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COMPARATIVE EVALUATION OF THE TREATMENT OUTCOMES FOR INTRABONY VERTICAL DEFECTS BY USING INTRA ORAL OSSEOUS AUTOGRAFT, DEMINERALIZED BONE MATRIX ALONE AND A COMBINATION OF DEMINERALIZED BONE MATRIX AND INJECTABLE PLATELET RICH FIBRIN - A CLINICAL AND RADIOGRAPHIC STUDY

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ABSTRACT

Background: Periodontal intrabony defects are a major problem to treat in periodontology, making regenerative therapy necessary to obtain a desired clinical outcome. Alternatives to autogenous bone grafts (ABG) used to improve periodontal regeneration include demineralized bone matrix (DBM) and platelet rich fibrin (PRF) injected (i-PRF).

Study Design: The study was a randomized, single blind, parallel arm clinical study that compared the efficacy of ABG, DMBM and DMBM + i-PRF for the treatment of periodontal intrabony defects.

Materials and Methods: The study subjects were 45 patients with chronically diseased periodontal tissues, who had intrabony defects and were randomly divided into three groups: (A) ABG, (B) DMBM and (C) DMBM + i-PRF (15 patients in each group). "Plaque Index (PI), Gingival Index (GI), Bleeding on Probing (BOP), Probing Pocket Depth (PPD), and Relative Clinical Attachment Level (RCAL) were measured at baseline, 3 months and 6 months. Baseline and 6 months, radiographs were used to assess residual bone level.

Statistical Analysis: Data were analyzed using Repeated Measures ANOVA for intragroup comparisons and One-way ANOVA with Tukey's post hoc test for intergroup comparisons. Statistical significance was set at $p < 0.05$.

Results: All groups demonstrated significant improvements in PPD, RCAL, and residual bone levels from baseline to 6 months ($p < 0.001$). Significant reductions in PI, GI, and BOP were also observed. Intergroup analysis revealed significantly greater RCAL gain and bone fill in the ABG group compared with the DMBM and DMBM + i-PRF groups ($p < 0.05$). No significant differences were observed between DMBM and DMBM + i-PRF.

Conclusion: All treatment modalities were effective in improving periodontal parameters; however, ABG demonstrated superior regenerative outcomes compared with DMBM alone or DMBM combined with i-PRF.

KEYWORDS: Periodontitis, Intrabony Defects, Periodontal Regeneration, Autogenous Bone Graft, Demineralized Bone Matrix, Injectable Platelet-Rich Fibrin.

INTRODUCTION

Periodontitis is a chronic inflammatory disease of the teeth's supporting structures: the gingiva, periodontal ligament, cementum and alveolar bone. It is started when microbial biofilm begins to accumulate and can lead to the progressive attachment loss of the teeth along with the destruction of the alveolar bone and can eventually cause tooth loss if not treated. Periodontitis is classified into four stages (I – IV) according to disease severity and complexity in 2018, which helps in better diagnosis and planning of treatment. [1-2]

Periodontal osseous defects in which supporting bone is lost around a tooth are known as intrabony defects and are recognized as difficult defects in periodontal therapy. Depending on the number of bony walls left, these defects can be categorized as being a one-wall, two-wall or three-wall defect. The main goals of periodontal regenerative therapy are to restore the lost periodontal tissues, enhance clinical attachment level, decrease probing pockets and provide long-term stability of the tooth. [3-6]

A number of different methods have been suggested to manage intrabony defects, such as autogenous bone grafting, barrier membranes, allografts, xenografts, and the use of biologic modifiers. Of these, autogenous bone grafts are the most effective due to their osteogenic, osteoinductive and osteoconductive characteristics. However, their clinical applications are restricted by donor site morbidity, the lack of available grafts, and greater surgical complexity. [7-9]

The resultant demineralized bone matrix (DMBM) is a xenogenic graft material that has come to light as a very promising alternative because of its biocompatibility, osteoconductive characteristics, and the exposure of bioactive growth factors during demineralization. Further, platelet concentrates have attracted considerable interest in the field of regenerative

periodontal therapy. The second-generation platelet concentrates, called as Injectable platelet rich fibrin (i-PRF), have a high concentration of leukocytes, platelets and growth factors that can stimulate angiogenesis, fibroblast proliferation and tissue regeneration. The previous studies have showed the positive effects of i-PRF on soft- and hard-tissue healing. [10-12]

While there have been multiple studies investigating the restoration of intraoral autogenous bone grafts, demineralized bone matrix and platelet concentrates, there is a lack of data comparing the clinical and radiographic results of using intraoral autogenous bone grafts, DMBM alone, and DMBM with i-PRF to restore periodontal intrabony defects. Thus, the present study was designed to assess and compare the efficacy of intraoral osseous autograft, demineralized bone matrix and demineralized bone matrix mixed with injectable platelet-rich fibrin as therapeutic agents for the management of periodontal intrabony defects. [13-14]

