Original Article

Outcome of novel pulp capping modalities after full pulpotomy in teeth diagnosed with irreversible pulpitis: A prospective randomized clinical trial

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Abstract

Objective: The study aimed to compare and evaluate the effect of biodentine (BD) alone, BD along with Lyophilised freeze dried platelet rich concentrate (LPC + BD), and BD along with low-level laser therapy (BD + LLLT) after pulpotomy in mature permanent molars with irreversible pulpitis.

Materials and Methods: The study was designed as a randomized, pragmatic, parallel, double-blinded clinical trial registered under the Clinical Trial Registry–India (CTRI/2020/02/023245). 120 permanent molars fulfilling the inclusion and exclusion criteria with symptoms of irreversible pulpitis were randomized after performing pulpotomy into three pulp capping groups: Group 1, BD; Group 2, lyophilized freeze-dried platelet-rich concentrate + BD (LPC + BD); and Group 3, Low level laser therapy + BD Group 3, LLLT + BD. The intergroup comparison was done using one-way analysis of variance followed by the Bonferroni test. The level of significance and confidence interval were 5% and 95%, respectively. Interobserver reliability was measured using Cohen's kappa analysis.

Results: At 1 week, there was a significant difference ($P < 0.005$) observed in the mean postoperative pain levels between the three groups with Group 1 (BD) exhibiting the highest postoperative pain followed by Group 2 (LPC + BD) and least pain was exhibited by Group 3 (LLLT + BD). A similar pattern was observed regarding the analgesic intake with maximum frequency in Group 1 (BD) and least with Group 3 (LLLT + BD). No significant difference in success rates was reported among the groups.

Conclusion: Pulpotomy as a treatment option for mandibular molars with irreversible pulpitis has an acceptable clinical success rate; however, long-term overall success rate remains questionable. The outcomes of incorporating adjunctive modalities with BD are remarkable and show tremendous potential for continued development and research.

Keywords: Biodentine; irreversible pulpitis; low-level laser therapy; lyophilized freeze-dried platelet-rich concentrate; pulpotomy

INTRODUCTION

The dental pulp is a unique soft connective tissue that encompasses a rich neurovascular network. Trauma or iatrogenic injury results in pulpal exposure which initiates a cascade of an inflammatory process. When neglected, it may result in pulpal necrosis that further undermines the tooth integrity.[1] There has been no universal consensus as to which treatment is the best to manage pulp exposure. Acknowledging the inherent healing potential of an infection-free pulp, the current endodontic therapy has made a paradigm shift from nonsurgical root canal therapy toward the regeneration of a healthy pulp–dentine complex.[2]

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The concept of vital pulp therapy (VPT) has general acceptance due to the ultimate preservation of vital pulp.[3] It serves a reparative function, retains defense by a feedback mechanism, and enables stress distribution. Pulpotomy has been proposed as an alternative for the management of irreversible pulpitis in permanent molars with closed apices. Factors that owe to the success of pulpotomy include absence/control of inflammation, hemostasis, choice of the pulp capping material, and an adequate seal of the tooth.[4]

Furthermore, the properties of pulp capping modality like antibacterial effect, sealing ability, induction of dentinal bridge formation, and root development are paramount.[5] Calcium hydroxide (CH) and mineral trioxide aggregate (MTA) have been considered the gold standard. However, disadvantages such as degradation over time, formation of tunnel defects, and poor sealing, CH is no longer an ideal choice. The properties of MTA are remarkable, making it a reliable alternative, but its long setting time, tooth discoloration, and initial high solubility remain a concern.[5,6]

Biodentine (BD) (Septodont, Saint-Maur-des-Fossés, France) is another bioactive calcium silicate-based cement technology of MTA with modified properties. It has a short setting time, washout resistance, biocompatibility, mechanical strength, successful marginal integrity, and easy manipulation without any discoloration potential. It encourages dentinal bridge formation without provoking an inflammatory reaction.[7,8] There has been a continuous research in natural biomaterials having anti-inflammatory and regenerative potential.[8] Platelet-rich plasma (PRP) has been extensively considered a pulp capping agent in VPT with promising results. Being strictly autologous, platelet concentrates are more biocompatible and elicit minimal or nil inflammatory response.[9] Another modality with promising results is laser therapy in the form of low-level laser therapy (LLLT) for hemorrhage control and pain relief as well as enhancing the repair process and photobiomodulation that may accelerate the regeneration of the pulp–dentine complex.[10] Supplementing pulp capping material like BD with adjuvants like PRP and LLLT may provide superior outcome and needs to be investigated.

