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SYSTEMATIC REVIEW AND META ANALYSIS

Endodontic Microsurgery or Single-Tooth Implant after Root Canal Failure? A Narrative Review and Clinical Decision Framework

ABSTRACT

Persistent apical periodontitis after root canal treatment requires a cause-directed assessment of whether to retain or replace the tooth. This structured narrative review compares endodontic microsurgery (EMS) with extraction and single-implant replacement and proposes a clinical decision framework. A focused PubMed search covering 1 January 2005 to 30 August 2026, repeated on 13 September 2026, retrieved 15 records. Six publications informed the core synthesis; one broader comparative study was retained as contextual evidence and eight records were excluded. Purposive supplementation produced 58 cited publications overall. Both pathways can achieve favourable outcomes, but survival, radiographic healing and freedom from complications are distinct endpoints. Separate-arm pooled proportions cannot establish treatment superiority or equivalence. EMS outcomes vary with follow-up, periodontal support, structural integrity, defect morphology and root-end management. Implant survival must be distinguished from crown survival and peri-implant health. Economic findings depend on the clinical scenario, time horizon and assumptions about replacement and reintervention. The proposed sequence first establishes whether active treatment is indicated, then assesses restorability, periodontal maintainability, orthograde retreatability, surgical feasibility, patient and site risks, and informed preference. EMS is a reasonable tooth-retention option when the tooth can be durably restored and the cause of failure is surgically manageable. Extraction and implant assessment are appropriate when retention is not predictable or the informed patient chooses replacement. The framework supports shared decision-making but is not a validated prediction tool.

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Introduction

Persistent or recurrent apical periodontitis after root canal treatment is most often sustained by intraradicular infection within anatomically inaccessible areas, but extraradicular infection, foreign-body reactions and cystic pathology may also contribute. Structural failure can compromise prognosis or mimic an endodontic presentation. Contemporary guidance places diagnosis and cause-directed treatment before tooth replacement. Orthograde retreatment is generally considered when disinfection can be improved without disproportionate structural damage; the European Society of Endodontology (ESE) S3 guideline states that apical surgery may be considered when non-surgical treatment or retreatment is impractical. This is a conditional clinical pathway, rather than proof that one intervention is universally more effective (1–3).

When orthograde treatment has failed or is not appropriate, the clinician may retain the tooth by endodontic microsurgery (EMS) or extract it and provide a single-tooth implant. Both are established treatments with different biological consequences. EMS retains the tooth and periodontal ligament and may preserve existing hard- and soft-tissue architecture, although recession, scarring and local bone loss can occur. Implant therapy replaces the tooth with an osseointegrated implant and prosthetic crown. Extraction is irreversible; implant placement may remain possible after failed EMS, but persistent infection, tissue loss and additional procedures can make subsequent rehabilitation more complex. Microsurgery should not be used to postpone extraction when durable tooth retention is not achievable (4–6).

The apparent simplicity of comparing percentages is misleading. Endodontic studies usually define success through both symptoms and radiographic healing, whereas implant studies often report survival of an implant that remains in function despite peri-implant inflammation, prosthetic repair or aesthetic compromise. Moreover, implant cohorts frequently use selective site and patient criteria, while EMS is often offered to previously treated teeth with an established lesion and complex restorative history. Comparisons that ignore these differences risk favouring the treatment assessed with the less demanding endpoint (7–9).

This narrative review aims to: (i) appraise current evidence on the effectiveness, complications and prognosis of EMS and single implants after unsuccessful endodontic treatment; (ii) identify clinically important differences in outcome definition and patient burden; and (iii) translate the evidence into a sequential decision framework. The emphasis is not on declaring a universally superior procedure, but on identifying the circumstances in which retaining or replacing a particular tooth is the more defensible choice. The question begins after root canal treatment and therefore excludes earlier tooth-preserving interventions such as vital pulp therapy in selected mature teeth (10).

Review approach

The preparation and reporting of this structured narrative review were informed by SANRA, a quality-assessment scale for narrative reviews, including justification of the topic, a focused clinical question, a described literature search, appropriate referencing and scientific reasoning (11). The review integrates heterogeneous clinical, biological, restorative, economic and patient-reported evidence. It was not prospectively registered and is not a systematic review; SANRA does not substitute for systematic-review methods or formal assessment of certainty.

A focused PubMed search was repeated on 13 September 2026 using the publication-date interval 1 January 2005 to 30 August 2026. The complete

query, including the date restriction, is reproduced in Table 1. Core eligibility required explicit consideration of apical surgery or EMS and implant replacement as alternative strategies. Systematic reviews, meta-analyses, comparative clinical studies and clinical decision reviews were eligible. Broader studies of non-surgical endodontic treatment and implants were considered contextual evidence because they cannot directly estimate the comparative effectiveness of EMS. Case reports and small case series without a relevant comparison, laboratory studies, implant-pathology reports without alternative-treatment evidence, combined procedures and publications addressing a different clinical question were outside the core scope.

