NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Quality in Sport. eISSN 2450-3118.

Journal Home Page
https://apcz.umk.pl/QS/index

NIEWOLA, Karolina, STENZEL, Paweł, HARIASZ, Natalia, ORDA, Karolina, WALCZAK, Dominika, KASPERSKA, Klaudia, SZUMIŁO, Jakub, MARKIV, Mariana, SŁOWIK, Michał, and ARCISZEWSKI, Kamil. Autologous Platelet Concentrates in Sports Medicine: Mechanisms of Tissue Regeneration and Clinical Applications – A Narrative Review. Quality in Sport. 2026;54:70256. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.54.70256

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 25.03.2026. Revised: 29.03.2026. Accepted: 31.03.2026. Published: 4.04.2026.

Autologous Platelet Concentrates in Sports Medicine: Mechanisms of Tissue Regeneration and Clinical Applications – A Narrative Review

Karolina Niewola[1]

ORCID http://orcid.org/0009-0003-8096-9742

E-mail:karolina.niewola@op.pl

[1]4th Military Clinical Hospital in Wroclaw, Wroclaw, Poland

Paweł Stenzel[2]

ORCID http://orcid.org/0009-0003-0347-8552

E-mail: stenzelpawel.t@gmail.com

[2]University Dental Clinic, Cracow, Poland

Natalia Hariasz[1]

ORCID http://orcid.org/0009-0000-5397-0324

E-mail:natalia.hariasz@gmail.com

[1]4th Military Clinical Hospital in Wroclaw, Wroclaw, Poland

Karolina Orda[1]

ORCID http://orcid.org/0009-0002-0996-137X

E-mail:orda.karolina19@gmail.com

[1]4th Military Clinical Hospital in Wroclaw, Wroclaw, Poland

Dominika Walczak[1]

ORCID http://orcid.org/0009-0007-1629-871X

E-mail:dominikajwalczak@gmail.com

[1]4th Military Clinical Hospital in Wroclaw, Wroclaw, Poland

Klaudia Kasperska[4]

ORCID http://orcid.org/0009-0002-3512-7696

E-mail:klaudia.kasperskaa@gmail.com

[3]Specialist Medical Center, Polanica-Zdroj, Poland**

Jakub Szumiło[5]

ORCID http://orcid.org/0009-0008-5105-4857

E-mail: jszumilo0@gmail.com

[4]Wroclaw Medical University, Wroclaw, Poland

Mariana Markiv[5]
ORCID http://orcid.org/0009-0006-0679-8131
E-mail:marianamarkiv@mail.com
[5]Jagiellonian University, Kraków, Poland

Michał Słowik[4]
ORCID http://orcid.org/0009-0004-1206-528X
E-mail:michal.slowik16@wp.pl
[4]Wroclaw Medical University, Wrocław, Poland

Kamil Arciszewski[6]
ORCID http://orcid.org/0009-0003-2679-0872
E-mail:kamilarciszewski01@gmail.com
[6]Sapienza University of Rome, Rome, Italy

Corresponding Author
Karolina Niewola, karolina.niewola@op.pl

ABSTRACT

Background. Sports-related musculoskeletal injuries remain a major problem in both professional and recreational athletes because of their high incidence, prolonged recovery, and the limited regenerative potential of some tissues. In this context, regenerative medicine has attracted increasing interest, particularly through the use of autologous platelet concentrates, which may enhance repair by delivering growth factors and other bioactive mediators to injured tissues.

Aim. To summarize current evidence on autologous platelets concentrates in sports medicine, with emphasis on their biological mechanisms, major formulations, clinical applications, and limitations.

Material and methods. A narrative literature review was conducted using PubMed, Scopus, and Web of Science, focusing mainly on studies published between 2010 and 2026. Eligible publications included randomized controlled trials, clinical studies, observational studies, and review articles evaluating autologous platelet concentrates in sports-related musculoskeletal injuries.

Results. Autologous platelet concentrates may promote tissue regeneration through the release of mediators involved in angiogenesis, cell proliferation, inflammatory modulation, and extracellular matrix remodeling. Major formulations include platelet-rich plasma, leukocyte-rich and pure platelet-rich plasma, platelet-rich fibrin, injectable platelet-rich fibrin, and concentrated growth factors. Clinical studies suggest potential benefits in selected tendon, muscle, ligament, and cartilage injuries, although findings remain inconsistent. The main limitations include protocol heterogeneity, variable product composition, and lack of standardization.

Conclusions. Autologous platelet concentrates are promising adjuncts in sports medicine, but their effectiveness appears to be indication-specific rather than universal. Further protocol standardization and high-quality clinical trials are needed to support broader evidence-based use.

Keywords: autologous platelet concentrates; platelet-rich plasma; platelet-rich fibrin; sports medicine; musculoskeletal injuries; tissue regeneration

Content

1. Introduction

Sports-related musculoskeletal injuries represent a major challenge in both elite and recreational athletes. The growing participation in organized and leisure-time physical activity has been accompanied by a high incidence of injury, often leading to pain, functional limitation, time loss from training, and increased healthcare utilization [1]. Injury surveillance from the Rio 2016 Olympic Games documented 1101 injuries over 17 days, affecting approximately 8% of participating athletes and illustrating the considerable burden of musculoskeletal trauma even in highly trained populations [1].

Across sports disciplines, most injuries involve soft tissues, particularly muscles, tendons, and ligaments, with the lower extremities being the most frequently affected anatomical region [1,2]. Muscle injuries alone account for an estimated 10–55% of all sports-related injuries and most commonly affect the hamstrings, quadriceps, and gastrocnemius because of the high mechanical demands associated with sprinting and explosive movement [3]. Tendon disorders also contribute substantially to the injury burden in physically active individuals. A large population-based epidemiological study reported an annual incidence of 15.48 ± 6.33 cases per 100,000 persons for tendinopathies, with lateral epicondylitis and Achilles tendinopathy among the most frequently diagnosed conditions [4].

Ligament injuries constitute another major category, particularly in dynamic and contact sports. Among them, ankle sprains are especially common, accounting for approximately 16–40% of all sports injuries, most often involving the lateral ligament complex; notably, 10–40% of affected patients may subsequently develop chronic ankle instability, predisposing them to persistent symptoms and recurrent injury [5]. Despite advances in rehabilitation and sports medicine, the management of these conditions remains challenging. Conventional treatment is largely based on rehabilitation, pharmacological symptom control, and, in selected refractory

cases, surgery. However, the effectiveness of these approaches is frequently constrained by the biological characteristics of musculoskeletal tissues, particularly tendons and ligaments, which exhibit low cellularity, poor vascularization, and limited metabolic activity. As a result, healing is often slow and incomplete, and the repaired tissue may fail to recover the structural and biomechanical properties of native tendon, increasing the risk of persistent symptoms and reinjury [6,7,8].

Exercise-based rehabilitation, especially eccentric loading protocols, remains one of the most widely recommended conservative strategies for tendinopathies, yet clinical outcomes are variable and often depend on adherence, lesion severity, and the degree of tendon degeneration. Even when effective, such programs may require prolonged rehabilitation, and a substantial proportion of patients achieve only partial recovery [8,9].

Pharmacological treatment, including non-steroidal anti-inflammatory drugs and corticosteroid injections, is widely used for pain relief, but its effects are largely symptomatic and do not necessarily translate into improved tissue regeneration. The role of NSAIDs in tendon healing remains controversial, and some evidence suggests that they may interfere with extracellular matrix remodeling and biological repair [6,4]. Corticosteroid injections may provide short-term benefit; however, repeated administration has been associated with inferior long-term outcomes, reduced tendon strength, and a potential risk of tendon rupture [8,9]. Surgical intervention, although often necessary in severe or treatment-resistant cases, does not consistently ensure full functional recovery and may be complicated by scar formation, adhesions, infection, prolonged rehabilitation, or persistent pain despite technically successful repair [7,8,9].

These limitations have contributed to growing interest in regenerative medicine as a means of addressing not only symptoms but also the biological basis of tissue repair. In sports medicine, this shift has supported the emergence of biologically oriented therapies designed to enhance endogenous healing and improve recovery outcomes [10–13]. Within this field, orthobiologics have gained particular relevance and are broadly defined as naturally derived biological substances used to support the repair and regeneration of musculoskeletal tissues, including blood-derived products, cell-based therapies, and bioactive scaffolds [10,11]. Their introduction reflects a broader transition from purely structural repair toward interventions intended to stimulate biological healing mechanisms [10].

Among these approaches, platelet-derived therapies have attracted considerable attention because of the central role of platelets in tissue repair. Platelets contain numerous growth factors, including PDGF, TGF-β, VEGF, IGF-1, FGF, and EGF, which regulate cellular proliferation, angiogenesis, and extracellular matrix synthesis during healing [12]. In addition, orthobiologic

therapies may modify the local inflammatory microenvironment, thereby creating more favorable conditions for regeneration [10]. Although regenerative interventions are increasingly used in clinical practice, they remain limited by variability in preparation protocols, inconsistent terminology, and heterogeneity in reported outcomes [11]. Within this context, autologous platelet concentrates (APCs) have emerged as one of the most extensively investigated orthobiologic strategies because of their autologous origin, relative ease of preparation, and ability to deliver concentrated growth factors directly to injured tissues [12,13].

APCs are blood-derived products obtained from the patient's own peripheral blood through centrifugation-based processing intended to concentrate platelets and other biologically active blood components within a reduced plasma volume [14,15,16]. Importantly, APCs do not represent a single uniform formulation, but rather a heterogeneous group of preparations that differ in platelet concentration, leukocyte content, fibrin architecture, cellular purity, and activation status, all of which may influence their biological behavior and clinical performance [14–16].

The concept of platelet concentrates evolved from earlier fibrin-based surgical sealants and blood-derived healing adjuvants toward more advanced regenerative formulations. Initial interest focused primarily on fibrin as a scaffold for wound repair, followed by increasing recognition of platelets as reservoirs of growth factors and, later, of the broader contribution of leukocytes, plasma proteins, and fibrin organization to the healing microenvironment [14].

