Peripheral Microcirculation Alterations as an Indicator of Predisposition to Tendon Degeneration of the Shoulder Joint: A Preliminary Study

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ABSTRACT

Introduction: The etiology of rotator cuff tear (RCT) is multifactorial and includes extrinsic and intrinsic factors. Alterations of the peripheral microcirculation represent a main intrinsic etiological factor; recent evidence demonstrates that at the level of the rotator cuff tendons there is significant reduction in capillary density and microvascular blood flow. On the basis of the alterations of the microcirculation present at the level of the rotator cuff (RC) tendons, the aim of our study was to evaluate the possible presence of alterations of the peripheral nail microcirculation, through capillaroscopic examination, in a consecutive series of patients with RCT, comparing them with an adequate control group. The hypothesis of our study is that the alteration of the local microcirculation is accompanied in patients with RCT by an alteration of the peripheral microcirculation that may represent a systemic predisposing factor for tendon degeneration.
Materials and methods: A case-control study was conducted. The Case Group consisted of 82 patients (mean age 61 years ± 8) with RCT, the size of which was assessed intraoperatively and classified into small, large and massive according to Snyder; the control group was represented by 43 healthy subjects (mean age 63 years ± 9). All control subjects underwent ultrasound examination to objectively exclude rotator cuff tears. All participants underwent a nail capillaroscopic examination of the hands to evaluate morphological and dynamic parameters. The data was subsequently analyzed.
Results: In the Case Group, 34 patients had a small RC lesion, 23 had a large lesion, and 25 had a massive lesion. The main capillaroscopic differences between cases and controls were found in the morphology of the capillary loops and in the flow. In the group of cases, 50% have normal loops, 47.56% have tortuous loops and 2.44% have branched loops; in the control group 62.79% had normal loops, 34.88% had tortuous loops and 2.33% had branched loops. The capillary flow was normal in 46.34% of the cases group, granular in 48.78% and slowed in 2.44%. 95.35% of the control group had normal flow and 2.33% grainy flow. Regarding the severity of the lesion, no significant differences were found between patients with small, large and massive lesion (small lesion: 50% normal loops, 41.2% normal flow; large lesion: 52% normal loops, 47.8% normal flow; massive lesion: 48% normal loops, 48% normal flow).
Conclusions: The prevalence of capillaroscopic alterations was higher in patients with rotator cuff tears: the capillary loops are more tortuous and present ectasias more frequently than in the control group. Additionally, capillary flow in patients with RCT is grainier and slowed. However, the compromise of the capillary picture is not proportional to the severity of the tendon lesion, limiting the direct clinical applicability of this finding. The results support the hypothesis that peripheral microcirculation disorders constitute an etiological factor predisposing to tendon degeneration and, therefore, rupture. Further longitudinal studies are needed to assess whether these alterations can predict healing outcomes and risk of re-tear after surgical repair.

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INTRODUCTION

The rotator cuff (RC) is a muscle-tendon complex that provides stability and mobility to the glenohumeral joint. It consists of four muscles: supraspinatus, infraspinatus, teres minor, and subscapularis. Rotator cuff tears (RCT) are among the most common shoulder pathologies, with prevalence increasing significantly with age, reaching over 80% in individuals older than 80 years (19, 45).

The etiology of rotator cuff tears is multifactorial, involving both extrinsic factors (anatomical variants, mechanical impingement) and intrinsic factors (age, smoking, vascular alterations). Among intrinsic factors, alterations of the microcirculation play a crucial role, leading to cellular modifications that interfere with collagen turnover and predispose tendons to degeneration and rupture (9–12, 46, 47).

Recent studies using advanced imaging techniques have confirmed that reduced blood flow in specific tendon regions, associated with microcirculatory disorders, contributes significantly to tendon degeneration. Biberthaler et al. (13) demonstrated through arthroscopic orthogonal polarization spectral imaging a marked reduction in functional capillary density at the edges of degenerative rotator cuff lesions compared to control tissue. More recent investigations have shown that microvascular blood flow is not uniform throughout the supraspinatus tendon and is significantly lower in pathologic tendons compared to normal tendons (46, 48).

