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Dermatoscopy limitation and the critical role of capillaroscopy in the evaluation of systemic sclerosis and Raynaud's phenomenon among African American Veterans

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ABSTRACT

Introduction: Nailfold capillaroscopy (NFC) is a crucial tool for assessing diagnostic microvascular abnormalities in patients with Raynaud's phenomenon (RP). While dermatoscopy is a widely accepted, cost-effective screening method for systemic sclerosis (SSc), its utility depends on optimal visibility for accurate interpretation. The objective of this study was to determine if skin pigmentation affects the interpretability of nailfold evaluation.
Methods: In an Institutional Review Board-approved study at the TVHS Hospital, patients undergoing evaluation for CTD-related RP were enrolled. Images were captured using two devices: a 200X dermatoscope (smartphone focus) and a 250X Smart G-Scope (USB automatic focus). Two capillaroscopy experts independently classified each image for clarity and the overall pattern (scleroderma or non-scleroderma). Skin pigmentation was assessed using the Fitzpatrick classification (I-VI).
Results: A total of 38 United States (US) Veterans with RP were assessed; 28% ($n = 11$) were self-identified as African American. Dermatoscopy analysis yielded blurry images in 63.6% (7/11) of patients with Fitzpatrick skin tones IV, V and VI, compared to 37% (10/31) in skin tones I, II, and III. The USB-capillaroscope improved interpretability across the entire cohort, especially in skin tones IV, V and VI. Notably, a Scleroderma (SD)-pattern was detected by the USB-capillaroscope in 4 of the 5 studies that had been uninterpretable with the dermatoscope.
Conclusions: In conclusion, dermatoscopy resulted in a high rate of uninterpretable examinations in patients with RP, particularly among African American Veterans. The USB-capillaroscope device significantly improved interpretability, underscoring that relying solely on dermatoscopy as a screening tool may lead to underdiagnosis of SSc.

Introduction

Raynaud's phenomenon (RP) is a common clinical manifestation, often indicating underlying connective tissue diseases (CTDs particularly when microvascular abnormalities are found on capillaroscopic evaluation of the nailfold. Nailfold capillaroscopy (NFC) is a non-invasive, cost effective, and essential tool for the evaluation of microvascular changes in patients with RP, playing a critical role in

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differentiating primary from secondary RP [1].

While dermatoscopy has gained acceptance as a screening method for nailfold microvascular assessment in systemic sclerosis (SSc) due to its accessibility and affordability, existing guidelines emphasize the importance of high-quality image acquisition for accurate interpretation. Previous studies have described a high percentage of unclassifiable images with dermatoscopy even in general population [2,3]. Furthermore, anecdotal evidence and clinical observations suggests that skin pigmentation might interfere with clarity and interpretability of dermatoscopy images, potentially leading to diagnostic challenges in diverse patient populations [4].

This study aimed to analyze the impact of skin pigmentation on the interpretability of dermatoscopy screening in patients undergoing evaluation for CTD-related RP. Specifically, we sought to determine if Fitzpatrick skin tones, which account for variations in skin pigmentation, influenced the clarity and diagnostic utility of dermatoscopic images. Uncovering possible limitations of dermatoscopy is crucial for subsequent optimizing of diagnostic approach of patients with RP therefore, we compared the performance of dermatoscopy with a high-magnification USB-based capillaroscopy device. Also, it has consequences regarding insurance of equitable healthcare outcomes for all patients, especially the in U.S. Veterans.

Methods

This study was conducted as an Institutional Review Board (IRB) approved research project (No. 1,618579-17) at the TVHS Hospital. Patients undergoing evaluation for CTDs-related RP were consented for participation at the time of their clinical care. Participants were recruited during the symptomatic winter months, from January through April 2025.