A major milestone in this evolution was the development of classification systems aimed at addressing long-standing inconsistencies in terminology. The most widely cited framework divides platelet concentrates into four principal families according to leukocyte content and fibrin structure: pure platelet-rich plasma (P-PRP), leukocyte-rich platelet-rich plasma (L-PRP), pure platelet-rich fibrin (P-PRF), and leukocyte-rich platelet-rich fibrin (L-PRF) [14]. PRP preparations are generally administered in liquid form, whereas PRF-based products form a denser fibrin matrix and are typically applied as solid or gel-like biomaterials [15]. Despite these advances, APC terminology remains only partially standardized, and the literature continues to be affected by substantial heterogeneity in preparation techniques, reporting quality, and product composition [16]. Nevertheless, the refinement of classification systems and the recognition that APCs are complex biologic constructs rather than simple platelet suspensions have provided the conceptual basis for their expanding role in regenerative sports medicine [16,17].

The aim of this narrative review is to critically examine the role of autologous platelet concentrates in sports medicine, with particular emphasis on the biological mechanisms through

which these products may support musculoskeletal repair and functional recovery. The review summarizes current knowledge on the molecular and cellular pathways involved in APC-mediated regeneration, including growth factor release, inflammatory modulation, angiogenesis, cell proliferation, and extracellular matrix remodeling. It also outlines the preparation principles and major categories of platelet concentrates used in regenerative practice, including PRP, leukocyte-rich and pure PRP formulations, PRF, injectable PRF, and concentrated growth factors. In addition, this review evaluates the available evidence regarding the use of APCs in common sports-related musculoskeletal conditions, especially tendon, muscle, ligament, and cartilage injuries, while addressing the main limitations of the current evidence base, ongoing controversies related to product heterogeneity and protocol standardization, and future directions for integrating platelet-based therapies into evidence-based sports medicine.

2. Methodology

2.1. Literature Search and Study Selection

A narrative literature review was conducted to identify studies addressing the biological mechanisms and clinical applications of autologous platelet concentrates in sports medicine. Electronic searches were performed in PubMed, Scopus, and Web of Science for articles published between January 2010 and January 2026. Earlier landmark studies were considered when necessary to provide historical context. The search strategy combined Medical Subject Headings (MeSH) and free-text terms, including: “autologous platelet concentrates”, “platelet-rich plasma”, “PRP”, “platelet-rich fibrin”, “PRF”, “injectable PRF”, “i-PRF”, “concentrated growth factors”, “CGF”, “sports medicine”, “musculoskeletal injuries”, “tendon injury”, “muscle injury”, “ligament injury”, and “tissue regeneration”. Boolean operators (AND, OR) were used to refine the search, and reference lists of relevant articles were screened to identify additional studies. Eligible publications included randomized controlled trials, clinical studies, observational studies, and review articles examining the biological properties or clinical applications of platelet concentrates in musculoskeletal injuries. Only English-language full-text articles were included. Conference abstracts, editorials, and studies unrelated to sports injuries or regenerative applications of platelet concentrates were excluded. The selected literature was analyzed using a qualitative narrative synthesis, focusing on three main aspects: types of platelet concentrates, mechanisms of tissue regeneration, and clinical applications in sports medicine. Particular attention was given to molecular mechanisms such as growth factor signaling, angiogenesis, cellular proliferation, and extracellular matrix remodeling, as well as

clinical evidence in tendon, muscle, ligament, and cartilage injuries. Variations in platelet preparation methods, platelet concentration, and leukocyte content were also considered due to their potential impact on therapeutic outcomes.

2.2. AI

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

3. Research results

3.1. Biological mechanisms of tissue regeneration induced by platelet concentrates

Autologous platelet concentrates promote tissue repair through the coordinated release of growth factors, cytokines, chemokines, adhesive proteins, and fibrin-associated structural components that regulate inflammation, angiogenesis, progenitor-cell activation, and extracellular matrix remodeling after injury [18]. Rather than acting as a single-factor intervention, these preparations create a biologically active microenvironment that influences several overlapping phases of healing, including hemostasis, inflammatory-cell recruitment, cellular proliferation, matrix deposition, and tissue maturation [19]. This concept applies not only to platelet-rich plasma (PRP), but also to platelet-rich fibrin and injectable platelet-rich fibrin, in which the fibrin architecture may prolong the local bioavailability of signaling molecules and thereby modify the kinetics of tissue regeneration [20].

The regenerative response begins with platelet activation after exposure to collagen, thrombin, or other local stimuli, followed by release of bioactive mediators stored mainly in α-granules and dense granules [19]. Among the most relevant molecules liberated from platelet-derived preparations are platelet-derived growth factor, transforming growth factor-β, vascular endothelial growth factor, insulin-like growth factor-1, fibroblast growth factors, and epidermal

growth factor, all of which regulate cell migration, proliferation, survival, and matrix synthesis [21].

PDGF supports early cellular repopulation of injured tissues and extracellular matrix formation through its mitogenic and chemotactic effects on fibroblasts, mesenchymal stromal cells, and vascular smooth muscle cells [21]. TGF-β is also a central mediator of repair, stimulating collagen production and connective tissue remodeling, although excessive activity may shift healing toward fibrosis [22]. VEGF is a key driver of angiogenesis, whereas IGF-1 and FGF contribute to anabolic signaling and cell-cycle progression in regenerating tissues [18]. Experimental evidence further indicates that EGF released from PRP can directly stimulate endothelial-cell proliferation, suggesting that platelet-derived EGF also participates in vascular regeneration [23].

Importantly, the biological effects of platelet products depend on platelet concentration, leukocyte content, preparation protocol, and fibrin organization [20]. Consistent with this, studies on platelet releasate have shown that higher platelet concentrations are associated with stronger proliferative responses and greater involvement of PDGF- and VEGF-dependent signaling in myogenic regulation [24].

Angiogenesis is one of the most consistently described mechanisms underlying the regenerative action of platelet concentrates, as newly formed microvessels improve oxygen delivery, nutrient exchange, and recruitment of reparative cells to the injured site [21]. VEGF promotes endothelial-cell proliferation, migration, and tube formation through receptor-mediated signaling, while PDGF and FGF support vessel maturation and stromal-endothelial interactions [21].

In vitro studies further confirm that platelet-derived preparations stimulate endothelial activity and that blockade of EGF attenuates part of this proliferative response [23]. In skeletal muscle, platelets also act as an early source of VEGF at a stage when necrotic myofibers are temporarily unable to provide sufficient proangiogenic signals, thereby linking the hemostatic response to subsequent vascular regeneration [19]. Injectable PRF may further strengthen this effect because it provides a slower and more sustained release of growth factors than PRP, which may be advantageous in poorly vascularized tissues or chronic lesions requiring prolonged biological stimulation [20]. Platelet-derived preparations also exert direct effects on cell populations involved in musculoskeletal repair.

Platelet-derived mediators stimulate the migration and proliferation of fibroblasts, endothelial cells, mesenchymal stromal cells, and tissue-resident progenitors, thereby amplifying

endogenous repair mechanisms [18]. In skeletal muscle, this includes activation of satellite cells, the principal stem-cell population responsible for post-injury regeneration [19].

Platelets are now recognized as active regulators of early regeneration, in part because platelet-secreted chemokines such as CXCL5 and CXCL7/PPBP participate in neutrophil recruitment to injured muscle, and disruption of this step compromises subsequent myofiber growth, angiogenesis, and functional recovery [19]. Platelet releasate and PRP also act directly on myogenic cells, increasing myoblast and muscle stem-cell proliferation in a dose-dependent manner through mechanisms involving PDGF and VEGF receptor signaling [9]. In addition, platelet releasate has been shown to increase muscle stem-cell commitment to differentiation through a signaling axis involving Cyclin D1, MyoD, Scrib, and myogenin [24]. Similarly, PRP enhances C2C12 myoblast proliferation, satellite-cell activation, and expression of MyoD, myogenin, and α-sarcomeric actin, with concurrent activation of AKT signaling [25]. These effects may be further potentiated when PRP is combined with bone marrow-derived mesenchymal stromal cells, suggesting that platelet products may enhance regeneration both directly and through stromal-cell paracrine activity [25].

In vivo, these mechanisms are supported by findings that PRP improves skeletal muscle healing in a concentration-dependent manner, increasing regenerative myofiber number and diameter, enhancing expression of myogenic regulatory factors, and improving functional recovery [26].

Extracellular matrix remodeling is another critical component of platelet-mediated regeneration, as restoration of tissue architecture requires controlled matrix synthesis, whereas excessive collagen deposition leads to fibrosis and incomplete functional recovery. Platelet preparations regulate this balance through their effects on fibroblast activity, collagen synthesis, fibronectin deposition, macrophage polarization, and angiogenesis [18].

TGF-β is central to this process because, although it supports connective tissue repair, it is also a well-established driver of fibrosis when present in excess [22]. This dual role may partly explain the heterogeneity of reported outcomes, since platelet concentrates contain both pro-regenerative and potentially pro-fibrotic mediators.

In skeletal muscle, selective neutralization of TGF-β1 within PRP reduced collagen deposition, enhanced angiogenesis, prolonged the presence of Pax7-positive satellite cells, and increased recruitment of M2 macrophages, indicating that the therapeutic efficacy of platelet products depends on the balance between regenerative and fibrotic signaling [22]. Additional evidence from muscle injury models suggests that PRP may also reduce fibrosis, as reflected by lower fibronectin expression and smaller scar areas, with stronger effects observed at higher platelet concentrations [26].

In PRF-based products, the fibrin scaffold may provide an additional advantage by functioning both as a provisional structural matrix and as a reservoir for gradual mediator release, thereby supporting coordinated tissue remodeling over time [20].

3.2. Types of autologous platelet concentrates

Autologous platelet concentrates comprise a heterogeneous group of blood-derived products whose biological activity depends on preparation method, platelet enrichment, leukocyte content, fibrin architecture, and activation strategy [15]. This heterogeneity is one of the main reasons why the generic term “PRP” is often scientifically insufficient, particularly because many studies still fail to report key methodological variables such as baseline platelet count, post-processing concentration, centrifugal force, or leukocyte composition [27].

