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Platelet-Rich Plasma in Regenerative Medicine: Biological Mechanisms, Preparation Methods, Clinical Applications, and Current Challenges

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Abstract **- Platelet-rich plasma (PRP) is a blood product that is enriched with platelets, growth factors, and cytokines. It is a gradually acknowledged technique in the field of regenerative medicine that not only promotes tissue healing but also induces the formation of new blood vessels and the regeneration of the extracellular matrix. Nevertheless, the clinical situations in which PRP therapy is applied, such as orthopedic, dermatological, dental, and wound healing treatments, is still considerably affected by the specific preparation, activation, and patient-matching techniques used and thus exhibit variable outcomes. This review intends to offer a critical discourse on the biological mechanisms, preparation techniques, clinical applications, and challenges facing PRP therapy, thereby giving a synthesis of evidence and spotting the chances for enhancing efficacy and standardization. Aided by the concentrated growth factors such as PDGF, TGF-β, VEGF, EGF, and IGF-1, PRP stimulates the formation of new tissue by attracting and turning active fibroblasts, endothelial cells, and osteoblasts which are the main players of the respective processes, additionally increasing the blood supply and releasing more extracellular matrix substances such as collagen. The different factors such as the concentrations of platelets and leukocytes, the methods of activation, the age of the patient, the presence of other diseases, and the type of pathology are all together responsible for the variability in clinical outcomes. Among the new techniques that could possibly overcome these issues are exosome-enriched PRP, platelet lysates and therapies that combine biomaterials or stem cells. However, the automatized preparation systems can deliver more uniform platelet concentrations than the manual ways do but the high price and lack of access are the two remaining hurdles. The following areas of work are important for maximizing the benefits of the therapy: standardization of PRP preparation and administration protocols, mechanistic studies, large-scale randomized controlled trials, and development of personalized, patient-specific formulations. The writers of this critique want to lay down a vast and detailed base for blending PRP into the area of evidential regenerative medicine, besides; they want to indicate the paths for further diagnostics and clinical studies.**

Keywords: Platelet-rich plasma; Regenerative medicine; Growth factors; Tissue repair; Autologous therapy; Clinical applications.

I. Introduction

The healing of tissues and organs which have sustained damage has not yet been fully resolved and is still a very difficult problem to deal with clinically, since the loss of healing can lead to morbidity, inability to use the affected body part, and a decrease in the quality of life for a long time [1]. The conventional methods of treatment, such as the use of drugs and surgical operations, have very little to offer in terms of regeneration, thus turning the attention of the medical researchers to biologically based therapies [2]. PRP is one of the biological treatments and has been recognized as a promising antilogous therapy because of its favorable safety profile and abilities to transport concentrated growth factors straight to the areas of tissue injury or degeneration [3, 4].

PRP is obtained through either centrifuge or specialized separation systems, which result in plasma with platelets being extracted at a higher concentration than in blood [5]. Platelets have multiple roles and among them, they are a source of bioactive molecules whose list is not complete as they include platelet-derived growth factor (PDGF), transforming growth factor-beta (TGF-β), vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), and insulin-like growth factor-1 (IGF-1). The mentioned factors, in partnership, regulate the healing stages including apoptosis, angiogenesis, and the organization of connective tissue [6, 7]. The adoption of such practices in medicine has been acknowledged in a number of areas like orthopedics, dermatology, and dentistry, and wound healing, but still the clinical outcomes vary widely [8]. The variability of this is attributed to factors such as the differences in the amounts of platelets and leukocytes, the activating methods, and the preparatory procedures; also patients' individual characteristics

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like age, diseases, and the initial count of platelets play a role [9, 10].

Moreover, the fundamental molecular mechanisms by which PRP generates its regenerative effects are still uncertain, and there are no common protocols accepted by all for its groundwork and usage [11]. The absence of such uniform procedures prevents PRP treatment's consistency and clinical use. Thus, a strict and deep review is required that will not only gather the existing evidence but also highlight the unsolved difficulties and suggest methods for the improvement of PRP application in regenerative medicine. The present review will investigate the biological rationale, methods of preparation, and usage of PRP in clinics, highlighting the areas of evidence-based outcomes, mechanistic insights, limitations in standardization, and future directions for both research and clinical translation [12].

