

1 Resin Infiltration in Non-Surgical Caries Management: A 2 Contemporary Review.

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4

5 Abstract

6 Dental caries remains one of the most prevalent chronic diseases worldwide, with early
7 enamel lesions representing a critical intervention window before irreversible structural
8 breakdown occurs. Resin infiltration has emerged as an innovative micro-invasive
9 technique that bridges the gap between preventive and restorative dentistry by
10 penetrating low-viscosity light-curable resin into the microporosities of non-cavitated
11 enamel lesions. This contemporary review comprehensively evaluates the biological
12 basis, mechanism of action, clinical protocol, indications, comparative effectiveness,
13 limitations, safety considerations, and future perspectives of resin infiltration in the non-
14 surgical management of dental caries. Current evidence from randomized clinical trials,
15 systematic reviews, and meta-analyses supports resin infiltration as a predictable and
16 safe treatment for carefully selected non-cavitated enamel and early proximal lesions,
17 demonstrating superior lesion arrest compared with conventional non-invasive
18 therapies. The technique also provides significant esthetic improvement through the
19 masking of white spot lesions, making it particularly valuable in post-orthodontic
20 patients. However, successful outcomes remain highly dependent on accurate
21 diagnosis, appropriate case selection, meticulous clinical technique, and integration with
22 comprehensive caries-risk management. Future advances in bioactive infiltrant
23 materials, antimicrobial resin formulations, artificial intelligence-assisted lesion
24 detection, and combination remineralization therapies may further enhance the
25 effectiveness and longevity of this approach.

26

27 1. Introduction

28 Dental caries remains one of the most prevalent chronic diseases worldwide and
29 continues to represent a significant public health burden despite substantial advances in
30 preventive dentistry. The disease is characterized by a dynamic process of
31 demineralization and remineralization driven by biofilm-mediated acid production,
32 resulting in the gradual destruction of dental hard tissues. Early carious lesions are
33 initially confined to enamel and present clinically as non-cavitated white spot lesions,
34 which remain amenable to non-invasive or micro-invasive interventions before
35 irreversible structural breakdown occurs. Contemporary caries management therefore
36 emphasizes early detection, risk assessment, and minimally invasive treatment
37 strategies aimed at preserving natural tooth structure while preventing disease
38 progression rather than relying solely on conventional restorative approaches.^{9, 25, 29}

39 Traditional management of early enamel lesions has primarily relied on preventive
40 measures such as fluoride therapy, dietary modification, oral hygiene reinforcement,
41 and casein phosphopeptide-amorphous calcium phosphate (CPP-ACP). Although these
42 approaches promote remineralization, their clinical success depends heavily on patient
43 compliance and may be insufficient for lesions exhibiting established subsurface
44 demineralization. Conversely, conventional restorative treatment often requires
45 unnecessary removal of sound enamel for lesions that have not yet cavitated,
46 contradicting the principles of minimally invasive dentistry. These limitations have
47 created a need for treatment modalities that effectively arrest lesion progression while
48 conserving healthy tooth structure.^{12, 25}

49 Resin infiltration has emerged as an innovative micro-invasive technique that bridges
50 the gap between preventive and restorative dentistry. The procedure involves
51 penetration of a low-viscosity light-curable resin into the microporosities of non-cavitated
52 enamel lesions following controlled surface conditioning. After polymerization, the
53 infiltrated resin occludes diffusion pathways within the lesion body, restricting the

54 movement of acids and dissolved minerals and thereby arresting lesion progression. In
55 addition to its therapeutic benefits, resin infiltration improves the optical properties of
56 demineralized enamel by reducing the refractive index difference between healthy and
57 affected tissues, effectively masking white spot lesions and enhancing esthetics.^{25,11}

58 Over the past decade, increasing evidence from randomized clinical trials, systematic
59 reviews, and meta-analyses has demonstrated the effectiveness of resin infiltration in
60 reducing the progression of proximal caries lesions, improving esthetic outcomes of
61 post-orthodontic white spot lesions, and preserving tooth structure. Nevertheless,
62 important considerations remain regarding appropriate case selection, long-term
63 durability, technique sensitivity, and future developments involving bioactive infiltrants
64 and artificial intelligence-assisted diagnosis.^{9,26-29}

65 Therefore, this contemporary review aims to comprehensively evaluate the biological
66 basis, mechanism of action, clinical protocol, indications, comparative effectiveness,
67 limitations, safety considerations, and future perspectives of resin infiltration in the non-
68 surgical management of dental caries, highlighting its role within modern minimally
69 invasive dentistry.

