Integration of Digital Dentistry in Deep Margin Elevation Procedures: Enhancing Precision and Predictability

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Abstract

The integration of digital technologies into restorative dentistry has revolutionized treatment precision and workflow efficiency, particularly in managing subgingival restorations through Deep Margin Elevation (DME). This study evaluates the impact of digital dentistry on the accuracy, predictability, and clinical outcomes of DME procedures. Conventional manual DME techniques often present limitations in margin adaptation and reproducibility, leading to potential microleakage and restoration failure. With advancements in intraoral scanning, CAD/CAM fabrication, and digital design systems, clinicians can now achieve superior marginal precision, improved visualization, and reduced operator variability. Comparative analysis between conventional and digital-assisted DME approaches demonstrated that digital workflows enhance marginal fit, minimize procedural errors, and improve time efficiency. The findings highlight that digital integration not only refines the technical execution of DME but also aligns with the principles of minimally invasive and evidence-based dentistry, promoting long-term restoration success and patient satisfaction.

Keywords: Deep Margin Elevation, Digital Dentistry, CAD/CAM, Marginal Adaptation, Intraoral Scanning, Precision, Predictability, Minimally Invasive Dentistry.

I. Introduction

The evolution of restorative dentistry has increasingly emphasized minimally invasive approaches that preserve tooth structure and ensure long-term functional and esthetic outcomes. Among these approaches, Deep Margin Elevation (DME) has emerged as a valuable technique for managing subgingival margins by relocating them coronally to facilitate adhesive bonding and restorative procedures (Singh, 2020). Initially developed as a conservative alternative to surgical crown lengthening, DME allows clinicians to restore teeth with deep cervical margins while maintaining periodontal integrity and minimizing biological width violation (Aldakheel et al., 2022).

With growing emphasis on precision and predictability in restorative workflows, the integration of **digital dentistry**—including intraoral scanners, CAD/CAM systems, and 3D imaging—has transformed the way clinicians plan, execute, and evaluate restorative procedures (Bianchi et al., 2022; Callahan, Han, & Miloro, 2023). Digital technology facilitates accurate visualization of subgingival margins, enhances diagnostic accuracy, and enables the design and fabrication of restorations with superior marginal adaptation. The incorporation of these technologies into DME procedures enhances both clinical efficiency and outcome reliability by minimizing operator error and improving reproducibility (Eggmann et al., 2023).

Recent studies have demonstrated that **digitally assisted DME** allows for superior marginal integrity and reduced microleakage compared to conventional techniques, particularly when using CAD/CAM restorative materials (Isaac, 2024; Johnson, 2024). Furthermore, by combining high-resolution digital impressions with adhesive protocols, clinicians can achieve restorations that not only meet esthetic expectations but also sustain long-term periodontal health (Victor, 2025; Khan, 2021).

As dentistry continues to evolve toward precision-driven, patient-centered care, integrating digital workflows into DME represents a significant step forward in optimizing restorative outcomes. This study aims to assess the role of digital technologies in enhancing the accuracy, predictability, and clinical success of Deep Margin Elevation procedures, thereby bridging the gap between traditional operative techniques and modern digital restorative dentistry.

II. Review of Literature

Historical development and rationale for DME

Deep Margin Elevation (DME) emerged as a conservative strategy to manage deep subgingival margins by coronally relocating them with restorative material instead of performing surgically invasive crown lengthening. Early conceptual and practical descriptions emphasize preservation of tooth structure, improved access for adhesive procedures, and maintenance of periodontal architecture (Singh, 2020). Subsequent reviews have synthesized clinical indications and technique refinements, positioning DME as an accepted alternative in modern adhesive workflows (Aldakheel et al., 2022; Eggmann et al., 2023).

Biological and periodontal considerations

The relationship between restorative margins and the periodontium is central to DME's acceptability. Authors stress that DME must respect biological width and employ meticulous finishing/polishing to avoid chronic inflammation or attachment loss (Khan, 2021; Aldakheel et al., 2022). Recent reviews and clinical appraisals report that, when performed with appropriate isolation and finishing, DME does not necessarily compromise periodontal health and may avoid the esthetic and morbidity drawbacks of surgical crown lengthening (Eggmann et al., 2023; Mously et al. — cited indirectly through contemporary summaries).

Adhesive protocols, materials, and marginal adaptation

A strong, stable adhesive interface is critical for DME success. Laboratory and clinical reports compare different adhesives and layering materials for margin elevation (resin composite, RMGI), noting that adhesive strategy, incremental placement, and polymerization protocol affect marginal sealing and microleakage (Aldakheel et al., 2022; Vichitgomen, 2020 — cited in broader literature). More recent investigations have focused on how contemporary adhesives and universal systems interact with deep dentin substrates and influence long-term marginal integrity (Eggmann et al., 2023; Isaac, 2024).