Tendon degeneration is characterized by thinning of collagen fibers, loss of structural organization, decreased fibroblast number, and progressive reduction in blood vessel density. These changes result in poor healing capacity and high risk of recurrence after surgical repair (3, 48, 50).

Since microcirculatory alterations are recognized as an important etiological factor in tendon injury, we investigated whether patients with rotator cuff tears present evident peripheral capillary alterations detectable through nailfold capillaroscopy. Capillaroscopy is a non-invasive, safe, and well-established method for assessing structural and functional alterations of the microcirculation (15, 51, 52). This technique has gained increasing recognition beyond its traditional use in connective tissue diseases, with recent applications in various conditions affecting peripheral microcirculation, including metabolic and cardiovascular disorders (53, 54).

The aim of our preliminary study is to evaluate the presence of peripheral capillary alterations (structural and flow-related) in a group of patients with rotator cuff tears compared to a control group of healthy subjects, and to assess whether there is a correlation between the severity of the tendon lesion and the degree of capillary alteration.

CLASSIFICATION OF ROTATOR CUFF TEARS

Rotator cuff tears can be classified based on location (articular, bursal, intratendinous), tendon involved, and lesion size. For this study, we used Snyder's classification (36), which distinguishes:

Partial tears:
- Grade 0: normal cuff with bursitis/synovitis
- Grade 1: modest inflammation without tendon lesions
- Grade 2: modest tendon degeneration without flap
- Grade 3: degeneration and fragmentation with good tissue quality
- Grade 4: partial lesion with severe degeneration

Complete tears (used in our study):
- Type I: small, complete, punctate lesion
- Type II: small lesion (<2cm) involving single tendon without retraction
- Type III: large lesion (3–4cm) involving single tendon with retraction
- Type IV: massive lesion involving two or more tendons with retraction and fibrosis

CAPILLAROSCOPY

Capillaroscopy allows microscopic visualization of the nailbed capillary pattern (15). The technique is particularly valuable for diseases involving microcirculatory dysfunction, offering advantages including non-invasiveness, high sensitivity, ease of execution, and potential predictive value (16–18, 51).

Key capillaroscopic parameters evaluated include:
Morphological (static) parameters:
- Loop morphology (hairpin, tortuous, branched, arborescent)
- Capillary density (normal: 9–14 capillaries/mm)
- Presence of avascular areas
- Ectasias and megacapillaries
- Microhemorrhages and hemosiderin deposits

Functional (dynamic) parameters:
- Flow characteristics (continuous, granular, slowed, intermittent)

Recent advances in quantitative capillaroscopy, including automated image analysis, have improved the objectivity and reproducibility of this technique (55, 56).

MATERIALS AND METHODS

A retrospective case-control study was conducted on 125 subjects. Group 1 (cases) comprised 82 patients (mean age 61 years ± 8) with rotator cuff tears repaired arthroscopically, while Group 2 (controls) consisted of 43 healthy subjects (mean age 63 years ± 9).

In the case group, diagnosis of rotator cuff tear was performed through physical examination and confirmed with Magnetic Resonance Imaging (MRI). The lesion size was assessed intraoperatively and classified according to Snyder's method as small, large, or massive.

Exclusion criteria for both groups:
- Scleroderma, systemic lupus erythematosus, Raynaud's phenomenon, and other rheumatic pathologies (which present characteristic capillaroscopic alterations)

- Permanent nail polish
- History of trauma due to domestic or professional/manual activity
- Diabetes mellitus, uncontrolled hypertension, or other systemic conditions known to significantly affect microcirculation

For the control group:
- Physical examination of anterior and posterosuperior rotator cuff tendons was performed
- All control subjects underwent shoulder ultrasound examination to objectively exclude rotator cuff tears, addressing the known presence of asymptomatic tears in the general population
- Subjects positive on clinical tests (internal rotation lag sign, Jobe test, external rotation lag sign) or showing tears on ultrasound were excluded

Inclusion Criteria (Cases)
- Diagnosis of rotator cuff tear
- RCT repaired arthroscopicallyand classified

Exclusion Criteria (Cases)
- Rheumatic pathology
- History of trauma
- Permanent nail polish
- Uncontrolled metabolic/vascular conditions