Clinical assessment

Comprehensive clinical data, including demographics, autoantibodies profiles and medical history, were obtained through a review of the electronic medical records. The presence of specific internal organ involvement was determined on established clinical guidelines and confirmed by objective diagnostic testing as part of standard of care [5,6]. For the purposes of this study, organ involvement was defined as follows:

- Interstitial Lung Disease (ILD): Defined by the presence of characteristic fibrosis or ground-glass opacities on high-resolution computed tomography (HRCT) of the chest.
- Pulmonary Arterial Hypertension (PAH): Defined by right heart catheterization (RHC) demonstrating a mean pulmonary artery pressure $\geq$20 mmHg and a pulmonary capillary wedge pressure $\leq$15 mmHg.
- Chronic kidney disease (CKD): Defined as persistent estimated glomerular filtration rate (eGFR) $<$ 60 ml/min/1.73 m^2, albuminuria, or other markers of kidney damage.
- Gastrointestinal involvement: Defined by characteristic symptoms of gastroesophageal reflux disease (GERD) requiring pharmacological treatment.

Skin pigmentation assessment

Skin pigmentation was assessed using Fitzpatrick Skin Phototype classification, a standardized scale developed to evaluate skin response to ultraviolet light (burning and tanning tendency) [7]. The scale categorizes skin into six types:

- Type I: white skin; always burns, never tans.
- Type II: white skin; always burns, minimal tan.
- Type III: white skin; burns minimally, tans moderately and gradually.
- Type IV: light brown skin, burns minimally, tans well.
- Type V: brown skin, rarely burns, tans deeply.
- Type VI: dark brown/black skin, never burns, tans deeply.

This classification served as basis for stratifying patients into lighter (I-III) and darker (IV-VI) pigmentation groups for analysis.

Nailfold evaluation procedures

Patients were prepared for dermatoscopy and NFC according to published protocols, which included a standardized acclimatization period of at least 15 min in a temperature-controlled room (21–22° C) to minimize vasospasm. Patients were seated comfortably with their hands positioned at heart level to ensure optimal blood flow. A thin layer of immersion oil was applied to the nailfold area to reduce light reflection and improve visualization of the capillaries [8]. Images of the nailfolds were obtained using two different devices (Fig. 1):

1 Dermatoscope with Smartphone Attachment: This device provided a magnification of 20X and utilized the smartphone's focus capabilities.
2 Smart G-Scope capillaroscope: This device offered a fixed magnification of 250X and features automatic USB focus, which adjusts the clarity of the image without altering the magnification. It is important to note that while EULAR/SCTC consensus guidelines recommend a 200X magnification for nailfold capillaroscopy, the 250X device was selected for this study based on its availability at the Veterans Affairs Hospital.

Image analysis and interpretation

All captured images were independently evaluated by two experienced capillaroscopy experts (TF, GM). Both capillaroscopists interpreted the individual capillaroscopic characteristic and the overall pattern (scleroderma or non-scleroderma) [4,9]. The inter-rater agreement for image clarity was assessed using Cohen's kappa statistic [10].

For dermatoscopy, the parameter of visibility was explicitly assessed (classified as good or blurry) to determine if the image was interpretable.

For both dermatoscopy and NFC microvascular findings, the reading and reporting of microvascular findings strictly followed the capillaroscopic protocol of the European Alliance of Association for Rheumatology (EULAR) Study Group on Microcirculation in Rheumatic Diseases/Scleroderma Clinical Trials Consortium (SCTC) and recent literature [11,12]. Therefore, final interpretation was performed visually by the authors (TF, GM) to ensure homogeneity and consistency.

The following standardized parameters were evaluated:

- Capillary Density: the number of capillaries in the distal row
  - Normal density: $\geq$7 capillaries per linear mm
  - Decreased density: $\leq$ 7 capillaries per linear mm
- Capillary dimension:
  - Dilated capillaries: dilations having an apical diameter of 20–50 μm
  - Giant capillaries: capillaries having an apical diameter of $>$ 50 μm
- Capillary morphology:
  - Normal morphology: capillaries with a hairpin shape; once or twice-crossing shape; or tortuous shape (i.e., limbs bend but do not cross), on the condition that the tip is convex.
  - Abnormal morphology: all capillaries whose shape does not correspond to the definition of a normal shape.
- Microhemorrhages: red or brown amorphous structures in the pericapillary/periungual region.

