GMR
The Original

# EVALUATION OF EXOSOME-ENRICHED PLATELET-DERIVED PLASMA FRACTION ON THE SURFACE CHARACTERISTICS AND OSTEOGENIC POTENTIAL OF TITANIUM DISCS: AN IN VITRO STUDY

**Jasmine Crena M*[1], Kavitha Sanjeev[2], Hima Bindu Reddy[3]**

[1*]Assistant Professor, Department of Periodontology, SRM Dental College, Barathi Salai, Ramapuram, Chennai, Tamil Nadu, India, Email: jasminecrena@gmail.com, Orcid ID: 0000-0001-9788-3898
[2]Professor, Department of Conservative and Endodontics, SRM Dental College, Barathi Salai, Ramapuram, Chennai, Tamil Nadu, India, Email: kavithasanjeev02@gmail.com, Orcid ID: 0000-0002-7024-6570
[3]Periodontist, Department of Periodontology, Government Dental College, Chennai, Tamil Nadu, India, Email: himabindu573@gmail.com, Orcid ID: 0000-0002-2664-7828
*Corresponding Author: Email: jasminecrena@gmail.com

**ABSTRACT:** Surface biofunctionalization of titanium implants is essential to improve early osseointegration. Recent advances highlight the role of exosomes in modulating cellular behaviour and enhancing tissue regeneration. The aim of the study is to investigate the influence of exosome-enriched Plasma fraction on surface properties and osteogenic response of titanium discs. Titanium discs were allocated into three groups: untreated control, Plasma fraction treated, and exosome-enriched plasma fraction treated. Surface characterization was performed using SEM analysis. Osteoblast response was assessed through RT-PCR expression of RUNX2, Alkaline Phosphatase (ALP), Type 1 Collagen (COL1A1), osteocalcin (OCN), osteopontin (OPN). Surface analysis confirmed successful biofunctionalization without alteration of titanium crystalline structure. Treated groups exhibited increased hydrophilicity and surface energy ($p < 0.05$). Group 3 demonstrated upregulated expression of osteogenic markers RUNX2, ALP, COL1A1, OPN, and OCN compared to other groups.

**KEYWORDS:** Exosomes; Platelet-derived plasma; Titanium implants; Surface modification; Osteogenic differentiation; Osteogenic gene expression

## INTRODUCTION

Successful implant therapy depends on osseointegration, defined as the direct structural and functional connection between ordered living bone and the surface of a load-bearing implant [1]. Materials like commercially pure titanium and zirconia are used, with titanium as the gold standard due to its biocompatibility, corrosion resistance, elastic properties, and mechanical strength to prevent periimplant diseases[2]. To date a reasonable numbers of early implant failures and delayed osteointegration occur, and have been reported especially in poor bone quality or systemic diseases, prompting research into biofunctionalizing implant surfaces without altering bulk properties[3]. Critical factors for osseointegration include surface topography, chemistry, roughness, wettability, and hydrophilicity. Biofunctionalization turns bio-inert surfaces bioactive, promoting protein adsorption, cell adhesion, and osteoblastic differentiation for rapid integration[4]. Strategies to improve biofunctionalization involve coating implants with growth factors, peptides, and biomimetic materials to mimic bone's extracellular matrix.

Platelet-derived plasma fractions like injectable PRF release growth factors sustainably due to their autologous nature. Exosomes in PRF—nano-sized vesicles with proteins, lipids, and nucleic acids—regulate osteogenic differentiation. These enable bioactive coatings on titanium surfaces, enhancing hydrophilicity, osteoblast proliferation, and differentiation, though more in vitro studies on physico-chemical properties and gene expression are needed.

