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Vascular Zone Matters: Clinical Outcomes of Arthroscopic Meniscal Repair in Red–Red, Red–White, and White–White Tears

Vasküler Zon Önemlidir: Kırmızı–Kırmızı, Kırmızı–Beyaz ve Beyaz–Beyaz Yırtıklarda Artroskopik Menisküs Onarımının Klinik Sonuçları

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Abstract

Objective: Meniscal repair is superior to meniscectomy in preserving knee biomechanics and preventing degenerative progression. However, the healing potential may differ depending on the vascular zone. This study aimed to compare the clinical and functional outcomes of meniscal tears located in distinct vascular regions.

Materials and Methods: A retrospective review was conducted on 118 patients who underwent arthroscopic meniscal repair between 2015 and 2025, with a minimum 12-month follow-up. Tears were categorized as red–red (RR, n=42), red–white (RW, n=53), or white–white (WW, n=23). Outcomes were assessed using IKDC, Lysholm, and VAS scores. Return-to-sport time, patient satisfaction, and complication rates were also analyzed. Group comparisons and multivariate logistic regression were performed to determine independent predictors of failure.

Results: At the 12-month follow-up, functional scores were significantly higher in the RR group (IKDC 89.3; Lysholm 91.7) and VAS scores were lower (1.8) than in other groups (p<0.001). The mean return-to-sport time was shorter in RR tears (5.8 months) than in RW (6.4) and WW (8.2) groups (p<0.001). Satisfaction was highest in RR (90.5%) and lowest in WW (60.9%) tears (p=0.004). Complications were least frequent in RR (14.3%) and most common in WW (39.1%; p=0.03). WW localization independently predicted repair failure (OR=4.98; 95% CI: 1.88–13.18; p=0.001).

Conclusion: Meniscal repair outcomes vary according to vascular zone. RR-zone tears achieve better function, faster recovery, and fewer complications, whereas WW-zone tears have a higher risk of reoperation. Vascular zone evaluation should guide surgical decision-making.

Keywords: Complication, functional outcome, knee arthroscopy, meniscus repair, vascular zone

Öz

Giriş: Menisküs onarımı, diz biyomekaniğinin korunması ve dejeneratif süreçlerin önlenmesinin sağlanması açısından menisektomiye göre daha üstün kabul edilmektedir. Ancak onarım başarısı, menisküsün bulunduğu vasküler zonun kanlanma düzeyine bağlı olarak değişiklik gösterebilmektedir. Bu çalışma, farklı vasküler bölgelerdeki menisküs yırtıklarında klinik ve fonksiyonel sonuçları karşılaştırmayı amaçlamıştır.

Materyal ve Metot: 2015–2025 yılları arasında artroskopik menisküs onarımı uygulanan ve en az 12 ay takip edilen 118 hasta retrospektif olarak incelendi. Yırtıklar kırmızı–kırmızı (RR, n=42), kırmızı–beyaz (RW, n=53) ve beyaz–beyaz (WW, n=23) zon olarak sınıflandırıldı. Fonksiyonel sonuçlar IKDC, Lysholm ve VAS skorlarıyla değerlendirildi; spora dönüş süresi, hasta memnuniyeti ve komplikasyon oranları kaydedildi. Gruplar arası farklar uygun istatistiksel testlerle analiz edildi ve onarım başarısızlığını öngören bağımsız değişkenler çok değişkenli lojistik regresyon analizinde belirlendi.

Bulgular: On ikinci ayda RR grubunda fonksiyonel skorlar anlamlı olarak daha yüksekti (IKDC: 89,3; Lysholm: 91,7) ve ağrı skorları daha düşüktü (VAS: 1,8) (p<0,001). Spora dönüş süresi RR grubunda (5,8 ay), RW (6,4 ay) ve WW (8,2 ay) gruplarına kıyasla daha kısaydı (p<0,001). Hasta memnuniyeti RR grubunda en yüksek (%90,5), WW grubunda en düşüktü (%60,9) (p=0,004). Komplikasyon oranı RR grubunda %14,3, WW grubunda %39,1 olarak saptandı (p=0,03). Lojistik regresyon analizinde WW lokalizasyonu onarım başarısızlığının bağımsız bir öngördürücüsü olarak belirlendi (OR=4,98; %95 GA: 1,88–13,18; p=0,001).