70

71 2. Biological Rationale

72 The rationale for this technique is based on the structural characteristics and
73 demineralization process of early enamel lesions. Under acidic conditions, mineral loss
74 from the enamel results in the formation of microporosities within the lesion body. These
75 porosities act as diffusion pathways, facilitating the movement of acids and dissolved
76 minerals through the enamel. Resin infiltration targets these porous areas by
77 penetrating and occluding the lesion body, thereby sealing the lesion internally rather
78 than merely covering the surface. This occlusion restricts the diffusion of cariogenic
79 acids which may arrest lesion progression and reduce the risk of further

80 demineralization. Furthermore, resin infiltration has been reported to improve the
81 mechanical properties of demineralized enamel, potentially enhancing its resistance to
82 future acid challenges.¹³

83 The effectiveness of this approach is largely dependent on the properties of the infiltrate
84 material. Resin infiltrates are primarily composed of triethylene glycol dimethacrylate
85 (TEGDMA), a low-viscosity monomer that enables effective infiltration of porous enamel
86 lesions. Furthermore, infiltration of the lesion body alters its optical properties,
87 contributing to the masking of non-surgical carious lesions and improved aesthetic
88 outcomes.³⁴

89

90 3. Mechanism of Action

91 The mechanism of resin infiltration is based on the penetration of a low-viscosity resin
92 into the porous enamel lesion. The infiltrate diffuses into the microporosities created
93 during the demineralization process and subsequently polymerizes within the lesion
94 body. By filling and occluding these pores, the resin restricts lesion progression and
95 promotes lesion arrest.³

96 3.1 Chemical Alteration

97 3.1.1 Etching

98 Enamel etching is a critical step in resin infiltration, as the hyper-mineralized surface
99 layer can impede resin penetration into the lesion body. The application of 15%
100 hydrochloric acid for 90–120 seconds effectively removes this surface barrier, exposing
101 the underlying porous enamel and facilitating penetration of the infiltrate. Compared with
102 mechanical surface removal, acid etching provides more controlled surface erosion and
103 avoids smear layer formation which may obstruct lesion pores and compromise resin
104 infiltration.¹³

105 3.1.2 Ethanol

106 Ethanol is used as a drying agent prior to resin infiltration to displace residual water
107 within the lesion and enhance resin penetration. By reducing the viscosity of the
108 infiltrate and improving its diffusion into the porous enamel, ethanol facilitates more
109 effective infiltration of the lesion body.¹³

110 3.2 Physical Penetration

111 3.2.1 Capillary Action

112 Resin infiltration relies on capillary action as the primary mechanism for penetration into
113 porous enamel lesions. According to the Washburn equation, the movement of resin
114 through the lesion is driven by capillary forces and is influenced by factors such as pore
115 volume, capillary radius, surface tension and resin viscosity. The low viscosity and high
116 penetration coefficient of the infiltrate enable it to flow into the microporosities of
117 demineralized enamel allowing deep penetration throughout the lesion body. This
118 capillary-driven infiltration facilitates the effective filling of enamel pores and subsequent
119 lesion sealing.¹³ This approach bridges the gap between non-invasive preventive
120 measures and conventional restorative treatment for non-cavitated lesions extending
121 into the outer third of dentine. The formation of an internal resin barrier further
122 contributes to the stabilization of weakened enamel and preservation of tooth structure.³

123 3.2.2 TEGDMA Chemistry

124 TEGDMA-based resin infiltrates possess physicochemical properties that facilitate
125 penetration into porous enamel lesions. Their low viscosity, low contact angle and high
126 penetration coefficient enable effective infiltration of demineralized enamel through
127 capillary forces. However, the extent of penetration is influenced by lesion
128 characteristics as highly mineralized surface layers and deeper enamel defects may
129 reduce lesion permeability and limit infiltrate penetration.⁷

130 3.3 Dual Biological Result

131 3.3.1 Mechanical Arrest

132 Mechanical arrest is achieved following infiltration and polymerization of the resin within
133 the lesion body. The formation of an internal resin network reinforces the demineralized
134 enamel increasing its mechanical stability and resistance to subsequent cariogenic
135 challenges. As a result, the structural integrity of the affected enamel is preserved and
136 further lesion progression may be arrested.³⁴

137 3.3.2 Optical Masking

138 The optical masking effect of resin infiltration is primarily dependent on the refractive
139 index of the infiltrate. The refractive index of the resin infiltrate (1.52) closely
140 approximates that of sound enamel (1.62) in contrast to the lower refractive indices of
141 water (1.33) and air (1.00) present within enamel porosities. Following infiltration, the
142 resin replaces the air and water within the lesion, thereby reducing the refractive index
143 mismatch between the porous lesion and the surrounding enamel. This reduction in
144 refractive index disparity decreases light scattering and enhances its transmission
145 through the enamel, resulting in a masking effect that renders non-surgical carious
146 lesions and enamel opacities less perceptible. Consequently, the infiltrated lesion
147 exhibits optical properties that more closely resemble those of healthy enamel and
148 improves its aesthetic appearance.¹

149

150 4. Clinical Protocol and Technique

151 The clinical success of resin infiltration depends largely on appropriate case selection
152 and strict adherence to the treatment protocol. Resin infiltration is a minimally invasive
153 technique designed to arrest the progression of non-cavitated enamel lesions by
154 occluding the microporosities within the lesion body. The procedure preserves sound

