





Review

How to Improve Meniscal Repair through Biological Augmentation: A Narrative Review

Pierangelo Za ^{1,2} , Luca Ambrosio ^{1,2,*} , Sebastiano Vasta ^{1,2}, Fabrizio Russo ^{1,2}, Giuseppe Francesco Papalia ^{1,2} , Gianluca Vadalà ^{1,2}  and Rocco Papalia ^{1,2}

- ¹ Operative Research Unit of Orthopaedic and Trauma Surgery, Fondazione Policlinico Universitario Campus Bio-Medico, 00128 Rome, Italy; p.za@unicampus.it (P.Z.); s.vasta@policlinicocampus.it (S.V.); fabrizio.russo@policlinicocampus.it (F.R.); g.papalia@policlinicocampus.it (G.F.P.); g.vadala@policlinicocampus.it (G.V.); r.papalia@policlinicocampus.it (R.P.)
- ² Research Unit of Orthopaedic and Trauma Surgery, Department of Medicine and Surgery, Università Campus Bio-Medico di Roma, 00128 Rome, Italy
- * Correspondence: l.ambrosio@unicampus.it

Abstract: Since the role of the menisci in knee stability, proprioception, and homeostasis has been well established, significant efforts have been made to repair meniscal tears, resulting in excellent clinical outcomes and a reduction in the progression of knee osteoarthritis (OA). However, varying failure rates have been reported, raising questions regarding the healing potential in cases of complex injuries, poorly vascularized and degenerated areas, and generally in the presence of unfavorable biological characteristics. Therefore, over the last few decades, different strategies have been described to increase the chances of meniscal healing. Biological augmentation of meniscal repair through various techniques represents a safe and effective strategy with proven clinical benefits. This approach could reduce the failure rate and expand the indications for meniscal repair. In the present study, we thoroughly reviewed the available evidence on meniscal repair surgery and summarized the main techniques that can be employed to enhance the biological healing potential of a meniscal lesion. Our aim was to provide an overview of the state of the art on meniscal repair and suggest the best techniques to reduce their failure rate.

Keywords: meniscus; meniscal repair; knee; arthroscopy; sports medicine; meniscectomy; platelet-rich plasma; microfracture



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1. Introduction

Meniscectomy was once a widely performed procedure [1–4] and considered the gold standard for treating symptomatic meniscal tears, offering good short-term clinical results, pain resolution, and functional improvement [5]. However, recent studies have questioned the effectiveness of meniscectomy [2,6–9]. Good clinical outcomes depend on meticulous surgical indications, suggesting that partial meniscectomy should be reserved for patients with mechanical symptoms and unstable meniscal lesions on magnetic resonance imaging (MRI), or those who did not respond to conservative treatment [10]. Additionally, arthroscopic meniscectomy has shown no superiority over sham surgery in cases of degenerative meniscopathy [9], and unsatisfactory results are to be expected if meniscectomy is performed without mechanical symptoms [11]. It is also essential to differentiate between medial and lateral meniscectomy. While the former has been linked to better functional outcomes [12], the latter has been associated with an increased risk of chondrolysis [13,14] and less favorable clinical results [15]. Furthermore, factors such as the integrity of the meniscal roots, lower limb alignment, presence of chondral lesions, concomitant instability, and body mass index (BMI) need to be considered when contemplating a meniscectomy [12,16–19].

For years, meniscectomy was unquestionably performed worldwide until long-term studies demonstrated a direct correlation with the progression of knee osteoarthritis (OA) [20–24].

This called into question the long-term effectiveness of meniscectomy and paved the way for the introduction of meniscal repair techniques. Meniscal repair has become a crucial consideration not only to improve clinical outcomes, but also for ethical and economic reasons. Indeed, the increasing incidence of OA leads to a higher number of joint replacement surgeries, thus placing a substantial financial burden on the healthcare systems [25]. Hence, the prevention of OA is essential from both cost and benefit perspectives.

We conducted a narrative review of the literature to highlight current advancements in meniscal repair and outline the primary techniques commonly employed to enhance the likelihood of biological healing in meniscal repair.

