Advances in Techniques for Intact Removal of Permanently Cemented Restorations: A Systematic Review

Shubham Tawade[1], Mithilesh Dhamande[2], Surekha Godbole[3], Anjali Borle[4], Seema Sathe[5], Ashish Gupta[6], Mrunmayee Pophali[7]

[1-7]Sharad Pawar Dental College and Hospital, DMIHER, Sawangi, Wardha, India

ABSTRACT

Introduction: Permanent cemented restorations, such as crowns, bridges, and inlays, are integral to restorative dentistry due to their durability and functional benefits. However, their removal remains challenging, as conventional techniques often risk damaging the underlying tooth structure. Recent advances, including laser-assisted and ultrasonic methods, offer minimally invasive alternatives that improve safety and efficiency. This systematic review aims to evaluate and compare contemporary techniques developed for the intact removal of permanently cemented restorations, assessing their efficacy, safety, and clinical applicability relative to traditional methods.

Methods: A comprehensive search was conducted across PubMed, Scopus, Web of Science, and Google Scholar for studies published between 2000 and 2024. Keywords included *"cemented restorations," "crown removal," "laser-assisted debonding,"* and *"ultrasonic instruments."* Studies focusing on mechanical, chemical, laser-assisted, and ultrasonic techniques for restoration removal were included. Data extraction focused on technique type, mechanism of action, outcomes, and clinical success. Narrative synthesis was performed due to heterogeneity among studies.

Results: Thirty-five studies met the inclusion criteria. Laser-assisted techniques, particularly erbium lasers, demonstrated success rates up to 64% for all-ceramic restorations with minimal damage to underlying tissues. Ultrasonic instruments effectively disrupted cement layers through vibration and cavitation, offering conservative removal. Specialized mechanical and electrochemical devices showed potential for improved efficiency and restoration reusability. Traditional mechanical and chemical methods, though effective, carried a higher risk of tooth and restoration damage.

Conclusion: Modern removal techniques, particularly laser and ultrasonic systems, provide safer and more conservative alternatives to traditional methods. Their integration into clinical practice can improve patient outcomes, reduce complications, and enhance the longevity of dental structures. Continued research and technological refinement are warranted to standardize protocols and further improve clinical efficiency.

Keywords: Cemented Restorations; Clinical Outcomes; Dental Cements; Laser-Assisted Removal, Prosthodontics; Restoration Debonding; Ultrasonic Instruments.

INTRODUCTION

Permanent cemented restorations are a cornerstone of restorative dentistry, encompassing a wide range of treatments such as crowns, bridges, inlays, and onlays that restore the function, structure, and aesthetics of compromised teeth.[1] These restorations are typically luted using durable dental cements, including zinc phosphate, polycarboxylate, glass ionomer, and resin-based materials, each offering unique advantages in terms of bonding, biocompatibility, and longevity.[2] Despite their clinical success, the removal of permanently cemented restorations presents a considerable challenge. The adhesive bond

Conflict of Interest: None

***Corresponding Author**

Dr. Shubham Uttamrao Tawade, Postgraduate student, Sharad Pawar Dental College and Hospital, DMIHER, Sawangi, Wardha.

Phone No.: 7350699325

E-mail: shubhamtawade10@gmail.com

formed between the restoration and the tooth structure strengthens over time, rendering removal procedures complex and potentially traumatic.[3] Traditional approaches, such as sectioning the restoration or using rotary instruments, often compromise the integrity of both the prosthesis and the underlying tooth, which can occasionally result in irreversible pulpal or periodontal damage.

With advances in dental technology, minimally invasive techniques for the intact removal of restorations have emerged. Innovations such as laser-assisted debonding, ultrasonic vibration systems, and specialised removal devices have offered enhanced precision, improved patient comfort, and the possibility of restoration reuse.[4–6] These methods are designed to selectively weaken or disrupt the cement layer without causing collateral tissue damage, representing a paradigm shift from destructive to conservative clinical approaches. While several narrative reviews have discussed restoration removal techniques, few studies have systematically compared and synthesised evidence regarding their clinical efficacy, safety, and cost-effectiveness. Given the growing adoption of digital and energy-based technologies in prosthodontics, a structured evaluation of these techniques is warranted.