The search retrieved 15 unique PubMed records. Eight were excluded from the core synthesis: three case reports or case series without a relevant comparison, two implant-pathology or site-effect reports, one combined-treatment study, one odontogenic-sinusitis cost model and one review of dynamic oral surgery outside the decision question. A further record, Hannahan and Eleazer (12), concerned non-surgical endodontic treatment and was retained only as contextual evidence. Six core publications remained: three systematic reviews or meta-analyses, two narrative or clinical decision reviews, and one retrospective comparative cohort (4,7–9,13,14). Table 1 provides

Table 1
Core search and disposition of retrieved records

Component	Specification
Design and scope	Structured narrative review informed by SANRA. No systematic-review or exhaustive-search claim.
Source and dates	PubMed; search repeated 13 September 2026. Publication-date interval: 1 January 2005 to 30 August 2026.
Complete core query	("endodontic microsurgery"(Title/Abstract) OR "apical surgery"(Title/Abstract) OR "periradicular surgery"(Title/Abstract) OR apicoectomy(Title/Abstract)) AND ("dental implant"(Title/Abstract) OR implants(Title/Abstract)) AND (outcome*(Title/Abstract) OR success(Title/Abstract) OR survival(Title/Abstract) OR cost*(Title/Abstract) OR "quality of life"(Title/Abstract) OR decision*(Title/Abstract)) AND ("2005/01/01"(Date - Publication) : "2026/08/30"(Date - Publication))
Records retrieved	15 unique PubMed records; uniqueness checked by PMID. A single database does not itself prove absence of duplicate publications.
Core eligibility	Explicit evaluation of EMS/apical surgery and implants as alternatives; clinical comparative studies, systematic reviews/meta-analyses and clinical decision reviews.
Excluded records n = 8	Case reports/series without a relevant comparison: PMIDs 40532150, 39619062, 20545551 (n = 3). Implant pathology/site effects: 36548276, 32452035 (n = 2). Combined treatment: 37279227 (n = 1). Other clinical questions: 34418111, 41598823 (n = 2).
Contextual reclassification n = 1	PMID 18928836, Hannahan and Eleazer: non-surgical endodontic treatment versus implants, not an EMS comparison (12).
Core publications n = 6	PMIDs 25306305, 39979225, 24065635, 28343928, 26778004, 42282368. Three systematic reviews/meta-analyses, two narrative/decision reviews and one retrospective comparative cohort.
Context and synthesis	Six core plus 52 contextual/methodological publications = 58 references. The latter include the reclassified cohort. Supplementation was purposive; overlapping primary studies were not counted as independent replications.
Critical appraisal	Descriptive appraisal of design, directness, outcomes and reporting. No independent duplicate screening, formal risk-of-bias scoring, new meta-analysis or certainty grading.

Abbreviations: EMS, endodontic microsurgery; PMID, PubMed identifier; SANRA, Scale for the Assessment of Narrative Review Articles. Publication-date limits are distinct from the date on which the search was repeated.

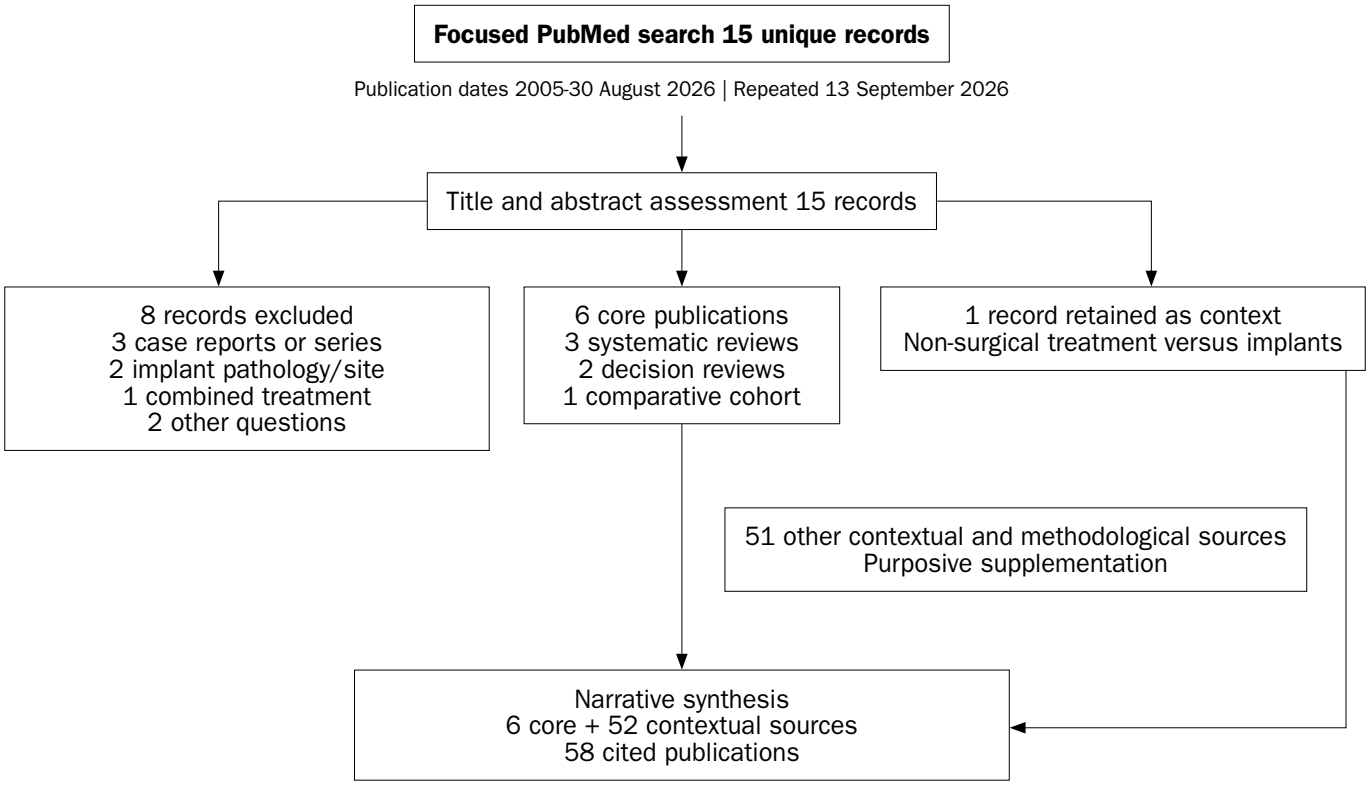


Figure 1
Evidence identification and selection. The figure distinguishes the six core publications from broader contextual and methodological references. The 58 cited publications are not 58 independent primary studies. The diagram describes a structured narrative review and is not a PRISMA flow diagram.

the disposition of the retrieved records with PubMed identifiers; Table 2 summarises the core evidence and Figure 1 shows the selection process.