MATERIALS AND METHODS

This single blind, randomized controlled clinical trial with three parallel groups was carried out with the approval of the Institutional Ethical Committee and registration at the Clinical Trial Registry-India (CTRI No. CTRI/2023/11/059834) from June 2024 to April 2026 in the Department of Periodontology and Oral Implantology. Forty-five patients with vertical intrabony defects and periodontitis between the ages of 30 and 55 were included and randomly divided among three groups (A, B, and C, 15 patients each).45 patients with vertical intrabony defects and periodontitis (30–55 years) were enrolled and randomly assigned to three groups (A, B, and C, 15 patients each). Patients who presented with probing pocket depth (PPD) ≥ 5 mm and radiographic defect depth (RDD) ≥ 3 mm after Phase I therapy were included whereas the smokers, pregnant women, medically compromised patients, patients with poor oral hygiene, contraindications to periodontal surgery and patients who had received periodontal therapy in the last six months were excluded. After reevaluation after Phase I therapy, they were randomly allocated by lottery. A blinded examiner recorded clinical parameters at baseline, 3 months, and 6 months: Plaque Index (PI), Gingival Index (GI), Bleeding on Probing (BOP), Probing Pocket Depth (PPD) and Relative Clinical Attachment Level (RCAL). To evaluate bone loss and bone fill, standardized intraoral periapical radiographs were taken at baseline and 6 months. The flaps were reflected and defects were debrided, then followed by group allocated regenerative procedures.

Statistical analysis

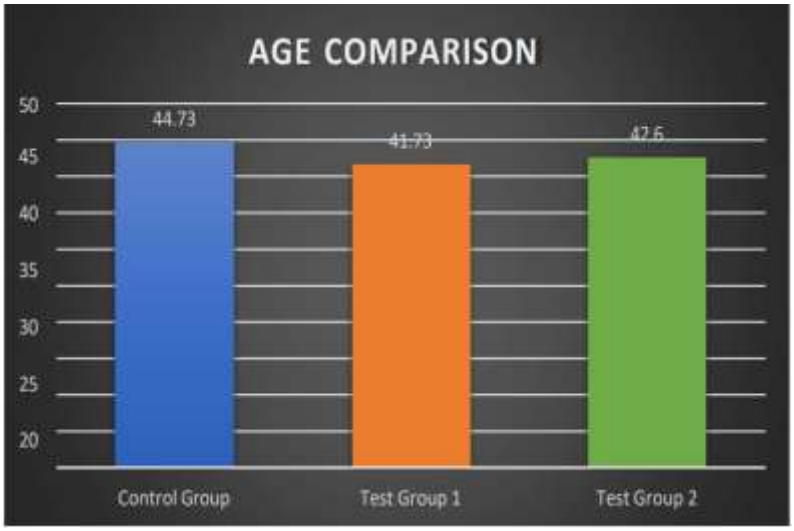
In this research, descriptive statistics have been used. The data were analysed using SPSS version 21. Quantitative variables were expressed as mean ± standard deviation and statistical analysis performed using the Shapiro–Wilk test, the Repeated Measures ANOVA with Tukey's post hoc test and paired t-test and one-way ANOVA, respectively, with $p < 0.05$ considered statistical significance.

RESULTS

A total of 45 patients with periodontal intrabony defects were enrolled in the study and none of the patients dropped out after 6 months. A total of 15 patients in each group were randomly divided into the groups: Autogenous Bone Graft (ABG), Demineralized Bone Matrix (DMBM) and Demineralized Bone Matrix with Injectable Platelet-Rich Fibrin (DMBM + i-PRF). The demographic characteristics were similar between the groups. No statistically significant difference was found between the mean age of participants in the ABG group (44.73 ± 8.72 years) and the mean age of participants in the DMBM group (41.73 ± 9.24 years) and the mean age of participants in the DMBM + i-PRF group (42.60 ± 8.54 years) ($p = 0.636$). There was also no significant difference between the groups for gender ($p = 0.315$). Clinical and radiographic assessment revealed marked improvement in all periodontal parameters (probing pocket depth reduction, relative clinical attachment gain and bone fill) in all the treatment groups throughout the study period.