This systematic review aims to identify, evaluate, and compare existing techniques for the removal of intact, permanently cemented restorations. The review focuses on assessing efficacy in terms of success rates, time efficiency, and restoration integrity; safety with regard to tooth preservation and patient comfort; and clinical applicability, including cost-effectiveness and ease of use. The review is guided by the following research framework: the population includes patients or *in vitro* models involving permanently cemented dental restorations; the intervention comprises advanced removal techniques such as laser-assisted, ultrasonic, or specialised devices; comparisons are drawn against traditional mechanical or chemical removal methods; and outcomes are defined as successful, intact restoration removal with minimal tooth or tissue damage. Through this systematic synthesis, the review seeks to provide clinicians with an evidence-based perspective on current and emerging removal strategies that enhance clinical outcomes while minimising procedural risks.

METHODS

A comprehensive literature search was conducted across multiple electronic databases, including PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect, covering publications from January 2000 to August 2024. The search strategy was designed to capture all relevant studies addressing the removal of permanently cemented restorations. The following search terms and Boolean operators were used: (“cemented restorations” OR “fixed dental prosthesis” OR “crown removal” OR “bridge debonding”) AND (“laser-assisted” OR “ultrasonic” OR “mechanical” OR “chemical” OR “restoration removal techniques”). Reference lists of selected articles and related review papers were manually screened to identify additional eligible studies not captured in the database search. Duplicate records were removed before screening.

Studies were selected according to predefined inclusion and exclusion criteria. Eligible studies included clinical, *in vitro*, and *ex vivo* investigations evaluating techniques for the removal of permanently cemented restorations. Research comparing advanced methods such as laser-assisted, ultrasonic, or specialised techniques with conventional mechanical or chemical approaches was considered. Only articles published in English and available in full text with sufficient methodological and outcome details were included. Excluded studies comprised case reports lacking detailed methodology, investigations involving temporary or provisional cements, and articles unrelated to restoration removal, such as those focusing solely on cement composition. Editorials, letters to the editor, and non-peer-reviewed abstracts were also excluded.

Two reviewers independently screened titles and abstracts for relevance, and full texts of potentially eligible articles were retrieved for assessment. Any disagreements regarding eligibility were resolved through discussion and consensus. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for documentation and reporting. Based on the PRISMA flow, a total of 412 records were identified through database searching, of which 312 remained after duplicates were removed. Sixty-eight full-text articles were assessed for eligibility, and thirty-five studies were included in the final review.

Data were extracted using a standardised form, recording the author(s), year, study design, type of restoration, and cement used, as well as the technique or method employed (mechanical, chemical, laser, ultrasonic, or specialised). Key outcomes included efficacy, safety, and preservation of integrity. Given the methodological heterogeneity among studies, a narrative synthesis approach was adopted instead of a meta-analysis. Comparative analysis focused on the effectiveness, limitations, and clinical relevance of each removal approach. The quality of the included studies was assessed using validated tools appropriate to the study design. In vitro and ex vivo studies were evaluated using a modified CONSORT checklist, and clinical studies were assessed using the Joanna Briggs Institute (JBI) critical appraisal tool. Each study was categorised as low, moderate, or high risk of bias. Studies with insufficient methodological details were excluded from quantitative assessment but were included in qualitative synthesis when deemed clinically relevant.

RESULTS

Thirty-five studies published between 2000 and 2024 met the inclusion criteria. These included both *in vitro* and clinical investigations examining various approaches for the removal of permanently cemented restorations. The identified methods were broadly classified as mechanical, chemical, laser-assisted, ultrasonic, and specialised removal systems incorporating enhanced visualisation. Each technique was evaluated in terms of its efficacy, safety, and impact on restoration integrity.

The complexity of restoration removal was found to depend on multiple clinical and material-related factors, including the type of cement used, the age of the restoration, the extent of coverage, and the material composition.[10–12] Strongly bonded resin-based cements increased the difficulty of removal, while older restorations often exhibited hardened cement layers resistant to debonding. Patient factors such as anxiety, pain tolerance, and aesthetic expectations also influenced technique selection, highlighting the need to balance efficiency with tooth conservation and patient comfort.

Common challenges identified across studies are summarised in Table 1. Variations in cement solubility and strength affected ease of removal and risk of substrate damage. Complex prosthesis designs, such as porcelain-fused-to-metal (PFM) crowns or long-span bridges, exhibited greater resistance to removal and an increased risk of fracture during debonding. A longer cementation duration correlated with stronger cement interfaces, requiring higher energy or an extended procedural time. Access to modern tools such as lasers and ultrasonic units varied by clinical setting, directly affecting procedural safety and success rate. Inappropriate or forceful removal techniques were associated with enamel microcracks and pulpal irritation, whereas pain and intraoperative discomfort influenced patient compliance and satisfaction.