Targeted topic searches and reference checking supplied contextual evidence on EMS outcomes and prognosis, implant survival and complications, outcome definitions, imaging, patient-reported outcomes and economics. These included randomised comparisons of navigation approaches and clinical evidence addressing restorability and diagnosis in root-filled teeth. In total, the manuscript cites 58 publications: six core publications and 52 contextual or methodological sources, including the broader comparative study identified by the core search. The supplementary selection was purposive rather than exhaustive; these counts describe cited publications, not independent primary studies or a complete census of eligible evidence.

Screening was not performed independently in duplicate, a formal risk-of-bias instrument was not applied, and no de novo meta-analysis or certainty-of-evidence grading was undertaken. Evidence was appraised descriptively for design, directness, follow-up, analysed sample, outcome definitions and reporting limitations. Estimates are attributed to individual studies or published syntheses, with confidence intervals where available. Related reviews may contain overlapping primary studies and should not be interpreted as independent replications. The narrow search terms and single-database core search limit sensitivity, and purposive supplementation does not eliminate selection or interpretation bias.

Clinical sequence before the microsurgery and implant decision

A persistent radiolucency is not, by itself, an indication for extraction or immediate reintervention. Diagnosis should integrate symptoms, time since treatment, serial radiographs, restora-

Publication and design	Scope and directness	Principal finding	Main limitation
Torabinejad et al. 2015 (7) Systematic review PMID 25306305	EMS and single implants in separate evidence sets.	High survival in both; higher implant survival at 4–6 years.	No direct comparison; success definitions incompatible.
Ko et al. 2025 (8) Systematic review and meta-analysis PMID 39979225	22 EMS and six implant studies; separately pooled proportions.	At ≥5 years: EMS 80% (95% CI 71–86%); implants 78% (70–85%).	Implant success reconstructed; no head-to-head estimate or equivalence test.
Chércoles-Ruiz et al. 2017 (13) Systematic review PMID 28343928	Initial treatment, retreatment and apical surgery versus implants.	Both retention and replacement can be valid options.	Broad interventions and heterogeneous comparative studies; indirect for modern EMS.
Setzer and Kim 2014 (9) Narrative review PMID 24065635	Endodontically treated teeth, EMS and implants.	Clarifies survival, success and complications.	Clinical context; no independent comparative estimate.
Torabinejad and White 2016 (4) Clinical decision review PMID 26778004	Options after unsuccessful initial root canal treatment.	Supports assessment of retreatment, surgery and other retention options.	Narrative clinical guidance, not a comparative trial.
Anand et al. 2026 (14) Retrospective cohort PMID 42282368	Microsurgical periapical surgery versus extraction and implants.	Reported success: 89.7% versus 92.3% at 24 months.	Clinical allocation; abstract/table sample discrepancy; limited endpoint definition and unclear blinding.

Abbreviations: CI, confidence interval; EMS, endodontic microsurgery; PMID, PubMed identifier. The reviews are not independent datasets and may contain overlapping primary studies. Hannahan and Eleazer is contextual evidence and is not included in this core table.

Table 2
Core publications and their relevance to the comparison

tion quality, periodontal probing and mobility. An asymptomatic lesion that is reducing, or a stable appearance compatible with scar healing after surgery, may warrant continued review. New symptoms, an enlarging lesion or evidence of structural failure require reassessment. Limited-field cone-beam computed tomography (CBCT) is justified when it can resolve a specific diagnostic or planning question; it should not be used routinely simply to demonstrate complete radiographic repair (2,15–17).

The clinician should investigate missed anatomy, inadequate canal disinfection, coronal leakage, obstruction, extruded material, perforation, resorption and possible root fracture. A cyst or extraradicular biofilm cannot be diagnosed reliably from lesion size or CBCT appearance alone; atypical lesions require specialist assessment and, where indicated, histopathological examination. Orthograde retreatment is often the initial retention option when the canals can be renegotiated and disinfection improved safely. Computational and laboratory studies suggest that irrigation protocols can change apical fluid exchange and cleaning of complex canal anatomy, but these surrogate findings do not establish improved clinical healing after retreatment (18,19). Historical comparisons suggest different early and later outcome patterns after retreatment and surgery, but their heterogeneity and older surgical methods limit application to current EMS (1–3,6). A post, bonded restoration or procedural blockage may favour surgery when coronal dismantling carries substantial fracture or perforation risk. In mandibular first molars, CBCT measurements of thin mesial-root dentine near the furcation further support case-specific assessment of perforation risk during re-instrumentation (20).