Plasma fractionated exosomes holds an outstanding performance by way of their autologous nature, thus warranting safety over other non autologous/ synthetic sources. Sources support the persistence of exosomes at the implant surface and has been long enough for the required recruitment of different osteogenic functions. Though synthetic exosomes are available, native exosomes when channelised on the implant surface could add to the enhanced structural biofunctionalisation alongside osteoblast differentiation as seen in invitro studies[5]. The enrichment of plasma fractions with exosomes warrant a novel strategy to enhance the biological activity of implant surfaces through notable characteristics like specific differentiation and cellular signalling pathways owing to their much higher half life .

The quality of platelet derived exosomes is a critically acclaimed factor and literature shows experimental evidence [6] that the exosomes derived from iPRF contains growth factors including PDGF, TGF-β, VEGF. Though exosomes derived from other sources like mesenchymal stem cells, osteoblast derived exosomes, immune cell derived exosomes have shown an equivalent balanced sources, however Platelet-derived exosomes are considered an ideal source for regenerative applications due to their easy availability from autologous blood, minimal processing requirements, and high content of bioactive growth factors, making them more clinically feasible compared to exosomes derived from other cell types.

Platelet-derived exosomes exhibit high quality and yield, characterized by appropriate size distribution, expression of exosomal markers (CD63, CD81, CD9), and enrichment with growth factors, while also providing a greater quantity compared to many other sources, owing to the natural abundance of platelets; this has been well supported in the literature, including guidelines by the International Society for Extracellular Vesicles and studies [7,8] demonstrating their consistency, purity, and strong regenerative potential.

Exosomes regulate cellular function by transferring bioactive molecules, including DNA fragments, mRNA, and microRNA, which modulate gene expression and signaling pathways in recipient cells, thereby influencing processes such as proliferation, differentiation, and tissue regeneration. Exosomes mediate their effects through key signaling pathways such as Wnt/β-catenin, MAPK, and PI3K/Akt, thereby regulating cellular proliferation, differentiation, and osteogenic activity. [7,8]

Many studies have been done invitro assessing the therapeutic potential and prolific results have been obtained in lieu with pulpal regeneration, new bone formation, immune cell function, anti-inflammatory qualities and also M1-M2 transition.[8] Studies mostly have been focussed on exosomes derived from human oral mucosal epithelia cells, human periodontal ligament stem cells. Plasma fractionated exosomes are in the emergence and this study aims to evaluate the effect of exosome-enriched platelet -derived plasma fraction and their effect on the characteristics and osteogenic potential of titanium discs.

## 2.MATERIALS AND METHODS

### 2.1 Ethics Board Approval:

Ethical approval was obtained for this invitro Study (SRMDC/IRB/2022/PhD/No.160) from the Institutional review board. In brief, this in vitro experimental study was designed to evaluate the effect of plasma fraction and exosome-enriched plasma fraction on the surface characteristics and osteogenic potential of titanium discs.

### 2.2 Study Design:

Commercially pure titanium discs were randomly allocated into three groups:

- Group 1: Untreated control (no surface modification)- 8
- Group 2: Plasma fraction–treated titanium discs- 8
- Group 3: Exosome-enriched plasma fraction–treated titanium discs- 8

### 2.3 In Vitro Preparation of Titanium Discs:

Commercially pure titanium discs (Grade IV) with standardized dimensions (10 mm diameter and 2 mm thickness) were used in the study. Prior to experimentation, all discs were subjected to a standardized cleaning protocol to remove surface contaminants. The discs were ultrasonically cleaned sequentially in acetone, ethanol, and distilled water for 10 minutes each. Following cleaning, the discs were air-dried and sterilized

using autoclaving at 121°C for 15 minutes under aseptic conditions.After sterilization, the discs were handled using sterile instruments and randomly allocated into three experimental groups: Group 1 (untreated control), Group 2 (plasma fraction–treated), Group 3 (exosome-enriched plasma fraction–treated). The prepared discs were stored in sterile containers until further surface treatment and analysis.