A widely used conceptual framework remains the classification proposed by Dohan Ehrenfest et al., which divides platelet concentrates into four major groups according to leukocyte content and fibrin structure: pure platelet-rich plasma, leukocyte-rich platelet-rich plasma, pure platelet-rich fibrin, and leukocyte-rich platelet-rich fibrin [14]. More recently, newer liquid fibrin derivatives such as injectable PRF have expanded this classification by combining injectability with fibrin-based regenerative signaling [20].

Platelet-rich plasma is broadly defined as an autologous plasma fraction obtained after centrifugation of whole blood and containing platelet levels above physiological baseline [15]. Because PRP remains liquid prior to activation, it can be injected or applied topically, which has contributed to its widespread use in sports medicine and orthopedic practice [14].

However, substantial variability exists among commercial systems and laboratory protocols, leading to major differences in platelet concentration, leukocyte carryover, red blood cell contamination, and growth factor release profiles [15]. This lack of standardization remains a major limitation of the field, since insufficient reporting prevents reliable comparison across studies and weakens interpretation of clinical outcomes [27]. Within this broader category, leukocyte-rich PRP and pure platelet-rich plasma represent biologically distinct formulations. Leukocyte-rich PRP contains platelets together with leukocytes and forms a low-density fibrin network after activation [14].

Because of its cellular composition, L-PRP is generally considered more inflammatory and has therefore been proposed as potentially advantageous in some tendon-healing settings, although this effect may be less desirable in intra-articular applications [15]. An umbrella review of rotator cuff surgery showed that leukocyte-rich PRP did not reduce retear rates or improve most

standard postoperative outcomes compared with non-PRP controls, although it did improve Simple Shoulder Test scores [28].

By contrast, pure platelet-rich plasma, also termed leukocyte-poor PRP, contains minimal leukocytes and is often regarded as preferable when limiting inflammation is clinically important, particularly in cartilage or joint pathology [14]. This distinction also appears clinically relevant, as leukocyte-poor PRP was associated with lower retear rates, reduced postoperative pain, and improved Constant scores in rotator cuff surgery, whereas similar benefits were not consistently demonstrated for leukocyte-rich preparations [28].

Platelet-rich fibrin is generally considered a second-generation platelet concentrate developed to avoid the use of anticoagulants and to preserve a more physiological clotting-based matrix [6]. Unlike PRP, PRF is characterized by a denser fibrin architecture, which allows it to function both as a source of bioactive mediators and as a structural scaffold for tissue healing [14].

In the classic consensus classification, PRF includes both pure PRF and leukocyte-rich PRF, depending on leukocyte content [14]. Because these formulations polymerize into a solid fibrin matrix, they are better suited to topical or surgical use than to direct injection, but this same fibrin network also supports a slower release of signaling molecules than conventional PRP [20].

Injectable platelet-rich fibrin was later developed as a liquid form of PRF by reducing centrifugation speed so that fibrinogen and thrombin remain temporarily unpolymerized, thereby enabling injection before clot formation [20]. In contrast to PRP, i-PRF is produced without anticoagulants, which may be biologically advantageous because coagulation itself forms part of the natural healing cascade [29].

Early protocols produced a formulation that remained injectable for approximately 15–20 minutes, while later refinements showed that i-PRF typically yields approximately two- to threefold platelet enrichment compared with whole blood, and that horizontal centrifugation with buffy-coat harvesting can increase cellular concentration further [20]. A major functional difference is that i-PRF provides a slower and more sustained growth factor release than PRP, which may support longer regenerative signaling and partly explain its growing interest in orthopedics and musculoskeletal repair [20].

Concentrated growth factors are generally regarded as a further development within the family of fibrin-rich autologous platelet concentrates, designed to provide a dense fibrin scaffold enriched with regenerative mediators. However, the currently available literature also highlights a major methodological limitation: many studies evaluating CGF and related products do not adequately report platelet concentration, leukocyte content, platelet-to-

leukocyte ratio, or activation status, making rigorous comparison with PRP- and PRF-based formulations difficult [30]. Thus, although CGF is an important component of the broader APC landscape, its exact biological and clinical distinctiveness remains limited by insufficient standardization and reporting quality [30]. The major formulation-related differences among APCs are presented in Table 1.

Overall, PRP, L-PRP, P-PRP, PRF, i-PRF, and CGF should not be regarded as interchangeable products, since they differ in cellular composition, fibrin organization, handling properties, and likely clinical behavior [15]. For this reason, future studies should move beyond generic terminology and describe platelet formulations with sufficient biological and procedural precision to allow meaningful interpretation and reproducible clinical application [27].

Table 1. Comparative characteristics of autologous platelet concentrate formulations

Formulation	Leukocyte content	Fibrin structure	Physical form	Anticoagulant	Release profile	Main advantages	Main limitations	Typical applications
PRP	Variable	Minimal before activation	Liquid	Usually used	Rapid	Broad availability, injectability, clinical versatility	Marked inter-system variability	Tendon, muscle, ligament, intra-articular use
L-PRP	High	Low-density fibrin network after activation	Liquid	Usually used	Rapid to intermediate	Greater cellular and inflammatory contribution; potential utility in	Higher inflammatory reactivity	Tendinopathies, selected surgical augmentation

						selected tendon lesions		
P-PRP / LP-PRP	Low	Minimal before activation	Liquid	Usually used	Rapid	Lower inflammatory burden; potentially better suited for intra-articular use	Substantial protocol dependence	Early OA, cartilage disorders, selected tendon conditions
PRF	Variable	Dense fibrin matrix	Solid / gel-like	Not used	Sustained	Scaffold effect, prolonged mediator release	Limited injectability	Surgical augmentation, chronic lesions
i-PRF	Variable	Fibrin network forms after injection	Liquid for limited time	Not used	Sustained	Combines injectability with fibrin-based signaling	Lower standardization	Soft-tissue repair, chronic lesions
CGF	Variable	Dense fibrin-	Clot / membrane-like	Generally not used	Sustained	Potentially strong scaffold	Poor reporting and	Experimental or

		rich matrix				and mediator reservoir	limited standard ization	adjuncti ve use

Table note: PRP, platelet-rich plasma; L-PRP, leukocyte-rich platelet-rich plasma; P-PRP, pure platelet-rich plasma; LP-PRP, leukocyte-poor platelet-rich plasma; PRF, platelet-rich fibrin; i-PRF, injectable platelet-rich fibrin; CGF, concentrated growth factors.

3.3. Clinical applications of platelet concentrates in sports medicine

3.3.1. Tendon injuries

Tendon disorders remain among the most intensively studied indications for autologous platelet concentrates in sports medicine, particularly in patellar tendinopathy, Achilles tendinopathy, and lateral epicondylitis, although the strength of evidence differs substantially across anatomical sites [31].

Available evidence indicates that PRP may be beneficial in patellar tendinopathy, particularly in refractory cases, but the literature remains methodologically limited and highly heterogeneous, precluding firm treatment recommendations [31]. This cautious interpretation is consistent with the broader review by Bosco et al., who concluded that PRP for jumper's knee remains promising but inconsistent, with outcomes influenced by patient selection, injection protocol, and disease chronicity [32].

The most favorable findings derive from studies suggesting that repeated PRP injections may provide more durable benefit than eccentric exercise in patients who have failed standard conservative management [31]. However, comparison across studies remains difficult because protocols vary in platelet composition, leukocyte content, injection number, activation strategy, and rehabilitation adjuncts [32].

More recent randomized evidence further supports a cautiously positive interpretation, as van der Heijden et al. found that all groups improved over 52 weeks, but the largest pain reduction occurred in the PRP group [33]. In the same study, only PRP was associated with significant improvement in ultrasound shear wave speed and a decrease in single-component UTE T2* relaxation time, suggesting that PRP may induce measurable tendon remodeling in addition to symptomatic improvement [33].

By contrast, evidence for PRP in Achilles tendinopathy remains largely unconvincing. A 2024 systematic review and meta-analysis by Ling et al. found no significant differences between

PRP and control treatment in VISA-A scores at short-, intermediate-, or long-term follow-up, and no significant changes in tendon thickness on ultrasound [34].

These conclusions are supported by an earlier 2023 meta-analysis by Vithran et al., which also found no significant improvement in VISA-A score, patient satisfaction, return to exercise rate, or long-term VAS outcomes with PRP compared with placebo or control treatment [35]. Notably, that analysis identified a significant improvement in VAS only at 12 weeks, while effects at 6 and 24 weeks remained non-significant, suggesting that any analgesic benefit may be transient rather than sustained [35].

Lateral epicondylitis represents another tendon-related disorder in which PRP has shown clinically relevant potential, although interpretation depends strongly on the comparator and timing of assessment. Niemiec et al. demonstrated that PRP-treated patients improved over time on VAS, DASH, PRTEE, and MAYO scores, with mean changes exceeding minimal clinically important difference thresholds for most outcome measures across clinically relevant follow-up intervals [36].

This analysis also suggested that both leukocyte-rich and leukocyte-poor PRP formulations may achieve clinically meaningful benefit, indicating that response may not depend exclusively on leukocyte content [36]. When PRP is compared directly with corticosteroid injection, the temporal pattern becomes particularly important: Maroun et al. showed that corticosteroids provide better short-term pain relief, whereas PRP is associated with superior long-term pain reduction and better long-term DASH scores [37].

However, the same study also noted that the long-term DASH advantage of PRP did not exceed the minimal clinically important difference threshold, indicating that statistical superiority does not automatically translate into clear clinical superiority [37]. Averell et al. further showed that although both low- and high-concentration PRP reduced pain in lateral epicondylitis, platelet concentration itself did not significantly influence comparative pain outcomes [38].