Fig. 1. Nailfold capillary equipment available at the study center. Left: dermatoscope with smartphone (magnification 20X), Right: Smart G-Scope USB-Capillaroscope (magnification 250X).

- Overall pattern: Classification as Scleroderma pattern versus non-scleroderma.

The Capillary.io software application (https://en.capillary.io/capillaroscopes/smart-g-scope/) was available and utilized solely for initial image collection [13], the final interpretation of microvascular characteristics was performed visually by the authors (GM, TF) to ensure homogeneity and consistency in reporting findings. This visual assessment was conducted using the EULAR/SCTC consensus framework, including the "Fast Track Algorithm" principles [9].

Data analysis

Patient demographics, including Fitzpatrick skin type, were collected. Fitzpatrick skin types were categorized into two groups for analysis: I, II, and III (lighter skin tones) and IV-VI (darker skin tones) [14].

Statistical analysis was performed to compare image clarity and the ability to interpret microvascular findings between the two device types and across different Fitzpatrick skin types. Descriptive statistics (percentages, means, standard deviations) were used to summarize the data. Chi-square test or Fisher's exact test were employed for categorical variables, and *t*-test were used for continuous variable where appropriate. A p-value of <0.05 was considered statistically significant. Kappa statistics were used to assess inter-rater agreement for image clarity and interpretability.

Results

A total of 38 U.S. Veterans were included in this study, with a mean age of 59.7 years (Table 1). The cohort was predominantly male (63 %) and primarily composed of white individuals (71 %), with African American participants making up 28 % of the population. A high percentage of participants (76.3 %) reported exposure to hazardous chemicals. Regarding laboratory data, over half of the cohort presented for ANA (52.6 %), with homogeneous (55 %), and speckled (20 %) patterns being most common. Anti-Scl-70 was the most frequent detected specific antibody (21.1 %) followed by anti-Sm (10.5 %). The most common clinical manifestation were chronic kidney disease and gastrointestinal manifestations, with a small percentage of patients also having interstitial lung disease (7.9 %) or pulmonary hypertension (2.6 %). Consequently, the cohort represents a clinical spectrum of CTD-related RP, with a significant proportion of patients exhibiting features consistent with a diagnosis of SSc.

Table 1
Demographic and clinical characteristics.

Parameters	[$n = 38$]
Age, mean ± Standard Deviation [min-max]	59.71 ± 12.3 [40–82]
Race	
African American	28 % [11]
White	71 % [27]
Gender	
Male	63 % [24]
Female	37 % [14]
Clinical Parameters	
Reported Exposure to Hazardous Chemicals	76.3 % [29]
Laboratory Data	
Positive ANA	52.6 % [20]
Pattern [n = 20]	
Homogeneous	55 % [11]
Speckled	20 % [4]
Nucleolar	15 % [3]
Centromere	10 % [2]
Anti-dsDNA	2.6 % [1]
Anti-SSA	-
Anti-SSB	-
Anti-RNP	5.3 % [2]
Anti-Sm	10.5 % [4]
Anti-RNA-Pol-III	5.3 % [2]
Anti-SCl-70	21.1 % [8]
Anti-RF	-
Anti-CCP	-
Clinical Manifestations	
Pulmonary Hypertension	2.6 % [1]
Interstitial Lung Disease	7.9 % [3]
Gastrointestinal Manifestations (GERD)	15.8 % [6]
Chronic Kidney Disease	18.4 % [7]

Dermatoscope image quality and interpretability

As detailed in Table 2, the dermatoscope demonstrated significant limitations in image quality, particularly in individuals with darker skin tones. Specifically, 63.6 % (7 out of 11) of images from patients with Fitzpatrick skin types IV, V and VI were classified as blurry, in contrast to 37 % (10 out of 27) of images from patients with Fitzpatrick skin types I, II and III ($p < 0.01$).

Furthermore, the interpretability of dermatoscopy images was significantly compromised in darker skin tones. 45 % (5 out of 11) of dermatoscopy examinations in patients with Fitzpatrick skin types IV, V and VI were deemed uninterpretable, compared to 37 % (10 out of 27) in those with Fitzpatrick skin types I, II and III. The inter-rater agreement for image clarity, including both blurriness and overall interpretability

Table 2
Dermatoscopy findings.