II. Methodology

Literature Search Strategy:

The thorough literature investigation took place in the databases of PubMed, Scopus, and Web of Science. The keywords used in the searching were "platelet-rich plasma," "PRP preparation," "regenerative medicine," "orthopaedic applications," "dermatology," "wound healing," and "clinical trials."[13, 14].

Selection Criteria:

The selection of articles was dependent on their clinical relevance and scientific validity, which meant taking under consideration the randomized controlled trials, the prospective and retrospective studies, systematic reviews, meta-analyses, and even patents that were describing PRP preparation methods[15,16]. Overviews of research lacking description of the methodology used or non-peer-reviewed publications were not included among the selected articles.

Data Extraction:

The information was taken out on PRP making techniques, amount of platelets, number of white blood cells, the methods of activation, medical uses, results of patients, and safety profiles. The information taken out was scrutinized to discover trends, differences in outcomes, and advances in technology [17,18].

III. Current State of the Art

3.1 Overview of Existing Technologies:

The main technique for PRP formation is centrifugation of the blood taken from the patient which is done in a way that the plasma is separated from the red and white blood cells. The resulting PRP can be divided into two classes according to their leukocyte level, leukocyte-rich PRP (L-PRP) with the maximum amount of leukocytes and platelets, and leukocyte-poor PRP (P-PRP), which reduces the inflammatory reactions [19,20]. PRP is produced by different methods such as standardized automated systems and manual preparation, which all differ in their reproducibility, platelet yield, and leukocyte content [21, 22].

3.2 Technological Advancements:

In the recent past, innovations were primarily focused on the purity of platelet concentration, the reduction of leukocyte content, and the improvement of point-of-care preparation. The combination of these developments in centrifugation techniques, plasma separation protocols, and activation methods has played a great role in achieving superior and more reliable PRP preparations [23, 24]. Moreover, the adoption of standardized preparation methods has already resulted in successful outcomes in musculoskeletal, dermatologic, and wound healing applications, as evidenced by comparative studies [25].

3.3 Regulatory and Clinical Landscape:

PRP is generally classified as a minimally manipulated autologous product. The extent of regulatory surveillance is different in each area with the US and EU clearing the use of preparation devices. The results from clinical tests showed that efficacy is different depending on the factors such as the concentration of the platelets, type of disease, and method of administration, thus, calling for a standard set of guidelines and regulatory cooperation. [26,27].

IV. Mechanism of Action and Design Considerations

4.1 Design Principles:

PRP kits concentrate platelets from a small sample of the patient's blood, conducting the cascade of the injection process into necessary vessels. Devices are engineered to maximize platelet recovery while controlling leukocyte content. Automated systems utilize closed sterile systems and dual-spin centrifugation to minimize contamination and improve reproducibility, enabling rapid point-of-care preparation suitable for outpatient and surgical settings [28,29].

4.2 Performance and Efficacy:

PRP has been shown to be very effective in the process of tissue regeneration through both preclinical and clinical trials, and in addition, it acts as a carrier for many growth factors like the platelet-derived growth factor (PDGF), transforming growth factor-beta (TGF-β), vascular endothelial growth

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factor (VEGF), epidermal growth factor (EGF), and insulin-like growth factor-1 (IGF-1). The combined effect of these factors results in three main advantages: the initiation of blood vessel creation (i.e., angiogenesis), the formation of the extracellular matrix, and the proliferation of cells [30, 31]. The results from the application of the technique in such different areas as orthopaedics, sports medicine, dermatology, dentistry, and wound healing have been inconsistent but overall indicated better pain relief, functional recovery, and tissue repair, notwithstanding the heterogeneity of the results due to the different preparation methods and patient-specific factors [32, 33].