Overall, the evidence indicates that the role of autologous platelet concentrates in tendon injuries is condition-specific rather than uniform. PRP appears most promising in patellar tendinopathy and in the longer-term management of lateral epicondylitis, whereas evidence in Achilles tendinopathy remains largely negative or inconclusive despite isolated short-term improvements in pain reported in some analyses [31].

Even where outcomes appear favorable, however, the field remains limited by inconsistent product characterization, heterogeneous control interventions, and variable reporting standards, all of which continue to hinder the development of robust evidence-based treatment algorithms for tendon injuries in sports medicine [35].

3.3.2. Muscle injuries

Muscle injuries, particularly acute hamstring strains, represent one of the most clinically relevant yet also most controversial indications for autologous platelet concentrates in sports medicine, because a promising biological rationale has not translated into uniform clinical benefit across randomized trials [39].

Basic science data suggest that PRP may support muscle repair by enhancing cellular proliferation, myogenic differentiation, angiogenesis, and histological tissue quality, but the available literature remains highly heterogeneous in formulation and methodology, which complicates clinical interpretation [39].

One of the earliest randomized controlled trials reported favorable clinical results. Hamid et al. found that a single autologous PRP injection combined with rehabilitation significantly shortened return-to-play time in acute grade 2 hamstring injuries compared with rehabilitation alone, with mean recovery times of 26.7 ± 7.0 versus 42.5 ± 20.6 days [40].

The same trial also showed significantly lower pain severity scores during follow-up in the PRP group, although no significant difference was observed for pain interference [40]. Importantly, the preparation used in that study was characterized by marked platelet and leukocyte enrichment, indicating that the reported effect was linked to a specific PRP formulation rather than to PRP as a uniform therapeutic entity [40].

However, subsequent higher-rigor evidence challenged the consistency of these benefits. In a three-arm randomized trial involving athletes with MRI-positive grade I or II hamstring injuries, Hamilton et al. found no significant advantage of a single PRP injection over intensive standardized rehabilitation alone in terms of return to sport or reinjury rates [41].

Although PRP shortened return-to-play time compared with platelet-poor plasma, it did not significantly outperform the no-injection group, leading the authors to conclude that rehabilitation remained the principal determinant of recovery [41]. The same study also found no significant between-group differences in MRI changes or isokinetic strength outcomes, which further weakened the rationale for routine PRP use in this setting [41].

More recent evidence has again shifted the balance toward a more favorable interpretation, at least in well-defined grade 2 hamstring injuries treated under standardized conditions. In a 2025 randomized controlled trial, Desouza and Shetty reported that ultrasound-guided PRP combined with standard rehabilitation significantly accelerated return to play compared with standard therapy alone, with mean return times of 26.4 ± 4.5 versus 34.2 ± 5.7 days [42].

Radiological healing at 21 days was also significantly greater in the PRP group, whereas reinjury rates, although lower, were not significantly different [42]. Subgroup analyses further

suggested that this effect was consistent across different grade 2 injury subtypes and across different hamstring muscles, implying that protocol standardization and image-guided delivery may meaningfully influence treatment response [42].

Taken together, the evidence does not support a uniform benefit of PRP in acute muscle injury, but it also does not justify a categorical dismissal of its therapeutic value. Positive trials have generally involved clearly defined grade 2 lesions treated with structured rehabilitation, whereas negative trials have emphasized that PRP may add little when rehabilitation is already optimized, especially in elite settings [41].

This inconsistency likely reflects variation in study design, comparator arms, return-to-play criteria, PRP composition, injection timing, image guidance, and injury severity [40]. Therefore, the available evidence supports a cautious and selective interpretation: platelet concentrates may be beneficial in some acute hamstring injuries, but their clinical value remains highly protocol-dependent and insufficiently standardized for universal recommendation [42].

3.3.3. Ligament injuries

Ligament injuries, particularly anterior cruciate ligament tears, remain an important target for biologic augmentation in sports medicine because graft incorporation, tendon-bone healing, postoperative pain, and restoration of knee stability directly influence recovery and return to sport [43]. PRP has therefore been investigated as an adjunct to ACL reconstruction, although current evidence remains inconsistent [44].

Recent meta-analyses indicate that PRP may provide selective rather than global benefit after ACL reconstruction. Serag et al. found that PRP significantly improved KT-1000 measurements, indicating better postoperative knee stability, but did not significantly improve Lysholm, IKDC, Tegner, or pain outcomes overall, and had no significant effect on femoral or tibial tunnel diameters [43].

Tayyab et al. reported that PRP significantly reduced pain at 3 and 6 months, but not at 12 months, suggesting a predominantly short-term analgesic effect [44]. Similarly, Zhang et al. found significant improvement in pain at 3 months, Lysholm score at 6 months, and IKDC score at 12 months, although these benefits were generally modest and often did not reach minimal clinically important difference thresholds [45].

A major limitation across all reviews is the marked heterogeneity of PRP protocols. Differences in platelet concentration, leukocyte content, activation methods, timing of delivery, injection site, graft type, and use of single versus repeated administration make direct comparison difficult and likely contribute to the divergent findings among pooled analyses [44].

Structural outcomes have also remained largely unimproved, as Serag et al. found no meaningful effect on tunnel widening [42]. Likewise, Zhang et al. reported no significant impact on graft maturation indices or most long-term stability measures, despite some early symptomatic improvement [45].

Overall, the available evidence does not support a routine role for PRP in ACL reconstruction, but it does suggest limited adjunctive value in selected settings, particularly for short-term pain reduction and possibly early recovery-related outcomes [44]. However, the lack of consistent long-term functional, radiological, and structural benefit indicates that PRP should presently be regarded as an optional biologic adjunct rather than a standard component of ligament reconstruction protocols [45].

3.3.4. Cartilage and joint injuries

Cartilage and joint disorders represent an increasingly important indication for autologous platelet concentrates in sports medicine, particularly in physically active patients with early degenerative joint changes, although the available evidence is driven mainly by studies on knee osteoarthritis rather than focal chondral lesions [46].

Current meta-analytic data suggest that PRP may provide clinically meaningful improvement in pain and function, but convincing evidence of structural disease modification remains limited [47].

The strongest evidence currently concerns knee osteoarthritis. In a 2025 meta-analysis of 28 randomized trials, PRP provided pain relief comparable to hyaluronic acid but superior functional improvement, with the best outcomes observed when PRP was combined with hyaluronic acid and in patients with earlier radiographic disease stages [48].

The same study suggested that treatment response may depend on procedural variables, with the most favorable outcomes reported for platelet concentrations of 600–900 × 10^9/L and for 3–5 injections given at 7–14-day intervals [48]. A broader meta-analysis across multiple joints reached a similar conclusion, showing that PRP improved pain in knee, ankle, and temporomandibular joint osteoarthritis, but not significantly in hip osteoarthritis, and also improved WOMAC, KOOS, and IKDC-related functional outcomes overall [49]. Importantly, that analysis suggested that leukocyte-poor PRP may be more effective than leukocyte-rich PRP for pain reduction in osteoarthritis, possibly because of a more favorable intra-articular inflammatory profile [49].

More recent knee-specific pooled evidence also supports a symptomatic benefit, while emphasizing persistent inconsistency across trials. A 2025 systematic review of randomized

controlled studies found that PRP produced moderate improvements in pain and function compared with control treatments, but did not demonstrate convincing structural improvement on MRI [47].

This limitation is particularly relevant in sports medicine, where symptom reduction alone may not be sufficient if restoration of load tolerance and tissue integrity is the ultimate goal. In sport-active patients aged 50 years or younger with symptomatic knee cartilage degeneration or osteoarthritis, three PRP injections resulted in significant improvements in IKDC, EQ-VAS, and Tegner scores up to 24 months [46].

However, return-to-sport outcomes were less favorable, as only 76.6% of patients returned to some sport activity and only 48.9% returned to their pre-symptom level [46].

Taken together, the available literature supports PRP as a potentially useful symptomatic treatment for selected cartilage-related and early degenerative joint conditions, particularly knee osteoarthritis, with the most consistent benefits observed in pain reduction and functional improvement rather than structural regeneration [48]. Nevertheless, the literature remains limited by heterogeneity in PRP formulation, injection protocol, comparator selection, and imaging endpoints, and direct evidence in focal cartilage injuries or athlete-specific chondral pathology is still sparse [47].

The available clinical evidence indicates that the therapeutic effects of autologous platelet concentrates are indication-specific rather than uniform across musculoskeletal conditions, as summarized in Table 2.

Table 2. Indication-specific clinical evidence for autologous platelet concentrates in sports medicine

Indication	Main APC formulation studied	Reported benefit	Main limitations of evidence	Overall evidence signal	Clinical interpretation
Patellar tendinopathy [31–33]	PRP	Pain reduction and possible tendon remodeling, particularly	Small sample sizes, heterogeneous protocols, variable injection	Promising but heterogeneous	PRP may be considered in selected refractory cases, but current

		in refractory cases	schedules and rehabilitation co-interventions		evidence remains insufficient for universal recommendations
Achilles tendinopathy [34,35]	PRP	Occasional short-term analgesic benefit reported	No consistent improvement in VISA-A score, return to sport, tendon morphology, or long-term outcomes	Inconclusive to unfavorable	Current evidence does not support PRP as a reliably effective treatment option
Lateral epicondylitis [36–38]	PRP (leukocyte-rich and leukocyte-poor)	Longer-term pain and functional improvement compared with corticosteroid injection	Comparator-dependent outcomes and variable clinical significance	Moderately favorable	One of the more convincing tendon-related indications for PRP
Acute hamstring injury [39–42]	PRP	Possible shorter return-to-play time and improved radiological	Conflicting randomized evidence and strong protocol dependence	Mixed / protocol-dependent	May be beneficial in selected standardized protocols but evidence

		healing in selected cases			remains inconsistent
ACL reconstruction [43–45]	PRP	Possible short-term reduction in pain and modest early recovery improvement	No consistent long-term superiority in structural or functional outcomes	Limited adjunctive value	Best regarded as an adjunct rather than routine therapy
Early knee osteoarthritis / cartilage degeneration [46–49,57–59]	PRP (often LP-PRP)	Improvement in pain and function	Limited evidence of structural regeneration and substantial trial heterogeneity	Symptomatic benefit more consistent than structural benefit	Reasonable symptomatic option in selected active patients with early disease

Table note: References are provided in the first column and apply to the entire corresponding row unless otherwise specified.