Sonuç: Menisküs onarımının başarısı, yırtığın bulunduğu vasküler zonla yakından ilişkilidir. RR zonundaki yırtıklar daha iyi fonksiyonel iyileşme, daha hızlı spora dönüş ve daha düşük komplikasyon oranları göstermektedir. Buna karşılık WW zonundaki yırtıklar daha yüksek başarısızlık riski taşımaktadır.

Anahtar Kelimeler: Diz artroskopisi, fonksiyonel sonuç, komplikasyon, menisküs onarımı, vasküler zon

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INTRODUCTION

The menisci are fibrocartilaginous structures that play a crucial role in load distribution, shock absorption, joint stability, and proprioception of the knee. Preserving meniscal integrity is essential for maintaining normal biomechanics.[1,2] Resection or loss of meniscal tissue reduces the contact area within the joint. This increases stress on the articular cartilage and accelerates degenerative changes, ultimately increasing the risk of osteoarthritis.[3,4]

Meniscal tears are among the most common intra-articular knee injuries, particularly among young, physically active individuals, and represent a frequent reason for knee surgery. Meniscectomy has traditionally been widely performed; however, long-term follow-up studies demonstrate a strong association with early osteoarthritis and functional decline.[5-7] Consequently, approaches that preserve the meniscus have become increasingly important, and arthroscopic repair is now considered the preferred treatment for young, active patients, as it aids the maintenance of joint function and reduces the risk of cartilage degeneration.[3,5]

The vascular supply of the meniscus is a key factor in determining its healing potential. Meniscal vascularisation gradually diminishes from the periphery to the centre, resulting in the widely accepted classification of vascular zones: red–red (RR), red–white (RW), and white–white (WW).[8,9] The RR zone is well vascularised and has the greatest potential for healing. In contrast, the WW zone is avascular and has a very limited capacity for intrinsic repair. As a transitional region, the RW zone exhibits intermediate vascularity. Therefore, the location of a tear within these zones is a critical factor in determining surgical outcomes.[10]

The success of meniscal repair has been reported to be affected by several factors, including age, sex, body mass index, concomitant anterior cruciate ligament (ACL) reconstruction, tear type, and size.[11-13] However, the vascular zone of the tear is consistently identified as one of the most important predictors of successful healing. Previous reports show that tears in the RR zone are associated with higher success rates, whereas tears in the WW zone often demonstrate increased retear rates and complications.[6,10] Nevertheless, current evidence remains inconclusive, as many studies are limited by small participant numbers, heterogeneous surgical techniques, and relatively short follow-up periods.[14-16] Although vascular zone localisation is considered a critical factor in meniscal repair, robust clinical evidence remains limited.

The aim of this study is to compare functional outcomes, complication rates, return-to-sport time, and patient satisfaction among RR, RW, and WW zone tears following arthroscopic meniscal repair.

MATERIALS AND METHODS

Ethical Approval: This study was approved by the Non-Interventional Clinical Research Ethics Committee of Düzce University (Date: 22/09/2025; Decision No: 2025/256) and conducted in accordance with the principles of the Declaration of Helsinki (2013 revision). Owing to the retrospective design, no additional interventions were performed, and the requirement for written informed consent was waived. All patient data were anonymised prior to analysis to ensure confidentiality.

Study Design and Setting: This retrospective, single-centre observational clinical study was conducted at the Department of Orthopaedics and Traumatology, Faculty of Medicine, Düzce University. Data were collected from the medical records of 118 patients who underwent arthroscopic meniscal repair between 2015 and 2025.

Inclusion and Exclusion Criteria: The inclusion criteria were defined as follows: patients aged between 18 and 50 years who underwent arthroscopic meniscal repair between 2015 and 2025, with a minimum of 12 months of clinical and radiological follow-up and complete medical records. The patients were excluded if they underwent previous surgery on the same knee, had concomitant multiligamentous injuries or severe knee instability, had advanced osteoarthritis (Kellgren–Lawrence grade ≥3), had a follow-up period of less than 12 months, or had incomplete or insufficient data. These criteria were designed to ensure a homogeneous study population and minimise the potential confounding effects of age and degenerative changes.

Radiological and Arthroscopic Evaluation of Zones: The location and vascular zone of the meniscal tears were determined based on preoperative magnetic resonance imaging (MRI) scans and intraoperative arthroscopic findings. MRI evaluations were performed using 1.5 Tesla scanners with sagittal and coronal T2-weighted sequences. The type and size of each tear (longitudinal, radial, bucket-handle, or complex) were recorded in standardised forms. The vascular zone classification was defined as follows:

Red–Red (RR) zone: Peripheral outer one-third of the meniscus with rich vascularity.