Inclusion Criteria (Controls)
- No rotator cuff tear
- Negative ultrasound for RCT

Exclusion Criteria (Controls)
- Rheumatic pathology
- History of trauma
- Positive physical examination
- Positive ultrasound findings
- Permanent nail polish

CAPILLAROSCOPIC EXAMINATION PROTOCOL

After 15 minutes of acclimatization in a room at 20–22 °C, participants sat with hands placed at heart level. Excluding thumbs, a drop of clearing oil (cedar or paraffin) was applied to nailbeds of fingers 2–5 on both hands to reduce light reflection and improve visualization.

A video-capillaroscope with optical probe was used for direct contact with the nailbed. The probe emits cold incident light, providing three-dimensional images without causing reactive hyperemia. Examination was performed first with low magnification (20×) for global assessment of the nailbed and microvascular network, then with high magnification (200×) for detailed capillary flow evaluation. Images were viewed on a high-definition color monitor and stored digitally.

The following capillaroscopic parameters were evaluated:

- Loop morphology (normal, tortuous, branched, arborescent)

- Capillary density (normal, reduced, very reduced)
- Avascular areas
- Subpapillary venous plexus visibility
- Megacapillaries presence
- Ectasias and/or microaneurysms
- Neoangiogenesis (absent, limited, diffuse)
- Hemosiderin deposits (absent, rare, frequent)
- Background color (rosy, deep red, cyanotic, pale)
- Pericapillary edema (absent, mild, intense)
- Capillary flow

The characteristic capillaroscopic pattern for each patient was determined by identifying parameters present in at least 5 out of 8 examined fingers as dominant.

RESULTS

OVERALL COMPARISON: CASES VS CONTROLS
Loop Morphology:
- Cases: 41 patients (50%) normal loops, 39 (47.56%) tortuous loops, 2 (2.44%) branched loops
- Controls: 27 subjects (62.79%) normal loops, 15 (34.88%) tortuous loops, 1 (2.33%) branched loops
- No arborescent loops in either group

Capillary Density:
- Cases: 81 (98.78%) normal density (~10 capillaries/mm), 1 (1.22%) reduced density
- Controls: 100% normal density

Avascular Areas:
- Cases: 0%
- Controls: 0%

Subpapillary Venous Plexus (PVSP) Visibility:
- Cases: 71 (86.59%) barely visible, 11 (13.41%) visible in some periungual areas
- Controls: 30 (69.77%) barely visible, 13 (30.23%) visible in some periungual areas

Megacapillaries:
- Cases: 0%
- Controls: 0%

Ectasias and Microaneurysms:
- Cases: 19.51% present
- Controls: 0%

Neoangiogenesis:
- Cases: 2/82 patients showed limited neoangiogenesis
- Controls: 0%

Hemosiderin Deposits:
- Cases: 5/82 patients
- Controls: 0%

Background Color:
- Cases: 76/82 pink, 6/82 other colors
- Controls: 39/43 pink, 4/43 other colors

Pericapillary Edema:
- Cases: 45.12% absent, 54.88% present (32.93% mild, 19.51% moderate, 2.44% intense)
- Controls: 58.14% absent, 41.86% present (34.88% mild, 6.98% moderate)

Capillary Flow (Most Significant Finding):
- Cases: 38 (46.34%) normal flow, 40 (48.78%) granular flow, 2 (2.44%) slowed flow, 2 not assessable
- Controls: 41 (95.35%) normal flow, 1 (2.33%) granular flow, 1 (2.33%) slowed flow

SUBGROUP ANALYSIS BY LESION SIZE

Small Lesions (n = 34):
- Morphology: 50% normal loops, 44.12% tortuous loops, 5.88% branched loops
- Flow: 41.2% normal, 55.88% granular (1 not assessable)

Large Lesions (n = 23):
- Morphology: 52.17% normal loops, 47.83% tortuous loops
- Flow: 47.83% normal, 43.48% granular, 4.35% slowed

Massive Lesions (n = 25):
- Morphology: 48% normal loops, 52% tortuous loops
- Flow: 48% normal, 44% granular, 4% slowed (1 not assessable)

No significant differences were found between small, large, and massive lesion groups in terms of capillaroscopic alterations.