EMS is most rational when the tooth is restorable, periodontal support is maintainable, orthograde access is unsafe or unlikely to resolve the cause, and the

apical pathology can be addressed surgically. Extraction should be considered for a root fracture that prevents predictable retention, non-restorable tissue loss or perforation, hopeless periodontal support, or an unacceptable surgical risk after specialist assessment. Active periodontal disease requires treatment and reassessment; it does not automatically favour implantation. In selected multirooted teeth, root resection may preserve the remaining tooth, although this lies outside the principal comparison. Intentional replantation may be considered in selected cases when conventional access is impractical. Replacement options also include fixed or removable prostheses, autotransplantation in suitable patients, orthodontic space management or no replacement (2,4,5).

Modern endodontic microsurgery

Modern EMS differs materially from traditional apical surgery. The operating microscope, microsurgical instruments, ultrasonic root-end preparation and calcium silicate-based root-end filling allow treatment of the apical anatomy with less bevel and less tissue removal. Resection of approximately 3 mm of the root end is commonly used to remove most apical ramifications and lateral canals; inspection of the resected surface under magnification helps identify isthmuses, missed canals and cracks. A preparation centred on the long axis of the canal and an adequate root-end filling are essential for controlling the apical pathway of infection (6).

The shift to microsurgical technique is reflected in pooled outcomes. A meta-analysis of traditional and microsurgical approaches reported weighted success of approximately 59% and 94%, respectively; another synthesis favoured microsurgical techniques with higher magnification (21,22). An updated meta-analysis estimated success at approximately 89% for modern surgery (23). These are study-defined outcomes, commonly combining absence of symptoms with complete or incomplete radiographic healing. They should not be presented as rates of strict complete healing or as controlled estimates of the effect of a microscope alone (24). Case selection, co-interventions and predominantly short- to medium-term follow-up also influence these figures.

Longer follow-up yields more variable estimates. A systematic review reported pooled success of 91.3% in randomised trials and 78.4% in prospective cohorts over 2–13 years, with survival ranging from 79% to 100% (25). The trials compared aspects of EMS, not EMS with implants, and the design-specific pooled values are not directly comparable. Pallarés-Serrano et al. reported lower healing in the 5–9-year than the 1–4-year follow-up cohort, partly associated with vertical root fractures; this should not be described as a within-tooth decline without paired longitudinal data (26). Yoo et al. analysed 309 of 721 EMS-treated teeth and reported 80.5% estimated 10-year survival and 63.4% study-defined success at the final assessment, conducted 10–17.5 years after treatment (27). Eligibility and follow-up selection limit generalisability. Sperou et al. reported 82.8% radiographic healing in 128 teeth at a median of 41.5 months, and 86.6% survival without reintervention in a separate analysis of 186 teeth at a median of 37.5 months (28). Periodontal involvement and shallower root-end fillings were associated with poorer outcomes; these observational associations are not validated individual prediction rules.

Root-end materials and regenerative adjuncts may influence selected cases. Calcium silicate-based materials are supported by clinical studies and a network meta-analysis, but comparative rankings do not establish a universally superior material (29). A randomised trial found no statistically detectable difference in 12-month healing between mineral trioxide aggregate and TotalFill,

or from adding a bone graft to small-to-medium lesions (30). Regenerative procedures may be considered for selected apicomarginal or through-and-through defects; the evidence is heterogeneous, and not all pooled comparisons show a clear benefit (31). Routine grafting of contained defects is therefore not justified by these findings.
CBCT and computer-assisted navigation can assist planning and localisation in anatomically demanding sites. Static guides constrain the planned osteotomy, whereas dynamic systems permit real-time tracking and adjustment. Systematic reviews and prospective clinical evidence support technical feasibility, but accuracy is a surrogate for clinical benefit (32–34). Recent randomised trials have compared static with dynamic navigation for early patient-reported outcomes and operative accuracy (35,36). These studies do not establish superior long-term healing or tooth survival compared with conventional EMS. Device cost, registration error, restricted access, radiation exposure and the learning curve should be weighed against a specific anticipated benefit.

Single tooth implants effectiveness and complications

Single implants can provide predictable replacement of teeth that cannot be retained. In a systematic review, estimated survival of implants supporting single crowns was 97.2% at 5 years (95% confidence interval (CI) 96.3–97.9%) and 95.2% at 10 years (95% CI 91.8–97.2%); the corresponding crown-survival estimates were 96.3% and 89.4% (37). Fixture and prosthesis survival must therefore be reported separately. A selected cohort of 511 implants in partially edentulous patients reported 98.8% implant survival at 10 years, but was not restricted to single-tooth replacement after failed endodontic treatment (38). Similarly, a 20-year series of older titanium plasma-sprayed implants reported 89.5% survival and 75.8–89.5% success depending on the definition (39). This illustrates endpoint dependence rather than providing a contemporary single-crown benchmark. Immediate placement and loading in the aesthetic zone also involve selected patients and sites (40).
Implant survival does not capture the full treatment complex. Biological, prosthetic and aesthetic complications may affect the fixture, surrounding tissues, abutment, screw or crown. A systematic review estimated peri-implantitis prevalence at 19.5% of patients and 12.5% of implants, with substantial variation in case definitions (41). A later synthesis restricted to World Workshop definitions estimated 25.0% at patient level (95% CI 21.1–29.3%) and 18.0% at implant level (95% CI 15.8–20.5%); most included studies had moderate or high risk of bias (42). These cross-sectional prevalence estimates concern heterogeneous implant populations, not the prospective risk for a newly placed single implant, and should not be compared directly with an EMS failure rate. Periodontal history, plaque control and supportive care are relevant to risk assessment, while the evidence for individual modifiers varies. Longitudinal diagnosis of peri-implant disease requires baseline probing and radiographic information (43).
The comparison with EMS should include the implant crown and surrounding tissues rather than osseointegration alone. A functioning implant may remain a survivor after prosthetic repair or treatment of peri-implant disease. Likewise, a retained tooth can require further treatment despite survival. Stable incomplete healing compatible with a surgical scar may be classified as success under established endodontic criteria, whereas strict complete-healing endpoints exclude it. Table 3 distinguishes these outcomes and summarises representative evidence.