Table 1: Intergroup Comparison of Age Distribution

Group	Mean Age (Years) ± SD
Control Group (BD)	44.73 ± 8.72
Test Group 1 (DMBM)	41.73 ± 9.24
Test Group 2 (DMBM + I-PRF)	42.60 ± 8.54
One-way ANOVA (F-value)	0.457
p-value	0.636 (NS)

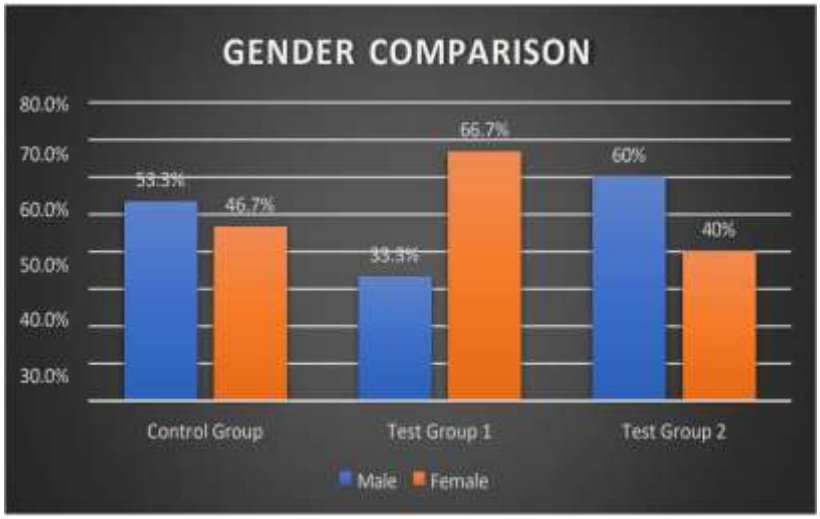


Graph 1: Age Comparison

The mean age was 44.73 ± 8.72 years in the Control group, 41.73 ± 9.24 years in Test Group 1, and 42.60 ± 8.54 years in Test Group 2. One-way ANOVA showed no statistically significant difference among groups (F = 0.457, p = 0.636), indicating comparable baseline age distribution.

Table 2: Intergroup Comparison of Gender Distribution

Group	Male n (%)	Female n (%)
Control Group (BD)	8 (53.3%)	7 (46.7%)
Test Group 1 (DMBM)	5 (33.3%)	10 (66.7%)
Test Group 2 (DMBM + I-PRF)	9 (60.0%)	6 (40.0%)
Chi-square Test (χ^2)	2.312	
p-value	0.315 (NS)	



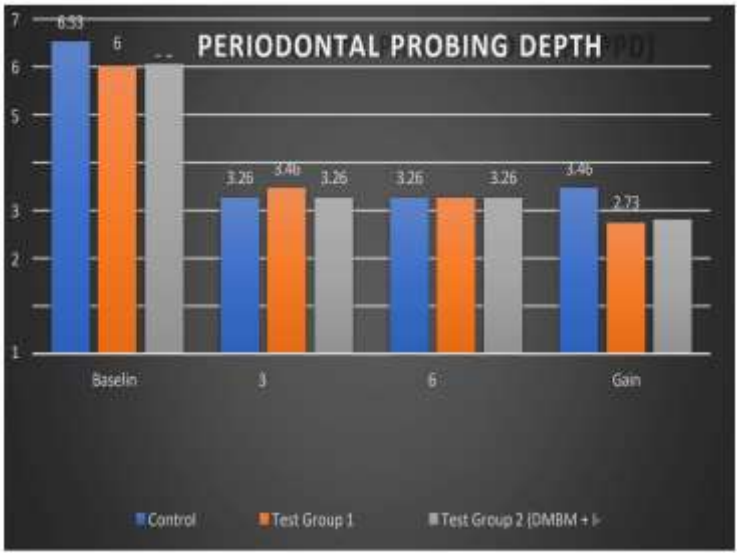
Graph 2: Gender Comparison

The Control group comprised 53.3% males and 46.7% females, Test Group 1 included 33.3% males and 66.7% females, while Test Group 2 consisted of 60.0% males and 40.0% females. Chi-square analysis revealed no significant difference in gender distribution among groups (χ^2 = 2.312, p = 0.315).

Table 3: Intragroup Comparison of Clinical Parameters

Time Interval	PPD – Control (BD)	PPD – Test 1 (DMBM)	PPD – Test 2 (DMBM + I-PRF)	CAL – Control (BD)	CAL – Test 1 (DMBM)	CAL – Test 2 (DMBM + I-PRF)
Baseline	6.53 ± 1.12	6.00 ± 1.13	6.06 ± 1.09	11.33 ± 1.63	11.86 ± 1.59	12.13 ± 1.76
3 Months	3.26 ± 0.96	3.46 ± 0.99	3.26 ± 0.70	8.00 ± 1.55	9.26 ± 1.62	9.46 ± 1.64