DISCUSSION

Our study evaluated the peripheral capillary pattern in patients with rotator cuff tears compared to healthy controls. The definition of a "normal" capillaroscopic picture remains subject to discussion, as various studies demonstrate significant variability in the healthy population.

Previous studies have documented this variability. Andrade et al. (39) demonstrated in 800 healthy subjects that capillary morphological anomalies were more frequent in subjects over 40 years (42% vs 33%). Fahrling et al. (40) found tortuous loops in 64% of healthy individuals. Hoerth et al. (41) developed a scoring system recognizing that capillary changes occur frequently among healthy individuals, finding that only 15% of 120 healthy volunteers showed no deviations in morphology, hemorrhages, or capillary density.

Recent advances in capillaroscopy have improved our understanding of normal variants. Ingegnoli et al. (42–44) described three main "normal" patterns: the "normal" pattern with 2–5 U-shaped capillaries/mm and ≤2 tortuous loops/mm; the "perfect normal" pattern with ≥5 U-shaped capillaries/mm; and "unusual normality" with at least 1 tortuous/arborescent loop or microhemorrhage. More recent work has emphasized the importance of standardized evaluation methods and quantitative assessment to reduce subjectivity (55, 56).

Our study demonstrated that the capillaroscopic picture of patients with rotator cuff tears is more compromised, both morphologically and dynamically, compared to controls. Morphologically, 50% of patients with RCT present alterations in capillary loop morphology, predominantly tortuous loops. Dynamically, over half of patients with RCT present altered capillary flow, represented in almost all cases by granular flow.

These findings are consistent with recent literature demonstrating the role of microcirculatory dysfunction in rotator cuff pathology. Gumina et al. (49) recently demonstrated through arthroscopic evaluation that macroscopic vasculature of the rotator cuff is influenced by pre-existing diseases and lifestyle factors that impair peripheral microcirculation.

However, a critical finding of our study is that considering only the case group, we did not demonstrate more severe peripheral microcirculation impairment in patients with greater tendon rupture severity. In patients with small, large, or massive lesions, approximately half presented morphological alterations of capillary loops and altered capillary flow, with no significant differences between groups.

This lack of correlation between peripheral microcirculatory alterations and tear size limits the direct clinical applicability of capillaroscopy for surgical planning or predicting tear progression. While capillaroscopy may identify patients with systemic microcirculatory dysfunction predisposing to tendon degeneration, it cannot stratify them based on current tear severity.

CLINICAL IMPLICATIONS AND LIMITATIONS

Our study has several important limitations that must be acknowledged:
1. Sample size: The relatively small number of subjects, particularly in the control group (n = 43), may limit the generalizability of findings.
2. Cross-sectional design: This study cannot assess whether capillaroscopic alterations predict healing outcomes or risk of re-tear after surgical repair, which would be the most clinically relevant application.
3. Definition of normal capillaroscopy: Despite recent advances (55, 56), significant variability in "normal" capillaroscopic patterns remains a challenge for interpretation.
4. Control group validation: Although we added ultrasound examination to objectively exclude rotator cuff tears in controls, this approach may not detect all small or partial tears that could be identified with MRI.
5. Lack of correlation with tear size: The absence of correlation between peripheral capillaroscopic findings and lesion severity significantly limits the practical utility of this examination for surgical decision-making.

Despite these limitations, our findings support the hypothesis that peripheral microcirculation disorders represent a systemic predisposing factor for tendon degeneration. Capillaroscopy, considering its ease of execution and low cost, could potentially be used to identify patients at higher risk for tendon pathology or poor healing. However, prospective longitudinal studies are needed to:
1. Assess whether capillaroscopic alterations predict healing outcomes after rotator cuff repair.
2. Evaluate the risk of re-tear in relation to peripheral microcirculatory status.
3. Determine if interventions targeting microcirculatory function could improve surgical outcomes.

Recent evidence suggests that biological augmentation strategies aimed at improving vascularization during healing may enhance outcomes (57). Understanding which patients have underlying microcirculatory dysfunction could help identify those who would benefit most from such interventions.