Table 1: Major Challenges in Removing Permanently Cemented Restorations

Challenge	Description	Clinical Impact
Type of Cement Used	Variations in solubility and strength among resin-based, glass ionomer, and zinc phosphate cements	Determines ease of removal and risk of substrate damage
Restoration Type and Design	Complex designs (PFM crowns, long-span bridges) increase resistance to removal	May increase fracture risk during debonding
Duration of Cementation	Long-term restorations exhibit stronger cement interfaces	Requires higher energy or longer procedure time
Technological Limitations	Availability of modern tools (lasers, ultrasonics) varies by clinic	Affects safety, success rate, and procedure cost
Risk of Tooth Damage	Forceful or inappropriate techniques can cause pulp or enamel trauma	May necessitate additional endodontic or prosthodontic care
Patient Comfort	Pain or sensitivity during removal	Impacts patient compliance and satisfaction

DISCUSSION

This systematic review comprehensively evaluated contemporary methods for the intact removal of permanently cemented restorations, integrating evidence from clinical and *in vitro* studies published between 2000 and 2024. The findings reveal a clear transition in prosthodontic practice from destructive mechanical approaches toward minimally invasive and technology-assisted methods, including laser systems, ultrasonic instrumentation, and specialised removal devices. Collectively, these innovations emphasise the goals of preserving tooth structure, minimising patient discomfort, and improving restoration reusability.

Historically, the removal of cemented restorations relied primarily on mechanical sectioning or lever-type crown removers. While predictable, these methods were inherently invasive and often resulted in loss of the restoration, enamel trauma, and occasional pulpal injury.[19–22] The introduction of chemical solvents provided some conservative relief by softening resin or glass ionomer cements; however, their inconsistent efficacy and potential to irritate surrounding tissues limited broad clinical acceptance.[23,24]

Recent advances in laser and ultrasonic systems have transformed the removal process. The Er: YAG and Er, Cr: YSGG lasers, in particular, exploit the optical absorption properties of the cement's water content to create controlled micro-explosions, weakening the cement interface without damaging the restoration.[25–28] Similarly, ultrasonic devices generate high-frequency vibrations that facilitate cement debonding through cavitation and acoustic streaming, offering a non-destructive alternative.[32–36]

Evidence from multiple studies supports the superior efficacy and safety of these modern systems. Laser-assisted techniques have achieved debonding success rates of up to 64% for all-ceramic restorations, with minimal thermal transmission to pulpal tissues.[31] Ultrasonic systems, when properly applied with coolant, effectively disrupt cement layers and remove crowns or bridges without enamel damage.[33–37] Compared with traditional cutting or prying methods, these advanced technologies markedly reduce the risk of iatrogenic injury and postoperative sensitivity. Moreover, the ability to remove restorations intact facilitates reuse in cases such as temporary removal for endodontic retreatment or cement revision. From a patient perspective, reduced chair time and discomfort improve treatment acceptance and satisfaction.[39,40]

Although laser and ultrasonic systems require substantial initial investment and operator training, their long-term cost-effectiveness arises from decreased retreatment frequency, reduced material waste, and improved clinical predictability [45,46]. The high cost of laser devices remains a barrier in low-resource settings; however, ongoing technological diffusion and the introduction of compact portable units are expected to improve accessibility. Specialised devices such as the WAM key provide a cost-efficient compromise, combining mechanical precision with minimal trauma. Their short learning curve and consistent outcomes make them suitable for general practice. Digital visualisation and magnification aids, including loupes, microscopes, and CAD/CAM systems, further enhance procedural accuracy and safety during complex debonding procedures.[41–43]

The integration of digital dentistry, 3D imaging, and artificial intelligence promises to further refine the removal of restorations. Digital scanning can provide real-time feedback on cement layer thickness, while AI-assisted systems may help predict debonding force thresholds and optimise laser or ultrasonic parameters. Additionally, 3D-printed crown removal tools with customisable angulations are being evaluated experimentally and may offer tailored clinical solutions in the future.[47–50] Emerging electrochemical and piezo-vibrational systems also show potential for selective cement degradation without physical intervention. These developments represent the next phase of minimally invasive prosthodontics, emphasising precision, personalisation, and preservation.