4.3 Mechanistic Overview of PRP-Mediated Regeneration

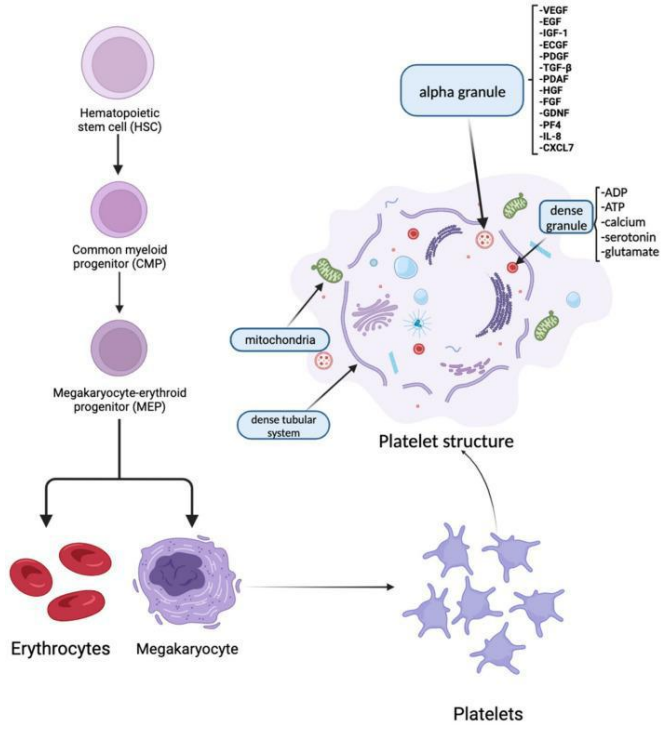

Figure 1: Mechanistic schematic: How platelet-rich plasma (PRP) promotes tissue repair and regeneration [34]

V. Comparative Analysis

5.1 Comparison with Existing Techniques:

Automated PRP preparation systems not only deliver better reproducibility but also offer greater precision in platelet concentration and uniformity in leukocyte profiles over manual methods. Nonetheless, due to the additional cost, manual systems are still the preferred choice in resource-limited scenarios. Efficacy is normally higher with the use of standardized systems, yet there are few studies that report no substantial difference in the results of patients which emphasizes the role of underlying disease and treatment protocol [35].

5.2 Cost and Accessibility:

High manufacturing expenses for automated platelet-rich plasma (PRP) systems restrict their use in low-resource locations. Manually prepared PRP is cheaper but requires more manpower and is less consistent due to operator variability. The market adoption of PRP devices depends on their price, training, the approval from regulation, and the patients' desire for the autologous regenerative therapies [36, 37].

Table 1: Comparison of Automated and Manual PRP Preparation Systems

Feature	Automated PRP	Manual PRP
Reproducibility	High, standardized	Variable, operator-dependent
Platelet Concentration	Consistent	Less predictable
Leukocyte Control	Standardized	Variable
Clinical Efficacy	Generally higher	Mixed outcomes
Cost	High	Low
Accessibility	Limited in low-resource settings	Widely used
Labor	Low	High

VI. Challenges and Limitations

PRP therapy has significant and difficult hurdles to overcome that among others limit its therapeutic potential, reproducibility, and clinical efficacy, so it is not widely used yet. One of the problems is that the different methods of preparing PRP cause inconsistency in the product compositions, thus making it more difficult to compare the results of the different studies [38,39]. The clinical outcomes range widely even within the same medical field and between different fields like orthopedics, dermatology, and wound-healing, and these variations are mainly patient-specific, pathology-specific, and administration protocol-specific [40–43]. The complete mechanistic knowledge is still lacking largely regarding the dose-response relationships, signaling pathways, and the role of leukocytes in modulating inflammation and tissue repair [30, 31]. There are no universal guidelines for PRP preparation, activation, platelet concentration targets, or administration frequency, which restricts reproducibility even more [44]. The differences in regulatory environments around the world have an impact on the accessibility and clinical adoption, while the price of automated systems prevents their use in less resourceful places [36, 37]. Moreover, there are not many large-scale high-quality randomized controlled trials, which weakens the evidence base [40, 41, 45]. The solution to these problems involves the uniformity of preparation protocols, mechanistic studies for revealing molecular pathways, personalized PRP formulations based on patient characteristics, and thorough clinical trials [45–47].