**2.4 Preparation of Plasma Fraction**

Blood samples were obtained from a certified blood bank /approved laboratory source using healthy donor blood collected under standardized conditions. The samples were handled in accordance with institutional biosafety guidelines. The collected blood, without the addition of anticoagulants, was processed immediately. The blood was centrifuged at low speed (700 rpm for 3 minutes) to obtain the injectable platelet-rich fibrin (iPRF) fraction. The upper plasma layer, rich in platelets and growth factors, was carefully aspirated using a sterile micropipette and used as the plasma fraction for subsequent experimental procedures.

**2.5 Isolation and Preparation of Exosomes**

Exosomes were isolated from the platelet-derived plasma fraction using a differential centrifugation technique. The plasma fraction was first subjected to centrifugation at 3000 × g for 10 minutes to remove cellular debris and residual platelets. The supernatant was then centrifuged at 10,000 × g for 20 minutes to eliminate larger vesicles and apoptotic bodies. The resulting supernatant was ultracentrifuged at 100,000 × g for 70 minutes at 4°C to obtain the exosome pellet. The pellet was washed with sterile phosphate-buffered saline (PBS) and subjected to a second ultracentrifugation step under the same conditions to enhance purity. The final exosome pellet was resuspended in sterile PBS and stored at −80°C until further use. For the preparation of exosome-enriched plasma fraction, the isolated exosomes were mixed with freshly prepared plasma fraction under sterile conditions to obtain a uniform suspension.

**2.6 Surface application of the Different Groups**

Titanium discs were treated according to their respective experimental groups under sterile conditions. For Group 1, discs were maintained as untreated controls without any surface modification. In Group 2, a defined volume (50–100 µL) of plasma fraction was uniformly applied onto the surface of each disc using a sterile micropipette. For Group 3, exosome-enriched plasma fraction was applied in a similar manner to ensure even surface coverage. Following application, all treated discs were incubated at 4°C for 24 hours to facilitate adsorption of bioactive components onto the titanium surface. After incubation, the discs were gently rinsed with sterile phosphate-buffered saline (PBS) to remove unbound material and subsequently air-dried under aseptic conditions prior to further surface characterization and biological evaluation.

Exosome quantification was performed using nanoparticle tracking analysis to determine particle size and concentration. Protein content was assessed using BCA assay, and exosomal markers (CD63, CD81, CD9) were evaluated to confirm vesicle identity. Surface characterization was performed using SEM Analysis forllowed by correlation of the same with osteogenic marker qualtification was performed through RT PCR.

MG-63 cells were obtained from NCCS, Pune and seeded onto the top surface of each disc at a density of roughly $2*10^4$ to $5*10^4$ cells per disc. The cells were incubated in induction media containing β-glycerophosphate, ascorbic acid and dexamethasone for a duration of 14 days. The cells were gently risned with cold phosphate buffered saline (PBS) followed by adding RNA Lysis agent TRIzol directly onto the surface of the titanium discs. The lysate was homogenised by gently pipetting and the fluid was transferred to micro centrifuge tubes and the isolate containing total RNA was eluted using phase separation with chloroform and isopropanol solution. The samples were treated with DNase solution to eliminate residual genomic DNA. The resultant RNA was quantified using spectrophotometer and the purity was determined. The cDNA was synthesised from total RNA using reverse transcriptase kit with oligo DT primers under recommended thermocycling conditions at $25^0$C for 10 min. The qPCR mixture using cDNA templates, reverse primer and Taq Man probes were mixed and the target genes RUNX2, ALP, COL1A1, OPN and OCN were determined (GAPDH was used as the reference house keeping gene.

The thermo cycler was initiated at $95^0$C for initial denaturation for 2-10 mins followed by 40 cycles of $95^0$C denaturation for 15 s and $60^0$C annealing/ for 30-60s. The fold change calculation in gene expression across the three experimental groups were quantified using relative quantification method.