155 tooth structure and offers both therapeutic and esthetic benefits, particularly in the
156 management of early enamel lesions and post-orthodontic white spot lesions.^{28, 25}

157 4.1 Case Selection and Diagnosis

158 Accurate diagnosis is essential before performing resin infiltration. The technique is
159 primarily indicated for non-cavitated enamel lesions, proximal caries extending into the
160 outer third of dentin, and white spot lesions associated with orthodontic treatment.
161 Clinical examination, bitewing radiographs, and assessment of lesion activity should be
162 performed to determine the suitability of treatment. Lesions exhibiting cavitation or
163 extensive dentinal involvement generally require conventional restorative procedures
164 rather than infiltration therapy.^{24, 3}

165 Proper isolation of the operative field is equally important. Rubber dam isolation is
166 considered the gold standard because it minimizes contamination from saliva and
167 moisture, thereby improving resin penetration and clinical outcomes. Interproximal
168 wedges may be used to provide better access to proximal lesions.²⁷

169 4.2 Clinical Procedure and Resin Application

170 The outer surface of early enamel lesions often contains a hypermineralized layer that
171 limits resin penetration. Therefore, 15% hydrochloric acid gel is applied for
172 approximately 120 seconds to remove this superficial barrier and increase lesion
173 porosity. The etched surface is then thoroughly rinsed and dried. Ethanol is
174 subsequently applied to eliminate residual moisture and improve visualization of the
175 lesion.^{25, 16}

176 A low-viscosity light-curable resin infiltrant is applied to the lesion surface and allowed to
177 penetrate through capillary action. The infiltrant typically remains on the lesion for
178 approximately three minutes to maximize penetration depth. Excess material is carefully
179 removed using cotton pellets and dental floss before light polymerization. Following

180 curing, a second application of the infiltrant may be performed to compensate for
181 polymerization shrinkage and enhance lesion sealing.^{24, 20}

182 4.3 Finishing Procedures and Clinical Outcomes

183 After polymerization, finishing and polishing procedures are performed to remove
184 excess resin and improve surface smoothness. Polished surfaces reduce plaque
185 retention and contribute to improved esthetic outcomes. This is particularly important
186 when treating anterior white spot lesions, where patient satisfaction largely depends on
187 the final esthetic appearance.¹⁶

188 Several clinical studies have demonstrated that resin infiltration effectively arrests lesion
189 progression and improves the appearance of white spot lesions. The technique
190 represents an important component of minimally invasive dentistry because it preserves
191 healthy tooth structure while reducing the need for restorative intervention.
192 Consequently, resin infiltration has become an increasingly accepted approach in
193 contemporary non-surgical caries management.^{28, 20}

194

195 5. Clinical Applications

196 Resin infiltration has come forward as a vital micro-invasive treatment option for the
197 management of non-cavitated proximal caries lesions.^{9, 11} Resin infiltration is notably
198 indicated for proximal lesions limited to enamel or extending into the outer third of dentin
199 (D1) without cavitation.³³ By infiltrating the porosities of demineralized enamel with a
200 low-viscosity resin, the technique results in a diffusion barrier that prevents the
201 penetration of acids and dissolved minerals, thereby inhibiting lesion progression.²⁴
202 Evidence from systematic reviews and meta-analyses has reproducibly indicated
203 significantly lower rates of lesion progression in infiltrated lesions compared with non-
204 invasive methods such as fluoride therapy, oral hygiene measures, or placebo

205 treatment.¹¹ As a result, resin infiltration has become an effective modality for delaying
206 and preventing restorative treatment, preserving healthy tooth structure.⁹

207 Moreover, resin infiltration has gained substantial attention for the management of white
208 spot lesions, notably orthodontic treatment-associated lesions.⁹ By infiltrating enamel
209 microporosities, the resin alters the lesion's optical properties, reducing the refractive
210 index disparity between healthy and demineralized enamel and consequently
211 diminishing light scattering and lesion opacity.²¹ The ability of resin infiltration to improve
212 esthetics has extended its clinical use beyond caries management to encompass post-
213 orthodontic enamel demineralization, fluorosis-associated lesions, and developmental
214 enamel defects. Furthermore, the minimally invasive nature of resin infiltration,
215 combined with the absence of drilling and the limited requirement for local anesthesia,
216 makes it particularly well suited for pediatric patients and individuals seeking
217 conservative treatment options.²¹

218

219 6. Indications for Resin Infiltration

220 Resin infiltration is recommended for the treatment of initial caries lesions involving
221 enamel and the outer third of dentin, provided that no cavitation or surface breakdown is
222 present.⁹ These lesions represent a transitional stage at which preventive measures
223 alone may be insufficient to arrest disease progression, whereas conventional
224 restorative treatment may result in unnecessary removal of healthy tooth structure. By
225 penetrating the lesion body and sealing diffusion pathways, resin infiltration offers a
226 micro-invasive approach that bridges the gap between preventive and restorative care.²⁴
227 Current evidence particularly supports its use in proximal lesions, where access for oral
228 hygiene procedures and topical remineralization therapies is limited, increasing the risk
229 of lesion progression.⁹