Dermatoscope Parameters	Fitzpatrick Skin Types I, II, and III [$n = 27$]	Fitzpatrick Skin Types IV, V and VI [$n = 11$]	P value
Blurry	37 % [10]	63.63 % [7]	< **0.01**
Unable to interpret (Overall)	**37 % [10]**	**45.45 % [5]**	
Scleroderma findings	44.44 % [12]	36.36 % [4]	
Normal findings	18.51 % [5]	18.18 % [2]	
Presence of Decreased Density	**25.92 % [7]**	**9.09 % [1]**	< **0.01**
Unable to interpret Decreased Density	37 % [10]	54.54 % [6]	
Presence of Giant Capillaries	**29.62 % [8]**	**18.18 % [2]**	< **0.01**
Unable to interpret presence of Giants Capillaries	37 % [10]	54.54 % [6]	
Presence of Abnormal Shapes	**25.92 % [7]**	**9.09 % [1]**	< **0.01**
Unable to interpret presence of Abnormal Shapes	37 % [10]	54.54 % [6]	
Presence of Microhemorrhages	**51.85 % [14]**	**36.36 % [4]**	< **0.01**
Unable to interpret presence of microhemorrhages	29.62 % [8]	45.45 % [5]	

was high (Cohen's kappa statistic >0.9).

Individual capillaroscopic characteristics also showed challenges in interpretability with the dermatoscope across skin types, with higher rates of uninterpretable results in Fitzpatrick skin types IV, V and VI. For example, the presence of giant capillaries could not be interpreted in 55 % (6 out of 11) of Fitzpatrick skin types IV, V and VI individuals, compared to 37 % (10 out of 27) in Fitzpatrick skin types I, II and III. Similar trends were observed for abnormal shapes, microhemorrhages and density.

Nailfold capillaroscopy smart G-Scope performance

The use USB-capillaroscope significantly improved image interpretability across the entire cohort, with a notable improvement in Fitzpatrick skin types IV, V and VI. Table 3 summarizes the quantitative capillaroscopy parameters obtained with USB capillaroscope.

While some parameters like capillary density show a slightly lower mean in darker skin tones (5.03 ± 1.72 vs. 6.2 ± 1.6 capillaries per mm), notable differences emerge in specific microvascular abnormalities. For instance, giant capillaries are more prevalent in Fitzpatrick skin types IV V, and VI (10.30 %) compared to lighter skin types (3.4 %). Similarly, dilated capillaries are significantly higher in darker skin tones (47.06 % vs 17.30 %). Interestingly, microhemorrhages are frequent in both groups, though slightly more common in Fitzpatrick skin types IV, V and VI (72.72 % vs. 63.3 %).

Table 3
NFC by USB-device findings.

Nailfold Capillaroscopy by USB-device Parameters	Fitzpatrick Skin Types I, II and III[$n = 27$]	Fitzpatrick Skin Types IV, V and VI [$n = 11$]	P value
Blurry			
Unable to interpret			
Scleroderma Pattern (Total)	**59.25 % [16]**	**45.45 % [5]**	**0.05**
Non-Scleroderma Pattern (Total)	**40.74 % [11]**	**54.54 % [6]**	**0.05**
Normal pattern	81.3 % [13]	18.18 % [2]	**0.05**
Non-specific	55.6 % [5]	36.36 % [4]	**0.05**
Capillary Density (No. per mm, Mean±SD, min-max)	6.2 ± 1.6 [1.9–8.3]	5.03 ± 1.72 [2.5–7.2]	**0.02**
Giant Capillaries	3.40 %	10.30 %	0.26
Abnormal Shapes	1 %	1.39 %	**0.01**
Microhemorrhages	63.30 %	72.72 %	0.12

Regarding microvascular patterns, while a normal pattern is more common in Fitpatrick skin types I, II, and II (81.3 % vs. 18.18 %), the scleroderma (SD)-pattern is observed in a substantial proportion of both groups, with 45.45 % in Fitzpatrick skin types IV-VI and 59.25 % in types I, II and III. Within the SD-pattern, late SD-pattern appears more frequently in skin types IV-VI (27.27 %) compared to early and active SD-pattern (9.09 %), suggesting potential differences in disease progression or presentation captures by the USB-capillaroscope across skin tones.