3.4. Safety profile and limitations

Autologous platelet concentrates are generally regarded as relatively safe interventions because they are derived from the patient's own blood and therefore avoid the immunogenic and transmissible risks associated with allogeneic products [27]. Across contemporary musculoskeletal literature, the most common adverse events after PRP administration are local and self-limited rather than severe or systemic [48].

In a large safety synthesis of PRP for knee osteoarthritis, pain was the most frequent adverse effect, followed by local swelling and occasional mild febrile reactions, with most events occurring within 24–48 hours and resolving spontaneously within 72 hours [48]. The same analysis identified leukocyte-rich PRP as the preparation associated with the highest adverse-

event rate, suggesting that leukocyte burden may contribute to post-injection inflammatory reactivity [48].

Comparative randomized evidence likewise indicates that serious complications remain uncommon, although mild synovitis, transient pain, nausea, dizziness, or palpitations have been reported after intra-articular PRP [50].

The major limitation of the current evidence base is not primarily safety, but inconsistency in biologic characterization, protocol design, and reporting quality. PRP represents a broad spectrum of preparations containing variable levels of platelets, leukocytes, red cells, and bioactive mediators, and this heterogeneity critically influences biologic activity and clinical outcome [51].

Murray et al. emphasized that inadequate reporting of basic formulation variables, including platelet and leukocyte concentrations, often makes comparison between studies difficult and replication impossible [51]. This concern is reinforced by broader evidence showing substantial variability in centrifugation methods, platelet concentration, leukocyte inclusion, activation, and delivery protocols across the PRP literature, with no universally accepted preparation standard currently in routine use [27].

Collins et al. likewise stressed that PRP should not be regarded as a single product, because differences in composition and preparation can substantially alter its biological behavior and likely contribute to conflicting clinical outcomes [15]. In a cross-specialty analysis, Oyadomari et al. showed that detailed reporting of PRP processing and composition remained uncommon, while many studies were judged to have high risk of bias [52].

Similar methodological inconsistency was also identified in the GTPS literature, where key technical parameters varied markedly across randomized trials, thereby limiting reproducibility and definitive interpretation [53]. These limitations extend beyond PRP to other platelet-derived formulations. Miron et al. showed that even within injectable PRF, differences in centrifugation speed, tube material, harvesting strategy, and buffy-coat collection can substantially alter platelet and leukocyte yield, as well as the duration of liquid handling and growth factor release kinetics [20].

Tanzadehpanah et al. likewise highlighted that PRP composition may vary according to preparation method, storage duration, storage conditions, and interaction with other materials, making cross-study comparison especially difficult in translational settings [21].

A further biologic limitation is that platelet products contain not only pro-regenerative mediators but also factors that may exert unfavorable effects depending on tissue context. In skeletal muscle, Li et al. demonstrated that neutralization of TGF-β1 within PRP reduced

fibrosis and enhanced regenerative features, suggesting that some endogenous PRP components may counterbalance or even limit its therapeutic benefit [22].

Even when favorable results are reported, interpretation may still be distorted by selective presentation. Richardson et al. found at least one form of spin in every abstract of systematic reviews and meta-analyses on PRP for knee osteoarthritis, with benefit often emphasized despite substantial bias in the primary literature [54].

Taken together, these data suggest that autologous platelet concentrates have a favorable short-term safety profile, but the current evidence base remains constrained by major methodological, biological, and reporting limitations [52]. Until product characterization and study design become more standardized, apparently conflicting results will remain difficult to interpret and robust evidence-based recommendations will remain limited [51].

4. Discussion

4.1. Summary of current evidence

This narrative review indicates that autologous platelet concentrates constitute a biologically plausible and clinically promising group of orthobiologic interventions in sports medicine, but their therapeutic value is not consistent across all musculoskeletal indications [5,10–16,18–20,27,60,61].

The regenerative rationale for APCs derives from their capacity to deliver a broad array of growth factors, cytokines, chemokines, and fibrin-associated structural elements involved in angiogenesis, progenitor-cell activation, extracellular matrix remodeling, and modulation of the early healing environment [17–23]. Rather than behaving as a single pharmacological agent, APCs function as complex biologic microenvironments capable of influencing several overlapping phases of tissue repair, including inflammatory-cell recruitment, proliferative activity, matrix deposition, and tissue maturation [17–20,51].

However, the evidence reviewed here indicates that this mechanistic potential translates into clinically meaningful benefit only in selected settings and remains strongly dependent on product composition, treatment protocol, and tissue-specific biology [15,20,27,51,55].

Among currently studied indications, the most convincing signal of efficacy is observed in selected tendon disorders, although responsiveness appears to be highly site-specific [31–38,55,56]. In patellar tendinopathy, PRP appears to provide potential benefit, particularly in refractory disease and possibly when repeated injections are used, but the evidence remains heterogeneous and insufficient to support firm recommendations [31–33,56].

Lateral epicondylitis is another indication in which PRP may offer clinically relevant longer-term benefit, especially when compared with corticosteroid injections that tend to provide superior short-term but less durable relief [36,37]. By contrast, Achilles tendinopathy remains the least encouraging tendon indication, with meta-analyses showing no consistent advantage over placebo or control treatment in pain, function, or tendon morphology [34,35,56].

Collectively, these findings suggest that tendon disorders should not be treated as a single therapeutic category with respect to APC responsiveness, because anatomical site, chronicity, comparator choice, product composition, and protocol design are all likely to influence treatment outcomes [31,32,35,55,61].

The discrepancy between biologic plausibility and clinical inconsistency is even more evident in muscle injury [18,19,24–26,39–42,55,56]. Experimental data strongly support the concept that platelet-derived preparations may enhance muscle healing by promoting angiogenesis, satellite-cell activation, myogenic differentiation, and attenuation of fibrosis [17,19,22,24–26]. Nevertheless, randomized trials in acute hamstring injury have produced conflicting results. Some studies have reported shorter return-to-play times and lower pain severity when PRP is added to rehabilitation, whereas others have not demonstrated meaningful benefit beyond optimized rehabilitation alone [40–42,55].

Notably, favorable studies have generally involved more tightly defined lesions, structured rehabilitation, and clearer procedural standardization, suggesting that the apparent benefit may depend on careful patient selection and protocol consistency rather than on PRP use per se [40,42,55]. This interpretation aligns with broader contemporary reviews indicating that PRP may shorten recovery and facilitate return to activity in selected sports injuries, while overall efficacy remains dependent on appropriate preparation protocols and patient-specific factors [39–42,55,56,60].

Accordingly, the evidence does not support a uniform role for APCs in acute muscle injury, but neither does it justify dismissing them as categorically ineffective [39–42,55,56].

In ligament-related applications, particularly anterior cruciate ligament reconstruction, APCs appear to provide at most selective adjunctive benefit rather than broad clinical improvement [43–45,55]. Meta-analytic data suggest that PRP may improve some early postoperative outcomes, such as short-term pain reduction and selected measures of early recovery, but these effects are generally modest and inconsistent [43–45].

More importantly, the literature does not demonstrate robust long-term superiority in functional scores, graft maturation, tunnel widening, or structural healing [43–45,55]. This pattern suggests that APCs may have a limited role as biologic adjuncts in carefully selected

reconstructive settings, but current evidence does not support their routine incorporation into standard ligament reconstruction protocols [44,45].

For cartilage and joint disorders, especially early knee osteoarthritis in physically active individuals, APCs appear to provide the most consistent symptomatic benefit, although evidence of true structural regeneration remains limited [46–49,57–59]. Multiple pooled analyses indicate that PRP can improve pain and function, with some data suggesting better outcomes in earlier disease stages or selected patient subgroups [47–49,58].

At the same time, structural improvement remains insufficiently demonstrated, and even guideline-level evaluations continue to conclude that the evidence is not yet strong enough to support unequivocal recommendation for or against PRP use in knee osteoarthritis [59]. This distinction is particularly relevant in sports medicine, where the therapeutic objective extends beyond pain reduction to restoration of load tolerance, tissue integrity, and return to pre-injury performance.

Overall, APCs should therefore be interpreted not as a uniform regenerative treatment class, but as a group of biologically distinct products with indication-specific and protocol-dependent clinical utility [15,20,27,31,39,44,47,51,58].

4.2. Advantages of platelet concentrates in sports medicine

Despite the limitations of the current literature, APCs retain clear clinical appeal in sports medicine because they may address several shortcomings of conventional treatment strategies [6–13].

Their autologous origin is a major advantage, minimizing the risk of immunogenic reaction and eliminating concerns related to disease transmission associated with allogeneic products [12,13,17,27]. In addition, APCs can be prepared rapidly from peripheral blood and administered in a minimally invasive manner directly to the injured tissue, making them logistically compatible with contemporary sports medicine practice [12–17,55,60].

This combination of biologic origin, procedural simplicity, and local targeted delivery distinguishes APCs from more complex regenerative approaches and helps explain their widespread clinical appeal [10–13,17].

A second advantage is their close mechanistic alignment with the biological challenges of musculoskeletal healing [6–8,18–23]. Many sports-related injuries involve tissues characterized by poor vascularity, low cellularity, and limited intrinsic regenerative capacity, particularly tendons, ligaments, and cartilage [6–8].

APCs are conceptually attractive in this setting because they can deliver mediators involved in angiogenesis, fibroblast recruitment, matrix synthesis, satellite-cell activation, and inflammatory modulation, thereby potentially enhancing endogenous repair in tissues that otherwise recover slowly and incompletely [18–23]. Their proposed mode of action therefore corresponds closely to a central therapeutic need in sports medicine: not merely reducing pain, but promoting a more favorable biologic environment for repair [10–13,18–20].

An additional strength is that APC-based therapies should not be viewed as a single intervention, but as a spectrum of biologically distinct formulations that may theoretically be matched to different tissue environments and therapeutic goals [14,15,20,27,29,30,58].