2. Materials and Methods

2.1. Literature Search Strategy

We conducted a comprehensive state-of-the-art literature search using databases such as PubMed, Scopus, and Google Scholar. The search covered articles published up to February 2024. Key terms included “meniscal repair” OR “meniscus repair” AND “biological augmentation”.

2.2. Inclusion and Exclusion Criteria

Eligible studies were peer-reviewed articles written in English that involved human subjects and specifically reported on the outcomes and techniques of meniscal repair and its biological augmentation. Exclusion criteria included case reports, non-English publications, studies with insufficient outcome data, and animal studies.

2.3. Data Extraction

Data extraction was performed by two independent reviewers (P.Z, L.A.). Demographic data, clinical and radiological outcomes, reoperation, and failure rates were extrapolated and collected in tables and synthesized narratively.

3. Why Repair?

Both the medial and the lateral menisci are important stabilizers and proprioceptors of the knee [26,27]. Meniscectomy alters these properties and results in elevated contact pressure in the femorotibial compartment, directly related to the extent of meniscal tissue removal [28–32]. It also disrupts knee kinematics and stability [21,33,34], promoting cartilage wear and OA progression [35,36]. The principle behind meniscal tissue repair is the potential for healing particularly due to the rich vascularization in the red-red zone and partly in the red-white zone of the meniscus.

Various methods for meniscal repair have been developed, including all-inside, out-in, and in-out techniques [37,38]. The selection of the best approach among these depends on the nature and location of the meniscal injury, along with the surgeon’s preference. When assessing the outcomes of meniscal repair, it is crucial to consider the specifics of the technique and devices used, the nature of the lesion, its location, and the characteristics of the population examined. The failure rate may also vary depending on the definition of failure adopted by different authors. Consequently, meniscal repair failure rates are highly variable in the literature [15,39–43]. Duethman et al. [15] reported a non-statistically significant difference in failure and reoperation rates between meniscal repair and meniscectomy groups. Conversely, Paxton et al. [43] reported a higher failure rate for meniscal repair. On the other hand, other authors [44–46] reported significant improvements in patient outcomes following meniscal repair compared to meniscectomy. Table 1 depicts the main studies comparing the results of meniscectomy versus meniscal repair [15,42,43,47–52].

Table 1. Studies comparing outcomes of meniscectomy versus meniscal repair.

| Study (Year) | Study Design (LOE) | Mean Age or Range (Years) | Mean Follow-Up (Months) | Tear Location | PROMs | | | | Radiological Outcomes | Failure Rate | Reoperation Rate |
|-------------------------------|---------------------------|--------------------------------|----------------------------------|---------------|---------|---------------|---------|-------|--|--------------------|--|
| | | | | | IKDC | Lysholm Score | TAS | KOOS | | | |
| Xu et al. [47] (2015) | Meta-analysis (III) | 22–33 | 84 | NS | MR: ↑ | MR: ↑ | MR: ↑ | NS | NS | MR: ↓ | NS |
| Bottomley et al. [48] (2023) | Retrospective study (III) | MR: 47 ME: 61 | MR: 57 ME: 47 | Mixed | MR: ↑ | MR: ↑ | MR: ↑ | MR: ↑ | NS | NS | NS |
| Ro et al. [49] (2020) | Meta-analysis (IV) | MR: 54 ME: 56 | MR: 33.5 ME: 47.2 | MMPRT | NS | MR: ↑ | MR = ME | NS | MR showed lower rates of OA progression | NS | MR 4.2% ME: 32% |
| Duethman et al. [15] (2021) | Retrospective study (III) | 17.4 | 100 | LM | MR: ↑ | NS | NS | NS | ME showed higher rates of symptomatic OA | MR: 27% ME: 27% | MR: 23% ME: 18% |
| Paxton et al. [43] (2011) | Systematic review (IV) | MR: 26.0–46.8 ME: 15.3–44.2 | >120 | Mixed | NS | MR = ME | NS | NS | MR showed lower rates of OA progression | NS | MR: 16.5% (0–48 months), 20.7% (>120 months) ME: 1.4% (0–48 months), 3.9% (>120 months) |
| D’Ambrosi et al. [50] (2022) | Systematic review (IV) | MR: 22.1 ME: 23.3 | NS | NS | NS | NS | NS | NS | NS | NS | MR: 17% (LM 25%, MM 25%, 50% NS) ME: 3.7% (LM 83%, MM 17%) |
| Migliorini et al. [51] (2023) | Meta-analysis (III) | 37.6 | 63 | NS | MR = ME | ME: ↑ | NS | NS | MR showed lower rates of OA progression | No differences | MR: 14% |
| Stein et al. [52] (2010) | Cohort study (III) | MR: 31.3 ME: 32.5 | 40 (mid-term) 104 (long-term) | MM | NS | NS | NS | NS | ME showed higher OA progression in the long-term | NS | ME: 10% |
| Shieh et al. [42] (2016) | Case-control study (III) | 15.3 | 40 | NS | NS | NS | NS | NS | NS | NS | MR: 18% ME: 7% |

