as blood flow, mapping blood vessel architecture to determine vascular patterns specific to disease processes without the use of contrast agents.[87] Therefore, D-OCT can assess morphological and angiographic features specific to nail psoriasis with greater detail than other non-invasive imaging techniques. While relatively limited in its penetration depth compared to US and HFUS, OCT may be the method of choice for imaging of the nail unit as its higher spatial resolution can reveal even minute changes. In addition to generating vertical scans in real-time, OCT devices can also reconstruct scans to produce horizontal sections and three-dimensional images for better visualization of the blood perfusion within the microcirculatory tissue bed. While OCT findings of structural nail changes predominantly reflect clinical features, this technique can also assess the disease extent in the deeper parts of nail bed, objectively quantify an increase in vessel size or density, and detect a thickened epidermis of the proximal nail fold, previously only seen on histopathology.[88] One practical drawback to OCT is the rather steep learning curve in terms of manoeuvring the device on nails. Operating the OCT probe requires practice and steady hands to reduce signal noise and variation in vessel compression that may affect D-OCT scans.

High-resolution MRI has been able to demonstrate the intimate relationship between the nail bed and the distal interphalangeal (DIP) joint capsule.[21,88,89] This is illustrated by the visible involvement of the nail bed on MRI scans in cases of an extensive inflammatory reaction of the DIP joint in patients with PsA. Scarpa et al. demonstrated that MRI involvement of the DIP joint is always associated with both distal phalanx changes and nail unit changes.[19,89] In contrast to other techniques, MRI can detect the presence of tenosynovitis as well as assess bone erosions and bone oedema.[19,28,90] The downside of high-resolution MRI imaging is the frequently limited field of view, often providing coverage of the entire DIP joint but only the proximal half of the nail and the long acquisition and elaboration time.[28] Furthermore, the correct interpretation of musculoskeletal MRI images can be challenging and may require additional, extensive training beyond radiology residency, such as a dedicated musculoskeletal imaging fellowship.

Evidence on PET/CT and FOI for psoriatic conditions of the nail unit is sparse. Since MRI can visualize and localize inflammation without the need for radionuclide injection and ionizing radiation exposure, the scope of PET/CT will likely not extend beyond specific research applications.[91] As a comparatively new technique in this field, FOI requires further investigation to demonstrate its value.[92]

As the aim of this study was to scope for features and provide a terminology for further investigation, additional studies are needed to determine the clinical utility of the glossary. The notable inter- and intra-method discrepancies of microvascular changes, in particular regarding 9 capillaroscopic features, warrant a critical reassessment before psoriatic activity can be quantified reliably using capillary metrics. The glossary could be further condensed by eliminating terms that only differ in their location or severity. However, the inclusion of different variants of a term may prevent hasty conclusions on their particular relevance and permit a more nuanced documentation and severity classification.

4.2 | Impact on healthcare

The currently available non-invasive optical and radiological imaging modalities vary substantially in their technical specifications, cost of acquisition and maintenance, necessary operator expertise, and correlation of imaging findings with clinical features of PND. Given the level of evidence, image resolution and accessible anatomy,

comprehensive imaging of the nail unit should integrate dermoscopy for surface, OCT or US for sub-surface, and MRI for deep-seated morphological changes.

For the successful implementation of imaging of psoriatic patients, similar to reflectance confocal microscopy in dermato-oncology, a streamlined terminology is essential to facilitate communication between healthcare practitioners in clinical practice and research settings. While this review only covered nail unit features, signs of intra-articular inflammation, such as periosteal reaction, bone oedema and elevated 18F-FDG uptake in the distal and proximal finger joints, have been reported alongside nail unit changes in the included articles. Although these musculoskeletal changes were beyond the scope of this work, they incentivize the expansion of the herein presented glossary to eventually cover all relevant psoriatic changes. By acknowledging the importance of musculoskeletal imaging for the optimal management of psoriatic patients and fostering close collaboration between all involved specialties, we could move one step closer toward truly multi-disciplinary management of this patient population.

In traditional clinical scoring systems for cutaneous psoriasis and psoriatic arthritis, such as PASI or CASPAR, involvement of the nail unit is often treated as a secondary manifestation and consequently only partially assessed or omitted.[93-101] Since the tools recommended by a recent expert consensus (NAPPA-Clin, NAPSI and mNAPSI) only evaluate 8 clinical PND features, our collection of 82 imaging characteristics can provide a more nuanced view of psoriatic nail involvement to aid clinicians and researchers in the diagnostic work-up, refining the clinical monitoring, and improving prognostic accuracy. With evidence on chronic subclinical inflammation and its role in PD progression growing,[102-104] non-invasive visualization of inflammatory signs of the nail unit may soon play a pivotal role in the clinical management of psoriatic patients.

5 | CONCLUSION

This review has identified and compared 7 non-invasive imaging techniques for the visualization of clinical and subclinical psoriatic changes in different nail unit structures. We have extracted and condensed 244 image feature descriptions into a glossary of 82 terms to facilitate the use of non-invasive imaging in clinical research and patient management.

CONFLICT OF INTEREST

Nothing to disclose.

AUTHOR CONTRIBUTIONS

Study conception and design: VKO, VDM, MH. Acquisition of data: VKO, VDM, SB. Analysis and interpretation of data: VKO, VDM, SB, PAP, MH. Drafting of manuscript: VKO. Critical revision: VDM, SB, PAP, MH. All authors have read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Supplementary Material 1 PRISMA checklist
Supplementary Material 2 Search strategy
Supplementary Material 3 Image feature terminology for description of morphological and morphometric characteristics of psoriatic nail units ranked by the number of studies
Supplementary Material 4 Overview of included studies and their imaging protocols

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