Why direct comparison remains difficult

Endodontic healing is commonly clas-

Endpoint	Definition	Representative evidence	Interpretation
Complete healing after EMS	No clinical disease and complete radiographic repair.	Complete, incomplete, uncertain and unsatisfactory categories (15,16).	Do not equate complete healing with all study-defined success.
Study-defined EMS success	Often includes complete or stable incomplete healing without symptoms.	Published modern pooled estimates approximately 89–94% (21–23).	Different imaging, definitions and follow-up; not a direct implant comparison.
Tooth survival after EMS	Tooth remains present; specify whether reintervention is allowed.	80.5% estimated survival at 10 years in the Yoo cohort (27).	Separate from 63.4% success at the final 10–17.5-year assessment.
Survival without reintervention	Tooth retained without further treatment during observation.	86.6% of 186 teeth, median follow-up 37.5 months (28).	Different denominator from the study's radiographic-healing analysis.
Implant-fixture survival	Implant remains in situ; biological/prosthetic complications may coexist.	Single-crown implants: 97.2% at 5 years and 95.2% at 10 years (37).	Does not demonstrate survival of the original crown or healthy peri-implant tissues.
Implant-crown survival	Original implant-supported crown remains in service.	96.3% at 5 years and 89.4% at 10 years (37).	Report crown replacement separately from fixture loss.
Comprehensive success and patient outcomes	Biological health, prosthetic integrity, symptoms, function, aesthetics and patient experience.	Criteria remain heterogeneous across pathways (44–47).	Use explicit domains and common observation periods; distinguish prevalence from incidence.

Abbreviations: CI, confidence interval; EMS, endodontic microsurgery. These rows illustrate endpoint differences; they are not a head-to-head comparative analysis. Study-defined success must not automatically be relabelled as complete radiographic healing.

Table 3
Outcome definitions and representative evidence.

sified on periapical radiographs as complete, incomplete, uncertain or unsatisfactory (15,16). Clinical signs and symptoms must be considered alongside imaging. Complete and incomplete healing are often grouped as success; uncertain or unsatisfactory healing should be reported separately, with follow-up appropriate to the clinical course. CBCT can reveal residual defects not visible on two-dimensional imaging, reducing the proportion judged completely healed without necessarily demonstrating clinically important persistent disease. Implant success criteria have also evolved to include biological, prosthetic, soft-tissue, aesthetic and patient-reported domains (44,45). Even when both arms report 'success', the underlying events and surveillance may differ. Randomisation between preservation and extraction can be ethically and practically challenging because it requires clinical equipoise and informed patient acceptance; it is not intrinsically impossible. Most relevant evidence nevertheless comes from separate or non-randomised cohorts. Treatment selection is influenced by restorability, periodontal status, lesion severity, patient preference and clinician expertise, creating confounding by indication. Implant and EMS studies may both select favourable patients. Differences in eligibility, missing follow-up and outcome assessment can therefore bias either pathway. Starting observation at implant loading also omits extraction, augmentation and pre-loading failures unless the complete pathway is explicitly followed.

The 2015 systematic review found higher implant survival at 4–6 years, but no direct treatment comparisons and incompatible success definitions (7). Ko et al. pooled 22 EMS and six single-implant studies without a direct comparison (8). At at least 5 years, EMS success was 80% (95% CI 71–86%) and

reconstructed implant success was 78% (95% CI 70–85%). The overall EMS estimate of 89% largely reflected shorter follow-up. These separate-arm estimates neither prove superiority nor establish equivalence. Hannahan and Eleazer compared implants with non-surgically treated teeth and provide indirect evidence only (12). Anand et al. reported 89.7% versus 92.3% success at 24 months (14). However, its abstract reports 166 patients while its tables contain 78 per group, the implant endpoint lacks a comprehensive prosthetic and peri-implant definition, and the claimed assessor blinding is inadequately explained. These reporting limitations, clinical allocation and imprecision substantially limit inference; a non-significant difference is not evidence of equivalence.

Broader systematic reviews of endodontically treated teeth and implant-supported prostheses report mixed survival findings and frequent additional interventions in implant pathways, with generally favourable patient satisfaction after both treatments (46,47). Their applicability to EMS is indirect because they include non-surgical treatment, retreatment and different restorative situations. Repeated inclusion of the same primary cohorts in several reviews also limits the apparent breadth of independent evidence. Overall, the literature does not establish a universally superior pathway, and raw survival percentages are insufficient for individual treatment planning.

Prognostic determinants and case selection

Restorability is the first treatment-selection gate. Assessment should include remaining supracrestal dentine, ferrule potential, crack pattern, root form, the anticipated crown-to-root relationship after resection, and the biological cost of crown lengthening or extrusion. Evidence supports the contribution of ferrule and residual dentine to restoration performance, but combines clinical, laboratory and finite-element studies and does not establish a universal threshold for extraction (48). A sound coronal seal and a maintainable definitive restoration are essential. EMS cannot compensate for an unrestorable coronal defect.