CONCLUSIONS

The prevalence of capillaroscopic alterations was higher in patients with rotator cuff tears: 47.56% of patients with RCT had tortuous capillary loops compared to 34.88% of controls. Most significantly, granular capillary flow was found in 48.78% of cases compared to only 2.33% of controls, while normal flow was present in 95.35% of controls versus 46.34% of cases.

However, the impairment of the capillary picture, assessed through capillaroscopy, is not proportional to the severity of the tendon rupture when comparing small, large, and massive tears. This lack of correlation limits the direct clinical applicability of capillaroscopy for surgical planning or predicting tear progression.

This preliminary study highlights that alteration of peripheral microcirculation is a frequent finding in patients with rotator cuff tears. The results support the hypothesis that peripheral microcirculation disorders constitute a systemic etiological factor predisposing to tendon degeneration and rupture.

Future directions should include:

1. Prospective longitudinal studies to assess whether capillaroscopic alterations predict healing outcomes and re-tear risk after surgical repair.
2. Investigation of whether interventions targeting microcirculatory function could improve surgical outcomes.
3. Larger multicenter studies with standardized quantitative capillaroscopy protocols to better define clinically relevant thresholds.

REFERENCES

1. Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. J Shoulder Elbow Surg. 1994; 3: 371–80.
2. Gomberawalla MM, Sekiya JK. Rotator Cuff Tear and Glenohumeral Instability: A Systematic Review. Clin Orthop Relat Res. 2014; 472: 2448–56.
3. Kannus P, Jozsa L. Histopathological changes preceding spontaneous rupture of a tendon. A controlled study of 891 patients. J Bone Joint Surg Am. 1991; 73: 1507–25.
4. Bank RA, TeKoppele JM, Oostingh G, Hazleman BL, Riley GP. Lysylhydroxylation and non-reducible crosslinking of human supraspinatus tendon collagen: changes with age and in chronic rotator cuff tendinitis. Ann Rheum Dis. 1999; 58: 35–41.
5. Zhang J, Pan T, Liu Y, Wang JH. Mouse treadmill running enhances tendons by expanding the pool of tendon stem cells (TSCs) and TSC-related cellular production of collagen. J Orthop Res. 2010; 28: 1178–83.
6. Zhang J, Wang JH. Mechanobiological response of tendon stem cells: implications of tendon homeostasis and pathogenesis of tendinopathy. J Orthop Res. 2010; 28: 639–43.
7. Zhang J, Wang JH. Production of PGE(2) increases in tendons subjected to repetitive mechanical loading and induces differentiation of tendon stem cells into nontenocytes. J Orthop Res. 2010; 28: 198–203.
8. Bi Y, Ehirchiou D, Kilts TM, et al. Identification of tendon stem/progenitor cells and the role of the extracellular matrix in their niche. Nat Med. 2007; 13: 1219–27.
9. Yuan J, Murrell GA, Wei AQ, Wang MX. Apoptosis in rotator cuff tendonopathy. J Orthop Res. 2002; 20: 1372–9.
10. Lian Ø, Scott A, Engebretsen L, et al. Excessive apoptosis in patellar tendinopathy in athletes. Am J Sports Med. 2007; 35: 605–11.
11. Gumina S, Natalizi S, Melaragni F, et al. The possible role of the transcription factor nuclear factor-kB on evolution of rotator cuff tear and on mechanisms of cuff tendon healing. J Shoulder Elbow Surg. 2013; 22: 673–80.
12. Karthikeyan S, Griffin DR, Parsons N, et al. Microvascular blood flow in normal and pathologic rotator cuffs. J Shoulder Elb Surg. 2015; 24: 1954–60.
13. Biberthaler P, Wiedemann E, Nerlich A, et al. Microcirculation associated with degenerative rotator cuff lesions: in vivo assessment with orthogonal polarization spectral imaging during arthroscopy of the shoulder. J Bone Joint Surg Am. 2003; 85: 475–80.
14. Determe D, Rongières M, Kany J, et al. Anatomic study of the tendinous rotator cuff of the shoulder. Surg Radiol Anat. 1996; 18: 195–200.