Previous studies have compared the success of various pulp capping agents.[11,12] However, to our knowledge, there is no clinical trial reported to date comparing the outcome of pulpotomy using BD and adjuvants like lyophilized freeze-dried platelet-rich concentrate and LLLT. The uniqueness of this study involves the treatment protocol and the novel pulp capping materials. This study aimed to evaluate and compare the outcome of VPT in cases of mature permanent teeth with irreversible pulpitis using BD, lyophilized freeze-dried platelet-rich concentrate, and LLLT.

MATERIALS AND METHODS

The study was approved by the Ethical Committee and Institutional Review Board under protocol number (IEC/2020/266) and the trial was registered under the Clinical Trial Registry–India (CTRI), hosted at ICMR's National Institute of Medical Statistics with the registration no. CTRI/2020/02/023245. The study was designed as a randomized, pragmatic, parallel, double-blinded clinical trial where the observer and the patient were blinded to the process. It was performed from February 2020 to September 2020 on patients referred to the endodontic specialty for treatment of maxillary and mandibular molars.

Criteria for selection of patients

Subjects fulfilling the inclusion and exclusion criteria were recruited from the pool of patients referred to the Department of Conservative Dentistry and Endodontics. The procedure was duly explained to the patient and written informed consent was obtained.

Inclusion criteria

- Vital mature permanent maxillary or mandibular molars with deep caries approximating the pulp space diagnosed as irreversible pulpitis without apical periodontitis (periapical index [PAI] =1 according to Brynolf *et al*., 1967)[12]
- Pulp sensibility testing with cold spray and electric pulp testing suggesting irreversible pulpal inflammation. A lingering response lasting for more than 10 s upon cold testing was suggestive of irreversible pulpitis
- Patients aged 15–45 years having good oral hygiene and absence of systemic disease.

Exclusion criteria

- Nonvital/nonrestorable tooth with cracks or subgingival caries
- Teeth with apical periodontitis as assessed using the PAI based on the findings of Brynolf[12]
- Marginal periodontitis, pathological mobility, or pus discharge through the associated sinus tract
- Tooth with evidence of internal/external resorption or pulp chamber/root canal calcifications
- Patient on any kind of antibiotic/analgesics medication, opioid, or steroid therapy since the past 7 days
- Pregnant/nursing patients
- Patients not willing to come for follow-up visits.

Sample size calculation

$$n = \frac{(\sigma 1^2 + \sigma 2^2)(Z_{1-\alpha/2} + Z_{1-\beta})^2}{\Delta^2}$$

The notation for the formula is:

n = sample size of groups

1 = standard deviation of Group 1 = 1.42

2 = standard deviation of Group 2 = 1.01

= difference in group means 0.815

$Z1\text{-}\alpha/2$ = two-sided Z value (e.g., Z = 1.96 for 95% confidence interval).

$Z1\text{-}\beta$ = 0.84 for power 80%. With the help of literature survey, we have found that the expected standard deviation and mean difference of parameter of Group 1 and Group 2 were 1.42 and 1.01, respectively, and the mean difference was 0.815 of two groups for variables. Using the above formula, we have found the sample size for each group was 30. To compensate for the attrition at follow-up, considering 10% loss, the minimum sample size was determined to be 33 patients per group.

Preoperative pain levels were measured using Visual Analog Scale (VAS) score (0–10). Pulp sensibility test was employed to determine preoperative pulp status where cold testing was used in conjunction with electric pulp test. An uncomfortable sensation in response to cold (Endo Ice, Coltene) that lingers after termination of the stimulus characteristic of irreversible pulpitis was noted. An electric pulp tester (EPT) (Kerr Vitality Scanner 2006, Kerr, Italia) probe was placed on the sound coronal third of the labial surface of the tooth isolated and the responses were recorded.

Randomization

Blinding was carried out by sequentially numbered opaque-envelope system in which each participant was provided with concealed assignment code. They were then randomized into three groups based on pulpotomy agent used (BD/LPC/LLLT) with equal numbers using randomizer.