Upward arrows indicate the superiority of MR with regards to the investigated outcomes, whereas the downward arrow indicates a lower failure rate in the MR group. Abbreviations: IKDC = International Knee Documentation Committee; KOOS = Knee injury and Osteoarthritis Outcome Score; LM = lateral meniscus, LOE = level of evidence; ME = meniscectomy; MM = medial meniscus; MMPRT = medial meniscus posterior root tears; MR = meniscal repair; NS = not specified, TAS = Tegner activity score.

In the authors’ opinion, the current failure rates of meniscal repair are unsatisfactory and need to be improved. However, surgeons should not be discouraged from performing meniscal repairs. When a repair fails, it is often possible to perform a new repair or a meniscectomy, which is usually less invasive than what would have been required initially. This approach allows for excellent long-term clinical outcomes even after the failure of a meniscal repair requiring revision [53]. Hagmeijer et al. [53] reported zero cases of failure after revising a meniscal repair at a mean follow-up of 17.6 years. Similarly, D’Ambrosi et al. [50] reported a return to sport rate of over 80% in a population of professional athletes. The causes of failure after meniscectomy include persistent pain, instability, and chondrolysis, complications that are challenging to manage and may necessitate more aggressive interventions such as a new meniscectomy, osteotomy, or osteochondral or meniscal allograft implantation. In contrast, the most common causes of failure after repair are nonspecific pain and suture failure, which can be more easily managed with a new repair or partial meniscectomy [50]. However, the failure rate of repairs remains high, particularly within one year after surgery [42,53]. Complex and bucket handle tears have the highest failure rates at 80% and 47%, respectively, while isolated meniscal lesions have a failure rate of 18.2% [53]. Isolated repair has a higher failure rate than meniscal repair with concomitant anterior cruciate ligament reconstruction (ACLR) [43,54–58]. A recent meta-analysis examining meniscal repair outcomes in 3829 patients with a minimum follow-up of two years documented an overall failure rate of 14.8%, which dropped to 8.5% in the presence of a concomitant ACLR [59]. Furthermore, medial meniscus repair tends to fail more often than lateral meniscus repair, while partial lateral meniscectomy has a higher reintervention rate compared to partial medial meniscectomy [43,50]. Recent data report failure rates of 6.1% and 10.8% for repairs of the lateral and medial meniscus, respectively. Repairs in adults do not have lower failure rates compared to younger people, indicating that advanced age does not adversely affect the failure rate. Therefore, it is not contraindicated to perform meniscal repair in patients over the age of 40 [39,54,56,60–62]. Although there is no consensus, Wouters et al. [63] recently reported that repairing a meniscal injury within three weeks of injury reduces the failure rate. Most failures occur in the first year due to impaired healing or reinjury [40,53]. The implementation of an early range of motion and immediate postoperative weightbearing does not appear to negatively impact the likelihood of clinical success following meniscal repair [64]. Key data on meniscal repair failure rates are summarized in Tables 2 and 3.