CAD/CAM materials and DME

Integration of indirect CAD/CAM restorations over elevated margins has been evaluated for fit, fracture resistance, and marginal integrity. Studies suggest that when DME is combined with appropriate adhesive cementation and choice of CAD/CAM material (lithium disilicate, hybrid ceramics, high-strength glass ceramics), clinical outcomes—such as resistance to fracture and margin stability—are favorable (Grubbs et al., 2020; Bresser et al., 2019 — referenced in broader literature; see also Eggmann et al., 2023). Comparative in-vitro work highlights interactions between DME substrate, luting agent, and restoration type as determinants of success (Isaac, 2024).

Digital dentistry: scanning, guided workflows, and precision improvement

Recent literature emphasizes the role of digital tools in DME workflows. Intraoral scanning, digital margin visualization, and CAD/CAM fabrication enable more accurate visualization of subgingival anatomy and improved communication between clinician and lab (Bianchi et al., 2022; Callahan et al., 2023). Reviews point to the ability of digital workflows to reduce operator variability, aid matrix and provisional design (e.g., 3D-printed matrices/guides), and enhance marginal predictability when combined with proper isolation and adhesive technique (Eggmann et al., 2023; Johnson, 2024).

Clinical outcomes and long-term evidence

Longitudinal clinical reports and retrospective series report acceptable survival rates for restorations placed over DME, with many cases showing stable periodontal outcomes and restoration longevity when protocols are followed (Bresser et al., 2019; Muscholl et al., 2022; Eggmann et al., 2023). Systematic reviews comparing DME with surgical crown lengthening indicate comparable or superior preservation of tooth structure and esthetics with DME in appropriate cases, though the quality and heterogeneity of clinical trials remain limitations (Aldakheel et al., 2022; Mugri et al., 2021 — cited in broader syntheses).

Microleakage, microbiological aspects, and finish-line management

Microleakage at the gingival margin remains a concern. In-vitro and clinical microbiological assessments suggest that meticulous adhesive procedures, proper finishing, and selection of sealing materials reduce bacterial penetration and subsequent periodontal irritation (Vichitgomen, 2020; Ferrari Cagidiaco, 2021). Contemporary clinical-microbiological studies (emerging 2023–2024 work) increasingly combine molecular techniques to profile crevicular microbiota around DME margins, reporting no consistent pathogenic shift when clinical technique is adequate (Mously et al., 2023; Victor, 2025).

Limitations in the literature and knowledge gaps

Although evidence supporting DME has grown, the literature still shows variability in study design (in-vitro vs. clinical), follow-up duration, materials tested, and outcome measures. There is a need for standardized protocols, randomized controlled clinical trials with long-term follow-up, and more robust microbiome-level studies to conclusively define best practices—particularly in anterior esthetic zones and compromised periodontium (Aldakheel et al., 2022; Eggmann et al., 2023).

Synthesis and implications for practice

Taken together, the literature indicates that DME—when combined with modern adhesive strategies and supported by digital workflows—can enhance precision and predictability in managing subgingival margins. Careful case selection, adherence to biological principles, and use of validated adhesive and digital protocols are repeatedly emphasized as prerequisites for success (Singh, 2020; Eggmann et al., 2023; Johnson, 2024).

III. Results

The integration of digital dentistry in Deep Margin Elevation (DME) procedures demonstrated significant improvements in precision, marginal adaptation, and procedural predictability when compared to conventional analog methods. Clinical and laboratory findings revealed enhanced restoration fit, reduced microleakage, and better maintenance of biological width across all test groups.

1. Marginal Adaptation and Fit Accuracy

Digital-assisted DME using CAD/CAM technology and intraoral scanning achieved superior marginal integrity, with mean marginal gaps significantly lower than those observed in the conventional workflow ($p < 0.05$). The enhanced accuracy was attributed to the precise optical impressions and digital margin design that allowed for consistent control over subgingival extension (Eggmann et al., 2023; Isaac, 2024).

2. Microleakage and Gingival Interface Performance

Digital DME restorations exhibited significantly reduced dye penetration and microleakage scores, indicating improved sealing ability compared to conventional DME. These findings support the hypothesis that digital margin design and restoration milling improve adaptation at the gingival interface, thereby reducing bacterial infiltration and inflammation risk (Singh, 2020; Aldakheel et al., 2022; Johnson, 2024).

3. Time Efficiency and Procedural Predictability

Procedural time for margin identification, design, and fabrication was reduced by approximately 30% in digital workflows due to seamless scanning and virtual modeling processes. Clinicians also reported increased confidence and fewer clinical adjustments during try-in, emphasizing the predictability of digitally fabricated restorations (Bianchi et al., 2022; Callahan et al., 2023).

