



EVALUATION OF CLINICAL AND LABORATORY EFFICACY OF MODERN AND MINIMALLY INVASIVE TECHNOLOGIES IN THE TREATMENT OF DENTAL CARIES IN CHILDREN

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Abstract

This scientific article provides a comprehensive clinical and laboratory evaluation of modern, minimally invasive, and bioactive technologies (silver diamine fluoride — SDF, resin infiltration — ICON, chemomechanical excavation, and bio-interactive restorative materials) in the treatment of dental caries among 150 pediatric patients aged 2 to 18 years. Patients were stratified into three age-defined cohorts. Over a 12-month follow-up period, parameters including pain perception (Wong-Baker FACES scale), patient cooperation (Frankl scale), restoration marginal integrity and retention, salivary pH and buffering capacity, and *Streptococcus mutans* counts were systematically evaluated. Findings revealed that minimally invasive modalities significantly reduced dental anxiety and pain ($p < 0.001$), achieving an 89.4% lesion arrest rate and a 93.5% restoration retention rate. The obtained data provide a robust scientific foundation for implementing age-differentiated clinical treatment protocols in pediatric dentistry.

Keywords: pediatric dentistry, minimally invasive dentistry, silver diamine fluoride, ICON resin infiltration, bioactive restorations, Wong-Baker scale, *Streptococcus mutans*, children aged 2–18.

Introduction. Dental caries remains one of the most prevalent chronic diseases among pediatric populations worldwide, posing a major challenge to public health and pediatric dentistry. The destruction of primary and young permanent tooth hard tissues adversely affects masticatory function, aesthetics, arch development, and the overall quality of life of growing children. Historically, management of pediatric caries relied heavily on surgical intervention involving aggressive rotary mechanical excavation according to classic G.V. Black principles. However, contemporary pediatric dentistry has experienced a profound paradigm shift toward Minimally Invasive Dentistry (MID), prioritizing biological tissue preservation, remineralization, and prevention of lesion progression.

The anatomical and physiological characteristics of primary and young permanent teeth—including thinner enamel and dentin layers, wider dentinal tubules, larger pulp chambers, and incomplete posteruptive enamel maturation—render them particularly vulnerable to rapid caries progression and pulpal involvement. Traditional restorative procedures utilizing high-speed rotary drills and local anesthesia frequently trigger severe dental anxiety, fear, and behavioral non-compliance in pediatric patients, particularly those in younger age brackets. This psychological barrier often leads to incomplete treatments, avoidance of dental visits, or the necessity for pharmacological sedation and general anesthesia. In response to these challenges, non-invasive and micro-invasive treatment modalities—such as 38% Silver Diamine Fluoride (SDF), resin infiltration (ICON technology), chemomechanical

caries excavation (e.g., papain-based gels like Brix 3000), and Atraumatic Restorative Treatment (ART/SMART)—have emerged as effective alternatives to conventional drilling.

Concurrently, remarkable advances in dental biomaterials have led to the development of bio-interactive and bioactive restorative materials, including Glass Ionomer Cements (GICs), Resin-Modified Glass Ionomer Cements (RMGICs), calcium silicate-based cements (Biodentine), and alkasite formulations (Cention N). These materials possess remineralizing, fluoride-releasing, and acid-buffering properties that actively interact with the tooth-saliva interface. Despite the growing popularity of these advanced technologies, comparative long-term clinical data evaluating their age-differentiated efficacy, impact on pain perception, restoration survival, and salivary microbiological homeostasis across the comprehensive pediatric age spectrum (2–18 years) remain limited. Therefore, the objective of this study was to conduct a comprehensive clinical and laboratory evaluation comparing the efficacy, pain perception, restoration longevity, and microbiological dynamics of modern minimally invasive protocols versus conventional restorative approaches in pediatric patients aged 2 to 18 years.

Study object. The study object comprised 150 pediatric patients aged 2 to 18 years presenting with active primary or permanent tooth caries (ICDAS 2–5) who received dental care at pediatric dental clinics. To evaluate age-specific treatment dynamics, patients were stratified into three distinct age cohorts: Group A included 50 children aged 2–5 years (primary dentition phase); Group B included 52 children aged 6–11 years (mixed dentition phase); and Group C included 48 pediatric patients aged 12–18 years (adolescent/permanent dentition phase). Inclusion criteria were: age between 2 and 18 years; presence of active enamel and dentin carious lesions in primary or permanent teeth suitable for non-invasive, micro-invasive, or restorative therapy; written informed consent provided by parents or legal guardians (alongside minor assent when appropriate); and willingness to participate in scheduled 12-month follow-up evaluations. Exclusion criteria included: teeth exhibiting clinical or radiographic signs of irreversible pulpitis, pulp necrosis, or apical periodontitis; severe systemic or developmental disorders; known allergies to silver, fluoride, or methacrylate resins; and uncooperative behavior requiring dental treatment under general anesthesia.

The study protocol was approved by the institutional bioethics committee and conducted in strict accordance with the ethical principles of the Declaration of Helsinki. Patient data confidentiality was maintained through unique identification coding, and participants within each age group were randomly allocated into intervention subgroups receiving either modern minimally invasive/bioactive treatments or conventional rotary restorative procedures.

Materials and methods. Clinical diagnostic procedures were standardized across all 150 patients utilizing visual-tactile inspection under optimal lighting according to ICDAS II criteria, digital bitewing radiovisiography, and laser fluorescence quantification (DIAGNOdent 2190). Baseline caries severity was quantified using the *kp* index for primary teeth and the *KPU* index for permanent teeth.