Periodontal support is equally important. Attachment loss, apicomarginal defects and lesion morphology are associated with EMS outcome, although findings are not uniform across studies (31,49,50). Defect size alone should not determine extraction. Mobility, deep isolated probing and a halo-like radiolucency warrant investigation for root fracture but are not individually diagnostic. Evidence from clinically assessed root-filled teeth indicates imperfect CBCT sensitivity and specificity; artefacts from filling materials or posts can complicate interpretation, and direct inspection may be required (51).

Anatomical and technical feasibility should be assessed on limited-field CBCT where the result is likely to alter management. Relevant features include cortical thickness, root inclination, lesion size and extension, maxillary sinus involvement, proximity to the inferior alveolar or mental nerve, access to palatal roots and the amount of root remaining after resection. Mandibular molars and palatal roots are not absolute contraindications, but the risk–benefit ratio and operator expertise differ. Guided access may convert a difficult site into a manageable one, although it cannot correct poor restorability or periodontal prognosis.

Patient-level factors modify both pathways. Diabetes control, smoking, immune status, antiresorptive or antiangiogenic medication, previous head-and-neck radiotherapy, bleeding risk, blood-pressure responses to local anaesthesia (52), capacity for plaque control and adherence to maintenance should be reviewed (2,5,17). Their implications are treatment-specific: factors affecting implant healing do not necessarily carry the same magnitude of risk for EMS, while surgical risks may affect

Domain	Features supporting retention or EMS	Features requiring reassessment or replacement planning
Restorability (5,48)	Maintainable coronal seal, residual dentine and achievable restoration.	Non-restorable tissue loss or fracture; excessive biological cost of reconstruction.
Periodontal support (31,49,50)	Disease can be controlled and attachment can be maintained.	Hopeless support or advanced furcation destruction. Active disease requires control before implant assessment.
Cause and access (2,4,6)	Surgically manageable apical cause when orthograde correction is impractical.	Persistent cause cannot be addressed safely. Consider alternative retention options and referral.
Anatomy (6,17)	Safe access and sufficient root structure after resection.	Unacceptable anatomical risk or inadequate residual support; lesion size alone is not decisive.
Implant site (5,40)	Retention may avoid augmentation or a difficult aesthetic reconstruction.	Assess prosthetic position, tissue volumes and augmentation; a suitable site does not itself justify extraction.
Patient and care (2,17,53,54)	Informed preference for retention; acceptable burden and maintenance.	Discuss medical risk, prior experiences, affordability and alternative preferences. Both pathways need continuing care.
Operator and access (17,32–34)	Appropriate training, magnification and root-end management.	Seek specialist input before declaring EMS infeasible; technology does not correct a poor biological prognosis.

Abbreviations: EMS, endodontic microsurgery. This is a qualitative framework, not a validated score. No single row establishes an absolute indication for extraction or an implant.

Table 4
Prognostic considerations for treatment selection.

both. These factors require individual assessment rather than blanket exclusion rules and may warrant liaison with the treating physician. Active oral disease should be stabilised before elective surgery or implant rehabilitation where feasible.

Implant-site assessment includes bone and soft-tissue volume, prosthetically appropriate three-dimensional positioning, smile line, neighbouring roots and the need for augmentation (5,40). A high implant-survival probability does not ensure an acceptable aesthetic result, particularly in a thin phenotype or high smile line. Conversely, severe structural compromise may favour extraction when retention would require disproportionate treatment. Operator competence matters for both pathways. Referral should be considered before a tooth is declared unsuitable for EMS, and access to technology cannot overcome poor restorability or periodontal prognosis (17). Key determinants are synthesised in Table 4.

Patient experience and economic value

Patients value pain control, function, appearance, treatment time, cost, predictability and the possibility of retaining their own tooth. Studies comparing non-surgical endodontic treatment or retreatment with implants generally report favourable satisfaction, but are indirect evidence for EMS (53,54). The five-year study was cross-sectional at recall and therefore cannot by itself demonstrate a longitudinal change in quality of life or an EMS-specific benefit (54). Consent should address both expected outcomes and uncertainty, including symptoms, further procedures and maintenance, rather than describing an implant as permanent or microsurgery as an inevitable final attempt.

Treatment burden differs. EMS often retains the tooth in function and may involve one surgical episode followed by healing review and restorative care. It can nevertheless cause pain, swell-

Dimension	Endodontic microsurgery	Extraction and single-implant replacement
Biological effect	Retains the tooth and periodontal ligament; local tissue change remains possible.	Removes the tooth and periodontal ligament; replaces function with implant and crown.
Pathway	Surgical assessment and EMS, followed by healing review and restorative care.	Extraction, possible augmentation, implant placement/healing and prosthetic restoration.
Burden and complications	Pain, swelling, recession/scarring and site-related surgical risks; recurrent disease or structural failure.	Surgical and aesthetic risks, implant loss, peri-implant disease and prosthetic repair or replacement.
Time	May be shorter when the existing restoration is maintainable.	Variable; immediate protocols are selective and augmentation may extend the pathway.
If treatment fails	Reassess cause and structure; further retention or extraction may be appropriate. Later implantation is not guaranteed.	Assess infection and tissue loss; further surgery, a replacement implant or another prosthesis may be needed.
Maintenance	Long-term periodontal/restorative care and review of healing.	Long-term peri-implant and prosthetic care, including baseline and serial records.
Economics	Some models favour EMS; the result depends on tooth/site, fees and subsequent care.	Some scenarios favour implant replacement; assess full pathway costs and uncertainty.