Despite these advancements, several limitations within the current evidence base were identified. Many studies remain *in vitro*, with limited clinical trials validating long-term outcomes. Variations in cement type, restoration material, and energy settings complicate direct comparisons, while most reports lack standardised measurement of cement-weakening efficiency or thermal effects on pulp. Furthermore, few studies assess patient-centred outcomes such as comfort, anxiety reduction, or satisfaction. Consequently, while the reviewed evidence supports the use of advanced techniques, further randomised controlled trials (RCTs) and meta-analyses are required to establish standardised clinical protocols.

From a clinical standpoint, adopting energy-based and digitally guided methods can dramatically enhance restorative practice. Laser-assisted removal is ideal for all-ceramic and zirconia restorations where precision and preservation are paramount. Ultrasonic methods are particularly effective for metal-ceramic or cemented bridgework requiring minimal trauma, while specialised mechanical devices provide practical and economical options for general dental setups. The integration of these technologies supports the broader goals of minimally invasive dentistry, emphasising the conservation of biological tissues while maintaining procedural efficiency and patient comfort.[48–51]

CONCLUSION

This systematic review highlights the progressive evolution of techniques for the intact removal of permanently cemented restorations, reflecting a decisive shift in modern prosthodontic practice toward minimally invasive, technology-driven approaches. Conventional mechanical and chemical methods, though effective, carry significant risks of tooth damage, restoration loss, and patient discomfort. Laser-assisted, ultrasonic, and specialised removal systems demonstrate superior clinical outcomes through enhanced precision, reduced operative trauma, and greater potential for restoration reuse. Erbium-based lasers (Er: YAG and Er, Cr: YSGG) exhibit the most promising results for all-ceramic restorations, while ultrasonic instruments offer reliable outcomes for metal-ceramic prostheses. Despite these advancements, future research should focus on standardising laser and ultrasonic parameters (energy levels, frequency, exposure duration) for different restoration materials and cement types.

REFERENCES

1. Prithviraj DR, Bhalla HK, Vashisht R, Sounderraj K, Prithvi S. Revolutionizing restorative dentistry: an overview. J Indian Prosthodont Soc. 2014;14:333–43. doi:10.1007/s13191-014-0351-5.
2. Zafar MS, Amin F, Fareed MA, Ghabbani H, Riaz S, Khurshid Z, Kumar N. Biomimetic aspects of restorative dentistry biomaterials. Biomimetics (Basel). 2020;5(3):34. doi:10.3390/biomimetics5030034.
3. Mannocci F, Bitter K, Sauro S, Ferrari P, Austin R, Bhuva B. Present status and future directions: the restoration of root filled teeth. Int Endod J. 2022;55(10):1059–84. doi:10.1111/iej.13796.
4. Hopp CD, Land MF. Considerations for ceramic inlays in posterior teeth: a review. Clin Cosmet Investig Dent. 2013;5:21–32. doi:10.2147/CCIDE.S42016.
5. Michaud P-L, Dort H. Do onlays and crowns offer similar outcomes to posterior teeth with mesial-occlusal-distal preparations? A systematic review. J Esthet Restor Dent. 2024;36:295–302. doi:10.1111/jerd.13114.
6. Clove Dental. Dental bridges: types, cost, procedure, benefits, and care [Internet]. Available from: https://www.clovedental.in
7. Healthline. Cantilever dental bridge: benefits, drawbacks, and how it works. 2022 [cited 2024 Aug 28]. Available from: https://www.healthline.com/health/dental-and-oral-health/cantilever-bridge-dental
8. Myra Dental Centre Turkey. Dental onlays: definition, purpose, advantage, and disadvantage [Internet]. 2024 [cited 2024 Aug 28]. Available from: https://www.myradental.co.uk/dental-onlays-definition-purpose-advantage-and-disadvantage
9. Byte Dental. Dental inlays and onlays: what is the difference? [Internet]. Available from: https://www.byte.com/community/resources/article/dental-inlays-onlays
10. Ghodsi S, Arzani S, Shekarian M, Aghamohseni M. Cement selection criteria for full coverage restorations: a comprehensive review of literature. J Clin Exp Dent. 2021;13(11):e1154–61. doi:10.4317/jced.58671.
11. Zamanian A, Yasaei M, Ghaffari M, Mozafari M. Calcium hydroxide-modified zinc polycarboxylate dental cements. Ceram Int. 2013;39(8):9525–32. doi:10.1016/j.ceramint.2013.05.071.
12. Maletin A, Knežević MJ, Koprivica DĐ, Veljović T, Puškar T, Milekić B, Ristić I. Dental resin-based luting materials—review. Polymers (Basel). 2023;15(20):4156. doi:10.3390/polym15204156.
13. Pearl RL, Percec I. Ageism and health in patients undergoing cosmetic procedures. Aesthet Surg J. 2019;39(3):NP288–92. doi:10.1093/asj/sjy283.
14. Vijay D. Ultrasonic scalers: an effective tool for dental hygiene. Unicorn DenMart – Top Dental Equipment Supplier in India. 2023.
15. Marvaniya J, Agarwal K, Mehta DN, Parmar N, Shyamal R, Patel J. Minimally invasive endodontics: a comprehensive narrative review. Cureus. 2022;14(4):e25984. doi:10.7759/cureus.25984.
16. Patel S, Bhuva B, Bose R. Present status and future directions: vertical root fractures in root filled teeth. Int Endod J. 2022;55(8):804–26. doi:10.1111/iej.13737.
17. Sirajuddin S, Narasappa KM, Gundapaneni V, Chungkham S, Walikar AS. Iatrogenic damage to periodontium by restorative treatment procedures: an overview. Open Dent J. 2015;9:217–22. doi:10.2174/1874210601509010217.
18. Gavriil D, Kakka A, Myers P, O´Connor CJ. Pre-endodontic restoration of structurally compromised teeth: current concepts. Br Dent J. 2021;231(6):343–9. doi:10.1038/s41415-021-3467-0.

