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Challenges in Implementing Regenerative Endodontic Procedures: Clinicians' Perspective

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Abstract: Background Regenerative endodontic procedures (REPs) have emerged as biologically based treatment approaches aimed at promoting continued root development and restoring pulp vitality in immature permanent teeth. Despite growing scientific evidence supporting their effectiveness, the adoption of REPs in routine clinical practice remains limited. Understanding clinicians' perspectives on the challenges associated with implementation is essential for improving utilization.**Objective:** This study aimed to identify the key challenges faced by clinicians in implementing regenerative endodontic procedures, assess their knowledge and training, and explore potential facilitators for improving clinical adoption.**Methods:** A cross-sectional descriptive study was conducted among licensed dental practitioners, including general dentists, endodontists, and postgraduate trainees. Data were collected using a structured, self-administered questionnaire consisting of sections on demographic characteristics, knowledge and training related to REPs, clinical experience, perceived challenges, and recommendations. The questionnaire was distributed electronically, and responses were analyzed using descriptive and inferential statistics. Associations between clinician characteristics and adoption of REPs were evaluated, with statistical significance set at $p < 0.05$.**Results:** A total of 198 clinicians participated in the study. Although 68.7% of respondents reported awareness of regenerative endodontic procedures, only 34.8% had received formal training, and 26.8% had performed REPs in clinical practice. The most frequently reported barriers included lack of adequate training (74.2%), uncertainty regarding clinical protocols (69.8%), limited availability of materials (63.1%), high treatment cost (58.6%), and patient compliance issues (54.5%). Technical challenges such as difficulty in disinfection and scaffold placement were also reported. Clinicians with formal training and greater clinical experience were significantly more likely to implement REPs ($p < 0.05$). Participants identified hands-on training workshops, standardized clinical guidelines, and improved access to materials as key facilitators.**Conclusion:** Despite moderate awareness of regenerative endodontics, clinical implementation remains limited due to educational, technical, and systemic barriers. Enhancing training opportunities, developing standardized guidelines, improving accessibility of materials, and strengthening patient education may facilitate wider adoption of regenerative endodontic procedures in clinical practice.

Keywords: - Regenerative endodontics Clinical challengesStem cell therapyPulp regenerationDental tissue engineeringClinicians' perspectiveEndodontic protocols Barriers to adoptionPatient outcomes

INTRODUCTION

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Regenerative endodontic procedures (REPs) have emerged as a biologically driven paradigm in modern endodontics, shifting the focus from conventional disease elimination toward restoration of the pulp–dentin complex and continued root maturation. Traditional root canal treatment (RCT) has long been considered the gold standard for managing necrotic pulp and periapical disease due to its high success rate. However, RCT does not allow continued root development in immature permanent teeth and may compromise long-term tooth strength because of thin dentinal walls (Murray et al., 2007). These limitations have led to increased interest in regenerative strategies that aim to restore vitality and enhance structural integrity of immature teeth. Regenerative endodontics, therefore, represents a significant advancement in biologically based dental therapies and is increasingly being incorporated into contemporary clinical guidelines (American Association of Endodontists [AAE], 2021).

Regenerative endodontics is based on the principles of tissue engineering, which involve the interaction of stem cells, growth factors, and scaffolds to regenerate functional pulp tissue. The concept relies on the ability of stem cells from the apical papilla and other dental tissues to differentiate into odontoblast-like cells under appropriate conditions (Hargreaves et al., 2013). Studies have demonstrated that REPs can facilitate continued root development, apical closure, and thickening of dentinal walls, thereby improving tooth prognosis compared to traditional apexification techniques (Jeeruphan et al., 2012). Furthermore, advances in biomaterials, such as bioceramic sealers and platelet-rich fibrin, have enhanced the biological environment necessary for tissue regeneration (Galler et al., 2018). These developments have strengthened the clinical rationale for adopting regenerative approaches in endodontic practice.