6 Months	3.26 ± 0.96	3.26 ± 0.91	3.26 ± 0.70	7.93 ± 1.53	9.26 ± 1.62	9.46 ± 1.64
Repeated Measures ANOVA (F)	145.32	132.18	158.64	123.23	101.87	107.23
Overall p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Baseline vs 3 Months	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Baseline vs 6 Months	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
3 Months vs 6 Months	1.000 (NS)	0.876 (NS)	1.000 (NS)	0.037*	0.043*	0.031*

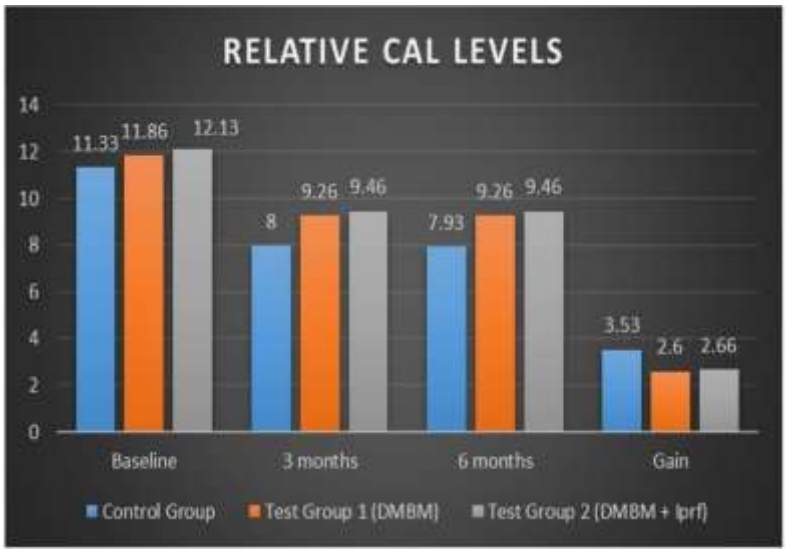


Graph 3: Intragroup comparison of periodontal probing depth (PPD)

All groups showed significant reductions in probing pocket depth (PPD) and clinical attachment level (CAL) from baseline to 6 months ($p < 0.001$). Mean PPD decreased from 6.53–6.06 mm to 3.26 mm, while CAL improved substantially. No significant PPD changes occurred between 3 and 6 months, whereas CAL continued improving.

Table 4: Intra- and Intergroup Comparison of Relative Clinical Attachment Level (RCAL)

Parameter	Control Group (BD) Mean ± SD	Test Group 1 (DMBM) Mean ± SD	Test Group 2 (DMBM + I-PRF) Mean ± SD	F-value	p-value
Baseline	11.33 ± 1.63	11.86 ± 1.59	12.13 ± 1.76	0.895	0.416 (NS)
3 Months	8.00 ± 1.55	9.26 ± 1.62	9.46 ± 1.64	3.476	0.040*
6 Months	7.93 ± 1.53	9.26 ± 1.62	9.46 ± 1.64	3.853	0.029*
Total Gain	3.53 ± 0.63	2.60 ± 0.73	2.66 ± 0.61	9.150	0.001*
Repeated Measures ANOVA (F)	123.23	101.87	107.23	—	—
Overall p-value	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 3 Months	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 6 Months	<0.001**	<0.001**	<0.001**	—	—
3 Months vs 6 Months	0.037*	0.043*	0.031*	—	—
Control vs Test 1	0.658 (NS)	0.102 (NS)	0.070 (NS)	—	—
Control vs Test 2	0.396 (NS)	0.049*	0.032*	—	—
Test 1 vs Test 2	0.900 (NS)	0.941 (NS)	0.941 (NS)	—	—

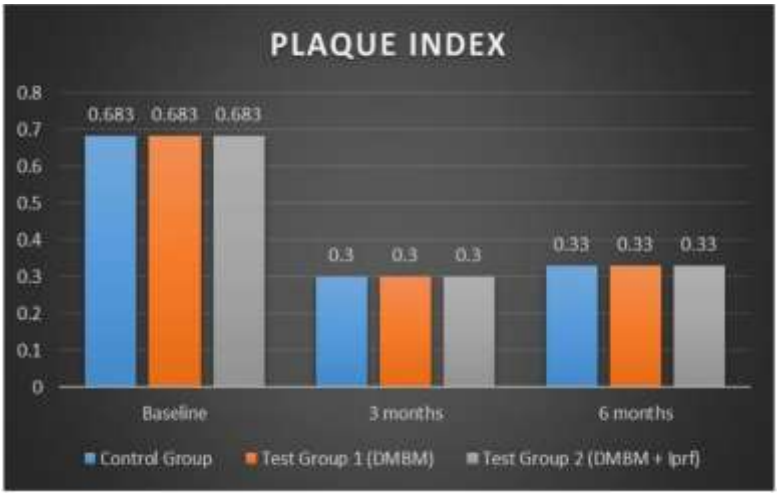


Graph 4: Intragroup comparison of Relative Clinical Attachment Level (RCAL)

RCAL improved significantly within all groups from baseline to 6 months ($p < 0.001$). The Control group demonstrated the highest attachment gain (3.53 ± 0.63 mm) compared with Test Group 1 (2.60 ± 0.73 mm) and Test Group 2 (2.66 ± 0.61 mm). Intergroup differences were statistically significant ($p = 0.001$).