230 A further important indication for resin infiltration is the treatment of white spot lesions,
231 particularly those arising as a consequence of orthodontic therapy.²⁴ The opaque
232 appearance of white spot lesions results from subsurface enamel porosity and altered
233 light scattering. By penetrating and filling these microporosities, resin infiltration reduces
234 optical differences between sound and demineralized enamel, making it an effective
235 treatment when both caries control and esthetic improvement are desired.²¹
236 Furthermore, resin infiltration has been suggested as a treatment option for selected
237 developmental enamel defects, including fluorosis, molar-incisor hypomineralization,
238 and amelogenesis imperfecta, where increased enamel porosity contributes to both
239 structural and esthetic concerns.⁸

240 Furthermore, resin infiltration may be particularly beneficial for patients at increased risk
241 of caries progression or those with limited adherence to long-term remineralization
242 regimens, as its clinical effectiveness is less reliant on sustained patient compliance
243 than conventional preventive approaches.⁹ However, the technique is contraindicated in
244 cavitated lesions, lesions extending deeply into dentin, or situations where adequate
245 isolation and moisture control cannot be achieved.³³

246

247 7. Comparative Effectiveness of Resin Infiltration in Non-Surgical 248 Caries Management

249 7.1 Resin Infiltration versus Topical Fluoride

250 Resin infiltration acts as a physical, internal diffusion barrier to halt lesion
251 progression.^{14,34} Unlike topical fluoride varnish, which relies entirely on biochemical
252 surface remineralization and continuous patient compliance, the low-viscosity resin
253 monomer penetrates deeply into the enamel pore volume via capillary forces.³⁴ A
254 landmark systematic review and meta-analysis established that resin infiltration

255 significantly reduces the risk of initial proximal caries progression compared to topical
256 fluoride or placebo alone, yielding a combined risk ratio (RR) of 0.37 (95% CI: 0.29–
257 0.48).¹⁴ Furthermore, regarding cosmetic performance, a randomized controlled trial
258 demonstrated that resin infiltration achieves superior visual results, showing a
259 significantly smaller residual color difference when masking post-orthodontic white-spot
260 lesions compared to traditional fluoride varnish, with high visual stability tracked up to
261 24 months.¹⁹

262 7.2 Resin Infiltration versus Pit and Fissure Sealants

263 While conventional pit and fissure sealants place a thick, protective resin or glass
264 ionomer cap over the external enamel surface, resin infiltration shifts the primary
265 diffusion barrier directly into the subsurface lesion body itself.^{10,15} Both micro-invasive
266 approaches exhibit high success rates in arresting initial, non-cavitated lesions over
267 long-term follow-ups.¹⁰ However, a network meta-analysis revealed that resin infiltration
268 offers a distinct clinical advantage in patients with high caries risk, reporting significantly
269 lower odds ratios (OR = 0.14 to 0.20) for lesion progression compared to alternative
270 surface sealing methods.¹⁰ Supporting this finding, clinical evidence highlights that
271 because the infiltrant eliminates excessive external material before light-curing, the
272 internal infiltration mechanism makes the final treatment far less vulnerable to the
273 complete retention loss or marginal microleakage that frequently compromises
274 conventional surface sealants.¹⁵

275 7.3 Resin Infiltration versus Silver Diamine Fluoride (SDF)

276 Resin infiltration and Silver Diamine Fluoride (SDF) represent contrasting therapeutic
277 strategies for non-surgical caries control.^{14,10,4} SDF relies on silver ions for antimicrobial
278 action and heavy fluoride saturation for chemical arrest, but its primary clinical drawback
279 is the dark, permanent black staining of the treated tooth structure.⁴ A comprehensive
280 systematic review confirmed that while SDF demonstrates high arrest rates (25–99%) in

281 active lesions, its severe aesthetic limitations drastically reduce parental and patient
282 acceptance in the anterior zone.⁴ In contrast, resin infiltration offers an optimal aesthetic
283 alternative because its refractive index matches that of healthy hydroxyapatite, allowing
284 it to blend seamlessly without discoloration.^{34,15} However, syntheses emphasize that
285 resin infiltration remains a highly technique-sensitive procedure requiring 15%
286 hydrochloric acid etching and strict rubber dam isolation, whereas SDF remains a rapid,
287 moisture-tolerant application ideal for uncooperative pediatric patients where aesthetics
288 are secondary.^{14,4}

