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REVIEW ARTICLE

MINIMALLY INVASIVE MANAGEMENT OF ODONTOGENIC CYSTS: A SCOPING REVIEW OF CONSERVATIVE SURGERY, REGENERATIVE TECHNIQUES, AND DIGITAL-ASSISTED APPROACHES

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Abstract

Background: Odontogenic cysts are common jaw lesions that may cause bone destruction, displacement of adjacent teeth, and involvement of critical anatomical structures. Conventional treatment may require extensive surgery and can be associated with postoperative morbidity and loss of healthy tissues. Increasing attention has therefore been directed toward minimally invasive and tissue-preserving approaches.

Objective: To map and synthesize current evidence on minimally invasive management of odontogenic cysts, focusing on conservative surgery, endoscopic techniques, piezoelectric surgery, regenerative procedures, and digital-assisted treatment planning.

Methods: A scoping review was conducted according to the PRISMA-ScR framework. After duplicate removal and title/abstract screening, 42 full-text articles were assessed and all 42 met the predefined eligibility criteria. Data on cyst characteristics, treatment modalities, minimally invasive techniques, regenerative procedures, clinical and radiographic outcomes, complications, and recurrence were descriptively and thematically synthesized.

Results: The evidence demonstrated a shift toward conservative and minimally invasive management. Decompression and marsupialization were associated with reduction in lesion size, preservation of adjacent structures, and progressive bone regeneration. Endoscopic-assisted procedures provided improved visualization through limited access, while piezoelectric surgery enabled precise bone cutting with preservation of surrounding tissues. Regenerative approaches, including guided bone regeneration and platelet concentrates, supported restoration of post-cystic bone defects. CBCT-based planning and digital workflows improved anatomical assessment and individualized surgical planning.

Conclusion: Minimally invasive, regenerative, and digitally assisted approaches represent increasingly important strategies for odontogenic cyst management and may reduce surgical morbidity while preserving anatomical structures. However, heterogeneity in study designs and outcome measures limits definitive comparisons. Further prospective studies with standardized outcomes and long-term follow-up are warranted.

Keywords: Odontogenic cysts; Minimally invasive surgery; Decompression; Marsupialization; Endoscopic surgery; Piezoelectric surgery; Bone regeneration

1.INTRODUCTION

Odontogenic cysts comprise a diverse group of pathological lesions arising from odontogenic epithelial remnants and are among the most frequently encountered cystic lesions of the jaws. Their development is associated with epithelial components involved in tooth formation and, in some cases, with inflammatory processes affecting the periapical and periodontal tissues. The current classification of odontogenic lesions reflects substantial differences in their histopathological characteristics and biological behavior, which are important considerations when establishing an appropriate treatment strategy.[1–4]

Although most odontogenic cysts are benign, their clinical behavior is not uniform. The rate of growth, lesion size, anatomical location, and relationship with adjacent teeth and vital structures may vary considerably between individual lesions. Many cysts remain asymptomatic for prolonged periods and are detected incidentally on routine radiographic examination. Once they become larger or secondarily infected, however, they may present with swelling, pain, infection, tooth displacement, or other functional disturbances.[5–7]

The clinical importance of odontogenic cysts is largely related to their capacity for progressive expansion and destruction of the surrounding jawbone. Large lesions may produce cortical thinning or perforation, displace adjacent teeth, and, in selected cases, compromise structures such as the inferior alveolar canal or the maxillary sinus. These changes may complicate subsequent treatment and can result in substantial osseous defects after removal of the lesion. Consequently, contemporary treatment is directed not only toward elimination of the pathological tissue and prevention of recurrence, but also toward preservation of teeth, surrounding bone, and important anatomical structures.[6–8]

Surgical enucleation has traditionally been the principal treatment for many odontogenic cysts because removal of the cystic lining permits direct elimination of the pathological tissue. Depending on the biological behavior and extent of the lesion, more extensive procedures may also be required. This is particularly relevant in lesions with extensive growth, cortical perforation, or a substantial risk of recurrence. Although conventional surgery remains an important and effective component of odontogenic cyst management, the extent of surgical intervention must be balanced against the potential loss of healthy tissue and the risk of postoperative complications.[8–10]

Over the past several decades, the management of odontogenic cysts has gradually moved toward more conservative and tissue-preserving strategies. This change reflects a broader shift in oral and maxillofacial surgery toward limiting unnecessary surgical trauma while maintaining adequate control of the underlying disease. Rather than applying an identical surgical procedure to every lesion, current approaches increasingly take into account cyst type, size, anatomical location, relationship with adjacent structures, recurrence risk, and the patient's future functional requirements.[9–11]

Decompression and marsupialization are among the most established conservative techniques, particularly for large cystic lesions in which immediate enucleation may result in considerable bone loss or increase the risk of injury to adjacent structures. By reducing intracystic pressure and maintaining controlled drainage, these procedures may permit gradual reduction of cyst volume and progressive bone regeneration. They have been used for a range of odontogenic lesions, including large developmental and inflammatory cysts, and may allow preservation of adjacent teeth and vital anatomical structures.[12–14] Nevertheless, conservative treatment generally requires prolonged clinical and radiographic follow-up, patient cooperation, and, in selected cases, subsequent enucleation after sufficient reduction of the lesion.[11–14]

The development of endoscopic techniques has provided an additional option for lesions situated in anatomically difficult regions. Endoscopic-assisted surgery allows visualization of areas that may be difficult to access through a conventional surgical field and can facilitate controlled removal of pathological tissue through a more limited approach. This has particular relevance for lesions involving the posterior mandible, maxillary sinus, and other regions in close proximity to neurovascular structures. Clinical reports have described endoscopic-assisted enucleation as a feasible tissue-preserving approach in appropriately selected cases, although its use requires specific equipment, surgical experience, and adequate training.[15–18]

Advances in three-dimensional imaging and digital planning have further influenced the contemporary management of odontogenic cysts. Cone-beam computed tomography (CBCT) provides detailed information about lesion dimensions, cortical bone integrity, root relationships, and the proximity of the lesion to important anatomical structures. Such information can improve preoperative assessment and help determine the most appropriate surgical access and treatment strategy.[19,20]

Virtual surgical planning and other digital workflows may further support individualized treatment planning, particularly in complex cases in which conventional two-dimensional imaging does not adequately demonstrate the three-dimensional anatomy.[21]

Preservation of the jawbone has become an increasingly important consideration, particularly when large cystic lesions result in substantial residual defects or when subsequent implant rehabilitation is anticipated. Regenerative procedures have therefore been incorporated into the management of selected post-cystic defects. Bone grafting materials and guided bone regeneration techniques can provide structural support and maintain space for new bone formation, while barrier membranes may limit soft-tissue ingrowth and create a more favorable environment for osseous regeneration.[22–25] The choice of regenerative material and technique depends on the size and morphology of the defect, the availability of residual bony walls, local vascularity, infection control, and the planned functional rehabilitation.[22–25]

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Biological adjuncts have also attracted increasing interest in regenerative treatment. Platelet-rich fibrin (PRF), for example, provides an autologous source of platelets and biologically active mediators that may contribute to angiogenesis, cellular activity, and tissue healing. Although the clinical evidence remains heterogeneous, the use of platelet concentrates in combination with established regenerative techniques represents a potentially useful approach for selected osseous defects.[26,27]

Another technological development relevant to minimally invasive surgery is the use of piezoelectric devices. These systems employ ultrasonic microvibrations to cut mineralized tissues while providing a degree of protection to adjacent soft tissues. This characteristic can be advantageous when bone removal is required close to nerves, vessels, or sinus membranes. Piezoelectric surgery has consequently become an established adjunct in oral and maxillofacial procedures in which precision and preservation of surrounding structures are important.[28–30] However, its application may be associated with longer operative times and requires appropriate operator experience; therefore, it should be regarded as a precision-enhancing surgical technology rather than a substitute for sound surgical principles.[28–30]

Regenerative management also reflects a broader change in the objectives of cyst surgery. Removal of the lesion alone may leave a substantial osseous defect, whereas preservation or reconstruction of the affected bone may be essential for maintaining jaw function and facilitating subsequent implant-supported rehabilitation. Available evidence suggests that bone grafting, barrier membranes, and biological adjuncts can contribute to reconstruction of post-cystic defects, although outcomes remain dependent on the characteristics of the defect, infection control, biomaterial selection, and patient-related factors.[22–27,31]

Conservative treatment may also include nonsurgical endodontic management in carefully selected inflammatory periapical lesions. Preservation of the involved tooth can be particularly important when a lesion is associated with a treatable root canal infection and adequate endodontic disinfection can be achieved. However, the distinction between inflammatory periapical lesions and true cystic pathology remains clinically important, and large lesions, persistent disease, or extensive bone destruction may still require surgical treatment.[35–37]

Despite the expanding range of minimally invasive techniques, the available evidence remains heterogeneous. Differences in cyst type, lesion size, anatomical location, treatment protocols, follow-up duration, and outcome assessment make direct comparison between individual approaches difficult. Evidence is relatively more established for conservative decompression and marsupialization, whereas endoscopic, piezoelectric, regenerative, and digitally assisted approaches have been investigated across a broader range of clinical settings and study designs.[12–32]

These developments indicate that minimally invasive management should not be regarded as a universal replacement for conventional surgery. Rather, it represents an expanding group of complementary strategies that can be incorporated into an individualized treatment plan according to the biological characteristics of the lesion, its anatomical relationships, the anticipated surgical morbidity, and the patient's functional requirements. The central objective is increasingly to achieve adequate pathological control while preserving healthy tissues and creating favorable conditions for subsequent healing and rehabilitation.[9,21–27,31,32]

The aim of the present scoping review was therefore to map and synthesize the available evidence on minimally invasive management of odontogenic cysts, with particular emphasis on conservative decompression and marsupialization, endoscopic-assisted surgery, piezoelectric techniques, regenerative procedures, and CBCT-based and digital-assisted treatment planning. By bringing these approaches together, the review seeks to clarify their current clinical applications, potential advantages, limitations, and areas in which further evidence is required.