Table 5: Intra- and Intergroup Comparison of Plaque Index (PI)

Parameter	Control Group (BD) Mean ± SD	Test Group 1 (DMBM) Mean ± SD	Test Group 2 (DMBM + I-PRF) Mean ± SD	F-value	p-value
Baseline	0.683 ± 0.22	0.683 ± 0.22	0.683 ± 0.22	0.00	1.00 (NS)
3 Months	0.30 ± 0.25	0.30 ± 0.25	0.30 ± 0.25	0.00	1.00 (NS)
6 Months	0.33 ± 0.24	0.33 ± 0.24	0.33 ± 0.24	0.00	1.00 (NS)
Repeated Measures ANOVA (F)	36.12	36.12	36.12	—	—
Overall p-value	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 3 Months	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 6 Months	<0.001**	<0.001**	<0.001**	—	—
3 Months vs 6 Months	0.067 (NS)	0.067 (NS)	0.067 (NS)	—	—
Control vs Test 1	1.00 (NS)	1.00 (NS)	1.00 (NS)	—	—
Control vs Test 2	1.00 (NS)	1.00 (NS)	1.00 (NS)	—	—
Test 1 vs Test 2	1.00 (NS)	1.00 (NS)	1.00 (NS)	—	—

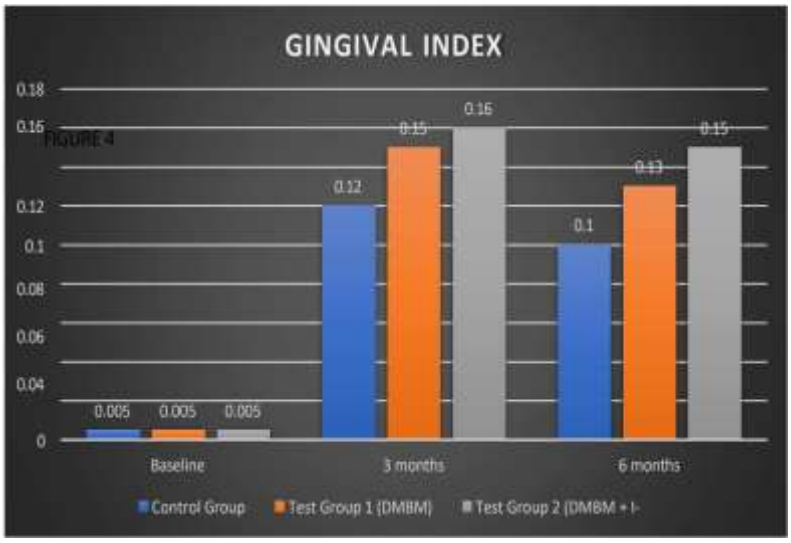


Graph 5: Intragroup comparison of Intragroup comparison of Plaque index (PI)

Plaque Index showed a significant reduction within all groups from baseline (0.683 ± 0.22) to 3 months (0.30 ± 0.25) and 6 months (0.33 ± 0.24) ($p < 0.001$). However, intergroup comparisons revealed no statistically significant differences at any time point ($p = 1.00$), indicating comparable plaque control.

Table 6: Intra- and Intergroup Comparison of Gingival Index (GI)

Parameter	Control Group (BD) Mean ± SD	Test Group 1 (DMBM) Mean ± SD	Test Group 2 (DMBM + I-PRF) Mean ± SD	F-value	p-value
Baseline	0.005 ± 0.00	0.005 ± 0.00	0.005 ± 0.00	0.00	1.00 (NS)
3 Months	0.120 ± 0.21	0.150 ± 0.22	0.160 ± 0.23	0.130	0.879 (NS)
6 Months	0.100 ± 0.21	0.130 ± 0.22	0.150 ± 0.22	0.199	0.820 (NS)
Repeated Measures ANOVA (F)	14.98	15.09	17.12	—	—
Overall p-value	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 3 Months	0.012*	0.040*	0.001*	—	—
Baseline vs 6 Months	0.003*	0.001*	<0.001**	—	—
3 Months vs 6 Months	0.084 (NS)	0.084 (NS)	0.084 (NS)	—	—
Control vs Test 1	1.00 (NS)	0.929 (NS)	0.925 (NS)	—	—
Control vs Test 2	1.00 (NS)	0.827 (NS)	0.806 (NS)	—	—
Test 1 vs Test 2	1.00 (NS)	0.992 (NS)	0.966 (NS)	—	—