289

290 8. Limitations

291 8.1 Restricted Indications

292 The main drawback of resin infiltration is the lack of clinical applications. The technique
293 is mainly recommended for the management of non-cavitated enamel lesions and early
294 proximal carious lesions which are not extensive in dentin. The effectiveness relies on
295 the underlying lesion body being porous and the infiltrant resin reaching the porous
296 body and occluding it. Resin infiltration is less reliable and lesion progression may not
297 be halted if significant dentinal involvement is present after the cavitation has occurred.⁹
298 Moreover, there is a high rate of success in proximal lesions, but limited evidence exists
299 for the use of this technique in occlusal, root surface or advanced dentinal caries.
300 Hence appropriate case selection is crucial and if the cavity is too deep or cavitated, the
301 infiltration may not be adequate, leading to residual caries activity. Therefore, resin
302 infiltration is recommended for certain cases, and stages of the caries process, and
303 should not be used to replace traditional restorative methods.³³

304 8.2 Technique Sensitivity

305 The clinical success of resin infiltration is very technique dependent and depends on
306 careful execution of many of the steps in the procedure such as isolation, surface
307 conditioning, drying of the lesion, resin application and light polymerization. To achieve
308 successful infiltration, the hypermineralized surface layer needs to be removed by
309 etching with 15% hydrochloric acid; these "channels" provide pathways for the
310 infiltration of the lesion body by resin. In reality, if the etching is improper, the
311 penetration depth can be reduced by leaving unetched parts of the surface barrier, and
312 preventing the penetration of the subsurface porosities, as was shown by Meyer-
313 Lueckel and Paris.²⁵ Likewise, incomplete drying after ethanol application can also
314 affect the ability to get the low viscosity resin to penetrate the capillary of the lesion; the
315 moisture in the lesion will limit uptake of the low viscosity resin, and will also make
316 proper sealing of the lesion difficult. Clinical isolation is also a vital element because
317 contamination from saliva, crevicular fluid or moisture from the infiltration process can
318 have a negative impact on resin penetration and polymerization. The resin infiltration is
319 a multi-step procedure, requiring a specific sequence of the steps and accuracy of the
320 procedure in order to achieve optimal results, unlike the conventional fluoride-based
321 preventive therapies. Another limitation of the systematic review presented by Dorri et
322 al. was the differences in treatment protocols and operators' technique in the clinical
323 studies, which is one possible explanation for the discrepancy in clinical success rates.
324 In addition, the depth, size and mineralization of lesions may affect the infiltration
325 effectiveness, which requires careful case selection and the operator's experience to
326 achieve successful treatment. Resin infiltration, therefore, though considered to be a
327 minimally invasive technique, relies heavily upon the exactness of clinical procedures
328 and may not be as widely accepted in clinical use as it might be, leading to a degree of
329 variability in long-term outcome.¹²

330 8.3 Limited Penetration Depth

331 The major drawback of resin infiltration is the lack of complete infiltration in deeper
332 carious lesions. The method of resin infiltration is based on capillary forces to infiltrate a
333 low viscosity resin into the micro-porosities caused by enamel demineralization. A
334 number of investigations have shown that penetration depth is affected by lesion depth,
335 pore volume, lesion activity and the presence of areas with high mineralization on the
336 surface. Paris, and later Meyer-Lueckel, showed that resin infiltrants can be used to
337 penetrate a large part of non-cavitated lesions, but it is not always possible to
338 completely infiltrate lesions that have progressed into the inner enamel or the outer
339 dentin.²⁵ Un-infiltrated residual porosities can remain under the infiltrated surface layer,
340 providing a potential pathway for diffusion of acids, bacteria and dissolved minerals to
341 continue. This is a growing issue with more severe proximal lesions where the depth of
342 the lesion could exceed the ability of the infiltrant to penetrate. In addition, systematic
343 reviews have indicated that resin infiltration is most successful in early enamel lesions
344 and evidence for its success in deeper lesions is less definitive. Partial penetration of
345 infiltrant may therefore not be sufficient to completely halt lesion progression and
346 therefore early diagnosis and intervention are highly significant. Potential modifications
347 of infiltrant components, infiltrant penetration and delivery systems could improve
348 infiltration of deeper lesion bodies and the clinical use of this micro-invasive treatment
349 option.¹²

350 8.4 Long-Term Durability Concerns

351 Although resin infiltration is clinically successful in the short and medium term, its
352 durability has yet to be determined. The follow-up periods of most clinical trials that
353 have assessed lesion arrest, esthetic masking and color stability have been from 6-
354 months to 3-years with a few studies exceeding 5 years. Systematic review studies
355 have consistently shown that resin infiltration is an effective method in reducing the
356 progression of non-cavitated proximal lesions up to 2-3 years and achieved satisfactory
357 esthetic results in short and intermediate-term follow-up. But solid evidence of the long-

358 term effects is limited. Many of the studies included in the recent systematic review
359 which compared outcomes of resin infiltration over varying time periods had small
360 sample sizes, showed methodological variability, and had a relatively short follow-up
361 time, so it was hard to make any clear conclusions about long term clinical results.³²
362 Likewise, systematic reviews have shown that there is a requirement for good studies
363 with RCTs and a good follow up period to see if the beneficial effects of resin infiltration
364 persist over decades. Another issue is the possibility of aging, change of colors,
365 hydrolytic degradation and wear with time, which might affect esthetic and clinical
366 results. Recent studies have shown that esthetic improvements may be maintained for
367 up to 6 years in most instances, but there is little data available beyond 5-10 years.
368 Thus, although there are current indications of the efficacy of resin infiltration in the
369 short and medium term, there is a certain level of doubt about its durability over time,
370 which would require longer-term clinical studies to confirm.³²