Use of USB-capillaroscope in uninterpretable dermatoscopy analysis

Crucially, the USB-capillaroscope was able to determine a microvascular pattern in all five cases that were previously uninterpretable using the dermatoscope, with 80 % (4 out of 5) showing SD-pattern (Table 4). The mean capillary density in this group was found to be 4.56 ± 1.91 capillaries per mm. Giant capillaries were present in 40 % with a mean of 62.3 ± 7.91 μm. Microhemorrhages were a prominent finding, present in 60 % of these previously uninterpretable images. This highlights the superior diagnostic capability of the USB-capillaroscope, especially in cases where dermatoscopy failed.

Lastly, Fig. 2 showcases a comparative analysis of DM and NFC across different Fitzpatrick skin scales, highlighting the impact of pigmentation on image interpretability and diagnostic advantage of NFC in darker skin tones. For illustrative purposes, representative images demonstrating various findings (blurry, normal, microhemorrhages, giant capillaries/dilated loops) were selected from individual patients across the specified Fitzpatrick skin types. These images were chosen to best exemplify the visual characteristics and interpretability challenges encountered with dermatoscopy (Figures A-H, captured with 20X magnification with a smartphone attachment) and the enhanced clarity with the USB-capillaroscope (Figures E.1-H.1), captured at a fixed 250X magnification.

Discussion

This study demonstrates significant limitations of dermatoscopy as a screening tool for nailfold microvascular evaluation in patients with RP, particularly among African American Veterans with Fitzpatrick skin types IV, V and VI. Our findings indicate that dermatoscopy produced a high rate of blurry and uninterpretable images in individuals with darker skin tones, suggesting that skin pigmentation can hinder the

Table 4
Microvascular evaluation performed with USB-capillaroscope of previous uninterpretable cases by dermatoscopy.

NFC by USB-capillaroscopy Parameters	Fitzpatrick IV-VI Cases with Uninterpretable Dermatoscopies					
	1	2	3	4	5	Mean±SD [min-max]
Density No per mm	6.8	3.6	6.4	3.5	2.5	4.56 ± 1.91 [2.5 - 6.8]
Apical diameter (μm)	67.9	24	56.7	33.3	25.9	41.56± 10.65 [24–67.9]
Giants (Y/N)	Yes	No	Yes	No	No	62.3 ± 7.91 [56.7 - 67.9]
Abnormal shape (%)	Yes	Yes	No	Yes	Yes	80 % [4]
Microhemorrhages (Y/N)	Yes	Yes	Yes	No	No	60 % [3]
Scleroderma Pattern	Active	Non-specific	Early	Late	Late	80 % [4]