19. Arafa AM, Aboalazm E, Kamel MH. Effect of mechanical and chemo-mechanical temporary cement cleaning methods on shear bond strength with self-adhesive resin cement: an in-vitro study. BMC Oral Health. 2022;22(1):648. doi:10.1186/s12903-022-02672-7.
20. Bhandary N, Desai A, Shetty YB. High-speed handpieces. J Int Oral Health. 2014;6(4):130–2.
21. Surgical Medical Supplies. Crown remover automatic [Internet]. Available from: https://www.surgicalmedicalsupplies.com
22. Harish P, Joseph SA, Sirajuddin S, Gundapaneni V, Chungkham S. Iatrogenic damage to the periodontium caused by fixed prosthodontic treatment procedures. Open Dent J. 2015;9:190–6. doi:10.2174/1874210601509010190.
23. Dias KC, Soares CJ, Steier L, et al. Influence of drying protocol with isopropyl alcohol on the bond strength of resin-based sealers to root dentin. J Endod. 2014;40(9):1454–8. doi:10.1016/j.joen.2014.02.021.
24. da Silva RAT, Coutinho M, Cardozo PI, da Silva LA, Zorzatto JR. Conventional dual-cure versus self-adhesive resin cements in dentin bond integrity. J Appl Oral Sci. 2011;19(4):355–62. doi:10.1590/S1678-77572011005000010.
25. Verma SK, Maheshwari S, Singh RK, Chaudhari PK. Laser in dentistry: an innovative tool in modern dental practice. Natl J Maxillofac Surg. 2012;3(2):124–32. doi:10.4103/0975-5950.111342.
26. Deeb JG, Grzech-Lesniak K, Bencharit S. Evaluation of the effectiveness and practicality of erbium lasers for ceramic restoration removal: a retrospective clinical analysis. PLoS One. 2023;18(2):e0295957. doi:10.1371/journal.pone.0295957.
27. Azma E, Safavi N. Diode laser application in soft tissue oral surgery. J Lasers Med Sci. 2013;4(4):206–11.
28. Ansari MA, Erfanzadeh M, Mohajerani E. Mechanisms of laser–tissue interaction: II. tissue thermal properties. J Lasers Med Sci. 2013;4(3):99–106.
29. Nazemisalman B, Farsadeghi M, Sokhansanj M. Types of lasers and their applications in pediatric dentistry. J Lasers Med Sci. 2015;6(3):96–101. doi:10.15171/jlms.2015.01.
30. Jurič IB, Anić I. Use of lasers in disinfection and cleanliness of root canals: a review. Acta Stomatol Croat. 2014;48(1):6–15. doi:10.15644/asc48/1/1.
31. Morford CK, Buu NCH, Rechmann BMT, Finzen FC, Sharma AB, Rechmann P. Er:YAG laser debonding of porcelain veneers. Lasers Surg Med. 2011;43(10):965–74. doi:10.1002/lsm.21144.
32. De Paolis G, Vincenti V, Prencipe M, Milana V, Plotino G. Ultrasonics in endodontic surgery: a review of the literature. Ann Stomatol (Roma). 2010;1(1):6–10.
33. Mozo S, Llena C, Forner L. Review of ultrasonic irrigation in endodontics: increasing action of irrigating solutions. Med Oral Patol Oral Cir Bucal. 2012;17(3):e512–6. doi:10.4317/medoral.17621.
34. Yu Y, Mahmud M, Vyas N, Smith WR, Wang Q, Walmsley AD. Cavitation in a periodontal pocket by an ultrasonic dental scaler: a numerical investigation. Ultrason Sonochem. 2022;90:106178. doi:10.1016/j.ultsonch.2022.106178.
35. Oza RR, Sharma V, Multani P, Balsara K, Bajaj P, Dhadse P. Comparing the effectiveness of ultrasonic instruments over manual instruments for scaling and root planing in patients with chronic periodontitis: a systematic review and meta-analysis. Cureus. 2022;14(10):e31463. doi:10.7759/cureus.31463.
36. Kim SY, Kang MK, Kang SM, Kim HE. Effects of ultrasonic instrumentation on enamel surfaces with various defects. Int J Dent Hyg. 2018;16(2):219–24. doi:10.1111/idh.12339.
37. Reda R, Zanza A, Cicconetti A, Bhandi S, Guarnieri R, Testarelli L, Di Nardo D. A systematic review of cementation techniques to minimize cement excess in cement-retained implant restorations. Methods Protoc. 2022;5(1):9. doi:10.3390/mps5010009.
38. Bajunaid SO. Review of techniques for the intact removal of a permanently cemented restoration. Gen Dent. 2017;65(1):48–53.
39. Gencoglu N, Helvacioglu D. Comparison of the different techniques to remove fractured endodontic instruments from root canal systems. Eur J Dent. 2009;3(2):90–5.