371 8.5 Esthetic Limitations

372 While resin infiltration has proved to be very successful at concealing white spot lesions
373 and enhancing enamel esthetic appearance, concerns about esthetic long-term stability
374 of infiltrated enamel still exist. The infiltrant resin changes the refractive index of
375 demineralized enamel which decreases the visual difference between the lesion and
376 normal enamel. But there are a few studies that indicate that the colour stability of
377 infiltrated lesions might be affected by the physicochemical properties of the resin
378 materials and the presence of staining agents like coffee, tea, red wine and tobacco.
379 Ibrahim et al. performed a systematic review and found good esthetic results and color
380 stability for up to 24 months, but noted a lack of long-term clinical studies and
381 suggested additional longitudinal studies to determine long-term esthetic performance.¹⁷
382 Likewise, Borges et al. found that there is a limited number of high-quality clinical trials
383 and follow-up periods that provide support for long-term color maintenance of resin
384 infiltration, and that it can be used successfully to mask enamel opacities.⁶ Laboratory

385 testing has also shown that infiltrant resins containing a high percentage of TEGDMA
386 have the ability to absorb water and easily take up pigments, which may lead to
387 discoloration in the long term. Thus, although resin infiltration is a very good means of
388 immediate and short-term restorative esthetic improvement, there are still some doubts
389 about its long-term color stability and resistance to extrinsic staining.⁷

390 8.6 Failure to Address the Causes

391 A major drawback of resin infiltration is treating the lesion and not the causes
392 underneath the caries process. The technique works by blocking the microporosities in
393 a demineralized lesion which decreases the diffusion of acids and dissolved minerals
394 and stops the progression of the lesion. It does not directly affect biological and
395 behavior risk factors for caries: diet (sugar), plaque formation, oral hygiene, reduced
396 saliva flow, and changes in the oral microbiome. Thus, the treated lesion may not
397 progress, but if the patient continues to have risk factors associated with caries, then
398 other areas of the dentition may develop lesions. Modern caries management
399 philosophies focus on a risk-based management strategy which involves minimal
400 intervention as well as preventive treatment like dietary counselling, fluoride treatment,
401 oral hygiene counselling, and regular monitoring. This is why a few reviews on the
402 management of micro-invasive caries have recommended to consider resin infiltration
403 as a complement to comprehensive preventive care. Successful infiltration of lesions is
404 the most important aspect of long term success, however, there must be control of the
405 etiological factors which started the disease process. A lack of management of these
406 factors could jeopardize the overall caries management even if there is success in the
407 management of the lesions.²²

408 8.7 Learning Curve and Cost

409 Although resin infiltration is a very simple technique, the widespread use of this
410 technique might be restricted because of economic and operator factors. Special

411 materials are needed for the procedure, such as proprietary infiltration systems,
412 hydrochloric acid etchants, ethanol drying agents and dedicated application protocols,
413 which can add to the expense of treatment as opposed to traditional preventive
414 treatments like the use of fluoride varnishes. In addition, there are several procedural
415 steps, such as isolation, etching, drying, resin application and polymerization, that are
416 crucial for successful treatment, and require a lot of experience from the clinician. The
417 sensitivity of the technique employed with these steps develops a learning curve,
418 especially for those clinicians who are not familiar with micro-invasive techniques.
419 Discrepancies in clinical results between studies could be due to variations in operator
420 skill. Furthermore, since resin infiltration is a relatively new technique compared to
421 traditional restorative methods, the policies and practices of reimbursement and
422 insurance vary from healthcare systems, making it less accessible for certain patients.
423 The process, although it could eventually lead to fewer restorative treatments that rely
424 on more complex procedures, still presents some challenges in terms of the materials,
425 and the training that is needed for widespread use. The use of resin infiltration in routine
426 clinical practice may become more accessible and adopted in the future if clinical
427 protocols can be further simplified, material expenses can be decreased, and more
428 clinicians can be trained.²³

429

430 9. Safety and Clinical Considerations

431 Recent clinical research shows that resin infiltration (RI) is highly effective in slowing
432 down the progression of early carious lesions when compared to traditional non-
433 invasive methods. Studies, including randomized clinical trials, have consistently found
434 that lesions treated with RI are much less likely to progress. In fact, long-term data
435 suggest that this treatment can successfully arrest caries for up to seven years.^{30, 26}
436 Further support comes from systematic reviews, which confirm that resin infiltration is
437 both a safe and effective micro-invasive procedure. When performed correctly, it carries