2. MATERIALS AND METHODS

2.1. Study Design and Reporting Framework

The present study was designed as a scoping review to map and synthesize the available clinical evidence concerning minimally invasive management of odontogenic cysts. The review was conducted in accordance with the methodological framework recommended by the Joanna Briggs Institute (JBI) for scoping reviews and was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[33,34]

A scoping review design was selected because the literature concerning minimally invasive treatment of odontogenic cysts is broad and heterogeneous, encompassing different cyst types, conservative surgical techniques, endoscopic procedures, piezoelectric surgery, regenerative interventions, imaging modalities, and digital treatment-planning approaches. The purpose was

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therefore to map the range of available evidence, characterize the clinical applications of the different approaches, summarize reported outcomes, and identify limitations and gaps in the current evidence base rather than to estimate a single pooled treatment effect.

The review focused on minimally invasive, conservative, tissue-preserving, regenerative, and technology-assisted strategies used in the management of odontogenic cystic lesions. The principal approaches of interest were decompression and marsupialization, conservative enucleation, endoscopic-assisted surgery, piezoelectric surgery, regenerative procedures, platelet concentrates, and CBCT-based or digitally assisted treatment planning. Selected nonsurgical endodontic and laser-assisted approaches were also considered when they were directly relevant to conservative or minimally invasive management of odontogenic cystic lesions.

The methodological framework, eligibility criteria, information sources, search strategy, study-selection process, and data-charting procedures were established before the final evidence synthesis.

2.2. Review Question and Objectives

The review was developed around the following primary research question:

What is the current evidence regarding minimally invasive approaches for the treatment of odontogenic cysts, and what clinical outcomes, advantages, limitations, and regenerative implications have been reported with these approaches?

The specific objectives were:

1. To identify and characterize minimally invasive treatment modalities reported in the literature for the management of odontogenic cysts.
2. To describe the clinical indications and applications of conservative, endoscopic-assisted, piezoelectric, regenerative, and digitally assisted approaches.
3. To summarize reported outcomes, including cyst reduction or resolution, radiographic bone regeneration, preservation of adjacent anatomical structures, postoperative morbidity, recurrence, and subsequent rehabilitation.
4. To identify the role of regenerative procedures, including bone grafting, guided bone regeneration, barrier membranes, and platelet-rich fibrin.

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5. To examine the contribution of CBCT and digital technologies to diagnosis, anatomical assessment, surgical planning, and management of anatomically complex lesions.
6. To identify limitations and gaps in the current evidence and areas requiring further clinical investigation.

2.3. Eligibility Criteria

Eligibility criteria were established according to the Population–Concept–Context (PCC) framework recommended by the JBI for scoping reviews.[34] The criteria were applied consistently during title and abstract screening and subsequent full-text assessment.

Population

The population consisted of patients diagnosed with odontogenic cystic lesions. Eligible lesions included inflammatory and developmental odontogenic cysts, including radicular cysts, dentigerous cysts, odontogenic keratocysts, and other clinically relevant odontogenic cystic lesions described in the literature.

Concept

The concept of interest was minimally invasive, conservative, tissue-preserving, regenerative, endoscopic, piezoelectric, or technology-assisted management of odontogenic cysts.

The interventions and treatment-related approaches of interest included:

- decompression;
- marsupialization;
- conservative or limited-access enucleation;
- endoscopic-assisted cyst surgery;
- piezoelectric surgery;
- bone grafting;
- guided bone regeneration;
- barrier membrane techniques;
- platelet concentrates, particularly platelet-rich fibrin;
- CBCT-based anatomical assessment and treatment planning;
- virtual surgical planning and other digital-assisted approaches.

Selected nonsurgical endodontic approaches were also considered when they were used for the management of inflammatory periapical lesions with cyst-like characteristics and were directly relevant to tooth preservation and avoidance of surgical intervention.

Context

Studies conducted in oral surgery, oral and maxillofacial surgery, endodontics, implant dentistry, and related dental specialties were considered eligible when the reported approach was clinically applicable to the management of odontogenic cystic lesions.

Inclusion Criteria

Studies were included when they:

1. addressed odontogenic cystic lesions;
2. evaluated or described a minimally invasive, conservative, regenerative, endoscopic, piezoelectric, or digitally assisted treatment or treatment-planning approach;
3. provided clinical, radiographic, surgical, or treatment-related outcome information;
4. were published in English;
5. were published between January 1, 1996, and August 31, 2026;
6. contained sufficient methodological or clinical information to permit extraction of relevant data.

Exclusion Criteria

Studies were excluded when they:

1. focused exclusively on non-odontogenic cysts or unrelated maxillofacial lesions;
2. described purely experimental or laboratory investigations without clinically applicable information;
3. were conference abstracts without sufficient clinical or methodological information;
4. did not provide a meaningful description of the treatment procedure or treatment-planning approach;
5. were unrelated to minimally invasive, conservative, tissue-preserving, regenerative, or technology-assisted management;
6. contained insufficient information for evaluation of the reported clinical approach or outcome.

The eligibility framework is summarized in Table 1.

Table 1. Population–Concept–Context Framework and Eligibility Criteria

PCC component	Definition in the present review
Population	Patients with odontogenic cystic lesions, including radicular cysts, dentigerous cysts, odontogenic keratocysts, and other developmental or inflammatory odontogenic cysts
Concept	Minimally invasive, conservative, tissue-preserving, regenerative, endoscopic, piezoelectric, and digital-assisted treatment or treatment-planning approaches
Interventions of interest	Decompression, marsupialization, conservative or limited-access enucleation, endoscopic-assisted surgery, piezoelectric surgery, bone grafting, guided bone regeneration, barrier membranes, platelet-rich fibrin, CBCT-based planning, and digital workflows
Context	Oral surgery, oral and maxillofacial surgery, endodontics, implant dentistry, and related dental specialties
Publication period	January 1, 1996–August 31, 2026
Language	English
Eligible evidence	Clinical studies, prospective and retrospective observational studies, comparative clinical studies, case series, and clinically relevant technical reports
Required information	Description of the treatment or treatment-planning approach and clinical, radiographic, surgical, or outcome-related information
Main exclusions	Non-odontogenic lesions, non-clinical laboratory studies, conference abstracts without sufficient information, insufficiently described procedures, and studies unrelated to minimally invasive or tissue-preserving management

2.4. Information Sources

A comprehensive literature search was performed using major biomedical and multidisciplinary electronic databases selected to provide broad coverage of oral and maxillofacial surgery, dentistry, endodontics, regenerative medicine, biomaterials, and minimally invasive surgical techniques.The following databases were searched:

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- **PubMed/MEDLINE**
- **Scopus**
- **Web of Science Core Collection**
- **ScienceDirect**
- **Cochrane Library**

The literature search covered publications from January 1, 1996, to August 31, 2026. This time frame was selected to capture both established conservative approaches and subsequent developments in minimally invasive surgery, regenerative procedures, piezoelectric technology, CBCT-based assessment, and digital-assisted treatment planning. The principal information sources and their intended contribution to the literature search are presented in Table 2.