Red–White (RW) zone: Middle one-third transition zone with reduced vascularity.

White–White (WW) zone: Inner one-third avascular region.

Among the 118 patients included in the study, 42 had RR tears, 36 had RW tears, and 40 had WW tears. Arthroscopic evaluation confirmed the MRI-based classification, as documented in the operative reports. Two orthopaedic surgeons independently performed the MRI assessments; in cases of disagreement, a third senior specialist reviewed the images and made the final decision.
Figure 1 illustrates a meniscal tear in the red–white zone (Zone 2), showing radiological and arthroscopic views obtained intraoperatively before and immediately after repair during the same surgical procedure.

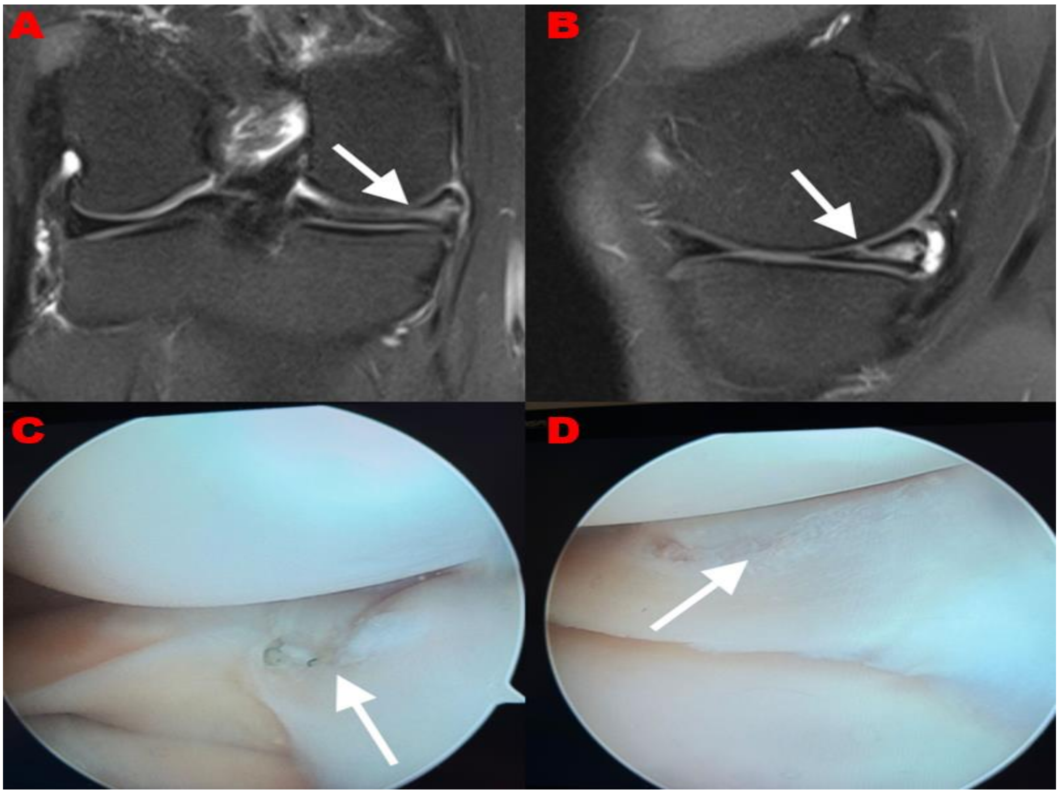

Figure 1. Radiological and arthroscopic appearance of a red–white meniscal tear. Coronal (A) and sagittal (B) MRI images demonstrate a longitudinal meniscal tear extending into the red–white vascular zone (arrows). Pre-repair arthroscopic evaluation (C) shows the unstable tear line prior to suturing, with no suture material present, located at the red–white junction. The post-repair intraoperative arthroscopic view (D) obtained during the same surgical session reveals a stable and well-aligned repair line following suture fixation, consistent with the healing potential of the red–white zone (arrows). No second-look arthroscopy was performed.