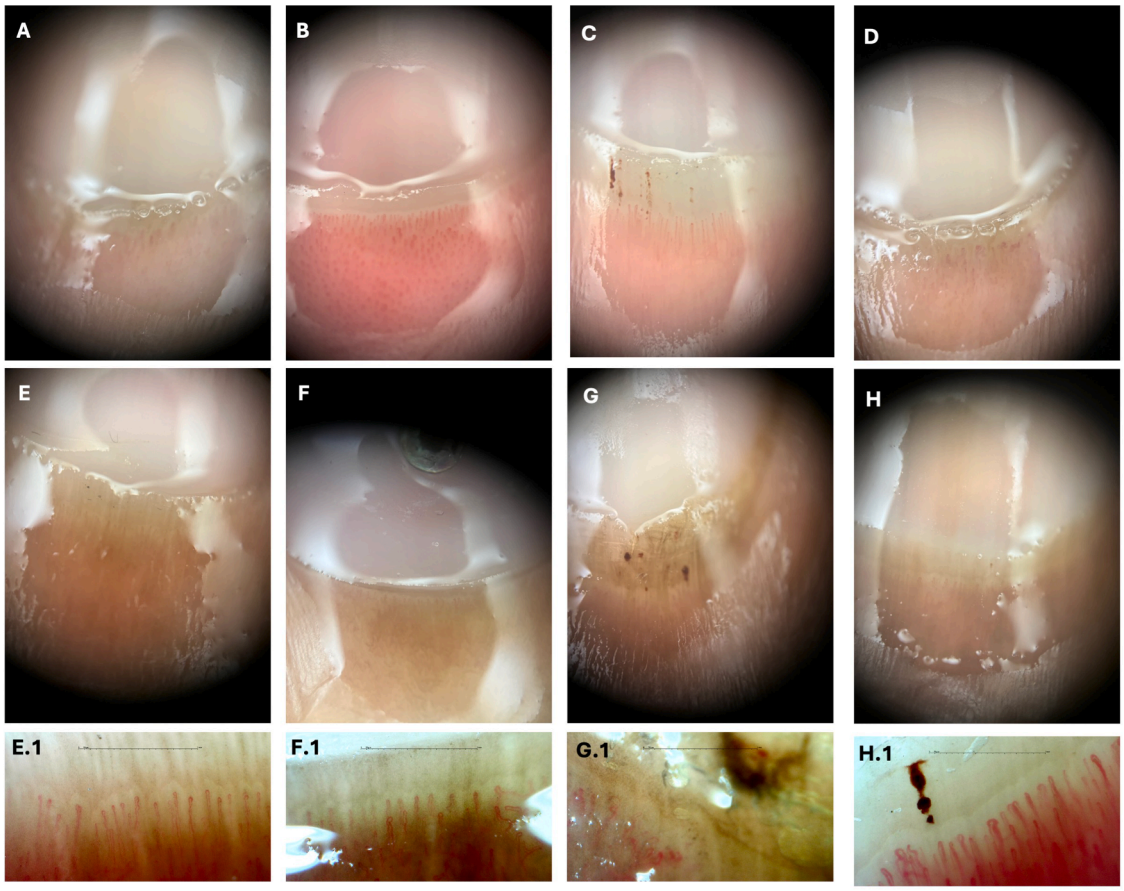

Fig. 2. A-D: Microvascular evaluation with Dermatoscopy (20X), A-D: Fitzpatrick skin scale I-III, E-H: Fitzpatrick skin scale IV-V; A, E: blurry findings, B, F: normal pattern, C, G: microhemorrhages, D, H: dilated capillaries and abnormal shapes; E.1-H.1: Corresponding USB-capillaroscopy evaluation (250X). E.1: normal pattern even if DM was blurry, F.1: normal pattern, G.1: abnormal shapes and hemorrhages; H.1: dilated loops and microhemorrhage.

effectiveness of this screening method. This is a critical finding, as a reliance on dermatoscopy alone in diverse populations may lead to missed or delayed diagnosis of microvascular involvement in SSc and other CTDs.

The observed higher percentage of blurry and uninterpretable images in Fitzpatrick skin types IV and V with the dermatoscope (63.6 % and 45.5 % respectively) compared to lighter skin tones (37 % for both blurry and uninterpretable) strongly suggests that the increased melanin content in darker skin can impede light penetration and image clarity. This inherent technical limitation of dermatoscopy, when applied to nailfold assessment in pigmented skin, can have a significant clinical implication. For example, the inability to interpret key microvascular features such as giant capillaries, abnormal shapes, microhemorrhages, and density, as shown in Table 1, directly impacts the diagnostic accuracy and the ability to detect early signs of SSc-related microangiopathy.

While Radic et al. demonstrated the promising utility of dermatoscopy as a valuable initial screening tool for RP, particularly for its ability to identify clear “normal” or “scleroderma” patterns [4], a significant caveat emerges regarding its broader generalizability and equitability implementation. The absence of stratification by Fitzpatrick skin types in their study, especially concerning types IV, V and IV, constitutes a notable limitation. Highlighting the importance to validate and potentially adapt capillaroscopy and dermatoscopy protocols specifically for populations with Fitzpatrick skin types IV, V and VI.