Table 2. Electronic Information Sources Used in the Review

Database	Main purpose in the literature search
PubMed/MEDLINE	Identification of biomedical, dental, oral surgery, endodontic, and maxillofacial literature
Scopus	Broad multidisciplinary coverage and identification of clinical and surgical publications
Web of Science Core Collection	Identification of indexed scientific literature and multidisciplinary studies
ScienceDirect	Retrieval of relevant dental, surgical, regenerative, biomaterials, and clinical literature
Cochrane Library	Identification of systematic reviews and controlled clinical evidence relevant to conservative and surgical treatment

2.5. Search Strategy

The search strategy was developed using combinations of controlled vocabulary and free-text terms related to odontogenic cysts and minimally invasive, conservative, regenerative, and technology-assisted management. The search was intentionally broad to reduce the risk of excluding relevant studies that used different terminology to describe similar clinical approaches. Where database-specific syntax permitted, controlled vocabulary and field-specific searching were used to improve retrieval of relevant records. The complete database-specific search strategies should be retained as supplementary search documentation. The main search terms included combinations of the following concepts:

Table 3. Main Search Concepts and Keywords

Search concept	Principal terms
Odontogenic pathology	“odontogenic cyst”, “odontogenic cysts”, “jaw cyst”, “radicular cyst”, “periapical cyst”, “residual cyst”, “dentigerous cyst”, “follicular cyst”, “odontogenic keratocyst”, “keratocystic odontogenic tumor”
Conservative management	“conservative treatment”, “conservative management”, “decompression”, “marsupialization”, “marsupialisation”, “conservative enucleation”, “limited-access enucleation”
Minimally invasive surgery	“minimally invasive surgery”, “endoscopic surgery”, “endoscopic-assisted surgery”, “endoscopic enucleation”
Precision surgery	“piezoelectric surgery”, “piezosurgery”, “ultrasonic bone surgery”
Regeneration	“guided bone regeneration”, “bone graft”, “bone grafting”, “bone regeneration”, “collagen membrane”, “barrier membrane”, “platelet-rich fibrin”, “PRF”, “platelet concentrate”
Digital and imaging technology	“CBCT”, “cone-beam computed tomography”, “three-dimensional imaging”, “digital planning”, “virtual surgical planning”, “computer-assisted surgery”, “navigation”
Adjunctive approaches	“endodontic treatment”, “root canal treatment”, “intracanal medicament”, “laser-assisted”, “laser surgery”
Boolean combination	Odontogenic cyst terms AND minimally invasive/conservative/regenerative/endoscopic/piezoelectric/digital treatment terms

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2.6. Study Selection Process

All records identified through the electronic database searches were collected and imported into reference-management software. Duplicate records were identified and removed before the screening process.

Following duplicate removal, the remaining records were independently screened by two reviewers in two sequential stages.

During the first stage, titles and abstracts were evaluated against the predefined eligibility criteria. Records that were clearly unrelated to odontogenic cysts, did not address minimally invasive, conservative, regenerative, or clinically relevant technology-assisted management, or did not contain sufficient clinical information were excluded at this stage.

Potentially eligible articles were subsequently retrieved for full-text assessment. The full texts were examined against all predefined inclusion and exclusion criteria.

Any disagreement between the reviewers was discussed and resolved by consensus. The final study-selection process was documented in accordance with PRISMA-ScR recommendations.[33]

The study-selection pathway is presented in the PRISMA-ScR flow diagram (Figure 1).

Table 4. Study Selection Process

Selection stage	Number of records/studies
Records identified through database searching	**123**
Records remaining after removal of duplicates	**96**
Records excluded during title/abstract screening	**54**
Full-text articles assessed for eligibility	**42**
Full-text articles excluded	**0**
Studies included in the final scoping review	**42**

Thus, 42 full-text articles fulfilled the predefined eligibility criteria and were included in the final evidence synthesis.

2.7. Data Extraction and Charting

Data were charted using a standardized data-charting form developed for the purposes of the present review and informed by the recommendations of the JBI scoping review methodology.[34]

The data-charting process was designed to capture both the clinical characteristics of the included studies and the specific features of the minimally invasive, regenerative, and technology-assisted approaches investigated.

For each included article, the following information was recorded:

- first author and year of publication;
- country in which the study was conducted;
- study design;
- number and characteristics of patients;
- type of odontogenic cyst;
- anatomical location of the lesion;
- lesion size, when reported;
- relationship with adjacent teeth and anatomical structures;
- treatment modality;
- conservative or minimally invasive component of treatment;
- use of decompression or marsupialization;
- use of endoscopic assistance;

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- use of piezoelectric surgery;
- use of regenerative materials or procedures;
- use of platelet concentrates such as PRF;
- use of CBCT or digital treatment planning;
- duration of follow-up;
- clinical outcomes;
- radiographic outcomes;
- evidence of cyst reduction or resolution;
- bone regeneration or reconstruction;
- postoperative complications;
- recurrence, when reported;
- preservation of adjacent teeth or anatomical structures;
- feasibility of subsequent implant rehabilitation, when reported.

Table 5. Data-Charting Variables

Domain	Variables extracted
Bibliographic information	Author, year, country
Study characteristics	Study design, sample size, clinical setting
Lesion characteristics	Cyst type, anatomical location, lesion size, relationship to adjacent structures
Primary treatment	Decompression, marsupialization, enucleation, endoscopic surgery, piezoelectric surgery, endodontic treatment
Regenerative treatment	Bone grafts, guided bone regeneration, collagen or barrier membranes, PRF, and other biological adjuncts
Digital and imaging technology	CBCT, three-dimensional imaging, virtual planning, computer-assisted planning, or navigation
Clinical outcomes	Cyst resolution or reduction, symptoms, preservation of teeth, postoperative morbidity
Radiographic outcomes	Bone regeneration, defect reduction, cortical healing, lesion dimensions
Safety outcomes	Complications, sensory disturbance, infection, membrane-related complications
Long-term outcomes	Recurrence, additional surgery, functional rehabilitation, implant rehabilitation
Follow-up	Duration and timing of clinical and radiographic evaluation

2.8. Organization of the Evidence

After data charting, the included studies were grouped according to the principal treatment strategy investigated. Because the available literature comprised heterogeneous study designs, patient populations, cyst types, treatment protocols, and outcome measures, the evidence was organized thematically rather than subjected to statistical pooling.

Five principal evidence categories were established:

1. Conservative decompression and marsupialization
2. Endoscopic-assisted surgery
3. Piezoelectric surgery
4. Regenerative approaches
5. Digital-assisted and CBCT-based treatment planning

Selected studies addressing conservative endodontic treatment and laser-assisted approaches were considered as adjunctive strategies when they were directly relevant to minimally invasive or tissue-preserving management of odontogenic cystic lesions.

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Table 6. Evidence Categories Used for the Thematic Synthesis

Evidence category	Principal approaches	Main outcomes considered
Conservative treatment	Decompression, marsupialization, conservative or limited-access enucleation	Lesion reduction, bone regeneration, preservation of adjacent structures, need for secondary surgery
Endoscopic-assisted surgery	Endoscopic-assisted enucleation and cyst removal	Surgical access, visualization, tissue preservation, postoperative morbidity
Piezoelectric surgery	Ultrasonic bone cutting and precision osteotomy	Surgical precision, preservation of surrounding soft tissues, operative morbidity
Regenerative treatment	Bone grafts, guided bone regeneration, barrier membranes, PRF	Bone-volume restoration, healing, reconstruction, implant-site preparation
Digital-assisted and CBCT-based treatment planning	CBCT, three-dimensional imaging, virtual planning, navigation, computer-assisted workflows	Anatomical assessment, treatment planning, surgical precision, preservation of anatomical structures
Adjunctive approaches	Conservative endodontic treatment and laser-assisted procedures	Tooth preservation, periapical healing, tissue preservation, healing, avoidance or reduction of surgical intervention

2.9. Outcome Assessment

The principal outcomes considered in the review were selected to reflect the clinical objectives of minimally invasive management of odontogenic cysts.

Primary Outcomes

The primary outcomes included:

- reduction or resolution of the cystic lesion;
- radiographic evidence of bone regeneration;
- preservation of adjacent teeth and important anatomical structures;
- successful pathological control;
- recurrence, when reported.

Secondary Outcomes

Secondary outcomes included:

- postoperative pain and swelling;
- sensory disturbances;
- infection and other postoperative complications;
- duration of treatment;
- need for secondary surgical intervention;
- quality and predictability of surgical access;
- restoration of jawbone volume;
- feasibility of subsequent implant rehabilitation;
- reported advantages and limitations of each approach.

Because the included studies used different definitions, follow-up periods, imaging methods, and outcome-assessment protocols, outcomes were not converted into a single standardized effect measure.

2.10. Data Synthesis

The extracted information was synthesized descriptively and thematically. The purpose of the synthesis was to identify

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patterns across the available literature and characterize the clinical applications, potential benefits, limitations, and reported outcomes of the different minimally invasive approaches.

The findings were organized according to the principal evidence categories and compared with respect to:

- clinical indication;
- biological rationale;
- degree of tissue preservation;
- reported treatment effectiveness;
- bone-healing and regenerative potential;
- preservation of adjacent structures;
- recurrence;
- postoperative complications;
- treatment duration;
- technical requirements;
- limitations of the available evidence.

Where studies reported different follow-up periods or outcome definitions, the findings were retained in their original context rather than directly compared as equivalent measures.

The evidence was subsequently summarized in comparative tables to facilitate interpretation of the clinical characteristics and reported outcomes of the different minimally invasive approaches.

No quantitative meta-analysis was performed because of substantial heterogeneity in study designs, cyst types, treatment protocols, outcome definitions, and follow-up periods.

2.11. Methodological Considerations

In accordance with the purpose of a scoping review, a formal risk-of-bias or methodological quality assessment was not performed.[33,34] The primary objective of the review was to map the existing evidence, identify the range of minimally invasive approaches used in odontogenic cyst management, characterize reported outcomes, and identify areas in which evidence remains limited.

The included literature comprised retrospective clinical studies, prospective observational studies, comparative clinical investigations, case series, and clinically relevant technical reports. The studies differed substantially in patient populations, cyst types, anatomical locations, treatment protocols, follow-up periods, and outcome definitions. Consequently, the evidence was synthesized descriptively and thematically rather than through a pooled effectiveness analysis.