Surgical Technique: All procedures were performed arthroscopically via the standard anteromedial and anterolateral portals. The repair technique used depended on the type, location, and zone of the tear. Inside-out or outside-in techniques were used for peripheral longitudinal tears, whereas all-inside techniques were predominantly used for posterior horn tears. All-inside repairs utilised bioabsorbable implants, whereas non-absorbable sutures were used in the other techniques. To promote biological healing, the tear margins were rasped to stimulate vascularisation. In cases requiring simultaneous anterior cruciate ligament (ACL) reconstruction, a combined one-stage procedure was performed. The operative notes recorded the technique type, the number of sutures, and the fixation devices used in detail.
Postoperative Rehabilitation Protocol: A standardised rehabilitation protocol was applied to all patients. During the first four weeks, the knee was immobilised with a brace, and partial weight-bearing was permitted. From the fourth week onwards, gradual range-of-motion exercises were introduced, with progressive weight-bearing permitted after six weeks. Strengthening, balance, and proprioception exercises were introduced after eight weeks. Running and sport-specific training were introduced from the twelfth week onwards. Return to full-contact sports was generally permitted after six months post-surgery, depending on individual recovery, and was approved jointly by the surgeon and physiotherapist. This uniform protocol ensured consistency across all patients.

Clinical and Functional Evaluation: Functional assessments were conducted at three time points: preoperatively and at 6 and 12 months postoperatively. The following scoring systems were used:
International Knee Documentation Committee (IKDC) Score: Assessed subjective knee function.
Lysholm Knee Score: Evaluated daily living activities and symptoms.
Visual Analog Scale (VAS, 0–10 cm): Measured pain intensity.
Patient satisfaction survey: Assessed through standardized follow-up questionnaires.
Return-to-sport time: Documented in months as the first return to professional or recreational sports.
Monitoring of Complications: Patients were routinely monitored for postoperative complications, including infection, joint stiffness, retear, and reoperation. Suspected retears were confirmed through clinical examination and follow-up MRI scans. Data on complications were collected from outpatient follow-up notes, emergency department visits, and radiological reports.
Data Collection: All clinical, radiological, and surgical data were obtained from the hospital's electronic medical records, operative reports, and follow-up documentation. Functional scores were obtained from standardised clinical assessment forms. Radiological assessments were performed independently by two orthopaedic surgeons, and any discrepancies between them were resolved through consensus with a third reviewer. All data were anonymised and systematically entered into digital spreadsheets for analysis.
Statistical Analysis: All statistical analyses were performed by using IBM SPSS Statistics version 26.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were expressed as the mean ± standard deviation (SD), and categorical variables were presented as frequencies and percentages. The Shapiro–Wilk test was used to assess the normality of the continuous data distribution. One-way analysis of variance (ANOVA) was used for normally distributed continuous variables to test between-group differences, and the Kruskal–Wallis test was used for non-normally distributed continuous variables. Post hoc pairwise comparisons were conducted with Bonferroni correction where appropriate. Categorical variables were compared using the chi-squared test or Fisher's exact test where appropriate. Functional outcome scores (IKDC, Lysholm, and VAS) and times taken to return to sport were analysed using ANOVA, followed by post hoc tests. Complication rates were compared using chi-square analysis. A multivariate logistic regression model was constructed to identify the independent predictors of meniscal repair failure. These included demographic factors (age, sex, and BMI), tear zone (red–red, red–white or white–white), concomitant anterior cruciate ligament (ACL) reconstruction, and surgical technique. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported. A p-value of <0.05 was considered statistically significant. Prior to data collection, an a priori sample size calculation was conducted using G*Power software (version 3.1, University of Düsseldorf, Germany). Assuming a medium effect size (f = 0.25), an alpha error of 0.05, and a power of 0.80 for a one-way ANOVA with three groups, the required sample size was estimated to be 108 patients. With 118 patients ultimately included, the study was adequately powered to detect clinically meaningful differences across the vascular zone.[17]

RESULTS

According to Table 1, the mean age of all patients was 29.7±7.4 years, and 69.5% were male. No significant differences were found among vascular zone groups for age (p = 0.42), sex (p = 0.88), body mass index (p = 0.61), operated side (p = 0.91), tear localization (p = 0.97), or simultaneous ACL reconstruction (p = 0.78).

Table 1. Demographic and clinical characteristics of patients according to vascular zones.