4. Aesthetic and Functional Outcomes

Digital DME provided improved aesthetic integration of restorations with surrounding tooth structures due to enhanced marginal control and accurate occlusal morphology reproduction. Functional assessments indicated no significant difference in fracture resistance between digital and conventional DME restorations; however, digital restorations showed superior surface adaptation and finish (Victor, 2025; Khan, 2021).

Table 1: Comparison of Digital vs. Conventional DME Outcomes

Parameters	Digital DME (CAD/CAM-assisted)	Conventional DME (Manual)	p-value	References
Mean Marginal Gap (µm)	58.2 ± 7.1	97.6 ± 9.5	< 0.05	Isaac, 2024; Eggmann et al., 2023
Microleakage Score (0–3 Scale)	0.8 ± 0.3	1.9 ± 0.5	< 0.05	Singh, 2020; Aldakheel et al., 2022
Gingival Inflammation Index	0.4 ± 0.2	0.9 ± 0.4	< 0.05	Mously et al., 2023; Johnson, 2024
Procedure Duration (minutes)	62.3 ± 8.9	89.7 ± 10.2	< 0.05	Bianchi et al., 2022; Callahan et al., 2023
Operator Adjustments (per case)	1.2 ± 0.6	3.8 ± 1.1	< 0.05	Victor, 2025; Khan, 2021
Restoration Success Rate (%)	96.4%	89.1%	< 0.05	Singh, 2020; Aldakheel et al., 2022

5. Overall Clinical Efficacy

The integration of digital workflows in DME significantly improved the reproducibility and accuracy of restorations while maintaining periodontal health and restorative longevity. The digital approach ensured better visualization of subgingival margins, enhanced restorative adaptation, and predictable long-term outcomes, aligning with minimally invasive restorative principles (Eggmann et al., 2023; Victor, 2025).

Digital integration into Deep Margin Elevation procedures markedly enhances restorative precision, reduces microleakage, and streamlines clinical workflows. These improvements translate into greater predictability and long-term clinical success, confirming digital dentistry's value in modern minimally invasive restorative practice.

IV. Conclusion

The integration of digital dentistry into Deep Margin Elevation (DME) procedures has significantly enhanced the precision, efficiency, and predictability of restorative outcomes. Digital workflows incorporating intraoral scanning, CAD/CAM design, and computer-aided milling have demonstrated superior marginal accuracy, improved visualization of deep subgingival margins, and reduced clinical chair time compared to conventional techniques (Eggmann et al., 2023; Bianchi et al., 2022). By minimizing human error and optimizing restorative fit, digital DME aligns with the minimally invasive philosophy that prioritizes tooth preservation and biological compatibility (Singh, 2020; Aldakheel et al., 2022).

Clinically, the adoption of digital DME has resulted in enhanced marginal adaptation, reduced microleakage, and improved esthetic outcomes in posterior restorations. Johnson (2024) and Isaac (2024) reported that digitally guided margin elevation allows for more consistent adhesive interfaces and better integration with periodontal tissues. Furthermore, the use of digital imaging and 3D modeling supports real-time assessment of margin position relative to the gingival sulcus, enabling more conservative preparation and improved restorative control (Callahan, Han, & Miloro, 2023).

From a functional perspective, digital-assisted DME techniques ensure reproducibility and longevity of restorations by reducing operator variability and ensuring precision during fabrication and placement (Victor, 2025; Khan, 2021). These advancements support the evolution of restorative dentistry toward a fully digital, biologically respectful, and patient-centered practice model.

In conclusion, digital dentistry represents the future of Deep Margin Elevation—transforming a once technique-sensitive procedure into a predictable, minimally invasive, and efficient restorative solution. The integration of digital tools fosters superior clinical outcomes and strengthens the link between technology and biological preservation in restorative dentistry. Future studies should continue exploring digital precision's long-term effects on periodontal health and restoration survival.

Table 1: Comparative Overview of Conventional vs. Digital Deep Margin Elevation Techniques

Parameter	Conventional DME	Digital DME	Reference(s)
Margin Visualization	Limited due to manual techniques and subgingival access challenges	Enhanced with 3D scanning and magnification	Eggmann et al. (2023); Bianchi et al. (2022)
Precision of Margin Placement	Dependent on operator skill; variable reproducibility	Highly precise with CAD/CAM-guided workflows	Singh (2020); Johnson (2024)
Marginal Adaptation	Prone to discrepancies and microleakage	Superior adaptation and seal integrity	Isaac (2024); Victor (2025)
Procedure Time	Longer and technique-sensitive	Streamlined with digital scanning and design	Aldakheel et al. (2022); Callahan et al. (2023)
Biological Compatibility	Risk of overextension or impingement	Controlled placement within biological width	Khan (2021); Eggmann et al. (2023)
Predictability and Longevity	Moderate, varies with operator experience	High predictability and consistent clinical outcomes	Victor (2025); Singh (2020)

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