15. Cutolo M, Sulli A, Smith V. Assessing microvascular changes in systemic sclerosis diagnosis and management. Nat Rev Rheumatol. 2010; 6: 578–87.
16. Guzzo G, Senesi M, Giordano N, Montagnani M. La capillaroscopia in medicina. Collana medico scientifica. 1996.
17. Seidenari S. Diagnostica non invasiva in dermatologia. Collana medico scientifica. 1998.
18. Cutolo M, Sulli A, Pizzorni C, Accardo S. Nailfold videocapillaroscopy assessment of microvascular damage in Systemic sclerosis. J Rheumatol. 2000; 27: 155–60.
19. Milgrom C, Schaffler M, Gilbert S, et al. Rotator cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J Bone Joint Surg Br. 1995; 77: 296–8.
20. Chard MD, Hazleman R, Hazleman BL. Shoulder disorders in the elderly: a community survey. Arthritis Rheum. 1991; 34: 766–9.
21. Crass J, Craig E, Feinburg S. Ultrasonography of rotator cuff tears: a review of 500 diagnostic studies. J Clin Ultrasound. 1988; 16: 313–27.
22. Minagawa H, Itoi E. Clinical relevance of the rotator cuff in shoulder with pain and dysfunction. Kansetsugeka. 2006; 25: 923–9.
23. Middleton WD, Reinus W, Totty W, Melson C, Murphy W. Ultrasonographic evaluation of the rotator cuff and biceps tendon. J Bone Joint Surg Am. 1986; 68: 440–50.
24. Cadogan A, Laslett M, Hing A, et al. A prospective study of shoulder pain in primary care: prevalence of imaged pathology and response to guided diagnostic blocks. BMC Musculoskelet Disord. 2011; 12: 119.
25. Mack LA, Matsen FA, Kilcoyne RF, Davies P, Sickler M. US evaluation of the rotator cuff. Radiology. 1985; 157: 205–9.
26. Hodler J, Fretz C, Terrier B, Gerber C. Rotator cuff tears: correlation of sonographic and surgical findings. Radiology. 1988; 169: 791–4.
27. Miller C, Karasick D, Kurtz A, Fenlin J. Limited sensitivity of ultrasound for the detection of rotator cuff tears. Skeletal Radiol. 1989; 18: 179–83.
28. Soble M, Kaye A, Guay R. Rotator cuff tear: clinical experience with sonographic detection. Radiology. 1989; 173: 319–21.
29. Brandt T, Cardone B, Grant T, Post M, Weiss C. Rotator cuff sonography: a reassessment. Radiology. 1989; 173: 323–7.
30. Nelson M, Leather G, Nirschl RP, Pettrone F, Freedman M. Evaluation of the painful shoulder. J Bone Joint Surg Am. 1991; 73: 707–15.
31. Teefey SA, Hasan SA, Middleton WD, et al. Ultrasonography of the rotator cuff. A comparison of ultrasonographic and arthroscopic findings in one hundred consecutive cases. J Bone Joint Surg Am. 2000; 82: 498–504.
32. Yamaguchi K, Ditsios K, Middleton WD, et al. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am. 2006; 88: 1699–704.
33. Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg. 2010; 19: 116–20.
34. Roy JS, Braën C, Leblond J, et al. Diagnostic accuracy of ultrasonography, MRI and MR arthrography in the characterisation of rotator cuff disorders: a systematic review and meta-analysis. Br J Sports Med. 2015; 49: 1316–28.
35. de Jesus JO, Parker L, Frangos AJ, Nazarian LN. Accuracy of MRI, MR arthrography, and ultrasound in the diagnosis of rotator cuff tears: a meta-analysis. AJR Am J Roentgenol. 2009; 192: 1701–7.
36. Snyder SJ. Arthroscopic classification of rotator cuff lesions and surgical decision making. In: Shoulder arthroscopy. Philadelphia: Lippincott Williams & Wilkins, 2002: 201–2.
37. Cutolo M, Sulli A, Smith V. How to perform and interpret capillaroscopy. Best Pract Res Clin Rheumatol. 2013; 27: 237–48.
38. Sander O, Sunderkötter C, Kötter I, et al. Capillaroscopy. Procedure and nomenclature. Z Rheumatol. 2010; 69: 253–62.
39. Andrade LE, Gabriel Junior A, Assad RL, et al. Panoramic nailfold capillaroscopy: a new reading method and normal range. Semin Arthritis Rheum. 1990; 20: 21–31.
40. Fahring C, Heidrich H, Voigt B, et al. Capillary microscopy of the nailfold in healthy subjects. Int J Microcirc Clin Exp. 1995; 15: 287–92.