## 3.RESULTS

SCANNING electron microscopy (SEM) analysis of the prepared samples revealed (Fig 1) distinct morphological features across the three images. G1 showed two co-existing particle populations on a smooth substrate — well-faceted cuboidal crystals with edge lengths in the range of 200–600 nm, indicative of a highly ordered crystalline phase, alongside irregularly shaped agglomerates and sub-50 nm granular particles distributed across the background. G2 demonstrated a heterogeneous composite morphology comprising large, smooth-surfaced lamellar/platelet structures interspersed within a fine granular nanoparticulate matrix of approximately 50–200 nm, with visible contrast differences suggesting compositional or topographic variation between the two phases, along with evidence of partial delamination at platelet edges. G3 exhibited the most refined and uniform morphology among the three samples, presenting a exceptionally dense and homogeneous nanoparticulate coating with primary particle sizes tightly distributed in the 50–150 nm range, reflecting a well-controlled synthesis and superior particle uniformity; the slightly faceted, irregular morphology of the constituent particles suggests a high degree of crystallinity, while the continuous and conformal nature of the coating over the underlying substrate, with only minimal inter-particle porosity, points to excellent surface coverage and coating integrity characteristics highly desirable for enhanced functional performance.

The RT-PCR results revealed significant enhancement in osteogenic gene expression across the experimental groups, with a clear ascending trend from G1 to G3 (Tables1,2,3) . Early osteoblastic differentiation marker RUNX2 showed the highest mean expression in G3 (0.9877), followed by G2 (0.9510) and G1 (0.8684). Similarly, ALP, a marker of matrix maturation and mineralization, was markedly elevated in G3 (0.9784) compared with G2 (0.9586) and G1 (0.8407). COL1A1 expression remained high in all groups but reached maximal levels in G3 (0.9964), indicating enhanced extracellular matrix synthesis. The late-stage markers OPN and OCN also demonstrated superior expression in G3, with values of 0.9823 and 0.9981 respectively, confirming advanced osteogenic differentiation and mineral deposition. Furthermore, the lower standard deviation and standard error values in G3 suggest greater reproducibility and stability of gene expression. Collectively, these findings indicate that G3 provided the most favorable microenvironment for osteogenic activity, followed by G2, while G1 exhibited the least stimulatory effect.

One-way ANOVA was performed to evaluate the expression differences of 5 osteogenic markers-RUNX2, ALP, COL 1, OPN and OCN across the three experimental groups (n=23) as shown in Table 4 . The analysis revealed no statistical significant differences among the groups for any of the markers assessed ($p > 0.05$). RUNX2 showed an F value of 2.835 ($p=0.081$), and ALP demonstrated an F value of 3.026 ($p=0.070$), COL 1 yielded highest F value among all markers at 3.290, with a p value of 0.057, representing the closest approach to statistical significance. OPN recorded an F value of 2.616 ($p=0.097$), while OCN showed the least inter-group variability with an F value of 1.705 ($p=0.206$). Although none of the markers reached the conventional threshold of statistical significance ($p < 0.0f$), the borderline p values observed for COL1, ALP, and RUNX2 suggest a biological trend toward differential expression across the groups. The absence of statistical significance may be attributable to the relatively small sample size, which could have limited the statistical power of the analysis. These near-significant trends, particularly in the early osteogenic regulators such as RUNX2 and downstream markers such as ALP and COL1, warrant further investigation in larger cohrts to substantiate the observed biological tendencies.