Table 2. Systematic reviews and meta-analyses reporting reoperation or overall failure rates of meniscal repair.

| Study (Year) | Study Design (LOE) | Mean Follow-Up (Months) | Tear Localization | Overall Failure Rate | Reoperation Rate |
|-------------------------------|-------------------------|-------------------------|-------------------|---------------------------|--|
| Schweizer et al. [65] (2021) | Meta-analysis (III) | 86 | MM and LM | 19.1% | MM 24.4%, LM 19.5% |
| Schweizer et al. [59] (2023) | Meta-analysis (IV) | 24–60 | MM and LM | 14.8% (MM 10.8%, LM 6.1%) | NS |
| Ro et al. [49] (2020) | Meta-analysis (IV) | 33.5 | MMPRT | NS | 4.2% |
| Migliorini et al. [51] (2023) | Meta-analysis (IV) | 63 | NS | NS | 14% |
| Migliorini et al. [51] (2023) | Systematic review (III) | 67 | MM and LM | 5.9% | 1.1% |
| Blanchard et al. [66] (2020) | Systematic review (IV) | 40.5 | MM and LM | | 12.4% |
| Dai et al. [67] (2021) | Systematic review (IV) | 19–58 (range) | MM and LM | MM: 15%; LM 14% | NS |
| D’Ambrosi et al. [50] (2022) | Systematic review (IV) | NS | NS | NS | 17% (LM 25%, MM 25%, 50% NS) |
| Paxton et al. [43] (2011) | Systematic review (IV) | >120 | MM and LM | NS | 16.5% (0–48 months), 20.7% (>120 months) |

Abbreviations: LM = lateral meniscus, LOE = level of evidence; MM = medial meniscus; MMPRT = medial meniscus posterior root tears, NS = not specified.

Table 3. Level III and IV clinical studies reporting reoperation or overall failure rates of meniscal repair.

| Study (Year) | Study Design (LOE) | Mean Follow-Up (Months) | Tear Location | Overall Failure Rate | Reoperation Rate |
|------------------------------|---------------------------|-------------------------|---------------|--|--------------------|
| Hagmeijer et al. [53] (2019) | Case series (IV) | 210 | MM and LM | 42% (complex tears 80%; bucket-handle tears 47%; simple tears 18.2%) | 36% |
| Ronblad et al. [54] (2020) | Case-control study (III) | 96 | MM and LM | 22.5% | MM 28.3%, LM 11.7% |
| Abdelkafy et al. [68] (2005) | Retrospective study (III) | 139 | | 12% | |
| Duethman et al. [15] (2021) | Retrospective study (III) | 100 | LM | 27% | 23% |
| Shieh et al. [42] (2016) | Case-control study (III) | 40 | | | 18% |

Abbreviations: LM = lateral meniscus, LOE = level of evidence; MM = medial meniscus.

However, biological healing time should be respected before returning to sport, which should not be early in the case of meniscal repair, especially in the young population. The current challenge is to lower the failure rate of a meniscal repair. Several techniques have been described to promote meniscal healing after repair.

4. Meniscal and Biological Augmentation

Over time, various techniques have been developed to enhance the chances of successful meniscal healing. The most common augmentation techniques for meniscal repair are shown Figure 1 and summarized in Table 4.