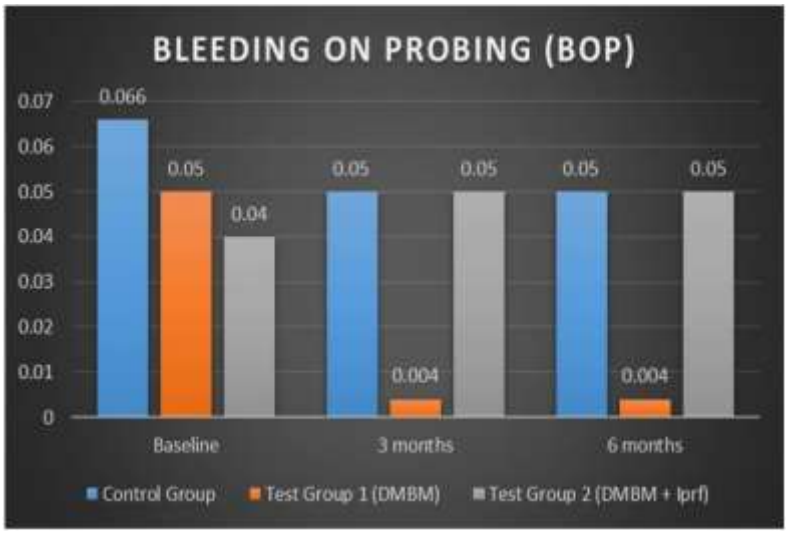
Graph 6: Intragroup comparison of Gingival index (GI)

Gingival Index demonstrated significant intragroup improvement in all groups over the study period ($p < 0.001$). Mean GI values remained low at 6 months, measuring 0.100 ± 0.21, 0.130 ± 0.22, and 0.150 ± 0.22 in the respective groups. No statistically significant intergroup differences were observed ($p > 0.05$).

Table 7: Intra- and Intergroup Comparison of Bleeding on Probing (BOP)

Parameter	Control Group (BD) Mean ± SD	Test Group 1 (DMBM) Mean ± SD	Test Group 2 (DMBM + I-PRF) Mean ± SD	F-value	p-value
Baseline	0.066 ± 0.25	0.050 ± 0.19	0.040 ± 0.25	0.077	0.968 (NS)

3 Months	0.050 ± 0.14	0.004 ± 0.01	0.050 ± 0.19	0.553	0.579 (NS)
6 Months	0.050 ± 0.14	0.004 ± 0.15	0.050 ± 0.19	0.294	0.747 (NS)
Repeated Measures ANOVA (F)	9.38	9.38	9.38	—	—
Overall p-value	0.002*	0.002*	0.002*	—	—
Baseline vs 3 Months	1.000 (NS)	1.000 (NS)	1.000 (NS)	—	—
Baseline vs 6 Months	0.021*	0.021*	0.021*	—	—
3 Months vs 6 Months	0.021*	0.021*	0.021*	—	—
Control vs Test 1	0.969 (NS)	0.637 (NS)	0.832 (NS)	—	—
Control vs Test 2	0.921 (NS)	1.000 (NS)	0.751 (NS)	—	—
Test 1 vs Test 2	0.988 (NS)	0.637 (NS)	0.989 (NS)	—	—

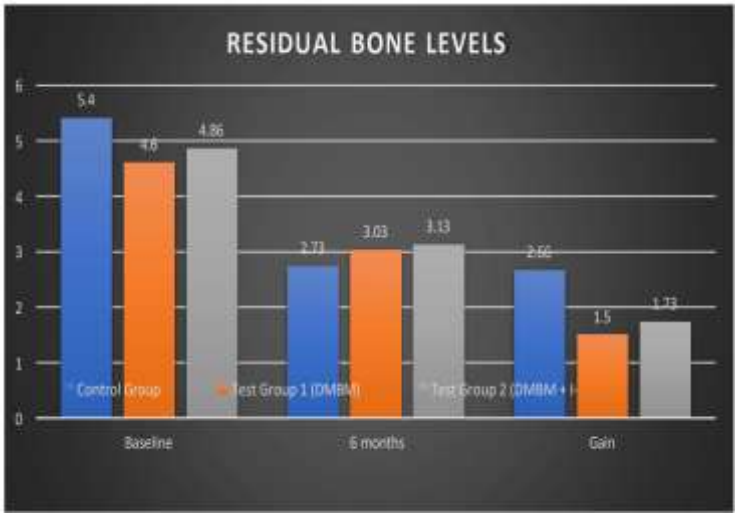


Graph 7: Intragroup comparison of Bleeding on Probing (BOP)

Bleeding on Probing (BOP) showed significant intragroup improvement in all groups over the 6-month period (overall p = 0.002). Mean BOP decreased from 0.066 ± 0.25 to 0.050 ± 0.14 in the Control group and remained low in both test groups. Intergroup differences were not statistically significant (p > 0.05).