Clinical procedure

The entire endodontic procedure was performed by a single operator in all the participants. A preoperative IOPA was determined before beginning with the clinical procedure. Teeth were anesthetized using 2% lignocaine (Neon, India) containing 1:80000 epinephrine (ICPA Health Products Ltd, India) and isolated under a rubber dam (GDC, UK) with proper field disinfection. Access was gained using a sterile high-speed handpiece under copious irrigation to the depth of 1.5–2 mm. The cavity was disinfected using a 5% sodium hypochlorite solution (Parcan, Septodent, USA). After exposure, the pulp was amputated to the level of canal orifices (full pulpotomy) using a sterile large size round diamond bur (ISO No 2/ISO 001 010). Hemostasis was achieved using 2.5% sodium hypochlorite solution (Parcan, Septodent, USA) on a slightly moistened cotton pellet for 2–6 min.

The teeth were then divided into three groups depending on the pulpotomy agent as follows:

- Group 1: Biodentine (Septodent, USA) group: Biodentine was obtained in the form of capsule containing powder and liquid, separately. BD was mixed according to manufacturer's instructions and placed in 2 mm thickness and then gently adapted using a moist cotton pellet. It was left for 12–14 min to achieve the initial setting [Figure 1]
- Group 2: Biodentine (Septodent, USA) with lyophilized platelet concentrates (Mothercell Regenerative Centre, Trichy, India) group: It was allogenic in nature, free of hepatitis B surface antigen, hepatitis C virus antigen, human immunodeficiency virus antibodies, and allergic reaction. 50 mg of lyophilized platelet concentrate (LPC) was dampened with saline and placed over the pulp stumps followed by placement of 2 mm thickness of BD [Figure 1]
- Group 3: Biodentine (Septodent, USA) with low-level laser therapy (SioLaser advance plus, Dentsply, Sirona, USA) group: Safety goggles were worn both by the operator and patient. Subsequently, red laser of 660 nm wavelength laser was delivered in continuous mode through a 4 mm multitip placed 2 mm away from the pulp. Laser parameters were set at lower level biostimulation program with 100 mw power output and 100 W/cm^2 power density delivered in 3 cycles of 60 s followed by placement of 2 mm of BD [Figure 1].

Self-cure glass ionomer cement (GC, GC Corporation, Tokyo) was placed over BD. Patients were then briefed about post-operative symptoms and advised medication when required. The restoration was replaced by composite (Te-Econom Plus, Ivoclar Vivadent) after 2 weeks.

Outcome assessment

Clinical assessment was done for time for post-operative pain using VAS scale, anti-inflammatory intake, and pulp sensibility (Cold test and Electric Pulp Testing). Postoperative radiographs were obtained using Rinn XCP Holder (Dentsply Sirona) using paralleling technique with exposure parameters 70 kVp, 8 mA, and 0.250 s for Group 1, 2, and 3 at 3 months, 6 months, and 1 year. An experienced radiologist along with an endodontist evaluated the pre and postoperative radiograph for estimation of PAI, dentine bridge formation, and canal calcification. Formation of abscess, swelling, sinus tract, and tenderness associated with the tooth and increase in PAI was determined as a failure.

Statistical analysis

Statistical analysis was done by statistical software SPSS software 20.0- IBM® SPSS® Statistics 20(IBM Corp., located in Armonk (N.Y., USA). Shapiro–Wilk test was used to determine the normal distribution of data. The intergroup comparison was done using one-way analysis of variance followed by the Bonferroni test. The level of