Characteristics		**All (n = 118)**	**Red–Red (n = 42)**	**Red–White (n = 53)**	**White–White (n = 23)**	**p-value**
Age (years), mean ± SD		29.7 ± 7.4	28.5 ± 6.8	29.9 ± 7.2	31.2 ± 8.1	0.42
Sex, n (%)	Male	82 (69.5)	28 (66.7)	37 (69.8)	17 (73.9)	0.88
	Female	36 (30.5)	14 (33.3)	16 (30.2)	6 (26.1)	
Body Mass Index (kg/m²), mean ± SD		25.2 ± 2.9	24.9 ± 2.8	25.4 ± 3.0	25.6 ± 2.7	0.61
Operated side (Right), n (%)		65 (55.1)	22 (52.4)	30 (56.6)	13 (56.5)	0.91
Tear localization (Medial/Lateral), n		72 / 46	25 / 17	33 / 20	14 / 9	0.97
Simultaneous ACL reconstruction, n (%)		44 (37.3)	16 (38.1)	21 (39.6)	7 (30.4)	0.78

ACL: anterior cruciate ligament; SD: standard deviation.

As shown in Table 2, IKDC (p < 0.001), Lysholm (p < 0.001), and VAS pain scores (p < 0.001) showed significant differences among vascular zones. Return-to-sport time (p < 0.001) and patient satisfaction (p = 0.004) also differed significantly between groups.

Table 2. Comparison of functional outcomes according to vascular zones.

Outcomes	Red–Red (n = 42)	Red–White (n = 53)	White–White (n = 23)	p-value
IKDC score (12 mo, mean ± SD)	89.3 ± 6.5	85.1 ± 7.2	77.6 ± 8.4	**<0.001**
Lysholm score (12 mo, mean ± SD)	91.7 ± 5.8	87.4 ± 6.7	79.2 ± 7.9	**<0.001**
VAS pain score (12 mo, mean ± SD)	1.8 ± 1.0	2.3 ± 1.2	3.6 ± 1.4	**<0.001**
Return to sport (months, mean ± SD)	5.8 ± 1.6	6.4 ± 1.9	8.2 ± 2.1	**<0.001**
Patient satisfaction, n (%)	38 (90.5)	42 (79.2)	14 (60.9)	**0.004**

IKDC: International Knee Documentation Committee; VAS: Visual Analogue Scale; SD: standard deviation; mo, month(s).

As presented in Table 3, total complication rates were 14.3%, 22.6%, and 39.1% for the red–red, red–white, and white–white groups, respectively (p = 0.03). Re-tear (p = 0.02) and re-operation (p = 0.01) rates showed significant differences, whereas infection (p = 0.79) and joint stiffness (p = 0.72) did not.

Table 3. Distribution of complications by vascular zones.

Complications	Red–Red (n = 42)	Red–White (n = 53)	White–White (n = 23)	p-value
Infection, n (%)	1 (2.4)	1 (1.9)	1 (4.3)	0.79
Joint stiffness, n (%)	2 (4.8)	3 (5.7)	2 (8.7)	0.72
Re-tear, n (%)	2 (4.8)	6 (11.3)	5 (21.7)	**0.02**
Re-operation, n (%)	1 (2.4)	4 (7.5)	5 (21.7)	**0.01**
Total complications, n (%)	6 (14.3)	12 (22.6)	9 (39.1)	**0.03**

According to Table 4, vascular zone was identified as an independent predictor of repair failure (red–white vs red–red, p = 0.043; white–white vs red–red, p = 0.001). Other parameters, including age ≥30 years (p = 0.25), sex (p = 0.78), BMI ≥27 kg/m² (p = 0.19), ACL reconstruction (p = 0.44), and surgical technique (p = 0.82), were not statistically significant.

Table 4. Multivariate logistic regression analysis for predictors of repair failure.

Variables	OR	95% CI	p-value
Age ≥30 years	1.42	0.77–2.63	0.25
Sex (male)	1.10	0.54–2.25	0.78
BMI ≥27 kg/m²	1.55	0.81–2.96	0.19
Red–White vs Red–Red	2.21	1.02–4.75	**0.043**
White–White vs Red–Red	4.98	1.88–13.18	**0.001**
ACL reconstruction	0.76	0.38–1.54	0.44
Surgical technique	1.08	0.55–2.12	0.82

OR: odds ratio; CI: confidence interval; BMI: body mass index; ACL: anterior cruciate ligament.

DISCUSSION AND CONCLUSION

This retrospective study examined the impact of vascular zone location on the clinical outcomes of meniscal repair. The findings suggest that tears in the red–red zone are associated with better functional outcomes and a higher rate of return to sport, whereas tears in the white–white zone are associated with a higher rate of failure and complications. These results highlight the important role of meniscal vascular anatomy in biological healing capacity.