The absence of formal methodological quality appraisal should therefore be considered when interpreting the findings, particularly when comparing outcomes reported across different study designs.

2.12. Ethical Considerations

As this study was a scoping review based exclusively on previously published literature and did not involve direct recruitment of human participants or access to identifiable patient-level data, institutional ethical approval was not required for the review itself.

3. RESULTS

3.1. Study Selection Process

The initial literature search identified 123 records from the selected electronic databases. After removal of duplicate records, 96 unique records remained for title and abstract screening. During this stage, 54 records were excluded because they did not address minimally invasive or tissue-preserving management of odontogenic cysts, focused exclusively on conventional surgical treatment, represented non-clinical investigations, or did not provide sufficient clinical information
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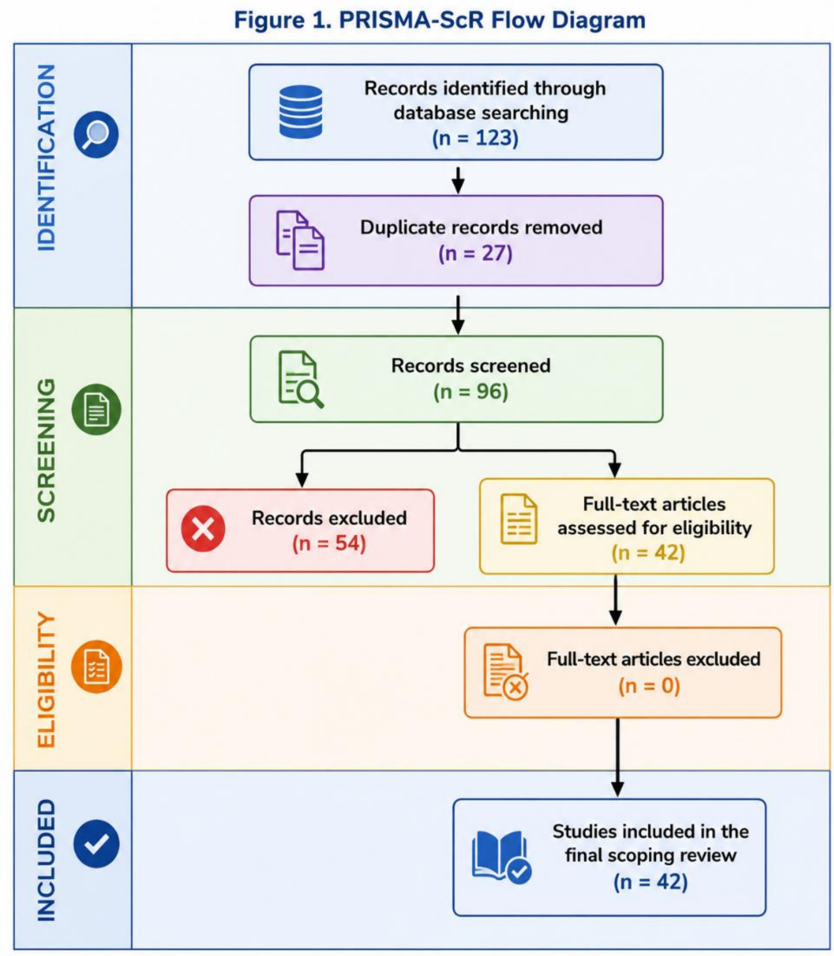
relevant to the review question.

A total of 42 articles were subsequently assessed in full text. Following detailed evaluation against the predefined eligibility criteria, no additional studies were excluded. Therefore, all 42 full-text articles fulfilled the inclusion criteria and were incorporated into the final scoping review synthesis. The study-selection process is presented in the PRISMA-ScR flow diagram (Figure 1).



The final evidence base consisted of 42 publications addressing different aspects of minimally invasive management of odontogenic cysts. The included literature covered conservative decompression and marsupialization, endoscopic-assisted surgery, piezoelectric surgery, regenerative reconstruction, CBCT-based and digital-assisted planning, and selected nonsurgical endodontic and laser-assisted approaches.

Table 7. Study Selection Process

Selection stage	Number of records
Records identified through database searching	**123**
Records remaining after removal of duplicates	**96**
Records excluded during title/abstract screening	**54**
Full-text articles assessed for eligibility	**42**
Full-text articles excluded	**0**
Studies included in the final synthesis	**42**

3.2. Characteristics of the Included Studies

The 42 included studies were published between 1996 and August 2026 and reflected the gradual development of

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conservative, tissue-preserving, regenerative, and technology-assisted approaches to odontogenic cyst management. The evidence base was heterogeneous and included retrospective clinical studies, prospective observational investigations, comparative clinical studies, case series, and technical or clinically oriented reports describing minimally invasive surgical procedures.

The majority of the included studies addressed inflammatory and developmental odontogenic cysts, particularly radicular cysts, dentigerous cysts, and odontogenic keratocysts. A substantial proportion of the reported clinical experience involved lesions of the posterior mandible, posterior maxilla, and maxillary sinus region, where preservation of the inferior alveolar nerve, adjacent teeth, cortical bone, and sinus structures was an important consideration.

The clinical characteristics of the included studies varied considerably. Lesions ranged from relatively small periapical cystic lesions to extensive cystic cavities associated with substantial bone destruction. In many reports, treatment selection was determined by lesion size, anatomical location, proximity to important structures, relationship with teeth, cortical bone involvement, and the possibility of future implant rehabilitation.

The outcomes most frequently reported across the included literature were reduction in cyst size, radiographic evidence of bone regeneration, preservation of adjacent teeth and anatomical structures, postoperative pain and swelling, surgical morbidity, recurrence, and the feasibility of subsequent reconstructive or implant treatment. Follow-up periods were variable, ranging from several months to more than five years, which limited direct comparison of long-term outcomes among treatment modalities.

Table 8. General Characteristics of the 42 Included Studies

Characteristic	**Findings across the included evidence**
Number of included studies	**42**
Main study designs	Retrospective clinical studies, prospective observational studies, comparative clinical investigations, case series, and technical/clinical reports
Main cyst types	Radicular cysts, dentigerous cysts, odontogenic keratocysts, and other developmental or inflammatory odontogenic cysts
Common anatomical sites	Posterior mandible, posterior maxilla, maxillary sinus region, and periapical areas
Main treatment approaches	Decompression, marsupialization, conservative or limited-access enucleation, endoscopic-assisted surgery, piezoelectric surgery, regenerative procedures, and CBCT/digital planning
Additional approaches	Selected nonsurgical endodontic treatment and laser-assisted procedures
Main clinical outcomes	Lesion reduction, preservation of anatomical structures, postoperative morbidity, healing, recurrence, and subsequent rehabilitation
Main radiographic outcomes	Reduction in lesion dimensions and progressive bone regeneration
Follow-up	Variable; several months to more than five years in individual reports
Overall evidence pattern	Increasing emphasis on tissue preservation, conservative treatment, regeneration, and digitally assisted planning

3.3. Classification of Minimally Invasive Treatment Approaches

Analysis of the 42 included studies demonstrated that minimally invasive management of odontogenic cysts could be organized into five principal treatment categories: conservative decompression and marsupialization, endoscopic-assisted surgery, piezoelectric surgery, regenerative approaches, and digital-assisted treatment planning. Selected nonsurgical endodontic and laser-assisted techniques were also identified as complementary approaches in specific clinical situations.

The different modalities were not interchangeable. Their clinical application depended primarily on cyst type, lesion size, anatomical location, biological behavior, relationship to adjacent teeth and vital structures, and the anticipated need for reconstruction. Overall, the evidence showed a movement away from extensive surgical removal alone toward treatment strategies designed to control the pathological lesion while preserving healthy bone and surrounding anatomical structures.

Table 9. Main Minimally Invasive Approaches Identified in the Included Studies

Treatment category	Main biological or technical principle	Principal clinical indications	Main advantages	Main limitations
Decompression	Reduction of intracystic pressure and stimulation of gradual lesion reduction and bone remodeling	Large cysts, particularly those close to vital structures	Preservation of bone and adjacent structures; reduced surgical trauma	Prolonged treatment and need for patient compliance
Marsupialization	Creation of a permanent drainage pathway and reduction of intracystic pressure	Large cystic lesions requiring reduction before definitive treatment	Simple and conservative; facilitates gradual reduction of lesion volume	Secondary surgery may be required
Endoscopic-assisted surgery	Magnified visualization through limited surgical access	Cysts in the maxillary sinus, posterior regions, and anatomically complex areas	Improved visualization and surgical precision; reduced tissue disruption	Specialized equipment, training, and technical expertise required
Piezoelectric surgery	Selective ultrasonic cutting of mineralized tissue	Lesions close to nerves, vessels, or sinus structures	Precise bone removal and improved protection of adjacent soft tissues	Longer operative time and equipment requirements
Guided bone regeneration and bone grafting	Space maintenance and guided regeneration of residual osseous defects	Large post-cystic bone defects	Restoration of bone volume and support for subsequent implant rehabilitation	Technique-sensitive; outcome depends on defect characteristics and surgical execution
Collagen membrane-assisted regeneration	Barrier function and exclusion of soft tissue from the bone defect	Contained or partially contained defects	Supports bone regeneration and defect stability	Risk of membrane exposure and need for careful soft-tissue management
PRF/i-PRF	Release of platelet-derived growth factors and modulation of healing	Adjunctive postoperative bone and soft-tissue healing	Autologous biological adjunct with potential healing benefit	Independent effect on definitive bone regeneration remains uncertain
CBCT-based digital planning	Three-dimensional assessment and surgical simulation	Complex lesions requiring precise anatomical planning	Improved anatomical assessment and treatment predictability	Does not itself constitute a treatment modality and depends on the surgical procedure
Digital-assisted surgery	Three-dimensional visualization, planning, and individualized surgical guidance	Complex cyst anatomy and difficult surgical access	Improved planning accuracy and potentially more controlled access	Availability, cost, and limited clinical evidence for some applications

3.3.1. Decompression and Marsupialization

Decompression and marsupialization were among the most frequently represented conservative treatment strategies in

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the included literature. They were predominantly used for large odontogenic cysts in which immediate complete enucleation could result in extensive bone removal or increase the risk of damage to adjacent anatomical structures.