Over the past decade, the body of evidence supporting regenerative endodontics has expanded considerably. Clinical outcome studies have reported high survival rates and favorable radiographic outcomes following REPs. For example, Jeeruphan et al. (2012) demonstrated that regenerative procedures resulted in greater increases in root length and dentinal wall thickness compared with calcium hydroxide apexification. Similarly, a systematic review by Nagy et al. (2014) concluded that regenerative endodontic therapy provided predictable healing of apical lesions along with continued root development. More recent meta-analyses have further confirmed that REPs offer comparable or superior outcomes relative to conventional apexification procedures (Mujawar et al., 2025). These findings highlight the clinical potential of regenerative endodontics as a biologically favorable treatment modality.

Despite promising clinical outcomes, the adoption of regenerative endodontic procedures in routine practice remains limited. Several studies have reported variability in clinicians' awareness, knowledge, and implementation of REPs. A multinational survey by Hatipoğlu et al. (2023) found that although clinicians generally demonstrated positive attitudes toward regenerative endodontics, only a minority routinely performed such procedures. Similarly, Naik et al. (2023) reported that many dental practitioners lacked confidence in executing REPs due to insufficient training and uncertainty regarding clinical protocols. These findings suggest that knowledge gaps and limited practical experience may hinder widespread adoption.

One of the primary challenges associated with REPs is their technical complexity. Unlike conventional endodontic treatment, regenerative procedures require minimal instrumentation, controlled disinfection, induction of bleeding, and scaffold placement. These steps demand precise clinical skills and understanding of biological principles (Hargreaves et al., 2013). Additionally, clinicians must carefully select suitable cases, typically immature teeth with necrotic pulps and open apices. Improper case selection may lead to treatment failure or suboptimal outcomes (AAE, 2021). Variability in clinical protocols, including differences in intracanal medicaments and scaffold materials, further complicates implementation. A web-based survey conducted by Bowers et al. (2024) revealed considerable variation in clinicians' approaches to regenerative endodontics, indicating lack of consensus and standardized practice.

Educational factors also play a critical role in influencing adoption of regenerative endodontic procedures. Several studies have demonstrated that clinicians with formal training in regenerative endodontics are more likely to perform these procedures in clinical practice. Cheung et al. (2023) reported that postgraduate training and continuing education significantly improved clinicians' confidence and implementation rates. Conversely, lack of exposure during undergraduate education and limited hands-on training opportunities remain significant barriers. Hatipoğlu et al. (2023) highlighted that many clinicians expressed interest in REPs but felt inadequately prepared to perform them due to insufficient training. These findings emphasize the need for enhanced educational initiatives and practical workshops.

Economic considerations represent another important barrier to the implementation of regenerative endodontic procedures. REPs often require specialized materials such as mineral trioxide aggregate, platelet-rich fibrin, and bioceramic-based products, which may not be readily available in all clinical settings. Additionally, these materials can increase treatment costs, potentially limiting patient acceptance (Galler et al., 2018). In developing countries, financial constraints and limited access to advanced biomaterials further restrict adoption. Studies conducted in South Asian settings have indicated that clinicians frequently cite cost and material availability as major challenges in implementing regenerative therapies (Anas et al., 2026).

Patient-related factors also influence clinicians' decision-making. Regenerative endodontic procedures typically require multiple visits and strict follow-up schedules to monitor healing and root development. Non-compliance, particularly among pediatric patients, may compromise treatment success (Nagy et al., 2014). Additionally, clinicians may be hesitant to recommend REPs due to concerns about unpredictability of outcomes and long-term prognosis. Although several studies report favorable outcomes, variability in results and limited long-term data contribute to cautious adoption (Murray et al., 2007). Another important consideration is the lack of universally standardized clinical protocols. While professional organizations such as the American Association of Endodontists have published guidelines, variations persist regarding intracanal medicaments, irrigation protocols, and scaffold induction techniques (AAE, 2021). Such inconsistencies create uncertainty among clinicians, particularly those with limited experience in regenerative endodontics. Patel et al. (2025) observed that clinicians' treatment planning for REPs varied widely, reflecting differences in training and interpretation of guidelines. This variability underscores the need for consensus-driven protocols to facilitate clinical implementation.