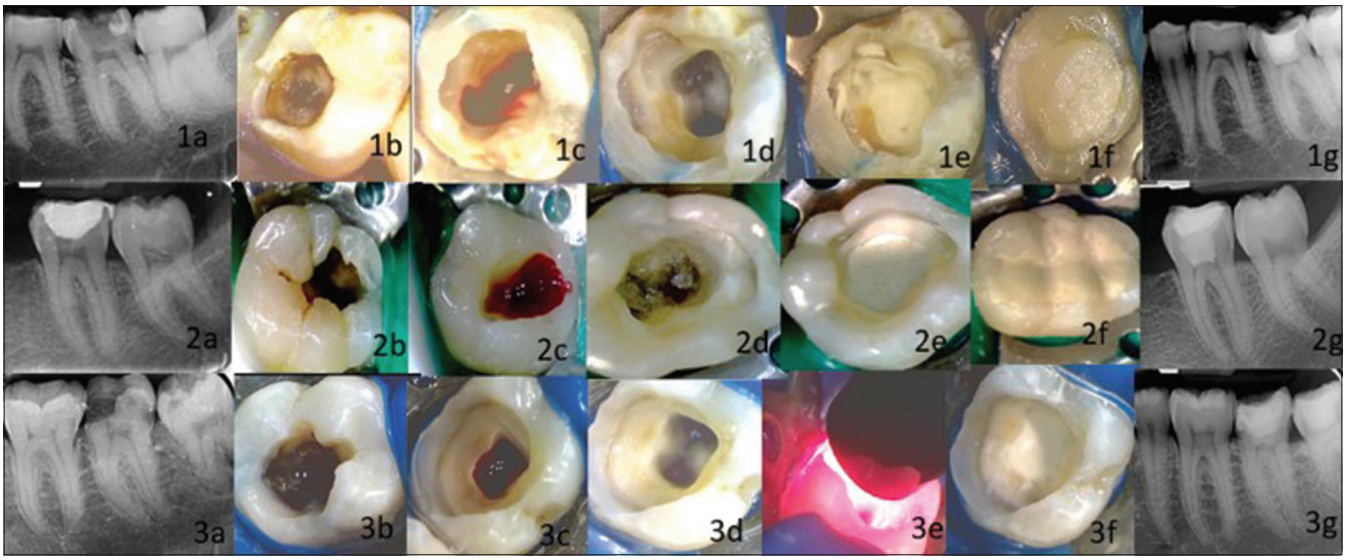

Figure 1: Figure shows pulpotomy procedure in Group 1 - Biodentine, Group 2 - Freeze-dried platelet concentrate + Biodentine and Group 3 - Low-level laser therapy + Biodentine. (1a) Pre-operative IOPA (Group 1) (1b) Gross caries (1c) Bleeding from orifice (1d) Pulp stumps after hemostasis (1e) Pulp capping by Biodentine (1f) Restoration immediate (1g) Postoperative IOPA after 1 year (Group 1). (2a) Pre-operative IOPA (Group 2) (2b) Gross caries (2c) Bleeding from orifice (2d) Placement of freeze-dried platelet concentrate (2e) Pulp capping by Biodentine (2f) Restoration immediate (2g) Postoperative IOPA after 1 year (Group 2). (3a) Pre-operative IOPA (Group 3) (3b) Gross caries (3c) Bleeding from orifice (3d) Pulpal stumps after hemostasis (3e) Photobiomodulation using low-level laser therapy (3f) Pulp capping by biodentine (3g) Postoperative IOPA after 1 year (Group 3)

significance and confidence interval was 5% and 95%, respectively. Interobserver reliability was measured using Cohen's kappa analysis.

RESULTS

The study was reported according to extension to the PRIRATE 2020 guidelines as depicted in Figure 2. Out of total of 312 patients that visited the Department of Conservative Dentistry and Endodontics for deep caries management of molars, 138 patients were excluded (21 were non restorable, 12 were unresponsive to pulp test, 32 declined to participate, 19 were tender to percussion, nine had furcal bone loss, 12 had calcified canals and 33 patients proceeded for extraction and finally 174 patients were recruited initially for the study and randomized into Group 1 (BD), Group 2 (LPC + BD) and Group 3 (LLLT + BD) with 58 patients each. one patient from BD group, two patients from LPC + BD group, and one patient from LLLT + BD did not receive the allotted treatment as the bleeding time exceeded 10 min and were excluded. A total of 57 patients from Group 1 and Group 3 and 56 patients from Group 2 received the allocated intervention. A total of 34 patients (10 from BD group, 11 from LPC + BD group, and 12 from LLLT + BD) were lost to follow-up at 1 year.

- At 1 week, there was a significant difference ($P < 0.005$) observed in the mean postoperative pain levels between the three groups with Group 1 (BD) exhibiting the highest postoperative pain followed by Group 2 (LPC + BD) and least pain was exhibited by Group 3 (LLLT + BD) [Table 1]
- A similar trend was reported at the end of 3 weeks. No postoperative pain was reported in any of the groups after 3 weeks [Table 1]
- A similar pattern was observed regarding the analgesic intake with maximum frequency in Group 1 (BD) and least with Group 3 (LLLT + BD). On pulp sensibility testing using EPT and cold spray, no response was recorded at 1 week, 3 week, 2 months, 3 months, 6 months, and 1 year [Table 1]
- There was no evidence of dentine bridge formation seen in any of the groups post operatively at 3 months; however, at 6 months and 1 year postoperatively, Group 3 (LLLT + BD) reported maximum dentine bridge formation followed by Group 2 (LPC + BD) and Group 1 (BD) with no significant differences among the groups [Table 1]
- Regarding canal calcification, none of the groups reported any signs postoperatively at 3 months; however, at 6 months, Group 1 (BD) revealed the greatest evidence of canal calcification followed by Group 2 (LPC + BD) and Group 3 (LLLT + BD) with no significant differences among the groups [Table 1]
- The overall success rate in Group 1 (BD) was 91.4%. In Group 2 (LPC + BD), it was reported to be 93.1%, while it was 95.5% for Group 3 (LLLT + BD). No significant differences in success rates were reported between the three groups
- The results of postoperative clinical and radiographic parameters with clinical success rates are elaborated in Table 2.