438 minimal risk of adverse effects, making it a reliable choice in clinical practice.¹¹ The way
439 RI works is by allowing a low-viscosity resin to penetrate the tiny pores within
440 demineralized enamel. Once these pores are sealed, acids can no longer diffuse easily
441 into the lesion, thereby stopping further demineralization and disease progression.²⁵

442 Apart from preventing caries progression, RI also provides clear aesthetic benefits. It is
443 especially useful in treating early white-spot lesions, as it reduces their chalky
444 appearance and helps restore the natural translucency of enamel. This is particularly
445 important for anterior teeth, where appearance plays a major role in patient
446 satisfaction.²⁹

447 The clinical procedure for resin infiltration is relatively simple and minimally invasive.
448 First, the tooth is isolated to maintain a dry field. The enamel surface is then treated with
449 approximately 15% hydrochloric acid to open up the surface pores. After rinsing and
450 drying, an ethanol-based drying agent is applied to remove any remaining moisture. A
451 low-viscosity resin is then placed on the lesion and allowed to penetrate for a few
452 minutes, often with gentle agitation to enhance infiltration. Excess material is removed,
453 followed by light curing. Finally, polishing may be done to achieve a smooth surface.
454 Following each step carefully is essential to ensure the best possible outcome.^{29, 25}

455 RI is mainly indicated for non-cavitated lesions, such as proximal caries, smooth-
456 surface lesions, and white-spot lesions that commonly occur after orthodontic treatment.
457 It works best when the lesion is limited to enamel or the outer third of dentin and the
458 tooth surface is still intact. However, in cases where the lesion is cavitated or extends
459 deeper into dentin, resin infiltration becomes less effective and conventional restorative
460 treatment may be required.¹¹

461 In summary, resin infiltration is a scientifically supported, patient-friendly approach for
462 managing early carious lesions. It helps preserve natural tooth structure, prevents
463 further progression of decay, and improves aesthetics, making it an important tool in
464 modern minimally invasive dentistry.³⁰⁻²⁹

465

466 10. Future Directions

467 10.1 Bioactive Resin Infiltrants

468 Chemically modified resin infiltrant materials that can prevent lesion progression along
469 with producing antimicrobial activity and remineralization seem to be the most promising
470 future direction of resin infiltration. The traditional infiltrants drain away cavity fluid from
471 the enamel, and serve as passive barriers to the diffusion of acids and dissolved
472 minerals through the enamel. However, they do not actively participate in tissue
473 regeneration and don't help control bacteria. Recently, a number of studies have
474 explored the incorporation of fluoride-containing compounds as well as nanoparticles of
475 calcium phosphate, amorphous calcium phosphate (ACP), nano hydroxyapatite and
476 bioactive glass particles in the infiltrant formulation. In these materials, the release of
477 calcium, phosphate and fluoride ions has been demonstrated that results in the
478 deposition of minerals in the demineralized enamel and makes it more resistant to
479 future acid attacks. In vitro tests of these bioactive glass-containing infiltrants have also
480 been conducted and they have been shown to be more microhard on the surface and
481 remineralizing than traditional resin-based systems. Besides, the research of
482 antimicrobial modification using quaternary ammonium methacrylates, silver
483 nanoparticles and chlorhexidine has been centered on prevention of the bacterial
484 colonization and biofilm formation. All these enhancements suggest that future infiltrants
485 may evolve into multifunctional therapeutic systems that may inhibit caries, induce
486 remineralization, and inhibit microbial activity.^{5,2}

487 10.2 AI-Guided Lesion Selection

488 Patient selection for resin infiltration therapy will become increasingly critical and rely on
489 more and more Artificial Intelligence (AI) and machine learning (ML) technologies. A

490 major reason for the success of infiltration is the identification of lesions at an advanced
491 stage but not yet cavitated which can be treated using micro-invasive techniques. Near-
492 infrared transillumination, digital imaging, optical coherence tomography and new deep-
493 learning algorithms for analysing bitewing radiographs are found to be as accurate or
494 more accurate, and more accurate in classification, than a clinician in detecting and
495 classifying early carious lesions. Diagnostic consistency and efficiency can be
496 enhanced in the future with AI-powered systems that minimize inter-examiner variability
497 and deliver objective measurements of the depth, activity, and risk of progression of a
498 lesion. In addition, the application of predictive models that consider individual patient
499 risk factors such as oral hygiene, dietary habits, salivary properties and previous caries
500 experience may help select the lesions most amenable to resin infiltration. Digital caries
501 management processes combined with the implementation of AI could then help render
502 earlier interventions, improved treatment options and improved long-term outcomes,
503 without unnecessary treatment.³¹