Table 8: Intra- and Intergroup Comparison of Residual Bone Level (RBL)

Parameter	Control Group (BD) Mean ± SD	Test Group 1 (DMBM) Mean ± SD	Test Group 2 (DMBM + I-PRF) Mean ± SD	F-value	p-value
Baseline	5.40 ± 1.05	4.60 ± 0.73	4.86 ± 0.99	2.830	0.070 (NS)
6 Months	2.73 ± 0.70	3.03 ± 0.74	3.13 ± 0.74	1.219	0.306 (NS)
Bone Fill Gain	2.66 ± 0.61	1.50 ± 0.46	1.73 ± 0.53	19.573	<0.001**
Repeated Measures ANOVA (F)	88.63	176.45	152.28	—	—
Overall p-value	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 3 Months	<0.001**	<0.001**	<0.001**	—	—
Baseline vs 6 Months	<0.001**	<0.001**	<0.001**	—	—
3 Months vs 6 Months	0.041*	<0.001**	<0.001**	—	—
Control vs Test 1	0.062 (NS)	0.504 (NS)	<0.001**	—	—
Control vs Test 2	0.275 (NS)	0.301 (NS)	<0.001**	—	—
Test 1 vs Test 2	0.718 (NS)	0.926 (NS)	0.470 (NS)	—	—



Graph 8: Intragroup comparison of Residual Bone level

Residual Bone Level showed significant improvement within all groups from baseline to 6 months ($p < 0.001$). The Control group exhibited the greatest bone fill gain (2.66 ± 0.61 mm), followed by Test Group 2 (1.73 ± 0.53 mm) and Test Group 1 (1.50 ± 0.46 mm). Intergroup differences were highly significant ($p < 0.001$).

DISCUSSION

The present research investigated and compared the clinical and radiographical success of three different techniques (Autogenous Bone Graft (ABG), Demineralized Bone Matrix (DMBM), and DMBM associated with Injectable Platelet-Rich Fibrin (i-PRF)) for the treatment of intrabony defects in the periodontal space. All the clinical parameters, such as probing pocket depth (PPD), relative clinical attachment level (RCAL), plaque index (PI), gingival index (GI), bleeding on probing (BOP), and residual bone level showed significant improvement in all the groups during the 6-month follow-up period. The results showed that all three treatments were effective in healing and regeneration in the periodontal tissues. [15-16]

Reduction of PPD and increase of RCAL was noted between baseline and 6 months, and this was likely due to effective debridement and regenerative therapy. The ABG group showed superior clinical attachment gain and radiographic bone fill, however, when analyzed between groups the ABG group outperformed the DMBM and DMBM + i-PRF groups. The improved performance of ABG might be attributed to being osteogenic, osteoinductive and osteoconductive, thus providing viable osteogenic cells and growth factors at the defect site. The results are similar to those of other studies which have documented that autogenous bone grafting is the best method for regeneration of the periodontium. [17-19]

The incorporation of i-PRF in DMBM provided good clinical and radiographic results, but no statistical differences were found between the two groups. This discovery might be due to the limited follow-up duration and the relatively small number of samples that were analyzed, which could not have been adequate to capture minor differences in regeneration. In addition, oral hygiene parameters were kept well controlled throughout the study and the effect of the inflammation caused by plaque on the treatment outcomes was minimized. ABG showed the most promising regenerative response with clinically significant results in periodontal intrabony defects compared to DMBM and DMBM plus i-PRF within the limitations of this study. [20]

CLINICAL IMPLICATIONS

Based on the results of the present study, it can be concluded that the regenerative therapy is effective in the treatment of periodontal intrabony defects. Significant clinical and radiographic changes were obtained with all three treatment modalities namely Autogenous Bone Graft (ABG), Demineralized Bone Matrix (DMBM), and DMBM with Injectable Platelet-Rich Fibrin (i-PRF), proving their usefulness in periodontal regeneration. Because of its osteogenic, osteoinductive, and osteoconductive characteristics, ABG has been proven to be the gold standard regenerative material with better results than others. When autogenous bone is limited or a second surgical site is not desired, however, both DMBM and DMBM + i-PRF showed good healing responses, with both potentially being useful alternatives. i-PRF has further biological properties with a prolonged release of growth factors that can improve wound healing and maturation. As a result, these regenerative materials may be considered as useful materials for the improvement of periodontal stability, pocket depth reduction, and promotion of bone regeneration in intrabony defect.