Table 1: Parameters and characteristics in three groups – Group 1: Biodentine, Group 2: Lyophilized freeze-dried platelet-rich concentrate, and Group 3: Low-level laser therapy at given time intervals

Parameters		Pain (VAS)		Anti-inflammatory intake		Cold test	EPT	TOP	
Time period	Group	Mean±SD	*P* - ANOVA test	Mean±SD	*P* - ANOVA test			Present	Chi square test results after 1 year
Baseline	Group 1 (58)	7.02±1.77	0.000	-		-	-		
	Group 2 (58)	7.21±1.239							
	Group 3 (58)	7.19±1.277							
24 h	Group 1 (58)	6.53±1.23	0.000	0.79±0.868	0.000 ($P<0.05$)				
	Group 2 (58)	6.33±0.97		0.33±0.543					
	Group 3 (58)	5.5±0.67		0					
1 week	Group 1 (56)	4.77±1.144	0.000 ($P<0.05$)	1.21±1.423	0.000 ($P<0.05$)	-	-	0	
	Group 2 (56)	3.04±0.972		0.38±1.019		-	-	0	
	Group 3 (57)	1.16±0.774		0		-	-	0	
3 weeks	Group 1 (56)	0.82±1.117	0.000 ($P<0.05$)	0.23±0.763	0.010 ($P<0.05$)	-	-	0	
	Group 2 (56)	0.67±1.213		0.02±0.134		-	-	0	
	Group 3 (57)	0.10±0.305		0		-	-	0	
1 month	Group 1 (56)	0	ANOVA - 0.5	0		-	-	0	
	Group 2 (56)	0	($P>0.05$)	0		-	-	0	
	Group 3 (57)	0		0		-	-	0	
3 months	Group 1 (54)	0		0		-	-	0	
	Group 2 (55)	0		0		-	-	0	
	Group 3 (55)	0		0		-	-	0	
6 months	Group 1 (51)	0	ANOVA 0.139	0	ANOVA - 0.126	-	-	0	
	Group 2 (52)	0	($P>0.05$)	0	($P>0.05$)	-	-	0	
	Group 3 (50)	0.10±0.505		0.08±0.396		-	-	0	
1 year	Group 1 (47)	0.25±0.967	ANOVA - 0.506	0.14±0.462	ANOVA - 0.126	-	-	4 (8.5%)	Chi-square
	Group 2 (44)	0.20±0.778	($P>0.05$)	0.13±0.542	($P>0.05$)	-	-	3 (9.3%)	test - 0.568
	Group 3 (45)	0.07±0.447		0.02±0.149		-	-	3 (6.6%)	($P>0.05$)

Parameters	PAI			Evidence of dentinal bridge		Evidence of canal calcification	
Time period	PAI 1	PAI 3	Test of significance	Present	Test of significance	Present	Test of significance
Baseline							
				-	-	-	
24 h				-	-	-	
1 week	56			-		-	
	56			-		-	
	57			-		-	
3 weeks	56			-			
	56			-		-	
	57			-		-	
1 month	56			-		-	
	56			-		-	
	57			-		-	
3 months	54			-		-	
	55			-		-	
	55			-		-	
6 months	51			17 (33.3%)	Pearson's Chi-square	5 (9.8%)	Pearson's Chi-square
	52			21 (40.3%)	test - $P=0.290$	1 (1.9%)	test - 0.024 ($P>0.05$)
	50		0	24 (48.0%)		-	
1 year	43 (91.4%)	4 (8.5%)	Chi-square test -	27 (57.4%)	Pearson's Chi-square	7 (14.9%)	Pearson's Chi-square
	41 (93.1%)	3 (9.3%)	0.568 ($P>0.05$)	30 (68.1%)	test - 0.095 ($P>0.05$)	2 (4.6%)	test - 0.023 ($P>0.05$)
	42 (93.3%)	3 (6.6%)		35 (77.8%)		1 (2.3%)	