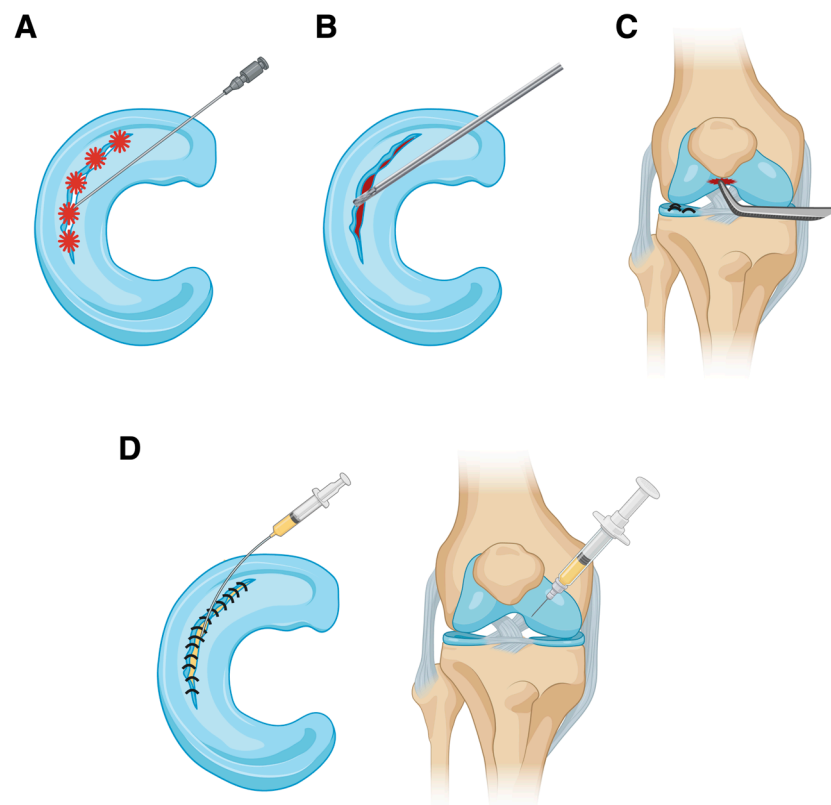


Figure 1. The main techniques to perform biological augmentation of repaired meniscal tears include trephination (A), abrasion (B), microfracture (C), and the administration of platelet-rich plasma, fibrin clots, or platelet-rich fibrin clots (D). These can be delivered directly into the repaired tear or injected into the knee joint after surgery. Created with BioRender.com.

4.1. Trephination

Trephination is a straightforward technique wherein a spinal needle is arthroscopically used to drill holes in the red-red zone, creating multiple channels to divert blood flow from a vascularized area to a less vascularized area. This allows growth factors and cells to reach the meniscal lesion, stimulating fibrous scar formation and its remodeling into fibrocartilaginous tissue [69,70]. Experimental studies on animals [70–72] have shown that trephination increases vascularization and improves tissue healing. In humans, this translates into enhanced clinical outcomes when trephinations are added to meniscal repair [73,74]. However, the effectiveness of trephinations as an isolated procedure is still debated [72].

4.2. Abrasion

Abrasion of the margins of the meniscal lesion and the parameniscal synovium can be performed using a shaver or rasp. This easy and fast mechanical stimulation elicits a damage response with the release of growth factors and cytokines that trigger a process of revascularization and healing [75,76]. Rasping the parameniscal synovium and abrading the tear edges seem to yield superior results compared to fibrin clots in murine [77] and rabbit models [78]. Excellent healing rates in humans have been reported after abrasion combined with meniscal repair, and further confirmed at arthroscopic second looks, although their effectiveness seems to be reduced in the case of tears in poorly vascularized zones [79–81].

4.3. Microfracture

A lower failure rate of a meniscal repair in case of concomitant ACLr is well documented [43,54–58,82], theoretically due to the release of mesenchymal stromal cells and growth factors from the bone tunnels [72,73], promoting angiogenesis, matrix synthesis, and cell proliferation [83–85]. Microfracture of the intercondylar notch aims to simulate this mechanism by creating holes that penetrate the subchondral bone, releasing marrow elements into the joint. Several studies have demonstrated the efficacy and safety of microfractures as an adjunctive technique to meniscal repair [86–88], with some authors even speculating on an efficacy superimposed on that obtained by concomitant ACLr [89]. A level I randomized controlled trial by Kaminski et al. demonstrated a 100% healing rate in 23 patients after vertical complete meniscal lesion repair when 6 to 7 microfracture holes into the lateral aspect of the intercondylar notch were performed using a special device [90]. A recent systematic review showed that bone marrow stimulation reduces the likelihood of failure in patients undergoing isolated meniscal repair, although it does not lead to improvements in knee symptom scores [91]. However, clinical results remain contradictory [92], thus questioning its broader applicability [93].