Abbreviations: EMS, endodontic microsurgery. Treatment duration and costs depend on the individual case and healthcare setting; both pathways require long-term maintenance.

Table 5
Patient-relevant comparison of complete treatment pathways.

ing, recession, scarring, sinus-related complications or sensory disturbance, depending on the site; persistent disease, fracture or other structural failure may require reintervention (6,17). Implant rehabilitation may involve extraction, augmentation, placement, healing, provisionalisation and a definitive crown. Immediate protocols shorten selected pathways but are not suitable for every site (40). Both teeth and implants require continuing maintenance. Failed EMS may leave an implant option, but the feasibility, tissue requirements, time and cost must be reassessed.

Economic evidence is scenario-dependent. A US decision model for a failed first molar ranked EMS as the most cost-effective option (55). In contrast, a UK lifetime model for a maxillary incisor favoured implant replacement over surgical retreatment after orthograde retreatment had failed (56). A Swedish one-year cohort found extraction more cost-effective than initial root canal treatment when subsequent replacement was uncommon; it did not compare EMS with a complete implant pathway (57). These findings cannot support a universal economic advantage for either strategy. Current fees, reimbursement, perspective, restoration and augmentation needs, time horizon, maintenance and subsequent interventions must be specified, and older models may not represent contemporary techniques. Methodological appraisal of dental economic studies reinforces the need to examine assumptions and uncertainty (58). Table 5 summarises the practical comparison without presenting context-dependent cost estimates as general treatment effects.

A sequential clinical decision framework

The proposed framework (Figure 2) starts by confirming diagnosis and whether active intervention is indicated, then applies six treatment-selection steps. A stable or improving asymptomatic finding can enter a moni-

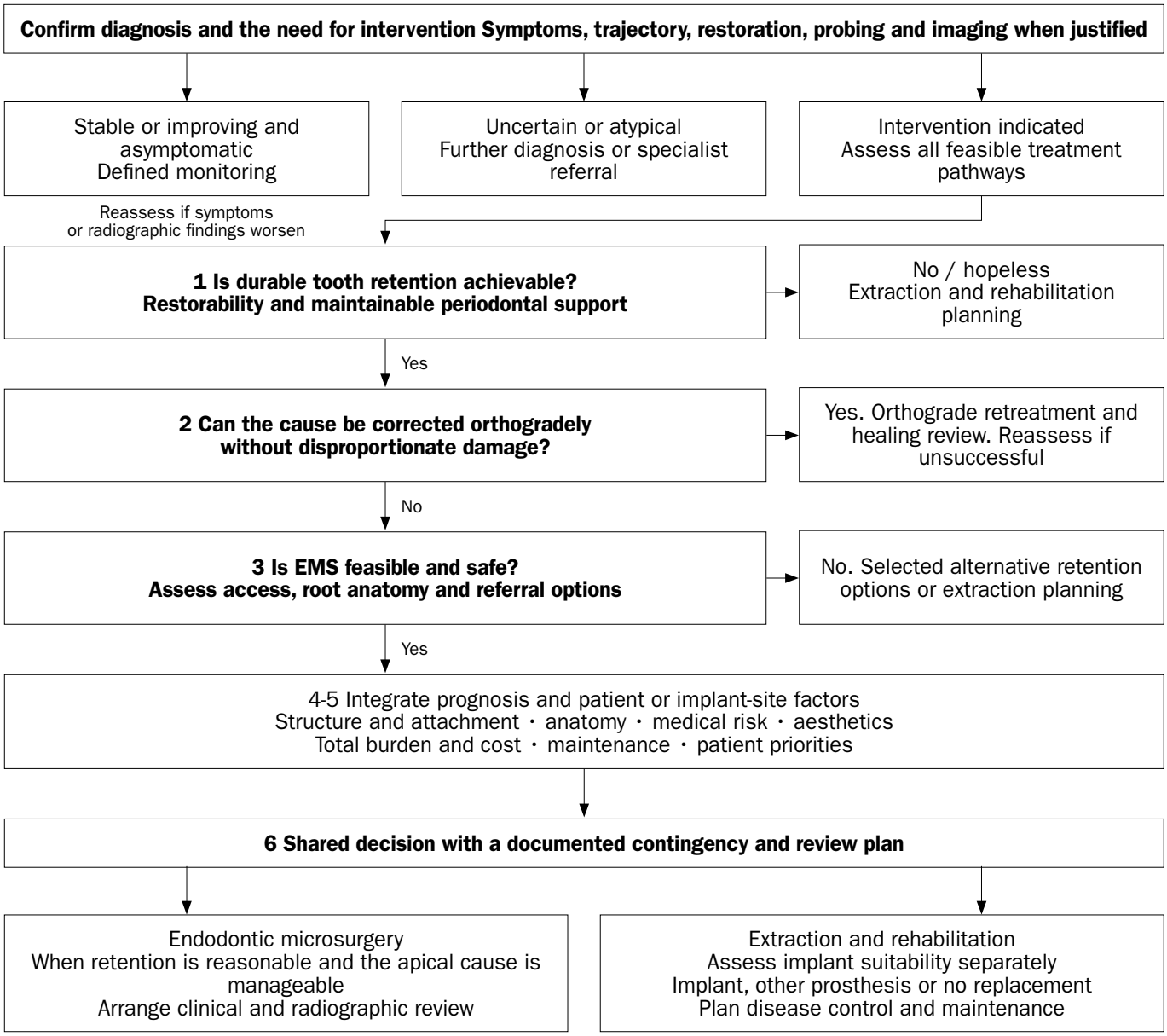


Figure 2
Therapeutic decision framework after unsuccessful root canal treatment. Diagnosis and the need for intervention precede treatment selection. Patient preferences, medical risks and maintenance requirements apply throughout. Persistent or worsening disease after retention treatment prompts renewed diagnosis and planning. EMS, endodontic microsurgery; CBCT, cone-beam computed tomography. This framework has not been externally validated.

toring pathway with defined review and escalation criteria. Acute symptoms and atypical findings require appropriate assessment before elective treatment selection. The framework is a cognitive aid, not a validated prediction model or a compulsory treatment sequence.