SD: Standard deviation, VAS: Visual Analog Scale, EPT: Electric pulp tester, PAI: Periapical index, TOP: Tenderness on percussion

DISCUSSION

The field of endodontics has undergone numerous advances in material science to treat irreversible pulpitis. According to the European Society of Endodontology position statement regarding deep caries lesion involving the entire dentine thickness, pulp exposure is unavoidable during the operative treatment of such cases.[13] The current researches have established that dental pulp stem cells have immense regenerative potential.[14-16] Employing endodontic biomaterials can provide a biological seal against bacterial microleakage and promote the

Table 2: Clinical and radiographic success rates following the pulpotomy procedure among the three groups: Group 1: Biodentine, Group 2: Lyophilized freeze-dried platelet-rich concentrate, and Group 3: Low-level laser therapy intergroup comparison done using ANOVA test

Groups	Clinical success rate								Clinical success rate at 1 year
	Postoperative pain - VAS score				Postoperative - tenderness on percussion				
	6 months		1 year		6 months		1 year		
	Absent, *n* (%)	Present, *n* (%)	Absent, *n* (%)	Present, *n* (%)	Absent, *n* (%)	Present, *n* (%)	Absent, *n* (%)	Present, *n* (%)	
Group 1	0 (100)	0	43 (91.4)	4 (8.5)	49 (100)	0	43 (91.4)	4 (8.5)	91.4%
Group 2	0 (100)	0	41 (93.1)	3 (6.8)	52 (100)	0	41 (93.1)	3 (6.8)	93.1%
Group 3	48 (96)	2 (4.4)	42 (95.5)	3 (6.6)	51 (100)	0	42 (95.5)	3 (6.6)	95.5%

Groups	Radiographic success rate		Radiographic success rate-success rate at 1 year
	Normal Periapical status		
	6 months	1 year	
Group 1	49,100%	43, 91.4%	91.4%
Group 2	52,100%	41, 93.1%	93.1%
Group 3	51, 100%	42,95.5%	95.5%
Intergroup comparison	0	0.568, (P>0.05)	0.568, (P>0.05)

Comparative evaluation of success rate (percentage) between the three groups at different follow-up times, VAS: Visual Analog Scale

noninflamed pulp to create dentine-like hard tissue.[17] This was the first randomized controlled trial comparing three novel pulp capping modalities-BD, BD with lyophilized freeze-dried platelet-rich concentrate powder, and BD along with low-lever laser therapy in permanent molars after complete pulpotomy in patients with irreversible pulpitis without apical periodontitis.

Immediate likelihood of postoperative pain has been shown to have a high occurrence of 25-40% and it is also influenced by factors like anxiety, status of pulpal inflammation, the existence of pre-treatment pain and the release of prostaglandins, leukotrienes, bradykinin and serotonin during the initial phase of inflammation.[18,19] This finding is in concurrence with Asgary and Ahmadyar reporting 27% pain in the pulpotomy group initially after treatment.[20] The present study reported significantly greater postoperative pain and analgesic intake at 1 week with Group 1 (BD) group and least with Group 3 (BD + LLLT). Eghbal *et al*. reported that the procedure of pulpotomy injured the odontoblasts and LTA-stimulated pulp fibroblasts, thereby showing an increased expression of interleukin-6 (IL-6), vascular endothelial growth factor, and IL-6.[21] The postoperative pain in Group 2 (BD + LPC) was comparatively less, which could be attributed to the anti-inflammatory and antimicrobial effect of platelet concentrate. PC inhibits inflammation by decreasing the early macrophage proliferation, promoting angiogenesis by increasing the tissues vascularity and epithelial cell production.[22,23] When activated, platelets release a group of biologically active proteins that bind to the transmembrane receptors of the target cells, thus leading to the expression of gene sequences that ultimately promote cellular recruitment, growth, morphogenesis, and modulate inflammation by the release of healing cytokines.[24] A significant pain reduction with minimal analgesic intake was observed in Group 3 (LLLT + BD). This finding can be attributed to the inhibition of the synthesis of inflammatory factors like immunoglobins and lymphokines as well as pain-related neurotransmitters like beta-endorphins.[25] Furthermore, LLLT increases the prostaglandin levels which exerts anti-inflammatory effect and eliminates pain-inducing substances including substance P, histamine, dopamine which in turn inhibits cyclo-oxygenase and causes degradation of bradykinin.[26,27] The decrease in the activity of C fibers reduces the firing frequency of nociceptors. All these reasons could explain the present study results.[27]