4.4. Platelet-Rich Plasma

Different protocols for platelet-rich plasma (PRP) use exist, inevitably affecting results as PRP can be used in single or multiple administrations, in the joint or directly inside the repaired meniscal lesion, as well as on biological supports such as scaffolds or clots. Various preparation techniques lead to multiple types of qualitatively different products. In vitro and in vivo studies support the benefits of PRP augmentation to meniscal repair [94–98]. This is also supported by human clinical studies [99–102], although results may be conflicting [103,104]. Despite the difficulties in demonstrating the theoretical preclinical benefits of PRP even in humans [95], Kaminski et al. [105] in their level I RCT demonstrated that injecting PRP into the meniscal lesion after repair improves the rate of healing and clinical outcomes. Otherwise, multiple intra-articular injections of PRP do not appear to have any clinical or healing advantage over its non-use [41]. A recent systematic review and meta-analysis of six comparative studies employing PRP augmentation in conjunction with meniscal repair emphasized the biological power of PRP and supported its use as an adjuvant to meniscal healing [106]. This point was also highlighted by the systematic

review of Haunschild et al. [107], which argued that PRP augmentation may have the potential to decrease the failure rate after meniscal repair. However, PRP may not improve knee symptom scores [91], although results from a recent systematic review reported mixed results [92,93].

4.5. Fibrin Clot

A fibrin clot (FC) is an autologous derivative of a patient’s peripheral blood. It contains growth factors and cytokines which provide both local chemotactic and mitogenic stimuli for cellular repair, triggering the formation of a fibrous connective tissue scar which remodels over time, potentially healing the meniscal tear [108–113]. It has been added to meniscal repair with documented good healing rates and clinical results, even in the case of degenerative lesions [114–117]. Nakanishi et al. [118] showed that during a two-week observation period, there were no significant differences between an FC and platelet-rich fibrin (PRF) clot in terms of the cumulative amount and pattern of growth factor release. Although FC is cheaper and faster to produce than a PRF clot, its application is more technically demanding, invasive, and time-consuming compared to other simpler techniques such as rasping, trephinations, and microfractures. The superiority of FC over these techniques has not been conclusively demonstrated [77], and a recent systematic review considered the current evidence on FC insufficient to draw definitive conclusions on its actual usefulness [93].

4.6. Platelet-Rich Fibrin Clot

In 2006, Choukroun et al. [119] developed a platelet derivative called PRF, which was subsequently used by Narayanaswamy et al. [120] as an alternative technique to FC. Compared to its derivatives, this second-generation PRF theoretically offers the advantage of being richer in platelets, which are slowly released over several weeks directly at the site of the repaired meniscal lesion [121–126]. Despite numerous well-documented advantages of PRF over PRP and FC [120,124,126,127], its clinical superiority over other techniques is still debated [118]. Although promising, there is insufficient evidence for definitive conclusions [93]. Further in vivo and high-quality research is necessary to clarify the clinical effectiveness of this novel technique.

Table 4. Main characteristics of the most common augmentation techniques for meniscal repair.

| Technique | Summary | Biology | Clinical Evidence | References |
|---------------|---|---|--|-------------------|
| Trephination | A spinal needle is used arthroscopically to create multiple holes in the inner wall of the meniscus to form vascular channels connecting the vascularized area (red-red zone) with the meniscal lesion. | Redirecting the blood supply by allowing migration of cells and factors that stimulate a healing response and remodeling. | Contradictory: effective in promoting meniscal healing only if combined with other techniques. | [70,71,73,74,113] |
| Microfracture | Once meniscal repair is complete, the arthroscopic fluid flow is interrupted and a blunt tip is used arthroscopically to perform microfractures in the intercondylar notch, at the origin of the PCL, or in the medial aspect of the lateral femoral condyle. These microfractures penetrate the subchondral bone until bone marrow elements are observed entering the joint through the microfracture holes. | Exposes the joint to bone marrow mesenchymal stromal cells and growth factors such as IGF-1, TGF-β, and several BMPs. | Improved meniscal healing at arthroscopic second looks and enhanced clinical results. | [86–88,105] |