The principal biological rationale of decompression is reduction of intracystic pressure through creation of a controlled communication between the cystic cavity and the oral environment. Reduction of intracystic pressure may lead to gradual shrinkage of the lesion and progressive remodeling of the surrounding bone. Marsupialization follows a closely related principle, with the cystic cavity being converted into an open pouch that permits continuous drainage and gradual reduction in size.

The reviewed studies described favorable clinical effects in large radicular and dentigerous cysts and in lesions located near the inferior alveolar nerve, maxillary sinus, or other structures where aggressive immediate surgery could produce substantial morbidity. Reported benefits included preservation of adjacent teeth, reduction of the risk of neurological injury, limitation of bone removal, and progressive restoration of the osseous defect.

However, conservative decompression and marsupialization were not associated with rapid resolution. Treatment frequently required prolonged follow-up, maintenance of the decompression device or surgical opening, patient cooperation with local care, and repeated radiographic assessment. In selected cases, a second surgical procedure was necessary after sufficient reduction of the cystic cavity. Thus, the evidence supported these techniques primarily as individualized conservative strategies for appropriately selected large lesions rather than universal substitutes for enucleation.

3.3.2. Endoscopic-Assisted Management

Endoscopic-assisted surgery represented one of the more technologically advanced approaches identified in the included evidence. The principal advantage of endoscopic assistance was improved visualization of the operative field through a relatively limited surgical access.

The technique was particularly relevant for lesions located in anatomically difficult areas, including the maxillary sinus, posterior maxilla, posterior mandible, and regions adjacent to neurovascular structures. Magnified visualization facilitated identification of the cystic cavity and its boundaries and allowed the surgeon to work with greater visual control while limiting unnecessary manipulation of surrounding tissues.

The available clinical reports suggested several potential benefits compared with conventional open approaches, including reduced surgical exposure, improved visualization, more precise removal of pathological tissue, and potentially lower postoperative swelling and discomfort. Endoscopic approaches were therefore most useful when adequate conventional visualization would require a substantially larger surgical access.

The main limitations were the requirement for specialized equipment, operator training, technical experience, and familiarity with three-dimensional orientation. The available studies also remained relatively limited in number and heterogeneous in design, making it difficult to establish standardized indications or definitive long-term superiority over conventional techniques.

3.3.3. Piezoelectric Surgery

Piezoelectric surgery was identified primarily as an adjunctive precision technology rather than an independent treatment for odontogenic cysts. Its principal clinical value was related to controlled bone removal in areas where important anatomical structures were located close to the surgical field.

Piezoelectric devices use ultrasonic microvibrations that permit selective cutting of mineralized tissue. This characteristic may reduce unintended injury to adjacent soft tissues and provide greater control during osteotomy. The included evidence particularly supported its use when lesions were located close to nerves, vessels, or the maxillary sinus.

The reported advantages included controlled bone removal, improved operative precision, preservation of surrounding tissues, and potentially safer surgical access in anatomically sensitive regions. These characteristics were consistent with the broader objective of minimally invasive cyst surgery, namely achieving adequate pathological control while

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minimizing unnecessary removal of healthy tissue.

The principal disadvantages were increased operative time compared with some conventional instruments, equipment requirements, and the need for adequate operator experience. Consequently, piezoelectric surgery was best interpreted as a tissue-preserving adjunct that may improve the safety and precision of cyst surgery rather than as a replacement for appropriate surgical principles.

3.3.4. Regenerative Approaches Following Cyst Removal

Regenerative treatment represented an important component of the evidence identified in the 42 included studies. In large cystic lesions, removal of the pathological tissue may leave a substantial osseous defect. The reviewed literature therefore increasingly considered management of the residual bone defect as an integral part of treatment rather than a separate secondary procedure.

The regenerative approaches identified included guided bone regeneration, particulate bone grafting, collagen barrier membranes, platelet-rich fibrin and related platelet concentrates, and selected combinations of these materials.

Bone graft materials were used primarily to provide an osteoconductive scaffold and to maintain the volume of the residual defect during healing. Xenogeneic materials, allogeneic materials, and synthetic substitutes were represented in the literature. Autogenous bone remained biologically important because of its osteogenic, osteoinductive, and osteoconductive properties, although donor-site morbidity and the requirement for an additional surgical procedure limited its routine use in some situations. Guided bone regeneration was particularly relevant to large or poorly contained defects. Barrier membranes were used to limit soft-tissue invasion and maintain a regenerative space for bone formation. Resorbable collagen membranes were frequently favored because they avoid the need for a second removal procedure, whereas non-resorbable membranes may provide greater mechanical stability in selected large or complex defects.

PRF and i-PRF were identified as biological adjuncts intended to support angiogenesis, growth-factor release, and early tissue healing. The available evidence suggested a potentially beneficial effect on postoperative healing, but the independent contribution of platelet concentrates to definitive bone regeneration remained less clearly established than the role of the primary surgical procedure and grafting strategy.

Overall, regenerative techniques were particularly relevant in patients in whom preservation or restoration of alveolar bone was important for subsequent implant-supported rehabilitation. However, the final regenerative outcome depended on defect size and morphology, residual bony walls, vascular supply, infection control, biomaterial selection, surgical technique, and patient-related factors.

Table 10. Biological Basis of Regenerative and Tissue-Preserving Approaches

Technique	Primary mechanism	Potential clinical or biological effect
Decompression	Reduction of intracystic pressure	Progressive lesion reduction and secondary bone regeneration
Marsupialization	Continuous drainage and decompression	Reduction of inflammatory stimulation and facilitation of healing
PRF/i-PRF	Release of platelet-derived growth factors	Enhanced angiogenic response and cellular activity
Guided bone regeneration	Barrier function and space maintenance	Selective regeneration of bone within the defect
Bone grafts	Osteoconductive scaffold formation	Support of new bone deposition and maintenance of defect volume
Bioceramic materials	Bioactive ion release and mineralization support	Potential stimulation of mineralized tissue formation
Collagen membranes	Exclusion of rapidly proliferating soft tissue	Maintenance of a favorable environment for bone regeneration

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3.3.5. Clinical Reconstruction of Post-Cystic Bone Defects

The included evidence demonstrated that regenerative reconstruction could be integrated directly into the surgical management of odontogenic cysts. In cases with substantial residual bone defects, the treatment sequence generally involved removal of the pathological tissue followed by assessment of the remaining defect and selection of an appropriate regenerative strategy.

The clinical reports emphasized the importance of preserving the surrounding bone architecture during cyst removal whenever possible. Following enucleation, regenerative materials could be used to maintain the contour and volume of the alveolar bone and to provide a favorable environment for subsequent bone formation.

This approach was particularly relevant when future implant rehabilitation was anticipated. Restoration of adequate bone volume after cyst removal may facilitate later implant placement and reduce the need for more extensive secondary reconstructive surgery.

The clinical sequence illustrated in Figure 2 demonstrates the concept of combining cyst removal with reconstruction of the resulting osseous defect rather than considering pathological removal as the sole endpoint of treatment.

3.3.6. Digital-Assisted Planning and CBCT-Based Surgery

Digital technologies represented an emerging component of minimally invasive odontogenic cyst management. CBCT was consistently identified as an important diagnostic and planning tool because it provides three-dimensional information about lesion dimensions, cortical bone integrity, tooth and root relationships, and proximity to critical anatomical structures.

The included literature indicated that digital planning could assist clinicians in evaluating lesion morphology before surgery, selecting an appropriate surgical access, anticipating the relationship of the cyst to nerves and sinus structures, and developing an individualized treatment strategy. Digital workflows also allowed more detailed preoperative visualization and surgical simulation. In complex lesions, this may contribute to more predictable access and reduce unnecessary manipulation of healthy tissues. However, the clinical evidence for advanced digital-assisted workflows remained less mature than the evidence for established conservative techniques such as decompression and marsupialization.