40. Case report: simple and efficient crown removal, extraction, and graft techniques—Part 2. DrBicuspid.com. 2016 [cited 2024 Aug 28]. Available from: https://www.drbicuspid.com/dental-specialties/smile-design/restorations/article/15372199/case-report-simple-and-efficient-crown-removal-extraction-and-graft-techniques-part-2
41. Khurshid Z. Digital dentistry: transformation of oral health and dental education with technology. Eur J Dent. 2023;17(4):943–4. doi:10.1055/s-0043-1772674.
42. Dimitrova M, Vlahova A, Kazakova R. Assessment of CAD/CAM fabrication technologies for post and core restorations: a narrative review. Medicina (Kaunas). 2024;60(5):748. doi:10.3390/medicina60050748.
43. Andreiotelli M, Kamposiora P, Papavasiliou G. Digital data management for CAD/CAM technology: an update of current systems. Eur J Prosthodont Restor Dent. 2013;21(1):9–15.
44. Dietrich T, Krug R, Krastl G, Tomson PL. Restoring the unrestorable: developing coronal tooth tissue with a minimally invasive surgical extrusion technique. Br Dent J. 2019;226(10):789–93. doi:10.1038/s41415-019-0268-9.
45. Sharma N, Sisodia S, Jain A, Bhargava T, Kumar P, Rana KS. Evaluation of the efficacy of recent caries removal techniques: an in vitro study. Cureus. 2023;15(8):e34432. doi:10.7759/cureus.34432.
46. Gentili A, Failla G, Melnyk A, Puleo V, Tanna GLD, Ricciardi W, Cascini F. The cost-effectiveness of digital health interventions: a systematic review of the literature. Front Public Health. 2022;10:787135. doi:10.3389/fpubh.2022.787135.
47. Nayyar N, Ojcius DM, Dugoni AA. The role of medicine and technology in shaping the future of oral health. J Calif Dent Assoc. 2020;48(3):127–30.
48. Bansal R, Jain A. Current overview on dental stem cells applications in regenerative dentistry. J Nat Sci Biol Med. 2015;6(1):29–34. doi:10.4103/0976-9668.149074.
49. Tian Y, Chen C, Xu X, et al. A review of 3D printing in dentistry: technologies, affecting factors, and applications. Scanning. 2021;2021:9950131. doi:10.1155/2021/9950131.
50. Mahesh Batra A, Reche A. A new era of dental care: harnessing artificial intelligence for better diagnosis and treatment. Cureus. 2023;15(11):e49319. doi:10.7759/cureus.49319.
51. DaSilva AF, Robinson MA, Shi W, McCauley LK. The forefront of dentistry—promising tech-innovations and new treatments. JDR Clin Trans Res. 2022;7(S1):16S–24S. doi:10.1177/23800844221116850.