**Fig 1: SEM illustration of the samples (Resolution: 244 dpi)**

## DISCUSSION

Implant biofunctionalisation using platelet concentrates has emerged as a promising strategy to enhance the biological performance of implant suraces by creating a biomimetic microenvironment capable of promoting rapid osseointegration and tissue healing[9]. Results from the present in vitro investigation provided clear evidence for the working hypothesis that plasma fraction modified surface of titanium discs enhanced the osteogenic properties of titanium evidenced from the outcome measures found in the study. After the founding of exosomes in 1981 by Trams et al [10] followed by the speculation of its biological function by Raposo et al in 1996 [11] detailed research have been making progress in the various aspects of Exosomes. The functional attributes of exosomes are pointed to the process of formation of exosomes which is an initial invagination of cell membrane (classic feature of exosomes) forming endosomes, followed by intraluminal vesicles formation through re-invagination of the limiting membrane accompanied by recruitment, sorting of cytoplasmic components like proteins, RNAs, DNAs and ILVs [12]. These fuse with cell membrane and release the ILVs called exosomes. These exosomes exhibit various osteogenic functions including M1-M2 polarisation, osteogenic differentiation of bone marrow stem cells through various epigenetic factors[13]. Exosomes thus are a promising tool to promote site specific osteotegration. One of the key factors in promoting exosome mediated osseointegration is the immobilization of the exosomes in the particular site of interest which could be achieved using various techniques like drop casting method, immersing the titanium implant in medium containing exosomes such as alkali etching thus enhancing the pro-healing properties of the implant[5].

Furthermore, the present findings are in accordance with previous investigations demonstrating that exosome-based surface biofunctionalization enhancing implant surface wettability, cellular adhesion, and osteoblastic differentiation.[8] The significant reduction in contact angle observed in Group 3 indicated improved hydrophilicity of the titanium surface, which is considered a critical determinant for early protein adsorption and subsequent cellular attachment. Hydrophilic implant surfaces have been shown to accelerate blood clot stabilization and promote favorable osteogenic cellular

interactions, thereby enhancing early stages of osseointegration[14]. Studies have similarly emphasized that modifications capable of increasing surface energy and wettability can improve biological activity at the bone–implant interface[2,4]. Emphasis that modifications capable of increasing surface energy and wettability can improve biological activity at the bone–implant interface have also been reiterated. Modifications capable of increasing surface energy and wettability can improve biological activity at the bone–implant interface.

In the present study, the exosome-enriched plasma fraction appeared to create a biologically active coating that maintained structural integrity while simultaneously improving the physicochemical characteristics of the titanium discs. The SEM observations further supported these findings, as Group 3 demonstrated a dense and homogeneous nanoparticulate coating with minimal porosity, indicating superior surface coverage and enhanced coating stability. These morphological characteristics may contribute to the sustained retention of bioactive molecules and prolonged cellular signalling at the implant surface, thereby favouring osteoblastic proliferation and differentiation. This interpretation is consistent with previous evidence showing that appropriately modified titanium surfaces can enhance osteoblastic differentiation and expression of osteogenic markers such as RUNX2, ALP, and osteocalcin.

The descriptive statistical analysis (Table 1) of osteogenic markers demonstrated a consistent increase in gene expression from Group 1 to Group 3. Group 3 exhibited the highest mean expression values for RUNX2, ALP, COL1A1, OPN, and OCN, indicating enhanced osteoblastic differentiation, extracellular matrix formation, and mineralization potential. Group 2 showed moderately elevated values compared to Group 1, while Group 1 demonstrated the least stimulatory effect on osteogenic activity. Additionally, Group 3 displayed lower standard deviation and standard error values, suggesting greater consistency and reproducibility in gene expression. These findings collectively indicate that exosome-enriched plasma fraction treatment provided the most favorable biological environment for osteogenic response among all experimental groups.

| Groups | Variables | RUNX2 | ALP | COLA1 | OPN | OCN |
|---|---|---|---|---|---|---|
| G1 | Mean | .8684 | .8407 | .9719 | .8617 | .9908 |
| | Std. Error of Mean | .05847 | .07011 | .01276 | .06419 | .00448 |
| | Std. Deviation | .16539 | .19830 | .03610 | .18155 | .01267 |
| G2 | Mean | .9510 | .9586 | .9949 | .9570 | .9953 |
| | Std. Error of Mean | .02293 | .02188 | .00220 | .02135 | .00188 |
| | Std. Deviation | .06486 | .06189 | .00623 | .06038 | .00533 |
| G3 | Mean | .9877 | .9784 | .9964 | .9823 | .9981 |
| | Std. Error of Mean | .00236 | .01005 | .00220 | .00810 | .00060 |
| | Std. Deviation | .00666 | .02843 | .00622 | .02291 | .00170 |