The available evidence therefore supported CBCT-based planning as an important component of contemporary treatment planning, particularly for anatomically complex lesions, while recognizing that imaging and digital technologies function primarily as planning and guidance tools rather than independent therapeutic interventions.

Table 11. Role of Digital Technologies in Minimally Invasive Cyst Surgery

Digital technology	Main application	Clinical contribution	Current evidence
CBCT	Three-dimensional anatomical assessment	Defines lesion size, cortical involvement, tooth relationships, and proximity to vital structures	Established and clinically useful
Digital 3D reconstruction	Visualization of lesion morphology	Improves spatial understanding of complex lesions	Increasing clinical use
Digital surgical simulation	Preoperative planning	Allows evaluation of surgical access and treatment options	Promising
Computer-assisted planning	Individualized treatment planning	May improve procedural predictability	Emerging
Digital-assisted surgical guidance	Intraoperative orientation	May facilitate precise access and tissue preservation	Limited clinical validation
AI-assisted segmentation and planning	Automated image analysis and treatment planning	Potential for improved efficiency and individualized planning	Early-stage evidence

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3.3.7. Selected Nonsurgical Endodontic Management

A smaller component of the included evidence addressed nonsurgical endodontic management of selected cyst-like periapical lesions, particularly inflammatory radicular lesions associated with non-vital but restorable teeth.

The underlying principle was elimination of the intracanal source of infection through adequate root canal disinfection, thereby reducing the inflammatory stimulus responsible for periapical pathology. Intracanal medicaments, particularly calcium hydroxide-based preparations, were discussed in relation to their antimicrobial effects and their potential to support periapical healing.

The available evidence indicated that selected small and well-contained periapical lesions may resolve following appropriate nonsurgical endodontic treatment. This approach offers the important advantage of preserving the affected tooth and avoiding surgical access to the cystic cavity.

However, accurate diagnosis and case selection remained critical. Large true cysts, lesions with extensive cortical destruction, persistent infection, or lesions that fail to respond to appropriate endodontic therapy may still require surgical treatment. Therefore, nonsurgical endodontic treatment was identified as a selective conservative option rather than a universal replacement for surgical management.

3.3.8. Laser-Assisted Approaches

Laser-assisted treatment represented an emerging and relatively less established component of the reviewed evidence. Er laser applications were described primarily as adjunctive techniques in selected cyst enucleation and periapical surgical procedures.

The potential advantages included precise tissue interaction, limited thermal damage when appropriate parameters are used, improved control of the surgical field, and possible reduction of microbial contamination. Some reports also suggested favorable effects on postoperative tissue healing.

Nevertheless, the clinical evidence supporting routine laser-assisted cyst management remained limited. The available studies did not justify considering laser therapy as a replacement for established conservative or surgical approaches. Instead, it was best regarded as an adjunctive technology requiring further prospective clinical evaluation.

3.4. Comparative Clinical Outcomes

The 42 included studies demonstrated that minimally invasive management can achieve favorable clinical outcomes, but the evidence was heterogeneous and direct comparison between treatment modalities was difficult. Differences in cyst type, lesion size, anatomical location, treatment protocol, follow-up duration, and outcome assessment methods prevented reliable quantitative comparison or pooled analysis.The strongest and most consistent clinical pattern was observed with decompression and marsupialization in appropriately selected large lesions. These approaches were associated with gradual reduction in cyst size and progressive bone regeneration while allowing preservation of adjacent anatomical structures. Their principal disadvantages were prolonged treatment duration, the need for regular monitoring, and dependence on patient compliance.

Endoscopic-assisted surgery demonstrated particular value in anatomically complex regions where conventional access could require greater tissue disruption. The principal benefit was improved visualization and precision through limited access. Piezoelectric surgery was mainly beneficial as an adjunct for precise bone removal near critical anatomical structures. Its clinical value was related to tissue preservation and controlled osteotomy rather than independent cyst treatment. Regenerative approaches showed particular importance for residual post-cystic defects. Bone grafting and guided bone regeneration were used to restore lost bone volume, preserve alveolar architecture, and improve conditions for subsequent implant rehabilitation. PRF and related platelet concentrates were generally reported as adjunctive biological measures rather than independent regenerative treatments.

CBCT-based planning improved anatomical assessment and treatment planning, especially for lesions with complex relationships to teeth, nerves, cortical bone, or the maxillary sinus. However, the clinical evidence for advanced digital workflows remained less extensive than that for established conservative surgical approaches.

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Table 12. Comparative Clinical Outcomes of Minimally Invasive Approaches

Minimally invasive approach	Main clinical indication	Treatment effectiveness	Recurrence considerations	Postoperative complication risk	Approximate healing pattern	Bone regeneration potential
Decompression	Large cysts close to vital anatomical structures	High in appropriately selected cases	Low–moderate with adequate long-term follow-up	Low	Soft-tissue healing approximately 2–4 weeks; radiographic bone regeneration commonly assessed over 6–24 months	High
Marsupialization	Large lesions requiring reduction before definitive treatment	Moderate–high	Moderate; depends on lesion biology and definitive treatment	Low–moderate	Approximately 2–6 weeks for soft-tissue healing; bone remodeling may continue for 6–24 months	Moderate–high
Nonsurgical endodontic treatment	Selected inflammatory radicular lesions associated with treatable teeth	Moderate–high in selected lesions	Low–moderate in appropriately selected cases	Very low	Approximately 1–3 weeks for early soft-tissue recovery; radiographic healing generally assessed over 6–12 months	Moderate
Endoscopic-assisted surgery	Lesions in anatomically difficult regions	High in selected cases	Low when complete pathological removal is achieved	Low	Approximately 1–3 weeks; bone healing depends on defect and regenerative protocol	Moderate–high
Piezoelectric surgery	Lesions close to nerves, vessels, or sinus structures	High as an adjunctive technique	Low when combined with complete lesion removal	Low	Approximately 1–3 weeks; bone regeneration commonly assessed over 6–18 months	Moderate–high
Er laser-assisted surgery	Selected enucleation and periapical surgical procedures	Moderate–high as an adjunct	Low when complete pathological removal is achieved	Low when appropriate parameters are used	Approximately 1–3 weeks; radiographic evidence generally assessed over 6–12 months	Potentially favorable, but clinical evidence remains limited
GBR with bone grafting	Large residual osseous defects	High for defect reconstruction	Primarily related to completeness of cyst removal	Moderate	Approximately 2–6 weeks for soft-tissue healing; bone maturation generally assessed over 6–	Excellent

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					12 months or longer	
Collagen membrane-assisted regeneration	Contained or partially contained defects	High	Low–moderate	Low–moderate, particularly with membrane exposure	Approximately 2–6 weeks; bone regeneration commonly assessed over 6–12 months	High
PRF/i-PRF	Adjunctive postoperative healing and regeneration	Promising adjunctive effect	Not independently established	Very low	May support early soft-tissue healing; definitive bone regeneration depends on the primary treatment	Moderate–high as a biological adjunct
CBCT-based digital planning	Complex lesions requiring precise planning	Improves treatment predictability	Not directly applicable	Low as a planning intervention	Depends on the surgical procedure	Depends on the definitive treatment

The comparative evidence therefore supports an individualized treatment strategy rather than a fixed hierarchy of minimally invasive techniques. The choice of treatment should take into account lesion type, size, anatomical location, relationship to vital structures, tooth vitality and restorability, biological behavior, and the anticipated need for bone reconstruction or future rehabilitation [1,5,9,32]. Following the comparative evaluation of the available treatment modalities, the evidence identified in this review was integrated into the clinical decision-making algorithm presented in Figure 2. The algorithm is intended as a synthesis of the treatment principles identified in the literature rather than as a validated clinical guideline. It illustrates how lesion characteristics and anatomical considerations may be used to guide selection among conservative, surgical, regenerative, and digital-assisted approaches.

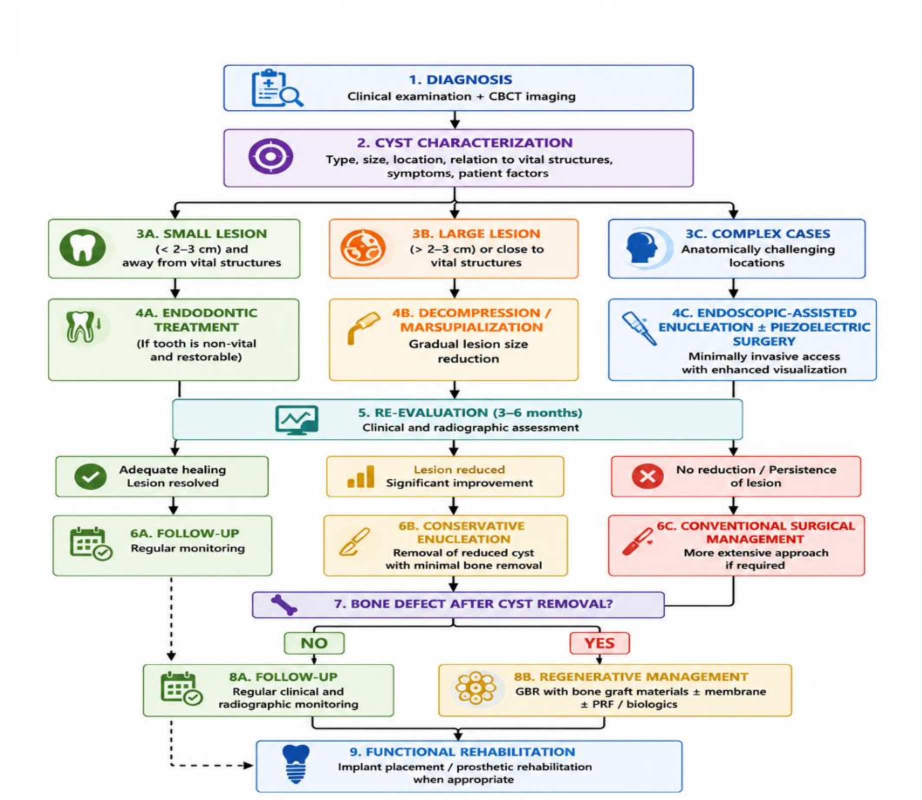

Figure 2. Treatment Algorithm for Minimally Invasive Management of Odontogenic Cysts.