In contrast, the USB-capillaroscope device with higher magnification and automatic focus, demonstrated improved interpretability across the entire cohort, especially in Fitzpatrick skin types IV-VI. This improvement is crucial, as the USB-capillaroscope was able to detect SD-pattern in 4 of the 5 studies that were uninterpretable with the dermatoscope in the darker skin tones.

This underscores the potential for underdiagnosis when dermatoscopy is used a sole screening tool in diverse populations. The ability of the USB-capillaroscope to reveal underlying microvascular abnormalities, even when dermatoscopy fails, highlights its critical role in insuring equitable and accurate diagnosis, particularly for African American U.S. Veterans included in this study who may be disproportionally affected by these limitations.

The individual capillaroscopic characteristics (density, giant capillaries, abnormal shapes, and microhemorrhages) were analyzed based on visual interpretation following the EULAR/SCTC consensus-based description and interpretation framework (fast-track algorithm) [9]. This is paramount as reliability data on the individual characteristics from automated systems are still evolving.

The implications of these findings extend beyond clinical accuracy. Delayed or missed diagnosis of SSc can lead to worse patient outcomes due to delayed initiation of appropriate management and monitoring for organ involvement [15,16]. Therefore, selecting the appropriate NFC device, especially in populations with diverse skin tones, is paramount. The USB-capillaroscope, with its enhanced image capabilities, appears to overcome some of the limitations posed by dermatoscopy in individuals with higher Fitzpatrick skin types.

The strengths of this study are its direct comparison of two NFC devices within a diverse patient cohort, specifically including African American Veterans, which addresses a gap in data regarding dermatoscopy efficacy in darker skin tones and lays a foundation for future research.

Additionally, data collection was conducted during the symptomatic winter months, ensuring that microvascular abnormalities related to

Raynaud's phenomenon were assessed during the peak of clinical activity. The inter-rater assessment by experts further enhances the reliability of the findings. Acknowledged limitations include the small sample size, which suggest the need for validation in larger, multicenter studies. Furthermore, a gold-standard nailfold videocapillaroscopy device [12] was not available at the study center.

In conclusion, our study strongly suggests that while dermatoscopy can be useful screening tool, its limitations in capturing interpretable images in darker skin tones, particularly among African American Veterans are significant. The USB-capillaroscope offers a more reliable alternative, demonstrating superior image quality and the ability to detect crucial microvascular patterns that might otherwise be missed. This emphasizes the need for careful consideration of device selection in NFC to ensure accurate and equitable evaluation of microvascular involvement in CTD-related RP across all patient population.

Conclusion

In patients with RP, especially among African American Veterans, the dermatoscopy device resulted in a high rate of uninterpretable examinations. The USB-capillaroscope device significantly improved the diagnosis of abnormal nailfold capillaroscopy findings. These results highlight that relying solely on dermatoscopy as a screening tool may risk underdiagnosing of systemic sclerosis in patients with Raynaud's phenomenon.

Data statement

The data that support the findings of this study were obtained from the TVHS Hospital and are subject to restrictions to protect patient privacy and confidentiality. As this research includes sensitive U.S. Veteran patient information, the raw data are not publicly available due to IRB regulations and institutional policies. Anonymized data may be made available from the corresponding author upon reasonable request and contingent upon the execution of appropriate data use agreements with the involved institutions.

CRediT authorship contribution statement

Genessis Maldonado: Conceptualization, Formal analysis, Investigation, Writing – original draft. **Maurizio Cutolo:** Writing – review & editing, Supervision. **Tracy Frech:** Conceptualization, Methodology, Formal analysis, Investigation, Supervision. **Mislav Radic:** Writing – review & editing. **Marcus Snow:** Writing – review & editing. **Vanessa Smith:** Writing – review & editing, Supervision.

Declaration of competing interest

Co-author TF is supported by VA Merit Award I01CX002111, but no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper. Co-author VS is a Senior Clinical Investigator of the Research Foundation – Flanders (Belgium) (FWO) grant number 1802,920 N and 1802,925 N. The other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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