LIMITATIONS

There are some limitations to this study, which should be taken into consideration when interpreting the findings of the study. The sample size was relatively small and may have reduced the number of differences that could have been detected among the treatment groups. Six months follow-up period may not have been long enough to assess the long-term stability and maturation of regenerated periodontal tissues. A radiographic evaluation was conducted with conventional intraoral periapical radiographs; less accurate methods of 3D radiographic assessment such as cone-beam computed tomography (CBCT) may not be as accurate. Furthermore, the histological examination was not performed, so cellular confirmation of true periodontal regeneration was not possible. Other factors such as patient-related factors, including differences in

healing ability and oral hygiene, were also suspected to have affected treatment outcomes. Further research with a larger number of patients, longer follow-up periods, newer imaging techniques, and histological examination is recommended to confirm the regenerative ability of DMBM and i-PRF in intrabony defects of the periodontium.

CONCLUSION

ll three treatment modalities (Autogenous Bone Graft (ABG), Demineralized Bone Matrix (DMBM), and DMBM with an Injectable Platelet-Rich Fibrin (i-PRF)) showed significant clinical and radiographic improvements on periodontal intrabony defects within the limitation of this study. All groups showed significant decreases in probing pocket depth, plaque index, gingival index, bleeding on probing and residual bone level, and significant increases in relative clinical attachment level, after 6 months. The results of this study validated the effectiveness of regenerative periodontal treatment to improve periodontal wound healing and defect resolution. The assessed treatment modalities showed that the ABG group demonstrated better clinical attachment gain and more bone fill in the radiograph than the DMBM and DMBM + i-PRF groups, thus reinforcing the status of autogenous bone grafts as the gold standard for periodontal" regeneration. The incorporation of i-PRF with DMBM led to good clinical outcomes, but no statistically significant improvement was achieved over DMBM alone during the study period. Thus, all the regenerative strategies were clinically good, but ABG had the more reproducible regenerative results. More research with larger sample size and longer follow-up periods is recommended for assessing the long-term effectiveness of DMBM and i-PRF therapies in periodontal intrabony defects

Indian mustard (Brassica juncea (L.) Czern & Coss) is well adapted to diverse agro-climatic conditions and plays a crucial role in ensuring edible oil security. However, its productivity is constrained by several factors, including a narrow genetic base, susceptibility to biotic and abiotic stresses, and suboptimal agronomic practices (Rakow and Woods, 1987; Singh et al., 2010). In regions like Uttar Pradesh, late sowing due to delayed harvesting of preceding crops often exposes the crop to terminal heat stress, significantly reducing yield (Kumar et al., 2018). Therefore, the development of high-yielding and stress-resilient varieties remains a key breeding objective.

Heterosis, or hybrid vigor, is a powerful genetic phenomenon widely utilized for yield enhancement. The study of heterosis provides essential insights into the genetic architecture of yield and its component traits, as well as the breeding potential of parental lines (Shull, 1908; Hayes et al., 1955). In a predominantly self-pollinated crop like Indian mustard, the exploitation of heterosis depends on its magnitude, direction, and the nature of gene action involved. Estimation of relative heterosis (over mid-parent) and heterobeltiosis (over better parent) is useful for identifying superior cross combinations (Fonseca and Patterson, 1968).

Furthermore, partitioning genetic variance into general combining ability (GCA) and specific combining ability (SCA) helps in understanding the relative importance of additive and non-additive gene effects (Griffing, 1956). The performance of F_1 hybrids is influenced by both fixable (additive) and non-fixable (dominance and epistatic) gene actions, which determine the scope for selection and hybrid development (Sprague and Tatum, 1942). Traits such as seed yield, oil content, seeds per siliqua, and 1000-seed weight are key determinants of productivity and economic value in mustard, necessitating their simultaneous improvement (Singh et al., 2017).

Diallel mating designs are effective tools for evaluating combining ability and identifying superior parents and cross combinations. Despite extensive research in mustard breeding, limited attention has been paid to environment-specific heterosis, particularly under contrasting sowing conditions such as timely and late sowing. Such evaluation is essential to identify stable and high-performing hybrids across environments (Allard, 1960; Falconer and Mackay, 1996).

In this context, the present study employs a half-diallel mating design to assess heterosis and combining ability among selected Indian mustard genotypes under contrasting environments. The objective is to identify promising heterotic cross combinations and superior parents for yield and oil-related traits, with particular emphasis on the agro-climatic conditions of Uttar Pradesh. The findings are expected to contribute to the development of high-yielding, high-oil mustard hybrids with improved adaptability, thereby supporting sustainable oilseed production and reducing import dependency.

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