Leukocyte-rich and leukocyte-poor PRP differ in inflammatory profile and may therefore behave differently in tendon versus intra-articular applications [14,15,17,28,49]. PRF and i-PRF offer further theoretical advantages through fibrin-based scaffold properties and slower growth factor release kinetics, which may be particularly relevant in chronic lesions or poorly vascularized tissues [20,29].

Although this potential has not yet been validated adequately in high-quality clinical trials, formulation diversity remains a conceptual advantage because it creates the possibility of more tissue-specific and biologically tailored regenerative strategies [14,15,20,27,30,58]. Their broad translational appeal is reinforced by the fact that platelet-derived preparations have already been explored across multiple disciplines, suggesting that their usefulness may extend beyond a single anatomical niche even if sports-medicine-specific protocols still require refinement [17,60].

4.3. Limitations of current studies

The principal limitation of the APC literature is not the absence of biologic rationale, but the marked heterogeneity of the products being studied and the insufficient methodological standardization across trials [15,20,27,51,52,55,58,60,61].

Terms such as PRP or APCs are often used as if they described uniform interventions, whereas in reality these preparations differ substantially in platelet concentration, leukocyte burden, red blood cell contamination, fibrin architecture, activation strategy, and growth factor release kinetics [14,15,20,27,30,51,60,61]. Because these variables can meaningfully alter biological behavior, studies labeled under the same therapeutic category may in fact be evaluating materially different interventions [15,27,51].

This issue is especially important in a field in which even subtle differences in inflammatory profile or matrix characteristics may influence outcome according to the tissue treated [15,17,20,22].

Interpretation is further complicated by major clinical heterogeneity [31,32,35,39–45,47–49,51,55]. Trials differ not only in formulation but also in number of injections, interval between injections, timing of administration in relation to injury onset or surgery, use of image guidance, comparator intervention, rehabilitation protocols, and endpoint selection [31,32,40–45,48,51,55].

Consequently, outcomes often cannot be meaningfully compared even when the same anatomical indication is being examined. This is particularly evident in the hamstring injury literature, in which differing return-to-play criteria, rehabilitation intensity, and PRP composition likely contributed to conflicting conclusions [40–42,55].

A similar problem is apparent in tendon and ACL studies, where heterogeneity in protocol design and comparator arms undermines the development of robust and generalizable treatment algorithms [31,35,44,45,55].

Methodological quality remains another major concern. Many available studies include relatively small sample sizes, incomplete biologic characterization of the tested products, inconsistent reporting of preparation variables, and, in some areas, substantial risk of bias [27,51–53,55].

Expert consensus has already indicated that PRP studies should report, at a minimum, baseline whole-blood characteristics, final platelet/leukocyte/erythrocyte composition, processing protocol, activation method, delivery details, rehabilitation protocol, and outcome assessment structure, yet many clinical studies still fail to provide this information adequately [51].

Insufficient reporting of platelet and leukocyte concentrations, centrifugation methods, activation status, and delivery protocols makes replication difficult and weakens the external validity of published findings [27,51,52]. Moreover, pooled analyses may create a misleading appearance of contradiction or consistency by combining trials that differ fundamentally in both biologic intervention and clinical design [15,27,51,58].

This problem extends beyond PRP to other APC formulations such as i-PRF and CGF, where the literature is even less standardized and frequently lacks sufficient technical detail for rigorous interpretation [20,30]. Persistent technical and biological nonuniformity therefore continues to weaken reproducibility and may partly explain why the literature contains both strongly favorable and clearly negative conclusions for apparently similar clinical indications [27,51,52,55,60,61].

Another limitation is that the biologic activity of platelet concentrates is not uniformly beneficial across all tissue contexts [18,20–22,58]. Although APCs contain numerous pro-regenerative mediators, they also include factors that may exert context-dependent unfavorable effects.

TGF-β is a particularly important example, because it contributes to connective tissue repair but may also promote fibrosis when present in excess [22]. More broadly, contemporary PRP biology suggests that leukocytes, erythrocytes, plasma proteins, and platelet dose may all modify the local balance between regeneration and inflammation, and that this balance is likely to be tissue- and disease-specific rather than universally advantageous [17,58].

This observation is highly relevant to the interpretation of inconsistent clinical outcomes, because it indicates that APCs should not be viewed as intrinsically regenerative under all conditions, but rather as complex biologic systems whose effects depend on the interplay between anabolic, angiogenic, inflammatory, and fibrotic signaling [18,20–22,58].

Finally, interpretation of the literature may be distorted not only by heterogeneity and bias, but also by selective presentation of favorable findings [52,54,58]. Broader systematic evaluations of PRP in musculoskeletal soft-tissue injuries continue to conclude that the overall evidence does not strongly support PRP over conventional treatment strategies and does not yet establish clear long-term physiological superiority or an optimal application protocol [55].

Thus, although APCs appear to have a favorable short-term safety profile, the current evidence base remains constrained by substantial biological, methodological, and reporting limitations that preclude definitive evidence-based recommendations in many sports medicine indications [27,48,50,51,59–61].

4.4. Future perspectives in regenerative sports medicine

Future progress in the field of APCs will depend primarily on more rigorous standardization of product characterization and study methodology [15,20,27,30,51,52,58,60,61].

At a minimum, future trials should consistently report baseline blood composition, final platelet concentration, leukocyte and erythrocyte content, centrifugation parameters, activation strategy, injection volume, number and timing of administrations, and method of delivery [20,27,51,52]. Without such reporting, the literature will continue to pool biologically dissimilar interventions under a common label, thereby perpetuating uncertainty regarding efficacy. Standardization is therefore not merely a technical issue, but a prerequisite for meaningful scientific comparison and clinically useful translation [15,27,51].

A second major direction is the development of indication-specific rather than universally applied APC protocols [14,15,20,28,29,49,58]. The present review strongly suggests that no single formulation is likely to be optimal across tendon, muscle, ligament, and intra-articular applications.

Leukocyte-rich preparations may theoretically be more relevant in some tendon-healing settings, whereas leukocyte-poor preparations may be preferable in joint disease in which excessive inflammatory reactivity is undesirable [15,28,49]. PRF and i-PRF may offer additional advantages in circumstances where scaffold properties or prolonged growth factor release are beneficial [20,29].

More recent conceptual work also points toward a transition from generic PRP to precision orthobiologics, in which product formulation is selected according to patient phenotype, tissue biology, inflammatory status, and disease stage rather than product label alone [58].

The continued absence of universally accepted preparation and application criteria suggests that future orthopedic and sports-medicine research should place equal emphasis on technical harmonization and clinical efficacy testing [51,60,61]. Future studies should therefore move beyond asking whether PRP works in general and instead investigate which APC formulation, at what concentration, at what time point, and in which tissue environment is most likely to produce clinically meaningful benefit [15,17,20,27,58].

Equally important is the need for more clinically relevant outcome assessment in sports medicine trials [31,39–49,51,55]. Pain reduction and questionnaire-based functional improvement remain important endpoints, but they are not sufficient on their own to define successful treatment in athletic populations.

Future studies should more consistently evaluate return to sport, return to pre-injury performance, reinjury rates, objective structural healing, imaging biomarkers, and long-term tolerance to sport-specific loading [42,46,47,56]. This is especially relevant in cartilage-related disorders, where symptomatic improvement may occur without convincing structural regeneration, and in muscle injuries, where earlier return to play must be balanced against the risk of recurrence [42,46,47,57]. A more sport-specific endpoint framework would substantially improve the clinical usefulness of future APC research.

Ultimately, the future of regenerative sports medicine is likely to lie in more precise and biologically informed orthobiologic strategies rather than in the undifferentiated use of platelet-derived products [10–13,15,18–20,58].

APCs should increasingly be integrated into a broader precision-medicine approach in which product formulation is matched to tissue biology, injury chronicity, phase of healing, and

rehabilitation context. Such an approach better reflects the current understanding that platelet concentrates are not uniform therapeutic entities, but dynamic biologic constructs with context-dependent behavior [15,18,20,27,58].

If future research succeeds in combining rigorous product characterization with indication-specific protocols and clinically meaningful endpoints, APCs may assume a clearer and more evidence-based role in the management of sports-related musculoskeletal injuries [27,51,52,55–61].

5. Conclusions

Autologous platelet concentrates represent a biologically credible and clinically promising class of orthobiologic therapies in sports medicine. Their regenerative potential is supported by the coordinated delivery of growth factors, cytokines, fibrin-associated scaffolding, and other bioactive mediators involved in angiogenesis, cell recruitment, extracellular matrix remodeling, and modulation of the local healing environment.

The available evidence indicates that their clinical value is selective rather than universal. APCs appear most useful in carefully chosen indications, particularly some chronic tendon disorders and early joint pathology, whereas the evidence for acute muscle injuries, ligament reconstruction augmentation, and structural cartilage restoration remains less consistent. This discrepancy between strong mechanistic plausibility and variable clinical outcomes appears to reflect not only differences in tissue biology and injury chronicity, but also substantial heterogeneity in product composition, preparation methods, application protocols, and study design.

A central conclusion emerging from this review is that the major obstacle to evidence-based implementation of APCs in sports medicine is not a lack of therapeutic promise, but a lack of standardization. Variability in platelet concentration, leukocyte and erythrocyte content, fibrin architecture, activation strategy, and delivery technique continues to limit comparability across studies and weakens the strength of current recommendations. This problem is compounded by inconsistent outcome reporting, insufficient product characterization, and the continued absence of universally accepted protocols for specific clinical indications.

APCs should therefore be regarded as promising adjuncts within regenerative sports medicine rather than definitive standard therapies for the broad spectrum of sports-related musculoskeletal injuries.

Future progress will require rigorous reporting standards, indication-specific treatment algorithms, and high-quality trials incorporating clinically meaningful endpoints such as return

to sport, return to pre-injury performance, reinjury rates, and objective structural healing. A more precise, tissue-oriented, and biologically informed use of platelet-derived products may ultimately allow APCs to assume a clearer and more evidence-based role in modern sports medicine practice.