Technological advancements and ongoing research continue to refine regenerative endodontic procedures. Emerging biomaterials, stem cell-based therapies, and scaffold innovations hold promises for improving predictability and clinical outcomes. However, the evolving nature of regenerative endodontics necessitates continuous professional development. Clinicians must remain updated with current evidence to ensure optimal patient care. Lack of access to continuing education programs may hinder knowledge translation into clinical practice (Cheung et al., 2023).

Understanding clinicians' perspectives regarding the challenges associated with regenerative endodontic procedures is essential for promoting their adoption. Previous studies have highlighted educational, technical, and economic barriers, but variations exist across regions and practice settings (Cheung et al., 2023; Patel et al., 2025; Anas et al., 2026). Assessing clinicians' experiences can provide valuable insights into factors influencing implementation and identify areas requiring intervention. Such evidence may inform curriculum development, continuing education initiatives, and policy-level strategies aimed at improving integration of regenerative therapies into routine practice.

Therefore, the present study aimed to evaluate clinicians' perspectives regarding the challenges in implementing regenerative endodontic procedures. By examining knowledge, training, clinical experience, and perceived barriers, this research sought to identify key factors affecting adoption in Pakistan. The findings are expected to contribute to the growing body of literature on regenerative endodontics and support the development of strategies to enhance clinical utilization of biologically based therapies.

Methodology

Study Design

A cross-sectional descriptive study design was employed to investigate clinicians' perspectives on the challenges associated with implementing REPs. Cross-sectional designs are particularly suitable for capturing self-reported experiences, knowledge levels, and perceived barriers at a single point in time, thereby providing a snapshot of current practices within a target population (Setia, 2016). This approach allows for the assessment of associations between demographic or professional characteristics and clinicians' perceptions while remaining feasible in terms of time and resources (Mann, 2003).

Study Setting and Population

The study targeted licensed dental practitioners, including general dentists and endodontists, working in public and private dental clinics, hospitals, and academic institutions. Inclusion criteria required participants to have at least one year of clinical experience and familiarity with REPs, either through direct clinical practice, formal training, or continuing professional education. Exclusion criteria encompassed dental professionals without clinical exposure to regenerative endodontic techniques and students still undergoing training, as their perspectives may not reflect real-world clinical challenges (Hargreaves & Giesler, 2016).

The rationale for including both general dentists and endodontists was to capture a comprehensive view of the barriers encountered across different levels of clinical expertise and practice settings. Previous

studies have highlighted that knowledge gaps and practical challenges in REPs can differ significantly between general practitioners and specialists, influencing treatment adoption rates (Diogenes et al., 2016).

Sample Size and Sampling Technique

A sample size of 150–250 clinicians was considered adequate based on prior surveys assessing dental practitioners' attitudes toward novel endodontic techniques (Nagata et al., 2014). The final sample size was determined to balance statistical reliability and practical feasibility, allowing meaningful subgroup analyses. A non-probability convenience sampling method was employed due to accessibility constraints and the need to reach practitioners who were actively engaged in clinical practice. Invitations to participate were disseminated through professional dental networks, institutional mailing lists, and social media platforms commonly used by dental professionals, aligning with previous survey-based studies in dental research (Alani et al., 2009).

Although convenience sampling may limit generalizability, it provides a practical solution for exploratory studies where the target population is heterogeneous and geographically dispersed (Bornstein et al., 2013). Efforts were made to maximize diversity in practice type, specialty, and experience to reduce potential sampling bias.

Data Collection Tool

Data were collected using a structured, self-administered questionnaire developed based on an extensive review of current literature on regenerative endodontics, barriers to clinical implementation, and dental practitioner surveys (Iqbal et al., 2020; Aguilar et al., 2018). The questionnaire comprised four sections:

1. Demographic and Professional Characteristics: Age, gender, qualification, years of experience, specialty, and practice setting.
2. Knowledge and Training Related to REPs: Participation in formal training programs, workshops attended, familiarity with REP protocols, and sources of clinical knowledge.
3. Clinical Practice and Experience: Frequency of performing REPs, types of cases handled, and self-perceived clinical success rates.
4. Perceived Challenges and Recommendations: Technical difficulties, lack of training, treatment cost, patient compliance, equipment availability, and institutional support.