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VII. Future Perspectives

Breakthroughs in PRP therapy shall be directed towards the aspects of reproducibility, efficacy, and clinical translation. The standardization of preparation protocols, which include platelet count, leukocyte content, and activation method, is considered fundamental to not only minimizing differences but also increasing study similarity and comparison [45, 46]. With regard to this indeed, the clarification of the molecular pathways, the mapping out of the dose-response relations and the understanding of the part played by the leukocytes in tissue repair and inflammation are, respectively, the areas for, the mechanistic studies and the immune component studies to be [30, 31]. Closer to this subject, the PRP derivatives of the next generation such as exosome-rich formulations and platelet lysates present a great potential to not only upgrade healing outcomes but also reduce differences across therapies [46]. The use of biomaterials and/or stem cells in conjunction with other treatments may result in additive effects for tissue regeneration [46, 47]. The idea of customizing PRP to the individual patient characteristics such as age, existing conditions, and platelet count could further increase treatment effectiveness. Moreover, it will be imperative to conduct large, high-quality randomized controlled trials that are costly but necessary for the establishment of evidence-based clinical guidelines, while, on the other hand, regulatory unification and low-cost technologies could be the initiatives making wider access and adoption possible [36, 37, 45]. On the whole, these tactics will help to promote PRP from a therapy that is variable but promising to a reproducible, standardized, and widely accepted mode in regenerative medicine.

VIII. Conclusion

Platelet-rich plasma (PRP) is an active, self-derived, and very strong therapy in the field of regenerative medicine that could be used in the areas of orthopedics, dermatology, dentistry, and healing wounds. The prospect of healing tissues with growth factors delivered right at the injury site is the reason for the therapeutic promise, but, the clinical outcomes still vary a lot among patients due to different ways of preparation, activation protocols, leukocyte content, and individual patient characteristics. At present, the absence of common protocols, the not fully revealed mechanism, and the differences in regulations are the main limitations that together prevent the wide-scale acceptance and reproducibility of PRP in clinics. However, progressively, the scientific and medical communities are unlocking the complete potential of PRP therapy through a focus on preparation and application standardization, mechanistic studies uncovering molecular pathways, patient-specific approaches tailored to individual characteristics, and the conduct of large, randomised controlled trials that will provide the basis for evidence-based guidelines. New methodologies and techniques change, exosome-enriched PRP, platelet lysates, and combination treatments with biomaterials or stem cells, all are gradually leading to improve therapeutic efficacy. PRP is a good method that can be used in regenerative medicine; however, its research needs to continue along with the innovations and the regulatory harmonization which will be the key factors in the realization of PRP's potential in terms of consistent and clinically relevant outcomes.

REFERENCES

[1] Marx RE. Platelet-rich plasma: Evidence to support its use. *J Oral Maxillofac Surg.* 2004;62(4):489–496.

[2] Dohan Ehrenfest DM, Rasmusson L, Albrektsson T. Classification of platelet concentrates: From pure platelet-rich plasma (P-PRP) to leucocyte- and platelet-rich fibrin (L-PRF). *Trends Biotechnol.* 2009;27(3):158–167.

[3] Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-rich plasma: From basic science to clinical applications. *Am J Sports Med.* 2009;37(11):2259–2272.

[4] Anitua E, Sánchez M, Orive G. The potential impact of the preparation rich in growth factors (PRGF) in different medical fields. *Biomaterials.* 2007;28(31):4551–4560.

[5] Andia I, Maffulli N. Platelet-rich plasma for managing pain and inflammation in osteoarthritis. *Nat Rev Rheumatol*. 2013;9(12):721–730.

[6] Filardo G, Kon E, Di Martino A, et al. Platelet-rich plasma vs hyaluronic acid in the treatment of knee osteoarthritis: Results at 5 years of a double-blind randomized controlled trial. *Am J Sports Med.* 2015;43(7):1575–1584.