6. Disclosure

6.1. Author Contributions

Conceptualization, K.N., and P.S.; methodology, J.S., P.S. and K.A.; software, K.A.; check, D.W., M.S., K.O., P.S. and K.N.; formal analysis, N.H., J.S., K.A. and P.S.; investigation, M.M., K.K., D.W., K.O., N.H. and K.N.; resources, D.W., K.O. and K.N.; data curation, M.M., N.H. and K.K.; writing – rough preparation, N.H., P.S. and K.A.; writing – review and editing, K.O., J.S., D.W., K.N. and M.S.; visualization, M.M. and K.K.; supervision, M.S.; project administration, M.S. and P.S. All authors have read and agreed to the published version of the manuscript.

6.2. Funding

The authors received no financial support for the research, authorship, and/or publication of this article

6.3. Institutional Review Board Statement

Not Applicable.

6.4. Informed Consent Statement

Not Applicable

6.5. Conflict Of Interest

The authors declare no conflict of interest.

References

1. Gimigliano F, Resmini G, Moretti A, et al. Epidemiology of Musculoskeletal Injuries in Adult Athletes: A Scoping Review. *Medicina*. 2021;57(10):1118. doi:https://doi.org/10.3390/medicina57101118
2. Zupančič M, Marušič J. Overview of systematic reviews on the most common sports injuries. *Exercise and Quality of Life*. 2024;16(1):5-18. doi:https://doi.org/10.31382/eqol202301006z
3. Barroso GC, Thiele ES. MUSCLE INJURIES IN ATHLETES. *Revista Brasileira de Ortopedia (English Edition)*. 2011;46(4):354-358. doi:https://doi.org/10.1016/s2255-4971(15)30245-7

4. Lau KKL, Ng JP, Ling SKK, Ong MTY, Yung PSH, Lui PPY. Incidence rates of tendinopathies and non-traumatic tendon ruptures in Hong Kong: a 25-year epidemiological study using big data from public hospitals. *Scientific Reports*. 2026;16(1). doi:https://doi.org/10.1038/s41598-025-33465-x
5. Jungmann PM, Lange T, Wenning M, Baumann FA, Bamberg F, Jung M. Ankle Sprains in Athletes: Current Epidemiological, Clinical and Imaging Trends. *Open Access Journal of Sports Medicine*. 2023;Volume 14(14):29-46. doi:https://doi.org/10.2147/oajsm.s397634
6. Ruiz-Alonso S, Lafuente-Merchan M, Ciriza J, Saenz-del-Burgo L, Pedraz JL. Tendon tissue engineering: Cells, growth factors, scaffolds and production techniques. *Journal of Controlled Release*. 2021;333:448-486. doi:https://doi.org/10.1016/j.jconrel.2021.03.040
7. Chen X, Jones IA, Park C, Vangsness CT. The Efficacy of Platelet-Rich Plasma on Tendon and Ligament Healing: A Systematic Review and Meta-analysis With Bias Assessment. *The American Journal of Sports Medicine*. 2017;46(8):2020-2032. doi:https://doi.org/10.1177/0363546517743746
8. Vivek Kumar Morya, Shahid H, Lang J, Kwak MK, Park SH, Noh KC. Advancements in Therapeutic Approaches for Degenerative Tendinopathy: Evaluating Efficacy and Challenges. *International Journal of Molecular Sciences*. 2024;25(21):11846-11846. doi:https://doi.org/10.3390/ijms252111846
9. Ackermann PW, Renström P. Tendinopathy in Sport. *Sports Health: A Multidisciplinary Approach*. 2012;4(3):193-201. doi:https://doi.org/10.1177/1941738112440957
10. Lattermann C, Leite CBG, Frisbie DD, et al. Orthobiologics in orthopedic applications: A report from the TMI Havemeyer meeting on orthobiologics. *Journal of Cartilage & Joint Preservation*. Published online May 4, 2022:100055. doi:https://doi.org/10.1016/j.jcjp.2022.100055
11. Sutton JS, Muran A, Zaslav K, Grande D. Orthobiologics: An Updated Definition. *Open Journal of Regenerative Medicine*. 2023;12(2):36-48. doi:https://doi.org/10.4236/ojrm.2023.122003
12. Dhillon RS, Schwarz EM, Maloney MD. Platelet-rich plasma therapy - future or trend? *Arthritis Research & Therapy*. 2012;14(4):219. doi:https://doi.org/10.1186/ar3914
13. Thu AC. The use of platelet-rich plasma in management of musculoskeletal pain: a narrative review. *Journal of Yeungnam Medical Science*. 2022;39(3):206-215. doi:https://doi.org/10.12701/jyms.2022.00290

14. Dohan DM, Andia I, Zumstein MA, Zhang CQ, Pinto NR, Bielecki T. Classification of platelet concentrates (Platelet-Rich Plasma-PRP, Platelet-Rich Fibrin-PRF) for topical and infiltrative use in orthopedic and sports medicine: current consensus, clinical implications and perspectives. *Muscles, Ligaments and Tendons Journal*. 2014;4(1):3. https://pmc.ncbi.nlm.nih.gov/articles/PMC4049647/
15. Collins T, Alexander D, Barkatali B. Platelet-rich plasma: a narrative review. *EFORT Open Reviews*. 2021;6(4):225-235. doi:https://doi.org/10.1302/2058-5241.6.200017
16. Wu WS, Chen LR, Chen KH. Platelet-Rich Plasma (PRP): Molecular Mechanisms, Actions and Clinical Applications in Human Body. *International Journal of Molecular Sciences*. 2025;26(21):10804. doi:https://doi.org/10.3390/ijms262110804
17. Everts P, Onishi K, Jayaram P, Lana JF, Mautner K. Platelet-Rich Plasma: New Performance Understandings and Therapeutic Considerations in 2020. *International Journal of Molecular Sciences*. 2020;21(20):7794. doi:https://doi.org/10.3390/ijms21207794
18. Alsousou J, Ali A, Willett K, Harrison P. The role of platelet-rich plasma in tissue regeneration. *Platelets*. 2012;24(3):173-182. doi:https://doi.org/10.3109/09537104.2012.684730
19. Graca FA, Minden-Birkenmaier BA, Stephan A, Demontis F, Labelle M. Signaling roles of platelets in skeletal muscle regeneration. *BioEssays : news and reviews in molecular, cellular and developmental biology*. 2023;45(12):e2300134. doi:https://doi.org/10.1002/bies.202300134
20. Miron RJ, Gruber R, Nima Farshidfar, Sculean A, Zhang Y. Ten years of injectable platelet-rich fibrin. *Periodontology 2000*. Published online November 30, 2023. doi:https://doi.org/10.1111/prd.12538
21. Tanzadehpanah H, Nobari S, Hoseini AJ, et al. Effect of platelet-rich plasma on angiogenic and regenerative properties in patients with critical limb ischemia. *Regenerative Therapy*. 2025;28:517-526. doi:https://doi.org/10.1016/j.reth.2025.01.008
22. Li H, Hicks JJ, Wang L, et al. Customized platelet-rich plasma with transforming growth factor β1 neutralization antibody to reduce fibrosis in skeletal muscle. *Biomaterials*. 2016;87:147-156. doi:https://doi.org/10.1016/j.biomaterials.2016.02.017
23. Bertrand-Duchesne MP ., Grenier D, Gagnon G. Epidermal growth factor released from platelet-rich plasma promotes endothelial cell proliferationin vitro. *Journal of Periodontal Research*. 2010;45(1):87-93. doi:https://doi.org/10.1111/j.1600-0765.2009.01205.x

24. Scully D, Sfyri P, Verpoorten S, et al. Platelet releasate promotes skeletal myogenesis by increasing muscle stem cell commitment to differentiation and accelerates muscle regeneration following acute injury. *Acta Physiologica*. 2018;225(3). doi:https://doi.org/10.1111/apha.13207
25. Sassoli C, Vallone L, Tani A, Chellini F, Nosi D, Zecchi-Orlandini S. Combined use of bone marrow-derived mesenchymal stromal cells (BM-MSCs) and platelet rich plasma (PRP) stimulates proliferation and differentiation of myoblasts in vitro: new therapeutic perspectives for skeletal muscle repair/regeneration. *Cell and Tissue Research*. 2018;372(3):549-570. doi:https://doi.org/10.1007/s00441-018-2792-3
26. Gao H, Zhao Z, Li J, et al. Platelet-rich plasma promotes skeletal muscle regeneration and neuromuscular functional reconstitution in a concentration-dependent manner in a rat laceration model. *Biochemical and Biophysical Research Communications*. 2023;672:185-192. doi:https://doi.org/10.1016/j.bbrc.2023.05.123
27. Rahman E, Rao P, Hany Niamey Abu-Farsakh, et al. Systematic Review of Platelet-Rich Plasma in Medical and Surgical Specialties: Quality, Evaluation, Evidence, and Enforcement. *Journal of Clinical Medicine*. 2024;13(15):4571-4571. doi:https://doi.org/10.3390/jcm13154571
28. Tang P, Rahmati M, Xiao W, et al. Differences in the effectiveness of leukocyte-rich platelet-rich plasma compared with leukocyte-poor platelet-rich plasma in the treatment of rotator cuff surgery: an umbrella review of meta-analyses. *Journal of Orthopaedics and Traumatology*. 2024;25(1). doi:https://doi.org/10.1186/s10195-024-00791-1
29. Costa FR, Augusto S, Martins RA, et al. The Role of Injectable Platelet-Rich Fibrin in Orthopedics: Where Do We Stand? *Current Issues in Molecular Biology*. 2025;47(4):239-239. doi:https://doi.org/10.3390/cimb47040239
30. Chen J, Jiang H. A Comprehensive Review of Concentrated Growth Factors and Their Novel Applications in Facial Reconstructive and Regenerative Medicine. *Aesthetic Plastic Surgery*. 2020;44(3):1047-1057. doi:https://doi.org/10.1007/s00266-020-01620-6
31. Llombart R, Mariscal G, Barrios C, Llombart-Ais R. The Best Current Research on Patellar Tendinopathy: A Review of Published Meta-Analyses. *Sports*. 2024;12(2):46-46. doi:https://doi.org/10.3390/sports12020046
32. Bosco F, Riccardo Giai Via, Giustra F, Alessandro Ghirri, Cacciola G, Alessandro Massè. Platelet-rich plasma for jumper's knee: a comprehensive review of efficacy, protocols, and future directions. *European journal of orthopaedic surgery & traumatology*. 2023;34(1):91-96. doi:https://doi.org/10.1007/s00590-023-03713-9