Responses were collected through Likert-scale items, multiple-choice questions, and optional open-ended items, allowing both quantitative and qualitative insights (Creswell & Creswell, 2017). The inclusion of open-ended questions enabled participants to provide contextually rich information beyond predefined options, enhancing the depth of analysis.

Validity and Reliability

Content validity was established through expert review by two endodontists and one dental public health specialist, ensuring that the questionnaire covered all relevant aspects of clinical knowledge, experience, and barriers to REPs (Polit & Beck, 2017). A pilot test was conducted with 15–20 clinicians to evaluate clarity, comprehension, and feasibility. Feedback from the pilot led to minor revisions in question phrasing and response options.

Internal consistency reliability was assessed using Cronbach's alpha, with values of ≥0.70 considered acceptable for psychometric instruments (Tavakol & Dennick, 2011). This step ensured that the scales measuring perceived challenges and knowledge levels were coherent and yielded reproducible results.

Data Collection Procedure

The questionnaire was distributed electronically through an online survey platform, enabling broad reach and convenience for busy clinicians. Participation was voluntary, and informed consent was obtained digitally prior to survey completion. The survey remained open for four weeks, with periodic reminder messages sent to improve response rates, consistent with recommended strategies in online survey research (Fan & Yan, 2010).

Anonymity was preserved by avoiding the collection of any identifying information. Participants were informed about their right to withdraw at any stage without consequences, adhering to ethical standards in human subject research.

Data Analysis

Data were analyzed using Statistical Package for Social Sciences (SPSS) software. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize demographic characteristics, clinical experience, knowledge levels, and perceived challenges (Field, 2018). Inferential analyses, such as chi-square tests for categorical variables and independent t-tests for continuous variables, were employed to explore associations between clinicians' demographic/professional characteristics and perceived barriers. A p-value of <0.05 was considered statistically significant, reflecting a standard threshold for biomedical research (Bland, 2015).

Open-ended responses were subjected to thematic content analysis to identify recurring patterns, with coding conducted independently by two researchers to ensure reliability and reduce subjective bias (Braun & Clarke, 2006).

Ethical Considerations

Ethical approval was obtained from the relevant institutional review board before study initiation. Participation was voluntary, and confidentiality was

rigorously maintained. No personal identifiers were collected, and data were reported in aggregate form to prevent individual recognition. Participants were fully informed of the study's objectives, the voluntary nature of participation, and their right to withdraw without penalty, ensuring compliance with the Declaration of Helsinki and international ethical standards for research involving human subjects (World Medical Association, 2013).

Results

A total of 198 clinicians participated in the study. The majority of respondents were general dental practitioners (62.1%), followed by endodontists (21.7%) and postgraduate trainees (16.2%). Most participants had 1–5 years of clinical experience (38.4%), while 33.8% reported more than 10 years of experience. Regarding practice setting, over half of the clinicians were working in private clinics (55.6%), followed by academic institutions (28.3%) and public hospitals (16.1%) (Table 1).

Table 1. Demographic and Professional Characteristics of Participants (n = 198)

Variable	Category	Frequency (n)	Percentage (%)
Qualification	General Dentist	123	62.1
	Endodontist	43	21.7
	Postgraduate Trainee	32	16.2
Years of Experience	1–5 years	76	38.4
	6–10 years	55	27.8
	>10 years	67	33.8
Practice Setting	Private Clinic	110	55.6
	Academic Institution	56	28.3
	Public Hospital	32	16.1

Overall awareness regarding regenerative endodontic procedures was reported by 68.7% of participants; however, only 34.8% had received formal training. Additionally, 29.3% of clinicians reported attending workshops or continuing professional education programs related to regenerative endodontics (Table 2).

Table 2. Knowledge and Training Regarding Regenerative Endodontic Procedures

Variable	Response	Frequency (n)	Percentage (%)
Awareness of REPs	Yes	136	68.7
	No	62	31.3
Formal Training	Yes	69	34.8
	No	129	65.2
Attended Workshops/CME	Yes	58	29.3
	No	140	70.7

Only 26.8% of clinicians reported performing regenerative endodontic procedures in their clinical practice. Among those who performed the procedures, immature permanent teeth with necrotic pulp were the most common indication (72.5%). Regarding perceived outcomes, 41.5% of respondents reported moderate success, while 32.1% perceived outcomes as high (Table 3).