Patients with RR zone repairs had significantly higher IKDC and Lysholm scores, indicating better functional recovery. This is consistent with the well-vascularised structure of the RR zone, which enhances biological healing.[18] The red–white (RW) zone demonstrated intermediate outcomes that were superior to those of the white (WW) zone but inferior to those of the red (RR) zone. This supports the notion that a partial vascular supply confers a limited yet meaningful healing potential. Similar findings have been reported in previous studies.1[9-23]; Orellana et al.[8] highlighted vascularization as a major determinant of repair success, reporting success rates exceeding 80% in RR tears. Consistent with these data, the results of the study further emphasize the pivotal role of vascular zone localization in predicting functional improvement.

A return-to-sport analysis revealed that patients with RR-zone repairs resumed activity earlier and at a higher rate than those with RW or WW zone repairs. In contrast, repairs in the WW zone were associated with lower rates and a delayed return. This may be due to insufficient vascular support, which compromises the biomechanical durability of the repair. Previous studies have also shown that limited vascularity in the WW zone is linked to higher re-tear rates and a delayed return to sport.[21,24,25] From a clinical perspective, these results highlight the importance of localizing tears when planning surgical strategies for athletic populations, for whom functional recovery and return to sport are critical.

Complication rates were lowest in the RR group and highest in the WW group. Retear requiring revision surgery was significantly more frequent in WW-zone repairs. This may be due to the WW zone's lack of vascular supply, which results in impaired biological healing and reduced suture resistance under load.[26,27] Gallacher et al. similarly reported failure rates of up to 32% in WW-zone repairs.[28] These observations emphasize the importance of additional biological augmentation techniques, such as platelet-rich plasma or bone marrow stimulation, especially for tears in the avascular zone.[29]

Multivariate logistic regression identified the location of the vascular zone as an independent predictor of repair failure, regardless of age, sex, body mass index, or concomitant anterior cruciate ligament reconstruction. This emphasizes the dominant role of vascular zone localization in determining outcomes.[26] Paxton et al.,[30] in a large series of over 500 patients, likewise reported the vascular zone as the strongest predictor of meniscal repair success. Overall, these findings reinforce the idea that the vascular zone is an important factor, regardless of demographic or surgical variables. The findings suggest that meniscal repair should not be approached from the perspective of a 'uniform success rate'; rather, the vascular zone must be considered a key determinant of healing. The high success rates of RR-zone repairs are particularly promising for young, athletic patients, whereas the limited success of WW-zone repairs necessitates more cautious surgical decision-making. As emphasized in previous studies.[10,17,23] The primary goal should remain the preservation of the meniscus, but patients with WW-zone tears must be counselled about what they can realistically expect from the repair.

Several limitations of the present study should be acknowledged. Firstly, the retrospective, single-centre design may restrict the generalizability of the findings to broader populations and different clinical settings. Secondly, vascular zone classification was based on arthroscopic observations and preoperative imaging, which may be subject to interobserver variability despite standardized assessment protocols. Thirdly, systemic and lifestyle-related factors that may influence meniscal healing, such as smoking status, metabolic comorbidities, and activity level, could not be comprehensively controlled for due to the retrospective nature of the study.

Fourthly, functional evaluation primarily relied on validated but subjective patient-reported outcome measures, without incorporating objective biomechanical assessments or routine postoperative magnetic resonance imaging to confirm structural healing. Furthermore, although a minimum follow-up period of 12 months was achieved, this duration may be insufficient to evaluate long-term joint preservation and the progression of osteoarthritic changes. Finally, variations in surgical technique, implant choice, and surgeon experience could not be fully standardized, which may have influenced individual outcomes despite adherence to accepted surgical principles.

In conclusion, this study illustrates the substantial impact of vascular zone localization on clinical outcomes of arthroscopic meniscal repair. Tears within the red–red zone were associated with superior functional recovery, lower complication rates, and an earlier return to sport than those in the red–white and white–white zones. Conversely, tears in the white–white zone were identified as an independent predictor of repair failure and reoperation. These findings emphasise the critical importance of vascular zone assessment in surgical decision-making. However, due to the retrospective, single-centre design and limited follow-up, the results should be interpreted with caution. Further large-scale, prospective, multicenter studies are required to confirm these observations and elucidate the true role of vascular zones in meniscal healing and repair outcomes.

Ethics Committee Approval: This retrospective study was approved by the Non-Interventional Clinical Research Ethics Committee of Düzce University (Date: 22/09/2025; Decision No: 2025/256) and conducted in accordance with the 2013 revision of the Declaration of Helsinki. Written informed consent was waived due to the retrospective design.

Conflict of Interest: The authors declare that they have no conflict of interest.

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