Table 4. Cont.

| Technique | Summary | Biology | Clinical Evidence | References |
|-------------|--|---|--|-----------------------|
| Abrasions | A rasp or shaver is used arthroscopically on the edges of the meniscal lesion and parameniscal synovium to revitalize the meniscal tissue and stimulate the release of growth factors from the synovial surface. | Promotes the release of IL-1 α , TGF- β 1, PDGF, and PCNA. | Good results shown by arthroscopic second looks. Less effective with lesions in poorly vascularized zones. | [75,77–81,108] |
| Fibrin clot | Peripheral blood is taken from the patient. The blood is placed in a sterile specimen cup and then stirred using a frosted glass syringe plunger until the clot is completely formed. Afterwards, it is washed with saline and introduced into the joint. | Composed of blood factors including 5% of platelets that are progressively released in situ. | Satisfactory outcomes with high healing rates despite failures are still present in a small variable percentage. Greater efficacy compared to other techniques is uncertain. | [114–116,118] |
| PRF clot | The patient’s peripheral blood is drawn and placed in a sterile glass tube and centrifuged. After centrifugation, the clot is left to consolidate for 5–10 min. Then, it is removed from the centrifuge and the sterile glass tube and separated between the red clot and white clot junction. Finally, it is introduced into the joint. | Composed by 85–95% of platelets as well as a fibrin matrix polymer, leucocytes, cytokines, and stem cells. Progressive and localized release of cytokines, antimicrobial peptides, cells, and growth factors. | The theoretical advantages are numerous, although adequate clinical studies demonstrating this are lacking. Theoretical superiority over fibrin clot is debated. | [119,120,124,126,127] |
| PRP | Single or multiple intra-articular or intra-lesion injections of PRP. | Introduces growth factors (PDGF, VEGF, TGF- β 1) to promote chemotaxis, angiogenesis, collagen matrix synthesis, and cell proliferation, eventually enhancing meniscal healing. | It is contradictory as it depends on the mode of use and the characteristics of the PRP. Intra-lesion injection appears more effective than intra-articular administration. | [94–102,105] |

Abbreviations: BMP = bone morphogenetic proteins; IGF-1 = insulin-like growth factor-1; IL = interleukin; PCL = posterior cruciate ligament, PCNA = proliferating cell nuclear antigen; PDGF = platelet-derived growth factor; PRF = platelet-rich fibrin; PRP = platelet-rich plasma; TGF- β = transforming growth factor β , VEGF = vascular endothelial growth factor.

4.7. Future Perspectives

Although several biological augmentation techniques have been introduced to improve meniscal healing rates, the overall quality of the evidence remains low. The strategies employed are significantly heterogeneous, and the underlying mechanisms are not yet fully understood [69,80,83]. Nonetheless, novel approaches, including both intraarticular and extraarticular systemic strategies, are under investigation [91–93]. Among these, stimulating endogenous irisin release could potentially enhance meniscal repair. Irisin, a myokine physiologically released by skeletal muscle during physical exercise, has been shown in previous studies to exert both paracrine and endocrine effects on various musculoskeletal tissues, including cartilage [128], tendon [129], and intervertebral disc [130]. By potentially stimulating meniscal healing, dedicated physical therapy protocols designed to increase endogenous irisin production could be implemented following postoperative repair. However, these theories remain speculative and require preclinical validation.

5. Conclusions

The current trend favors meniscal injury repair due to its numerous advantages over meniscectomy, especially in the medium and long term. However, the relatively high failure rate and the challenge of repairing biologically disadvantaged meniscal injuries remain significant issues. The biological augmentation of meniscal repair through various techniques represents a safe and effective option with proven clinical benefits. This approach could reduce the failure rate and expand the indications for meniscal repair. However, conclusive evidence from standardized, high-quality research is needed to establish the definitive efficacy of these biological augmentation techniques.

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