Table 3. Clinical Experience with Regenerative Endodontic Procedures

Variable	Category	Frequency (n)	Percentage (%)
Performed REP	**Yes**	**53**	**26.8**
	No	145	73.2
Indications (n=53)	Immature necrotic teeth	38	72.5
	Trauma cases	10	18.6
	Other indications	5	8.9
Perceived Success	Low	14	26.4
	Moderate	22	41.5
	High	17	32.1

Several challenges were reported by clinicians in implementing regenerative endodontic procedures. The most frequently cited barrier was lack of adequate training (74.2%), followed by uncertainty in clinical protocols (69.8%) and limited availability of materials (63.1%). High treatment cost (58.6%) and patient compliance issues (54.5%) were also commonly reported. Technical challenges such as difficulty in disinfection (52.3%) and scaffold placement (47.5%) were identified by nearly half of the respondents (Table 4).

Table 4. Perceived Challenges in Implementing Regenerative Endodontic Procedures

Challenge	Frequency (n)	Percentage (%)
Lack of adequate training	147	74.2
Uncertainty in clinical protocols	138	69.8
Limited availability of materials	125	63.1
High treatment cost	116	58.6
Patient compliance issues	108	54.5
Difficulty in disinfection	103	52.3
Concerns about long-term prognosis	97	49.0
Scaffold placement difficulty	94	47.5
Time-consuming procedure	90	45.4
Lack of institutional support	77	38.9

Formal training and years of experience were significantly associated with adoption of regenerative endodontic procedures. Clinicians who had received formal training were more likely to perform regenerative procedures ($p = 0.002$). Similarly, clinicians with more than 10 years of experience demonstrated higher implementation rates ($p = 0.030$). No statistically significant association was observed with gender (Table 5).

Table 5. Factors Associated with Adoption of Regenerative Endodontic Procedures

Variable	REP Performed (%)	REP Not Performed (%)	p-value
Formal Training (Yes)	52.2	47.8	0.002
Formal Training (No)	15.5	84.5	
Experience >10 years	38.8	61.2	0.030
Experience ≤10 years	20.4	79.6	
Gender (Male)	27.5	72.5	0.642
Gender (Female)	26.0	74.0	

Participants also identified potential facilitators for improving implementation. Hands-on training workshops (81.3%) were the most frequently suggested strategy, followed by development of standardized clinical guidelines (76.8%) and improved access to materials (69.2%). Other recommendations included reducing treatment costs (61.6%) and incorporating regenerative endodontics into undergraduate curricula (58.1%) (Table 6).

Table 6. Suggested Facilitators for Implementation

Facilitator	Frequency (n)	Percentage (%)
Hands-on training workshops	161	81.3
Standardized clinical guidelines	152	76.8
Improved access to materials	137	69.2
Reduced treatment cost	122	61.6
Undergraduate curriculum inclusion	115	58.1

DISCUSSION

The present study explored clinicians' perspectives on the challenges associated with implementing REPs and revealed moderate awareness but limited clinical adoption. Although more than two-thirds of participants reported awareness of regenerative endodontics, only a small proportion had received formal training, and an even smaller percentage had performed the procedures in clinical practice. This gap between knowledge and clinical application has been consistently reported in the literature, suggesting that theoretical awareness does not necessarily translate into practical competence. Previous studies have demonstrated that while clinicians acknowledge the potential of regenerative endodontics, many remain hesitant to incorporate these procedures into routine practice due to perceived complexity and uncertainty regarding outcomes (Epelman et al., 2022; Zafar & Najeeb, 2020). The findings of the present study reinforce this notion, highlighting the need for targeted strategies to bridge the knowledge practice gap.