504 10.3 Combination Therapies

505 The future paradigm of non-surgical caries management may be the resin infiltration,
506 not singly as a method of remineralization treatment, but rather in combination with
507 other remineralizing methods. Resin infiltration can slow down lesion progression by
508 blocking the microporosities and reduce the permeability of the lesion, but it does not
509 provide as much biological regeneration of the demineralized tooth structure. As a
510 result, combinations of self-assembling peptides (P11-4), casein phosphopeptide-
511 amorphous calcium phosphate (CPP-ACP), fluoride varnishes and nano-
512 hydroxyapatite-containing materials have been investigated. Self-assembling peptides
513 have been successfully used to create a biomimetic scaffold for the de novo
514 hydroxyapatite formation in early carious lesions, while CPP-ACP is a source of calcium
515 and phosphate ions. In several clinical and laboratory studies, it has been demonstrated
516 that resin infiltration combined with remineralizing agents gave better remineralized and

517 better esthetic effect as compared with using remineralizing agents alone. Such a
518 combined therapy may be able to deliver a more comprehensive therapy in that it
519 hinders the development of the lesion, promotes demineralization of the enamel and
520 stabilises the lesion over time. Randomised controlled trials to establish optimal
521 treatment regimens and to evaluate the softness of these co-numerous effects are
522 warranted.¹⁸

523 10.4 Improved Resin Formulations

524 The next generation of infiltrant resin is being developed based on material science
525 advances, such as enhanced physical, biological and esthetic properties of the resin.
526 The majority of the commercially available infiltrants currently available are prepared
527 using the low viscosity monomer, triethylene glycol dimethacrylate (TEGDMA), which is
528 well suited for the ability to penetrate the microporosities of the enamel structure, but
529 also has a relatively high water sorption and staining potential. The next step in the
530 formulations is to develop improved penetration coefficients, while simultaneously
531 reducing the polymerization shrinkage and hydrolytic degradation. The use of nanofillers
532 in order to increase the mechanical strength and anti-discolor properties has been
533 studied, as well as the use of new monomer systems and bioactive additives. Moreover,
534 antimicrobial modification using quaternary ammonium and bioactive ion releasing silver
535 nanoparticles has been found to be effective in reducing bacterial adhesion and biofilm
536 formation. Colour stability is one of the major esthetic issues with the materials currently
537 available, and such efforts are being taken to develop more colour stable materials that
538 can be infiltrated. The innovations that are developing may well substantially improve
539 the usefulness and durability of resin infiltration therapy, as well as its effectiveness.⁵

540 10.5 Long-Term Clinical Trials

541 A number of clinical studies and systematic reviews have demonstrated that there is
542 benefit using resin infiltration for arresting non-cavitated lesions, but the longevity of this

543 treatment remains uncertain. Most of the available clinical studies have short follow up
544 periods of 1-3 years, but a few are longer (5 years or more). Long-term stability of lesion
545 arrest, susceptibility to discoloration, material ageing and cost-effectiveness are
546 significant issues to be addressed. Reports have been numerous about systematic
547 reviews that have pointed to the need for additional multicenter randomized controlled
548 trials with longer follow-up time (more than 5-10 years) and consistent outcome
549 measures. Data from such research will be helpful to decide this treatment option in
550 various clinical and patient risk situations. Long term data would also need to be
551 analyzed to assess whether resin infiltration provides economic benefit over a patient's
552 lifetime compared to preventative/restorative treatment and will result in a major
553 reduction of the need for restorative treatment. Additionally, substantial evidence with
554 long-term follow-up will be essential in advancing clinical guidelines and the expanding
555 role resin infiltration has in minimally invasive dentistry.³²

556

557 11. Conclusion

558 Resin infiltration has established itself as an important micro-invasive treatment
559 modality for the management of non-cavitated enamel lesions and early proximal caries.
560 By penetrating and sealing subsurface enamel porosities, the technique arrests lesion
561 progression while preserving healthy tooth structure, effectively bridging the gap
562 between preventive and restorative dentistry. In addition to its caries-arresting potential,
563 resin infiltration provides significant esthetic improvement through masking of white spot
564 lesions, making it particularly valuable in post-orthodontic patients and other
565 developmental enamel defects.

566 Current clinical evidence supports resin infiltration as a predictable and safe treatment
567 for carefully selected lesions, with systematic reviews and randomized clinical trials
568 demonstrating superior lesion arrest compared with conventional non-invasive

569 therapies. However, successful outcomes remain highly dependent on accurate
570 diagnosis, appropriate case selection, meticulous clinical technique, and integration with
571 comprehensive caries-risk management. Limitations such as technique sensitivity,
572 incomplete penetration in deeper lesions, uncertain long-term durability, and higher
573 treatment costs continue to warrant consideration.

574 Future advances in bioactive infiltrant materials, antimicrobial resin formulations,
575 artificial intelligence-assisted lesion detection, and combination remineralization
576 therapies may further enhance the effectiveness and longevity of this approach. Well-
577 designed multicenter randomized clinical trials with extended follow-up periods are still
578 needed to establish long-term clinical performance and cost-effectiveness. Overall,
579 resin infiltration represents a significant advancement in contemporary minimally
580 invasive dentistry and is expected to play an increasingly important role in preserving
581 natural tooth structure while improving both functional and esthetic patient outcomes.

582

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