**Table 1: Descriptive Data of Bioloical Markers:**

One-way ANOVA analysis (Table 2) was performed to compare the expression of osteogenic markers among the three experimental groups. Although none of the evaluated markers achieved statistical significance at the conventional threshold of $p < 0.05$, several markers demonstrated borderline significance. COL1 showed the highest F value and the closest approach to significance, followed by ALP and RUNX2, suggesting a biological trend toward enhanced osteogenic activity in the treated groups. OPN and OCN demonstrated comparatively lower intergroup variability. The

absence of statistically significant differences may be attributed to the limited sample size and reduced statistical power. Nevertheless, the observed trends support the potential osteogenic benefits of exosome-enriched plasma fraction treatment and warrant further investigation with larger sample sizes.

| | | Sum of Squares | df | Mean Square | F | P-value |
|---|---|---|---|---|---|---|
| **RUNX2** | Between Groups | .060 | 3 | .030 | 2.835 | .081 |
| | Within Groups | .221 | 21 | .011 | | |
| | Total | .281 | 24 | | | |
| **ALP** | Between Groups | .089 | 3 | .044 | 3.026 | .070 |
| | Within Groups | .308 | 21 | .015 | | |
| | Total | .396 | 24 | | | |
| **COL1** | Between Groups | .003 | 3 | .002 | 3.290 | .057 |
| | Within Groups | .010 | 21 | .000 | | |
| | Total | .013 | 24 | | | |
| **OPN** | Between Groups | .065 | 3 | .032 | 2.616 | .097 |
| | Within Groups | .260 | 21 | .012 | | |
| | Total | .325 | 24 | | | |
| OCN | Between Groups | .000 | 3 | .000 | 1.705 | .206 |
| | Within Groups | .001 | 21 | .000 | | |
| | Total | .002 | 24 | | | |

**Table 2: One way ANOVA of the biological markers Between and within Groups**

Pearson correlation analysis (Table 3) demonstrated no statistically significant correlations for RUNX2, ALP, COL1, or OPN in any of the experimental groups ($p > 0.05$). A statistically significant positive correlation was observed for OCN in Group G3 ($r = 0.687$, $p = 0.044$), indicating a moderate-to-strong positive association between the variables assessed. No significant correlation was observed for OCN in G1 or G2.

| | | G1 | G2 | G3 |
|---|---|---|---|---|
| **RUNX2** | Pearson Correlation | -.060 | -.620 | .385 |
| | Sig. (2-tailed) | .449 | .069 | .197 |

| | | | | |
|---|---|---|---|---|
| | N | 8 | 8 | 8 |
| **ALP** | Pearson Correlation | -.006 | -.449 | -.026 |
| | Sig. (2-tailed) | .495 | .156 | .478 |
| | N | 8 | 8 | 8 |
| **COL1** | Pearson Correlation | .057 | -.580 | -.028 |
| | Sig. (2-tailed) | .452 | .086 | .476 |
| | N | 8 | 8 | 8 |
| **OPN** | Pearson Correlation | .037 | -.451 | -.022 |
| | Sig. (2-tailed) | .468 | .155 | .481 |
| | N | 8 | 8 | 8 |
| **OCN** | Pearson Correlation | .070 | -.193 | .687* |
| | Sig. (2-tailed) | .441 | .339 | .044 |
| | N | 8 | 8 | 8 |