33. van der Heijden RA, Stewart Z, Moskwa R, et al. Platelet-Rich Plasma for Patellar Tendinopathy: A randomized controlled trial correlating clinical outcomes and quantitative imaging. *Deleted Journal*. Published online July 8, 2024. doi:https://doi.org/10.1093/radadv/umae017
34. Ling SKK, Mak CTK, Lo JPY, Yung PSH. Effect of Platelet-Rich Plasma Injection on the Treatment of Achilles Tendinopathy: A Systematic Review and Meta-analysis. *Orthopaedic Journal of Sports Medicine*. 2024;12(11). doi:https://doi.org/10.1177/23259671241296508
35. Arthur Vithran DT, Xie W, Opoku M, Essien AE, He M, Li Y. The Efficacy of Platelet-Rich Plasma Injection Therapy in the Treatment of Patients with Achilles Tendinopathy: A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine*. 2023;12(3):995. doi:https://doi.org/10.3390/jcm12030995
36. Niemiec P, Szyluk K, Jarosz A, Iwanicki T, Balcerzyk A. Effectiveness of Platelet-Rich Plasma for Lateral Epicondylitis: A Systematic Review and Meta-analysis Based on Achievement of Minimal Clinically Important Difference. *Orthopaedic Journal of Sports Medicine*. 2022;10(4):232596712210869-232596712210869. doi:https://doi.org/10.1177/23259671221086920
37. Maroun R, Daher M, Boufadel P, Lopez R, Khan AZ, Abboud JA. Platelet rich plasma versus corticosteroids for lateral epicondylitis: a meta-analysis of randomized clinical trials. *Clinics in Shoulder and Elbow*. Published online February 10, 2025. doi:https://doi.org/10.5397/cise.2024.00801
38. Averell N, Goodwin B, Park S, et al. The concentration of platelets in PRP does not affect pain outcomes in lateral epicondylitis: a systematic review and meta-analysis. *Pain management*. 2024;14(4):223-233. doi:https://doi.org/10.1080/17581869.2024.2360381
39. Kunze KN, Hannon CP, Fialkoff JD, Frank RM, Cole BJ. Platelet-rich plasma for muscle injuries: A systematic review of the basic science literature. *World Journal of Orthopedics*. 2019;10(7):278-291. doi:https://doi.org/10.5312/wjo.v10.i7.278
40. A Hamid MS, Mohamed Ali MR, Yusof A, George J, Lee LPC. Platelet-Rich Plasma Injections for the Treatment of Hamstring Injuries. *The American Journal of Sports Medicine*. 2014;42(10):2410-2418. doi:https://doi.org/10.1177/0363546514541540
41. Hamilton B, Tol JL, Almusa E, et al. Platelet-rich plasma does not enhance return to play in hamstring injuries: a randomised controlled trial. *British Journal of Sports Medicine*. 2015;49(14):943-950. doi:https://doi.org/10.1136/bjsports-2015-094603

42. Desouza C, Shetty V. Efficacy of platelet-rich plasma in grade 2 hamstring muscle injuries: results from a randomized controlled trial. *European Journal of Orthopaedic Surgery & Traumatology*. 2025;35(1):259-259. doi:https://doi.org/10.1007/s00590-025-04377-3
43. Serag I, Abouzid M, Hikal H, et al. Platelet-rich plasma in anterior cruciate ligament reconstruction: An updated systematic review and quantitative meta-analysis of randomized controlled trials. *Chinese Journal of Traumatology*. Published online July 23, 2025. doi:https://doi.org/10.1016/j.cjtee.2025.02.008
44. Tayyab M, Ahmad Z, Akbar R, et al. Efficacy of Platelet-Rich Plasma Augmentation in Anterior Cruciate Ligament Reconstruction: An Updated Systematic Review and Meta-Analysis of Clinical Trials. *Cureus*. Published online October 9, 2025. doi:https://doi.org/10.7759/cureus.94181
45. Zhang Y, Xiao Z, Fan Z, Zhang Y, Xu J, Wang K. The impact of platelet-rich plasma injection on anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Frontiers in Bioengineering and Biotechnology*. 2025;13:1625271-1625271. doi:https://doi.org/10.3389/fbioe.2025.1625271
46. Altamura SA, Di Martino A, Andriolo L, et al. Platelet-Rich Plasma for Sport-Active Patients with Knee Osteoarthritis: Limited Return to Sport. *BioMed Research International*. 2020;2020:1-6. doi:https://doi.org/10.1155/2020/8243865
47. Nawaz HMT, Jawwad MA, Khan MU, Qadir MJ, Farooq MO, Nawaz MH. Efficacy of Platelet-Rich Plasma Injections in Knee Osteoarthritis: A Systematic Review and Meta-Analysis. *Cureus*. Published online October 10, 2025. doi:https://doi.org/10.7759/cureus.94288
48. Wang C, Yao B. Efficacy and safety of platelet-rich plasma injections for the treatment of knee osteoarthritis: a systematic review and meta-analysis of randomized controlled trials. *European journal of medical research*. 2025;30(1):992-992. doi:https://doi.org/10.1186/s40001-025-03253-4
49. Xiong Y, Gong C, Peng X, et al. Efficacy and safety of platelet-rich plasma injections for the treatment of osteoarthritis: a systematic review and meta-analysis of randomized controlled trials. *Frontiers in Medicine*. 2023;10. doi:https://doi.org/10.3389/fmed.2023.1204144
50. Diaz Haaz DI, Rizo Castro O. Efficacy and Safety of Intra-articular Platelet-Rich Plasma (PRP) Versus Corticosteroid Injections in the Treatment of Knee Osteoarthritis: A Systematic Review of Randomized Clinical Trials. *Cureus*. Published online March 21, 2025. doi:https://doi.org/10.7759/cureus.80948

51. Murray I, Geeslin AG, Goudie EB, Petrigliano FA, LaPrade RF. Minimum Information for Studies Evaluating Biologics in Orthopaedics (MIBO): Platelet-Rich Plasma and Mesenchymal Stem Cells. *The Journal of Bone & Joint Surgery*. 2017;99(10):809-819. doi:https://doi.org/10.2106/jbjs.16.00793
52. Nazaroff J, Oyadomari S, Brown N, Wang D. Reporting in clinical studies on platelet-rich plasma therapy among all medical specialties: A systematic review of Level I and II studies. Negida A, ed. *PLOS ONE*. 2021;16(4):e0250007. doi:https://doi.org/10.1371/journal.pone.0250007
53. Mahajan U, Papaleontiou A, Imam MA, Mahmood A. Assessing Standardisation in Platelet-Rich Plasma (PRP) Injections for the Management of Greater Trochanteric Pain Syndrome (GTPS): A Systematic Review of the Available Literature. *Cureus*. 2024;16(11):e74690. doi:https://doi.org/10.7759/cureus.74690
54. Richardson MK, Kistler NM, Mayfield CK, Liu KC, Lieberman JR, Heckmann ND. Spin and reporting bias in the use of platelet-rich plasma for the treatment of knee osteoarthritis. *European Journal of Orthopaedic Surgery & Traumatology*. 2025;35(1):348-348. doi:https://doi.org/10.1007/s00590-025-04353-x
55. O'Dowd A. Update on the Use of Platelet-Rich Plasma Injections in the Management of Musculoskeletal Injuries: A Systematic Review of Studies From 2014 to 2021. *Orthopaedic Journal of Sports Medicine*. 2022;10(12):232596712211408. doi:https://doi.org/10.1177/23259671221140888
56. Machaj D, Mazurek A, Machaj D, Józefowicz W. The Role of Platelet-Rich Plasma Therapy in Treating Sports Injuries. *Quality in Sport*. 2024;25:54905. doi:https://doi.org/10.12775/qs.2024.24.54905
57. Jakub Dziewic, Przygoda M, Śnieżna J, et al. Advancements in Regenerative Medicine for Articular Cartilage Repair in the Management of Osteoarthritis: A Review of Modern Treatment Methods. *Quality in Sport*. 2025;37:57092-57092. doi:https://doi.org/10.12775/QS.2025.37.57092
58. Andia I, Silvestre A, Del Amo C, Eymard F, Bard H. The Platelet-Rich Plasma research ecosystem: From mechanistic insights to precision treatment in knee osteoarthritis. *Regenerative Therapy*. 2025;30:1036-1045. doi:https://doi.org/10.1016/j.reth.2025.10.017
59. Phillips M, Bhandari M, Grant J, et al. A Systematic Review of Current Clinical Practice Guidelines on Intra-articular Hyaluronic Acid, Corticosteroid, and Platelet-Rich Plasma Injection for Knee Osteoarthritis: An International Perspective. *Orthopaedic Journal of*

Sports Medicine. 2021;9(8):232596712110302. doi:https://doi.org/10.1177/23259671211030272

60. Kiełkowicz A, Pisera P, Pactwa F, et al. Platelet-rich plasma - a revolutionary therapeutic option in multi-disciplinary indications. *Journal of Education, Health and Sport*. 2024;51:140-154. doi:https://doi.org/10.12775/jehs.2024.51.011
61. Janocha A, Jerzak A, Hitnarowicz A, Kmak B, Szot A, Pociecha A. Platelet-rich plasma as a new treatment method in orthopedics. *Journal of Education, Health and Sport*. 2024;67:49195. doi:https://doi.org/10.12775/jehs.2024.67.49195