41. Hoerth C, Kundi M, Katzenschlager R, Hirschl M. Qualitative and quantitative assessment of nailfold capillaries by capillaroscopy in healthy volunteers. Vasa. 2012; 41: 19–26.
42. Ingegnoli F, Gualtierotti R, Lubatti C, et al. Nailfold capillary patterns in healthy subjects: A real issue in capillaroscopy. Microvasc Res. 2013; 90: 90–5.
43. Smith V, Beeckman S, Herrick AL, et al. An EULAR study group pilot study on reliability of simple capillaroscopic definitions to describe capillary morphology in rheumatic diseases. Rheumatology (Oxford). 2016; 55: 883–90.
44. Cutolo M, Melsens K, Herrick AL, et al. Reliability of simple capillaroscopic definitions in describing capillary morphology in rheumatic diseases. Rheumatology (Oxford). 2018; 57: 757–9.
45. Milgrom C, Schaffler M, Gilbert S, et al. Rotator cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J Bone Joint Surg Br. 1995; 77: 296–8.
46. Karthikeyan S, Griffin DR, Parsons N, et al. Microvascular blood flow in normal and pathologic rotator cuffs. J Shoulder Elbow Surg. 2015; 24: 1954–60.
47. Matthews TJ, Hand GC, Rees JL, et al. Pathology of the torn rotator cuff tendon. Reduction in potential for repair as tear size increases. J Bone Joint Surg Br. 2006; 88: 489–95.
48. Levy O, Relwani J, Zaman T, et al. Measurement of blood flow in the rotator cuff using laser Doppler flowmetry. J Bone Joint Surg Br. 2008; 90: 893–8.
49. Gumina S, Candela V, Passaretti D, et al. The association between arterial hypertension and rotator cuff tear: the influence on rotator cuff tear sizes. J Shoulder Elbow Surg. 2013; 22: 229–32.
50. Chung SW, Park JS, Song JH, et al. Quality of the rotator cuff cable and deltoid muscle in patients with rotator cuff disease: a clinical and histologic study. J Shoulder Elbow Surg. 2023; 32: 348–56.
51. Lambova SN, Müller-Ladner U. The role of capillaroscopy in differentiation of primary and secondary Raynaud's phenomenon in rheumatic diseases: a review of the literature and two case reports. Rheumatol Int. 2009; 29: 1263–71.
52. Cutolo M, Pizzorni C, Sulli A. Capillaroscopy. Best Pract Res Clin Rheumatol. 2005; 19: 437–52.
53. Grover S, Rastogi A, Misra DP, et al. Nailfold capillaroscopy patterns and associations in patients with diabetes mellitus: A systematic review. Microvasc Res. 2022; 140: 104294.
54. Trombetta AC, Smith V, Pizzorni C, et al. Quantitative alterations of capillary diameter have a predictive value for development of the capillaroscopic systemic sclerosis pattern. J Rheumatol. 2016; 43: 599–606.
55. Ruaro B, Sulli A, Smith V, et al. Short-term follow-up of digital ulcers by laser speckle contrast analysis in systemic sclerosis patients. Microvasc Res. 2015; 101: 82–5.
56. Cutolo M, Herrick AL, Distler O, et al. Nailfold videocapillaroscopic features and other clinical risk factors for digital ulcers in systemic sclerosis: a multicenter, prospective cohort study. Arthritis Rheumatol. 2016; 68: 2527–39.
57. Hernigou P, Flouzat Lachaniette CH, Delambre J, et al. Biologic augmentation of rotator cuff repair with mesenchymal stem cells during arthroscopy improves healing and prevents further tears: a case-controlled study. Int Orthop. 2014; 38: 1811–8.