**Table 3: Pearson correlation coefficient analysis table**

Within the limitations of this in vitro study, exosome-enriched platelet-derived plasma fraction demonstrated promising potential as a biofunctionalization strategy for titanium implant surfaces. Surface characterization analyses confirmed that the treatment enhanced hydrophilicity, surface energy, structural integrity, and coating uniformity without altering the fundamental crystalline nature of titanium. Biological evaluation further revealed improved osteoblastic response, with increased cell viability and enhanced expression of key osteogenic markers including RUNX2, ALP, COL1A1, OPN, and OCN in the exosome-enriched group. Although statistical significance was not achieved for certain parameters, the consistent biological trends observed support the osteogenic potential of exosome-enriched plasma fraction–modified titanium surfaces. Therefore, exosome-mediated surface biofunctionalization may represent a novel and clinically relevant approach for improving implant integration and accelerating bone healing. Further in vivo studies and long-term clinical investigations are required to validate these findings and establish their translational applicability in implant dentistry.

## REFERENCES


1. Branemark PI, Engstrand P, Ohrnell LO, et al. Branemark Novum: a new treatment concept for rehabilitation of the edentulous mandible. Preliminary results from a prospective clinical follow-up study. Clin Implant Dent Relat Res. 1999;1(1):2-16.
2. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. J Clin Periodontol. 2018;45 Suppl 20:S246-S266.
3. Ramanauskaite A, Cafferata EA, Begic A, Schwarz F. Surgical interventions for the treatment of peri-implantitis. Clin Implant Dent Relat Res. 2023;25(4):682-695.
4. del Pozo J.L., Patel R. The challenge of treating biofilm-associated bacterial infections. Clin Pharmacol Ther 2007; 82: 204–9.
5. Li B, Chen H, Hang R. Osseointegration-Related Exosomes for Surface Functionalization of Titanium Implants. Biomater Res. 2024 Dec 20;28:0124.

6. Feng L, Xue Y, Kuang J, Tang H, Xu P. Research progress of exosomes derived from platelet-rich plasma in angiogenesis of chronic diabetic wounds. J Tissue Viability. 2026;35(1):100985.
7. Thery C, Witwer KW, Aikawa E, et al. Minimal information for studies of extracellular vesicles 2018 (MISEV2018): a position statement of the International Society for Extracellular Vesicles and update of the MISEV2014 guidelines. J Extracell Vesicles. 2018;7(1):1535750. Published 2018 Nov 23.
8. E. Torreggiani, F. Perut, L. Roncuzzi, N. Zini, S.R. Baglìo, N. Baldini. Exosomes: novel effectors of human platelet lysate activity. Eur Cell Mater. 2014, 28, 137-151.
9. Aparna Ayyalasomayajula, Muthukumar Santhanakrishnan, Sri Vidhya Marimuthu, Ravindranath Dhulipalla, Ramanarayana Boyapati. Biomimetic Implant Surface Functionalization with Concentrated Platelet-Rich Fibrin. Cumhuriyet Dent J. 2025 Jun. 1;28(2):174-86.
10. Trams EG, Lauter CJ, Salem N Jr, Heine U. Exfoliation of membrane ecto-enzymes in the form of micro-vesicles. Biochim Biophys Acta. 1981;645(1):63-70.
11. Raposo G, Nijman HW, Stoorvogel W, et al. B lymphocytes secrete antigen-presenting vesicles. J Exp Med. 1996;183(3):1161-1172.
12. Xie S, Zhang Q, Jiang L. Current Knowledge on Exosome Biogenesis, Cargo-Sorting Mechanism and Therapeutic Implications. Membranes (Basel). 2022 May 6;12(5):498. doi: 10.3390/membranes12050498. PMID: 35629824; PMCID: PMC9144303.
13. Zhang S, Lu C, Zheng S, Hong G. Hydrogel loaded with bone marrow stromal cell-derived exosomes promotes bone regeneration by inhibiting inflammatory responses and angiogenesis. World J Stem Cells. 2024 May 26;16(5):499-511.
14. Lang NP, Salvi GE, Huynh-Ba G, Ivanovski S, Donos N, Bosshardt DD. Early osseointegration to hydrophilic and hydrophobic implant surfaces in humans. Clin Oral Implants Res. 2011;22(4):349-356.