Step 1—restorability and periodontal maintainability. Establish whether a durable restoration and maintainable periodontal support can be achieved,

including after disease control. Non-restorable tissue loss, a root fracture incompatible with retention or hopeless attachment loss favours extraction. Diagnostic uncertainty or potentially reversible periodontal disease warrants assessment and reassessment before an irreversible decision.

Step 2—cause and orthograde accessibility. Consider orthograde retreatment when a missed canal, inadequate disinfection, coronal leakage or removable obstruction can be corrected without disproportionate damage. Assess subsequent healing before escalating treatment. When access is unsafe or unlikely to resolve the cause, consider surgical assessment; an apparently adequate filling alone does not prove an extraradicular source.

Step 3—technical feasibility of EMS. Evaluate surgical access, root length after resection, adjacent anatomy and the ability to identify, prepare and seal the relevant root-end anatomy. Consider navigation or referral when they address a defined limitation. If safe, meaningful surgery cannot be achieved, discuss selected alternatives such as intentional replantation or extraction and rehabilitation.

Step 4—tooth- and site-specific prognosis. Integrate mobility, attachment, defect morphology, root structure and restorative quality. A large lesion or unfavourable crown-to-root relationship is a prognostic consideration rather than an isolated validated contraindication. Multiple adverse factors should reduce confidence in retention and be explained to the patient.

Step 5—patient and implant-site modifiers. Assess medical and periodontal risks, plaque control, bone and soft-tissue anatomy, aesthetics, previous treatment experience, time, total cost and capacity for maintenance. The same critical assessment should be applied to retention and replacement; uncontrolled periodontal disease is not an argument for immediate implantation.

Step 6—shared decision and contingency planning. Present realistic outcomes, uncertainties, complications and subsequent options. For a restorable tooth with maintainable support and surgically manageable apical disease, EMS is a reasonable option to discuss before extraction. Implant replacement may be selected when retention is unpredictable or the informed patient chooses it after balanced counselling and assessment of implant suitability. Document why orthograde retreatment was or was not selected and arrange review. Extraction does not commit the patient to an implant: other prosthetic options or no replacement may be appropriate. Table 6 summarises the sequence.

Controversies and research priorities

Several scenarios remain contentious. A tooth with a cast post and apical lesion may be an excellent EMS candidate because surgery avoids destructive post removal, but only if the crown and root remain restorable. A deep mandibular molar apex may become accessible through static or dynamic navigation, although technology cannot eliminate neurovascular risk. Suspected vertical root fracture demands diagnostic restraint: unnecessary extraction should be avoided, but repeated surgery on a fractured root is equally inappropriate. Future comparative studies should enrol patients for whom both pathways are clinically feasible and define a common starting point at treatment allocation. Prospective registries can capture treatment selection, baseline restorability, periodontal status and patient preference, although adjustment cannot remove all residual confounding. Outcomes should distinguish radiographic healing, tooth or fixture survival, crown survival, survival without reintervention, complications, patient-reported outcomes and total costs. Long-term follow-up, ideally extending to 10 years or more, should report the number at risk, losses and reasons for censoring, with analyses accounting for multiple

teeth or implants within patients. Navigation studies should assess clinical benefit, radiation exposure, learning curves and cost alongside accuracy. The proposed framework requires external evaluation of feasibility, reproducibility and patient understanding before any claim of clinical validation.

Strengths and limitations

This review integrates evidence across treatment outcomes, prognosis, patient experience and economics while making endpoint asymmetry explicit. The PubMed core search and record disposition are reproducible as documented, but the narrow search has limited sensitivity and supplementary selection was purposive. Screening and study weighting were not independently duplicated; risk of bias and certainty were not formally graded, and no new pooled estimate was calculated. Several reviews contain overlapping primary studies. Few studies directly compare EMS with implant replacement in patients eligible for both, and the recent comparative cohort has material reporting limitations. Older implant surfaces, historical surgical techniques, specialist settings and selective follow-up restrict applicability. The decision framework is evidence-informed and unvalidated; it supports specialist assessment and shared decision-making rather than estimating an individual probability of success.

Conclusion

Modern EMS and single-tooth implant replacement can both achieve favourable outcomes. The available literature does not establish general superiority or equivalence because populations, outcome definitions and follow-up differ. A cause-directed sequence is clinically reasonable: establish whether intervention is required, assess restorability and periodontal maintainability, consider orthograde retreatment when feasible, and discuss EMS when the tooth has a defensible retention prognosis and the cause is surgically manageable. This sequence is a clinical synthesis consistent with tooth-preservation principles, rather than a treatment hierarchy proven by direct comparative trials.
Extraction and rehabilitation are appropriate when predictable retention cannot be achieved or an informed patient chooses replacement. Implant suitability, other replacement options and the option of no replacement require separate consideration. Decisions should reflect the complete treatment pathway, including biological and prosthetic complications, reintervention, time, cost, maintenance and patient priorities.

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