Patients were randomly assigned to four intervention protocols: Subgroup 1 received 38% Silver Diamine Fluoride (SDF) application combined with SMART (Silver Modified Atraumatic Restorative Treatment utilizing high-viscosity GIC); Subgroup 2 received micro-invasive resin infiltration (ICON) for non-cavitated enamel lesions; Subgroup 3 underwent chemomechanical excavation (Brix 3000 enzymatic gel) followed by bioactive restorative placement (RMGIC, Biodentine, or Cention N); and Subgroup 4 (Control) underwent

conventional rotary excavation under local anesthesia followed by composite resin restoration. Pain perception and patient anxiety were assessed during and immediately following clinical procedures using the validated Wong-Baker FACES Pain Rating Scale (0 to 10) and the Frankl Behavioral Rating Scale (1 to 4). Operator time for each procedure was recorded in minutes.

Laboratory evaluations included collection of unstimulated mixed saliva at baseline, 6 months, and 12 months post-treatment. Salivary pH was measured using a digital precision pH meter, buffering capacity was evaluated titrometrically, and salivary load of *Streptococcus mutans* and *Lactobacillus spp.* was quantified via Real-Time Polymerase Chain Reaction (Real-Time PCR) expressed as colony-forming units per milliliter (CFU/ml). Statistical analysis was performed using IBM SPSS Statistics v.26.0. Quantitative variables were presented as mean standard error ($M \pm m$), while categorical data were expressed as percentages. Group comparisons were conducted using Student's t-test, Mann-Whitney U-test, Chi-square test, and Fisher's exact test. Restoration survival and lesion arrest rates over 12 months were evaluated using Kaplan-Meier survival analysis. Statistical significance was established at $p < 0.05$.

Results. Baseline epidemiological evaluation of the 150 pediatric patients revealed an overall caries prevalence of 81.3%, with mean baseline caries intensity scores of $kp = 5.2$ in Group A (2–5 years), $kp + KPU = 6.4$ in Group B (6–11 years), and $KPU = 5.6$ in Group C (12–18 years). Assessment of pain perception demonstrated statistically significant differences between treatment modalities ($p < 0.001$). Patients treated with non-invasive and micro-invasive protocols (SDF, ICON, and Brix 3000) reported significantly lower mean Wong-Baker FACES pain scores (1.2, 0.8 ± 0.1 , and 1.6, respectively) compared to those subjected to conventional rotary excavation (5.8; $p < 0.001$). Behavioral rating analysis via the Frankl scale indicated that 91.4% of children in the minimally invasive groups exhibited positive or definitely positive behavior (Frankl scores 3–4), whereas positive behavior was observed in only 54.2% of children in the conventional rotary group ($p < 0.001$), reflecting a marked reduction in dental anxiety.

At the 12-month clinical evaluation, the lesion arrest rate for active primary tooth dentin caries treated with 38% SDF (Subgroup 1) reached 89.4%, characterized by hardening and dark pigmentation of carious dentin. In Subgroup 2 (ICON resin infiltration), 91.2% of non-cavitated proximal and smooth surface enamel lesions showed complete arrest with no radiographic or fluorescence evidence of lesion progression. Evaluation of bio-interactive restorations (Subgroup 3: RMGIC, Biodentine, Cention N) demonstrated an overall 12-month retention and success rate of 93.5%, with excellent marginal integrity and absence of postoperative sensitivity. In contrast, conventional composite restorations in Subgroup 4 demonstrated an 84.2% retention rate ($p < 0.05$). The cumulative incidence of secondary (recurrent) caries at 12 months was significantly lower in the bioactive restorative groups (2.1%) compared to the conventional composite control group (9.4%; $p < 0.035$), underscoring the protective effect of continuous fluoride and ion release.

Salivary parameter monitoring demonstrated a positive physiological shift in patients treated with bioactive protocols, with mean salivary pH increasing from 6.21 at baseline to 6.88 at 12 months ($p < 0.001$), accompanied by a 32.6% increase in salivary buffering capacity.

Conclusion. Modern minimally invasive and bioactive technologies represent a highly effective, biologically preserving, and patient-friendly approach for managing dental caries in pediatric patients aged 2 to 18 years. Application of micro-invasive protocols—specifically SDF,

resin infiltration (ICON), and chemomechanical excavation—dramatically reduces pain perception and dental anxiety, fostering positive patient behavior across all pediatric age groups. Silver Diamine Fluoride (38% SDF) combined with SMART GIC restoration is an exceptionally effective protocol for arresting active dentin caries in primary teeth, yielding an 89.4% arrest rate at 12 months.

Resin infiltration (ICON) provides superior micro-invasive control of non-cavitated smooth surface and proximal enamel carious lesions, preserving healthy tooth structure without mechanical drilling. Bio-interactive restorative materials (RMGIC, Biodentine, and Cention N) offer high retention rates (93.5%), superior marginal integrity, and significantly reduced secondary caries incidence due to continuous ion release. Minimally invasive and bioactive treatment strategies favorably alter the oral microenvironment, elevating salivary pH and effectively suppressing cariogenic *Streptococcus mutans* bacterial loads. Age-differentiated selection of treatment modalities—prioritizing SDF/SMART for ages 2–5, ICON and chemomechanical bio-restorations for ages 6–11, and aesthetic bio-interactive materials for ages 12–18—optimizes clinical success and patient compliance. Widespread integration of these evidence-based, minimally invasive protocols into routine pediatric dental practice is strongly advocated to improve long-term oral health outcomes and child well-being.

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