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The proposed algorithm begins with clinical examination and appropriate radiographic, including CBCT-based, assessment. Treatment selection is subsequently guided by lesion size, anatomical location, relationship to adjacent vital structures, tooth vitality and restorability, and the anticipated need for definitive pathological control. Selected inflammatory periapical lesions associated with treatable teeth may initially be considered for nonsurgical endodontic management. Larger lesions in which preservation of adjacent structures is a major concern may be considered for decompression or marsupialization, followed when indicated by definitive surgical management. Lesions in anatomically difficult regions may be managed with endoscopic-assisted or piezoelectric techniques when these approaches provide a clinically appropriate advantage. Following lesion removal, residual osseous defects may be evaluated for regenerative reconstruction using bone-graft materials, guided bone regeneration, collagen membranes, and selected biological adjuncts. Long-term clinical and radiographic follow-up remains necessary to evaluate lesion resolution, bone regeneration, and the need for further treatment.

3.5 Overall Evidence Pattern

Taken together, the 42 included studies demonstrated a consistent change in the clinical philosophy of odontogenic cyst management. Rather than focusing exclusively on complete surgical removal through the most extensive possible access, contemporary approaches increasingly emphasized preservation of healthy bone, teeth, nerves, sinus structures, and other adjacent tissues.

The evidence was strongest for established conservative approaches, particularly decompression and marsupialization in appropriately selected large lesions. Endoscopic and piezoelectric technologies provided additional means of improving surgical access and precision in anatomically difficult cases. Regenerative techniques extended the concept of minimally invasive treatment beyond removal of the cyst itself by addressing the residual osseous defect and preparing the site for future functional rehabilitation.

Digital technologies, particularly CBCT-based planning, increasingly supported individualized treatment selection and surgical planning. However, the evidence for advanced digital and emerging technologies remained less mature than that for conventional conservative approaches.

Across the included literature, treatment success was strongly dependent on appropriate case selection. Cyst size, anatomical location, biological behavior, relationship to adjacent teeth and vital structures, cortical involvement, infection control, and the patient's future restorative requirements all influenced the choice of treatment. No single minimally invasive technique was appropriate for all odontogenic cysts.

The comparative evidence therefore supports an individualized treatment pathway in which conservative decompression or marsupialization may be selected for large lesions, endoscopic or piezoelectric techniques may be used when precise access is required, regenerative procedures may be added when significant osseous defects remain, and CBCT-based digital planning may guide the overall surgical strategy. The evidence also demonstrated that minimally invasive treatment should not be interpreted as synonymous with avoiding surgery altogether. In many cases, the minimally invasive concept refers instead to reducing the extent of surgical trauma while maintaining adequate pathological control. The final treatment objective remains complete and appropriate management of the cystic lesion together with preservation or restoration of the surrounding anatomical and functional structures. Overall, the 42 included publications support a contemporary treatment model combining conservative surgery, precision-enhancing technologies, biological regeneration, and digital planning. At the same time, substantial heterogeneity in study designs, patient populations, treatment protocols, definitions of healing, and duration of follow-up limits definitive comparisons between modalities. This heterogeneity also indicates the need for prospective comparative studies using standardized clinical and radiographic outcome measures and sufficiently long follow-up periods.

3.3.5. Clinical Reconstruction of Post-Cystic Osseous Defects

The management of large odontogenic cysts does not end with removal of the pathological lesion. In extensive defects, preservation and reconstruction of the remaining osseous architecture are important components of minimally invasive and tissue-preserving treatment, particularly when subsequent functional rehabilitation or dental implant placement is anticipated. The literature therefore describes the use of bone grafting, barrier membranes, and guided bone regeneration as adjunctive procedures following cyst removal [22-25,41]. Within this scoping review, a clinical illustration is included to demonstrate the treatment sequence described in the literature, rather than to present a new clinical case or to provide

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case-report evidence. The purpose of the illustration is to translate the principal regenerative concepts identified during evidence mapping into a clinically understandable sequence. As illustrated in Figure , management may involve surgical exposure and removal of the cystic lesion, preparation of the residual osseous cavity, placement of bone-graft material, application of a barrier membrane, primary soft-tissue closure, and subsequent radiographic assessment of bone regeneration [22-25,41]. This type of clinical illustration is particularly relevant to a scoping review because the review maps different treatment modalities and describes how they are applied across the available literature. It does not constitute additional evidence and is not intended to demonstrate treatment efficacy in an individual patient. Instead, it provides a visual representation of the regenerative treatment pathway identified from the reviewed literature, thereby linking the evidence on bone grafting and guided bone regeneration with their potential clinical application.

G. Hakobyan specifically described bone-grafting procedures for reconstruction of osseous defects associated with dental implants, including defects remaining after removal of cystic lesions. This work provides a clinically relevant example of the reconstructive principle addressed in this section and supports the inclusion of bone grafting as a component of post-cystic defect management [41].