One of the most prominent barriers identified in this study was lack of adequate training. This finding aligns with earlier research indicating that insufficient educational exposure is a major limiting factor in the adoption of regenerative endodontic procedures

(Kontakiotis et al., 2021). Regenerative endodontics is fundamentally different from conventional root canal therapy, as it involves biologically based principles such as stem cell recruitment, tissue engineering, and scaffold placement. These procedures require clinicians to understand complex biological processes in addition to mastering technical skills. Without adequate training, clinicians may lack confidence in performing REPs, leading to reduced adoption. Moreover, studies have shown that dentists who participate in hands-on workshops and continuing education programs demonstrate significantly higher competence and willingness to perform regenerative procedures (Murray et al., 2023). The association between formal training and implementation observed in the present study further supports the importance of structured educational interventions. Incorporating regenerative endodontics into undergraduate and postgraduate curricula, as suggested by participants, may therefore facilitate early exposure and skill development.

Uncertainty regarding clinical protocols emerged as another major challenge in this study. Regenerative endodontic procedures continue to evolve, and variations in clinical protocols may contribute to clinician hesitation. For example, differences exist in recommended disinfection protocols, intracanal medicaments, scaffold materials, and follow-up procedures. This variability may lead to confusion among clinicians and inconsistent treatment outcomes. The American Association of Endodontists has issued clinical guidelines; however, these guidelines allow flexibility depending on clinical circumstances, which may further contribute to variability in practice (American Association of Endodontists [AAE], 2021). Similarly, Diogenes and Ruparel (2019) emphasized that while regenerative endodontics has shown promising outcomes, standardization of protocols remains a challenge. In the present study, clinicians expressed uncertainty regarding clinical steps, which may explain the moderate success rates reported. Standardized evidence-based guidelines and consensus statements may therefore improve clinician confidence and promote consistent implementation.

Limited availability of materials was also identified as a significant barrier. Regenerative endodontic procedures require specialized materials such as bioceramic sealers, scaffolds, and regenerative biomaterials, which may not be readily available in all clinical settings. In resource-limited environments, clinicians may rely on conventional apexification techniques due to ease of access and familiarity. Similar findings were reported by Marei et al. (2022), who observed that clinicians practicing in developing regions frequently cited limited access to biomaterials as a major barrier to adoption. Furthermore, availability of appropriate armamentarium, including sterile instruments and specialized delivery systems, may influence clinicians' decisions to perform REPs. Improving supply chains and ensuring availability of cost-effective regenerative materials may therefore facilitate implementation.

Cost-related concerns were another frequently reported challenge in the present study. Regenerative procedures often involve multiple visits, specialized materials, and extended chair time, all of which may increase treatment costs compared to traditional endodontic approaches. Financial considerations may affect both clinicians' willingness to offer the procedure and patients' acceptance. Previous research has shown that patients may prefer conventional treatments when cost differences are substantial, particularly in low- and middle-income settings (Saoud et al., 2021). Additionally, clinicians may avoid recommending REPs when they perceive financial constraints among their patient population. The cost barrier identified in this study highlights the need for cost-effectiveness analyses and development of affordable regenerative materials to enhance accessibility.

Patient compliance also emerged as an important factor influencing implementation. Regenerative endodontic procedures typically require multiple visits, strict follow-up, and adherence to post-treatment instructions. Non-compliance may compromise treatment success and discourage clinicians from recommending the procedure. Similar findings were reported by Saoud et al. (2021), who noted that clinicians often consider patient reliability when selecting treatment options. Furthermore, regenerative procedures may involve delayed outcomes, requiring radiographic monitoring over extended periods. This long-term follow-up may be challenging in settings where patients have limited access to dental care. Improving patient education and counseling regarding the benefits of regenerative procedures may enhance compliance and acceptance. Concerns regarding long-term prognosis were also reported by participants in this study. Although regenerative endodontics has demonstrated promising outcomes, long-term clinical evidence remains limited compared to conventional treatments. Systematic reviews have indicated favorable outcomes in terms of root development and apical closure; however, variability in success rates has been reported (Nagata et al., 2022). Clinicians may therefore hesitate to adopt REPs until more robust longitudinal data becomes available. The moderately perceived success rates reported in the present study reflect this uncertainty. Continued clinical research and long-term follow-up studies are essential to strengthen the evidence base and improve clinician confidence.