[7] Sánchez M, Anitua E, Azofra J, et al. Comparison of surgically repaired Achilles tendon tears using platelet-rich fibrin matrices. *Am J Sports Med.* 2007;35(2):245–251.

[8] Mishra A, Woodall J Jr, Vieira A. Treatment of tendon and muscle using platelet-rich plasma. *Clin Sports Med*. 2009;28(1):113–125.

[9] Cervelli V, Lucarini L, Spallone D, et al. Application of platelet-rich plasma in plastic surgery: Clinical and in vitro evaluation. *Tissue Eng Part C Methods.* 2009;15(4):625–634.

[10] Cho JW, Kim SA, Lee KS, Lee HR. The use of autologous platelet-rich plasma to treat androgenic alopecia. *Dermatol Surg.* 2010;36(12):1888–1893.

[11] Carter MJ, Fylling CP, Parnell LK. Use of platelet rich plasma gel on wound healing: A systematic review and meta-analysis. *Wound Repair Regen.* 2011;19(5):1–14.

ISSN (online): 2581-3048
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[12] Gentile P, Garcovich S. Systematic review: Platelet-rich plasma in tissue regeneration. *Stem Cells Int.* 2019;2019:9306397.

[13] Dhillon RS, Schwarz EM, Maloney MD. Platelet-rich plasma therapy—future or trend? *Arthritis Res Ther*. 2012;14(4):219.

[14] Everts PA, Knape JT, Weibrich G, et al. Platelet-rich plasma and platelet gel: A review. *J Extra Corpor Technol*. 2006;38(2):174–187.

[15] Kon E, Filardo G, Di Martino A, et al. Platelet-rich plasma (PRP) for the treatment of cartilage lesions: From preclinical rationale to clinical evidence. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(3):333–342.

[16] Andia I, Maffulli N. Platelet-rich plasma in tendon healing: From basic science to clinical applications. *Sports Med Arthrosc.* 2013;21(2):103–110.

[17] Patel S, Dhillon MS, Aggarwal S, Marwaha N, Jain A. Treatment with platelet-rich plasma in addition to conventional management in osteoarthritis of the knee: A randomized controlled trial. *Arthritis Res Ther.* 2013;15(4):R190.

[18] Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-rich plasma: From basic science to clinical applications. *Am J Sports Med.* 2009;37(11):2259–2272.

[19] Dohan Ehrenfest DM, Rasmusson L, Albrektsson T. Classification of platelet concentrates: From pure platelet-rich plasma to leucocyte- and platelet-rich fibrin. *Trends Biotechnol.* 2009;27(3):158–167.

[20] Anitua E, Sánchez M, Orive G. The potential impact of plasma rich in growth factors in different medical fields. *Biomaterials.* 2007;28(31):4551–4560.

[21] Marx RE. Platelet-rich plasma: Evidence to support its use. *J Oral Maxillofac Surg.* 2004;62(4):489–496.

[22] Mishra A, Woodall J Jr, Vieira A. Treatment of tendon and muscle using platelet-rich plasma. *Clin Sports Med*. 2009;28(1):113–125.

[23] Sanchez M, Anitua E, Azofra J, et al. Comparison of surgically repaired Achilles tendon tears using platelet-rich fibrin matrices. *Am J Sports Med.* 2007;35(2):245–251.

[24] Filardo G, Kon E, Di Martino A, et al. Platelet-rich plasma vs hyaluronic acid in the treatment of knee osteoarthritis: Results at 5 years of a double-blind randomized controlled trial. *Am J Sports Med.* 2015;43(7):1575–1584.

[25] Andia I, Maffulli N. Platelet-rich plasma: Underlying biology and clinical applications. *Sports Med Arthrosc.* 2013;21(2):103–110.

[26] Cervelli V, Lucarini L, Spallone D, et al. Application of platelet-rich plasma in plastic surgery: Clinical and in vitro evaluation. *Tissue Eng Part C Methods.* 2009;15(4):625–634.

[27] Cho JW, Kim SA, Lee KS, Lee HR. The use of autologous platelet-rich plasma to treat androgenic alopecia. *Dermatol Surg.* 2010;36(12):1888–1893.