Complete amputation of coronal pulp has been correlated with the loss of low threshold A-delta fibers, thereby disabling the response of residual pulp to pulp sensibility testing.[28] There was a significant reduction in response to EPT and cold test postoperatively after 1 week, which was further reduced after a month and no significant response was observed after 2 months. This finding could be attributed to the formation of a calcific barrier which acts as an insulator and prevents the conduction of electrical impulses by the intradental A delta nerve fibers.[28]

Few cases demonstrated evidence of dentine bridge, but its presence or absence has not been shown to determine success or failure which can be corroborated with previous studies. The calcific bridge formation could be attributed to the repair and regenerative attempts of radicular pulp in response to pulpotomy and pulp capping material and an attempt to seal the wound.[29] BD has shown the ability to stimulate the release of TGF-beta and in various studies it has been shown to promote OD-21 cell proliferation and biomineralization.[30] LPC contributed to biocompatibility, bioactivity, and pulpal healing by the release of growth factors such as PDGF and transforming growth factor-beta which leads to proliferation and differentiation of stem cells.[31] Furthermore, LPC modulates the release of healing cytokines such as IL-4 helps moderates inflammation and inhibits IL-1b-mediated stimulation of MMP-1, MMP-3 and synthesis of prostaglandin E-2.[32] LLLT provided