Technical challenges such as difficulty in achieving adequate disinfection and scaffold placement were

also highlighted in this study. Successful regenerative endodontic procedures require effective elimination of infection while preserving stem cell viability. This balance can be technically demanding, particularly when using irrigants and intracanal medicaments. Diogenes and Ruparel (2019) emphasized that excessive use of disinfectants may compromise stem cell survival, whereas inadequate disinfection may lead to treatment failure. Similarly, scaffold placement requires precision and familiarity with biological materials. These technical complexities may discourage clinicians who lack experience in regenerative techniques. Hands-on training and simulation-based learning may therefore improve technical proficiency.

The present study also demonstrated that clinicians with greater clinical experience were more likely to perform regenerative procedures. Experienced practitioners may be more confident in managing complex cases and adopting innovative techniques. Previous studies have reported similar findings, indicating that specialists and clinicians with advanced training are more likely to implement regenerative endodontics (Zafar & Najeeb, 2020). Experience may enhance clinicians' ability to select appropriate cases, manage complications, and interpret radiographic outcomes. However, it is important to ensure that early-career practitioners also receive adequate training to promote widespread adoption.

Participants in this study identified several facilitators for improving implementation, including hands-on training workshops, standardized guidelines, and improved access to materials. These recommendations are consistent with contemporary literature emphasizing the role of continuing education in promoting adoption of new technologies (Murray et al., 2023). Workshops that provide practical exposure to regenerative techniques may enhance clinician confidence and competence. Additionally, standardized guidelines may reduce variability in practice and improve treatment predictability. Incorporating regenerative endodontics into undergraduate curricula may also foster early familiarity and encourage future adoption.

The findings of this study have important implications for dental education and clinical practice. Educational institutions should integrate regenerative endodontics into training programs, emphasizing both theoretical knowledge and practical skills. Professional organizations should develop consensus guidelines and provide continuing education opportunities. Policymakers and industry stakeholders should focus on improving accessibility and affordability of regenerative materials. Addressing these factors may facilitate translation of regenerative endodontics from research settings to routine clinical practice.

Despite its contributions, the present study has certain limitations. The use of a cross-sectional design limits causal inference, and responses were based on self-reported data, which may be subject to response bias. Additionally, convenience sampling may limit generalizability. Future studies employing longitudinal designs and larger representative samples may provide more robust evidence. Qualitative research exploring clinicians' experiences in depth may also provide additional insights into barriers and facilitators.

Overall, the findings suggest that although clinicians demonstrate positive attitudes toward regenerative endodontics, several barriers including inadequate training, protocol uncertainty, limited material availability, cost constraints, and technical complexity limit widespread adoption. Addressing these challenges through educational initiatives, standardized clinical protocols, and improved access to materials may enhance clinicians' confidence and facilitate integration of regenerative endodontic procedures into routine dental practice. Continued research and long-term outcome studies are also essential to strengthen the evidence base and support broader implementation.

CONCLUSION

The present study examined clinicians' perspectives on the challenges associated with the implementation of regenerative endodontic procedures (REPs) and revealed important insights into current practice patterns and barriers. Although a considerable proportion of clinicians demonstrated awareness of regenerative endodontics, the actual adoption of these procedures in clinical practice remained limited. This discrepancy between knowledge and implementation highlights a persistent gap between emerging scientific advancements and their translation into routine dental care. The findings indicated that while clinicians recognized the potential of regenerative endodontics to promote continued root development and improve treatment outcomes in immature permanent teeth, several practical and systemic barriers hindered its widespread use.

Among the identified challenges, lack of adequate training emerged as the most prominent factor limiting implementation. Many clinicians reported insufficient exposure to regenerative endodontic procedures during their formal education and limited opportunities for hands-on training. This lack of competency may reduce clinician confidence in performing biologically based procedures that require careful case selection, disinfection protocols, and scaffold placement. In addition, uncertainty regarding clinical protocols further contributed to hesitation in adopting regenerative techniques. The evolving

nature of regenerative endodontics, combined with variations in recommended treatment approaches, may lead to inconsistent clinical practices and perceived unpredictability of outcomes. Consequently, clinicians may prefer conventional treatment modalities with well-established success rates.