[28] Carter MJ, Fylling CP, Parnell LK. Use of platelet-rich plasma gel on wound healing: A systematic review and meta-analysis. *Wound Repair Regen.* 2011;19(5):1–14.

[29] Gentile P, Garcovich S. Systematic review: Platelet-rich plasma in tissue regeneration. *Stem Cells Int.* 2019;2019:9306397.

[30] Alves R, Grimalt R. A review of platelet-rich plasma: History, biology, mechanism of action, and classification. *Skin Appendage Disord.* 2018;4(1):18–24.

[31] Everts PA, Devilee RJ, Brown Mahoney C, et al. Platelet-rich plasma: New performance understandings and tissue healing potential. *Curr Pharm Biotechnol.* 2013;14(7):1138–1145.

[32] Sanchez M, Anitua E, Delgado D, Prado R, Orive G. Platelet-rich plasma in regenerative medicine: A concise review. *Transfus Apher Sci.* 2018;57(3):309–314.

[33] Andia I, Abate M. Platelet-rich plasma: Underlying biology and clinical applications. *Regen Med.* 2013;8(5):647–658.

[34] Gentile P, Garcovich S. Platelet-Rich Plasma (PRP) in Dermatology: Cellular and Molecular Mechanisms of Action. *Biomedicines.* 2022; 12(1):7. doi:10.3390/biomedicines12010007. (CC BY 4.0)

[35] Dohan Ehrenfest DM, Bielecki T, Del Corso M, et al. Do the fibrin architecture and leukocyte content influence the growth factor release of platelet concentrates? An evidence-based answer. *J Biomed Mater Res A.* 2010;94(4):1574–1582.

[36] Mishra A, Woodall J Jr, Vieira A. Treatment of tendon and muscle using platelet-rich plasma. *Clin Sports Med*. 2009;28(1):113–125.

[37] Filardo G, Kon E, Di Martino A, et al. Platelet-rich plasma for the treatment of knee osteoarthritis: Current concepts. *Expert Opin Biol Ther.* 2014;14(7):1013–1028.

[38] Giusti I, D'Ascenzo S, Mancini S, et al. Platelet concentrates for tissue regeneration: Current achievements and perspectives. *Platelets.* 2014;25(5):353–361.

[39] Everts PA, Knape JT, Weibrich G, et al. Platelet-rich plasma and platelet gel: A review. *J Extra Corpor Technol*. 2006;38(2):174–187.

[40] Dhillon RS, Schwarz EM, Maloney MD. Platelet-rich plasma therapy—future or trend? *Arthritis Res Ther*. 2012;14(4):219.

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[41] Kon E, Filardo G, Di Martino A, et al. Platelet-rich plasma (PRP) for the treatment of cartilage lesions: From preclinical rationale to clinical evidence. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(3):333–342.

[42] Andia I, Maffulli N. Platelet-rich plasma in tendon healing: From basic science to clinical applications. *Sports Med Arthrosc*. 2013;21(2):103–110.

[43] Patel S, Dhillon MS, Aggarwal S, Marwaha N, Jain A. Treatment with platelet-rich plasma in addition to conventional management in osteoarthritis of the knee: A randomized controlled trial. *Arthritis Res Ther*. 2013;15(4):R190.

[44] Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-rich plasma: From basic science to clinical applications. *Am J Sports Med*. 2009;37(11):2259–2272.

[45] Dohan Ehrenfest DM, Rasmusson L, Albrektsson T. Classification of platelet concentrates: From pure platelet-rich plasma to leucocyte- and platelet-rich fibrin. *Trends Biotechnol*. 2009;27(3):158–167.

[46] Sanchez M, Anitua E, Delgado D, Prado R, Orive G. Platelet-rich plasma in regenerative medicine: A concise review. *Transfus Apher Sci*. 2018;57(3):309–314.

[47] Gentile P, Garcovich S. Systematic review: Platelet-rich plasma in tissue regeneration. *Stem Cells Int*. 2019;2019:9306397.

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