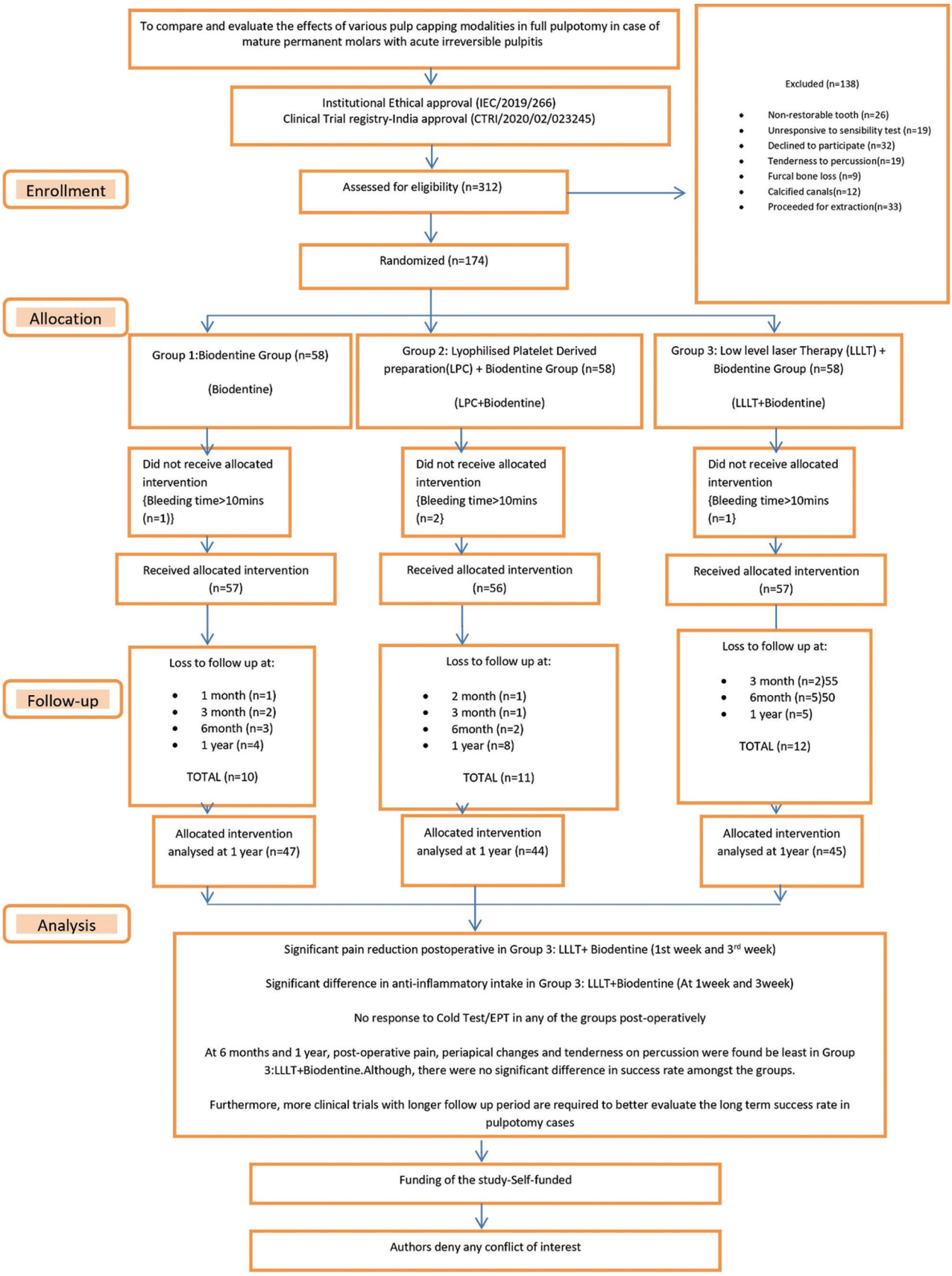

Figure 2: PRIRATE 2020 guidelines flowchart

photobiomodulation to produce mitochondrial boosting and biomodulatory effect on pulp cells and expression of collagen, fibronectin, and tenascin, which in turn induced regeneration, rapid healing, and repair.[32]

Canal narrowing was observed in a few cases at 1-year follow-up in Group 1 and Group 2 in otherwise clinically asymptomatic teeth but was not considered as failure. Although the basic mechanism is obscure, various studies have attributed this to the injury to the neurovascular supply affecting signaling mechanism responsible for differentiation of undifferentiated mesenchymal cells into odontoblast or osteoblast.[33] The condition may also be correlated to the stressed pulp behavior which could be due to the procedure itself or due to the pulp capping material.[34] Furthermore, the interplay between wound healing, repair, and regeneration may contribute either toward calcific changes or mineralization.[35] Mass and Zilberman reported increased pulp calcifications in 28.3% teeth after partial pulpotomy in permanent molars after a mean period of 49 months.[36] On the contrary, Taha and Abdelkhader showed no evidence of canal calcification even after 1 year.[37]

Only permanent molars were selected for the study, so that tooth type does not act as a confounding factor. Complete disinfection of the site and an aseptic protocol were followed to minimize any contamination. Full coronal pulpotomy was selected as it is a standardized procedure. After pulp-capping in all the groups, a second layer of GIC restoration was placed immediately to ensure a good seal with minimal marginal leakage.[38] BD has been stated as a weak restorative material in the initial phases of setting and is unable to bear compressive forces of composite restoration and thus permanent restoration was placed after 2 weeks.[39] The findings of our study revealed a 95.5% success rate after pulpotomy using LLLT and BD, clinically as well as radiographically. This is in accordance with a systematic review and meta-analysis conducted by Stringhini Junior *et al*., which reported >95% clinical and radiological success rate.[40] Furthermore, the 93% success rate with platelet concentrates is in accordance with the systematic review by Noor Mohamed *et al*.[41] A study by Kalaskar and Damle reported 100% success rate with lyophilized platelet concentrates.[42] There were a few limitations of the present study. This was a single-center trial with a short-term follow-up. The radiographic outcomes were completely based on the 2-dimensional evaluations with limitations like 3D anatomic compression and obstructions. The decision to not expose a patient to a CBCT investigation was made evaluating the risk/benefit ratio and considering the ALARA principle in this case.[42] Furthermore, further studies using diagnostic methods based on pulpal blood flow should be considered for better case selection. Furthermore, the present study did not evaluate the success rates of occlusal versus interproximal lesions separately which could be emphasized in future studies. A histological examination could not be performed as it was a clinical study conducted on human teeth and the clinical and radiographic parameters may not provide information about the histological criteria. A histological study may better explain the influence of these three pulpotomy agents on pulpal healing.[43]

CONCLUSION

Within the limits of our present clinical study and based on the positive outcomes, we can conclude that the clinicians can safely rely upon advanced noninvasive and regenerative approaches. Further studies with longer follow-ups are required to better determine both clinical and radiographic success. Pulpotomy as a treatment option for mandibular molars with irreversible pulpitis has an acceptable clinical success rate; however, long-term overall success rate remains questionable. While the other modalities are showing great potential as adjunctive pulp capping agents when used along with Biodentine, it continues to provide good results even when used separately. With ongoing research and development, novel pulp capping modalities are expected to revolutionize the field of vital pulp therapy.

Authorship declaration

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Conflicts of interest

There are no conflicts of interest.

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