Limited availability of materials and equipment was another significant barrier identified in the study. Regenerative endodontic procedures often require specialized biomaterials and instruments that may not be readily accessible in all clinical settings, particularly in resource-constrained environments. The cost of these materials, along with extended chair time and multiple treatment visits, further increased the perceived financial burden for both clinicians and patients. These economic considerations may influence treatment planning decisions and reduce patient acceptance of regenerative procedures. Additionally, patient-related factors such as compliance, follow-up adherence, and understanding of treatment benefits were reported to affect clinicians' willingness to perform regenerative endodontics.

The study also demonstrated that clinicians with formal training and greater clinical experience were more likely to implement regenerative procedures. This finding underscores the importance of educational exposure and professional development in facilitating adoption of innovative techniques. Experienced clinicians may be more confident in managing complex endodontic cases and interpreting treatment outcomes, thereby increasing their willingness to utilize regenerative approaches. Furthermore, participants highlighted the importance of hands-on workshops, standardized clinical guidelines, and improved accessibility of materials as key facilitators for implementation. These findings suggest that addressing educational, technical, and systemic barriers may significantly enhance clinical adoption.

Overall, the results of this study indicate that despite growing interest in regenerative endodontics, several challenges continue to limit its integration into routine dental practice. The findings emphasize the need for structured training programs, standardized clinical protocols, improved material availability, and enhanced patient education to support the successful implementation of regenerative endodontic procedures. Addressing these barriers may help bridge the gap between scientific advancements and clinical application, ultimately improving patient outcomes and advancing the field of endodontics.

Recommendations

Based on the findings of this study, several recommendations are proposed to facilitate the effective implementation of regenerative endodontic procedures in clinical practice. First, dental education programs should integrate regenerative endodontics into undergraduate and postgraduate curricula. Early exposure to biologically based treatment approaches may enhance theoretical understanding and encourage clinicians to adopt innovative procedures in their future practice. In addition, competency-based training modules and simulation-based learning should be incorporated to improve technical skills and clinical confidence.

Second, continuing professional development opportunities should be expanded to include hands-on workshops and clinical demonstrations focusing on regenerative endodontics. These training initiatives should emphasize case selection, disinfection protocols, scaffold placement, and follow-up evaluation. Professional dental associations and academic institutions should collaborate to provide structured training programs that address the specific learning needs of clinicians. Such initiatives may help reduce uncertainty and improve consistency in clinical practice.

Third, the development and dissemination of standardized, evidence-based clinical guidelines are essential. Consensus guidelines developed by professional organizations may reduce variability in treatment protocols and enhance predictability of outcomes. Regular updates to these guidelines should be ensured to reflect emerging scientific evidence and technological advancements. Clear clinical algorithms and decision-making frameworks may also assist clinicians in selecting appropriate cases for regenerative procedures.

Fourth, efforts should be made to improve accessibility and affordability of regenerative biomaterials and equipment. Collaboration between policymakers, healthcare institutions, and industry stakeholders may facilitate the development of cost-effective materials suitable for routine clinical use. In addition, institutional support for procurement of specialized materials may encourage clinicians to incorporate regenerative procedures into practice. Cost-reduction strategies, including bulk purchasing and local manufacturing, may further enhance availability.

Fifth, patient education should be strengthened to improve acceptance and compliance with regenerative endodontic procedures. Clinicians should provide comprehensive counseling regarding treatment benefits, expected outcomes, and follow-up requirements. Educational materials, including brochures and visual aids, may help patients better understand the regenerative approach and increase adherence to treatment protocols. Improved patient awareness may also enhance demand for regenerative procedures.

Finally, further research is recommended to evaluate long-term outcomes and cost-effectiveness of regenerative endodontic procedures. Longitudinal clinical studies with larger sample sizes may provide robust evidence regarding treatment predictability and durability. Qualitative studies exploring clinicians' experiences may offer deeper insights into contextual barriers and facilitators. Additionally, comparative studies assessing regenerative endodontics against conventional treatment modalities may inform clinical decision-making and policy development.

Implementation of these recommendations may contribute to overcoming existing barriers, improving clinicians' competence and confidence, and facilitating the integration of regenerative endodontic procedures into routine dental practice.

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