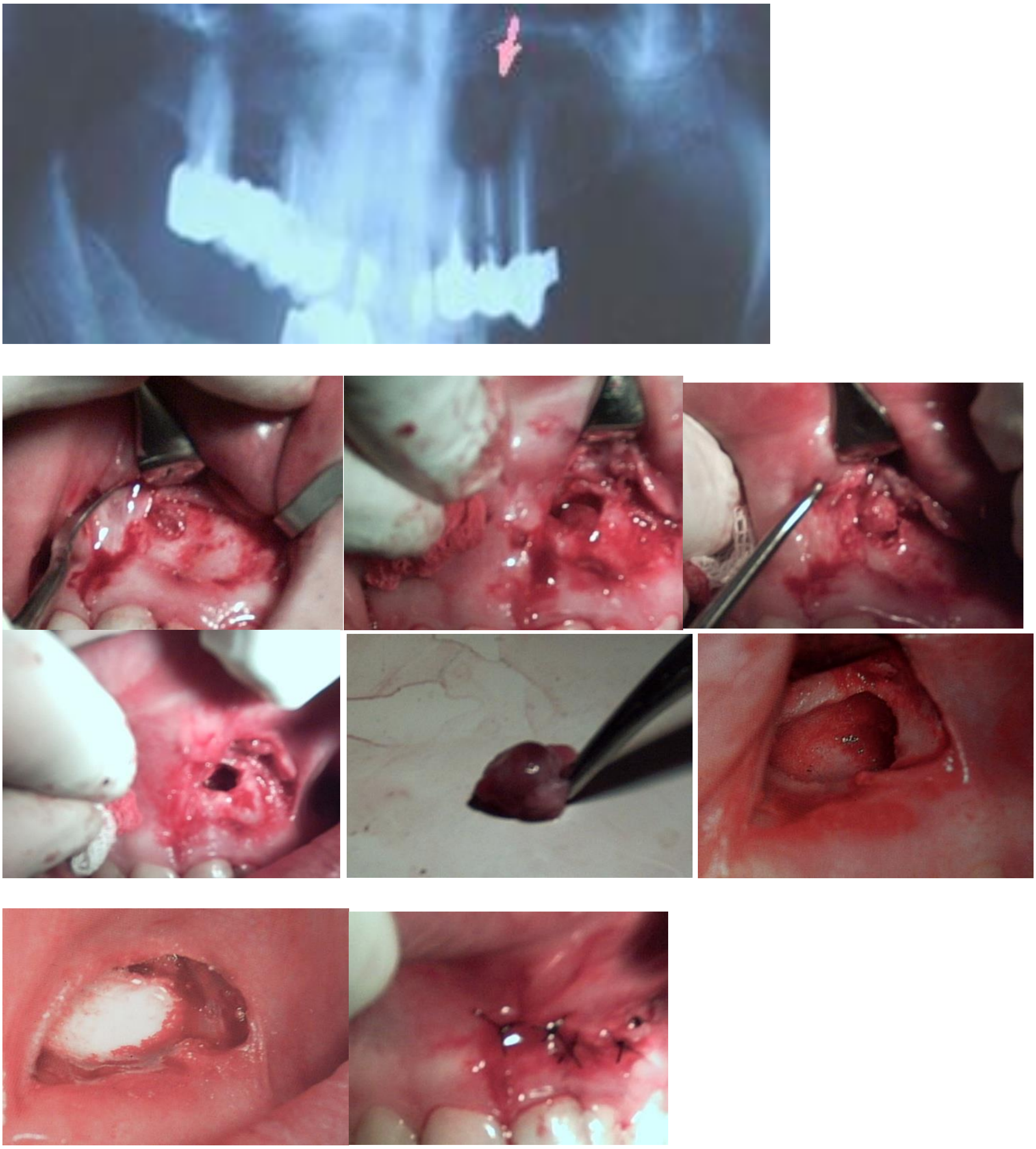

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Figure 3. Clinical sequence illustrating regenerative reconstruction of a post-cystic osseous defect. **(A)** Preoperative clinical and radiographic assessment of the cyst-associated osseous defect. **(B)** Surgical exposure of the affected region. **(C)** Removal of the cystic lesion and meticulous preparation of the residual osseous cavity. **(D)** Preparation of the defect for regenerative reconstruction. **(E)** Placement of bone-graft material within the residual defect. **(F)** Coverage of the grafted area with a barrier membrane to support guided bone regeneration. **(G)** Primary closure of the surgical site. **(H)** Postoperative radiographic assessment demonstrating progressive reconstruction of the osseous defect. The sequence is presented as a representative clinical illustration of regenerative principles described in the literature and is not intended to represent an independent case report [41].

4. DISCUSSION

The present scoping review maps the available evidence concerning minimally invasive management of odontogenic cysts and demonstrates a gradual expansion of treatment concepts beyond conventional extensive surgical removal. The literature includes established conservative approaches, such as decompression and marsupialization, as well as endoscopic and piezoelectric surgical techniques, regenerative procedures, nonsurgical endodontic treatment, and digital-assisted planning. The evidence does not support the replacement of conventional surgery by a single minimally invasive technique. Instead, it supports the use of different approaches according to lesion characteristics and the clinical objectives of treatment [1,5,9,32].

Conventional enucleation and other surgical procedures remain important methods for definitive management of odontogenic cysts. Their principal advantage is direct removal of the pathological lesion. Nevertheless, extensive surgical access may require removal of surrounding bone and may increase the risk of injury to adjacent anatomical structures in large or anatomically complex lesions. These considerations have contributed to the development of treatment strategies designed to reduce surgical morbidity while maintaining adequate pathological control [8,10,32].

Decompression and marsupialization represent the most established conservative strategies identified in this review. Their principal biological effect is reduction of intracystic pressure and gradual reduction of the lesion. The systematic review by Berretta et al. supports the use of these procedures for reduction of cystic jaw lesions, while clinical studies have demonstrated their application in large lesions, including lesions in children and lesions for which preservation of surrounding structures is clinically important [9,11-14]. The principal limitations are the prolonged treatment period, the need for regular follow-up, patient compliance, and the possibility that a second surgical procedure may ultimately be necessary.

The endoscopic literature demonstrates another way in which surgical morbidity may be reduced. Endoscopic-assisted enucleation allows direct visualization through a more limited access and has been described for large mandibular cysts and lesions involving difficult anatomical regions [15-18]. Navigation-based endoscopic enucleation represents a further development of this concept by combining endoscopic visualization with navigation technology [16]. These procedures are technically demanding, however, and their wider use depends on equipment availability and surgical expertise. The current evidence is therefore more appropriately interpreted as supporting selected applications rather than routine use for all odontogenic cysts.

Piezoelectric surgery has similarly been incorporated into contemporary oral and maxillofacial surgery as a method of controlled bone manipulation. The selective cutting properties of ultrasonic devices may be useful when access is required near anatomical structures that should be preserved. The literature included in this review supports the use of piezoelectric surgery as an adjunctive technique, but it does not establish it as a distinct treatment for the underlying cystic pathology [28-30]. Its principal value lies in the manner in which the surgical access or bony component of treatment is performed.

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Regenerative treatment represents an important extension of minimally invasive cyst management. Once a cyst has been removed, a large residual osseous cavity may remain. The management of this defect becomes particularly important when the patient is expected to undergo subsequent implant-supported rehabilitation. Bone-graft materials can provide structural support and an osteoconductive environment, while barrier membranes can help maintain a protected space for bone formation [22-25]. The literature therefore supports considering reconstruction as an integral part of treatment planning in selected extensive defects rather than as a separate procedure unrelated to cyst management.

The clinical importance of regeneration is also illustrated by the literature describing reconstruction of large odontogenic cystic defects and by the work of Hakobyan, which specifically addressed bone-grafting procedures for osseous defects associated with dental implants, including defects arising after removal of cystic lesions [22-25,31,41]. In the context of this scoping review, such evidence is relevant because it demonstrates how preservation of the residual anatomical architecture and subsequent restoration of bone volume can be incorporated into a broader treatment pathway. The purpose is not to present an individual clinical case as evidence, but to identify the reconstructive principle represented in the literature.

Platelet-rich fibrin has received increasing attention as a biological adjunct to regenerative treatment. Its proposed effects include provision of a fibrin matrix, release of biologically active mediators, and support of angiogenic and tissue-healing processes [26,27]. Nevertheless, the evidence mapped in this review does not justify treating PRF as an independent substitute for adequate surgical treatment or established regenerative principles. Its role is better understood as an adjunct whose potential contribution may depend on the defect, the primary reconstructive procedure, and other patient-related factors.

Nonsurgical endodontic management provides another example of treatment aimed at preserving rather than removing anatomical structures. In selected inflammatory periapical lesions, successful control of intracanal infection may allow resolution of the associated periapical pathology while preserving the tooth [35,36]. Calcium hydroxide and contemporary bioceramic materials have favorable biological properties that support their use in endodontic treatment [35-37]. However, the distinction between a clinically diagnosed cyst-like lesion and a histologically confirmed true cyst is essential. The available evidence does not support the conclusion that nonsurgical endodontic treatment is an appropriate substitute for surgery in all true odontogenic cysts.

Digital-assisted planning has a different but increasingly relevant role. CBCT provides three-dimensional information that can improve understanding of lesion anatomy and its relationship to adjacent structures [19,20]. Virtual surgical planning and three-dimensional printing may further support individualized operative preparation in selected complex cases [21]. At present, these technologies should be regarded principally as diagnostic and planning tools. The evidence does not support assigning them an independent therapeutic effect on cyst recurrence or bone healing.

Laser-assisted procedures, including Er applications, represent a further emerging area. The systematic review included in the reference set concerns laser application in oral periodontal therapy rather than providing direct evidence for routine treatment of odontogenic cysts [40]. Therefore, the role of laser-assisted surgery in this review should be interpreted cautiously. Potential biological and technical advantages have been proposed in oral surgical applications, but the available evidence is insufficient to establish laser treatment as a standard modality for odontogenic cyst management [40].

Overall, the evidence mapped in this scoping review indicates that minimally invasive treatment should be understood as a treatment philosophy rather than as a single operative technique. The central principles are reduction of unnecessary tissue injury, preservation of teeth and surrounding anatomical structures when clinically appropriate, control of the pathological process, and restoration of function and tissue volume when required. The most appropriate treatment therefore depends on the individual lesion rather than on the theoretical superiority of one minimally invasive technique.

The available literature also demonstrates important differences in the maturity of the evidence base. Decompression and marsupialization have a comparatively established clinical literature, whereas endoscopic surgery, advanced digital workflows, and laser-assisted procedures remain supported by smaller or more heterogeneous bodies of evidence. Regenerative procedures have a broader biological and reconstructive literature, but their specific application after odontogenic cyst removal also varies substantially between studies [9,15-18,22-31]. These differences should be considered when interpreting the findings of the present scoping review.

The principal research gap is the absence of standardized comparative studies that evaluate different minimally invasive approaches using common definitions of treatment success, recurrence, bone regeneration,

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complications, and long-term functional outcomes. Future studies should therefore use clearly defined diagnostic criteria, standardized radiographic assessment, consistent follow-up intervals, and clinically meaningful outcome measures. Particular attention should also be directed toward prospective evaluation of digital planning and emerging technologies before they become incorporated into routine clinical algorithms.

This scoping review has several limitations that should be considered when interpreting its findings. First, the available literature is heterogeneous with respect to study design, diagnostic criteria, cyst classification, lesion size, anatomical location, treatment protocols, follow-up duration, and outcome definitions. This heterogeneity prevents direct comparison of all treatment modalities and limits the possibility of identifying a single superior minimally invasive approach.

Second, the evidence base includes retrospective clinical studies, case series, observational investigations, technical reports, and other non-randomized forms of evidence. Such studies are valuable for mapping the available clinical literature and identifying treatment trends, but they provide different levels of certainty regarding treatment effectiveness and long-term outcomes. In accordance with the purpose of a scoping review, the present study mapped this evidence rather than undertaking a formal pooled assessment of intervention effectiveness.

Third, the interpretation of cyst resolution is complicated by differences in diagnostic methodology. In particular, periapical lesions described clinically as cysts are not necessarily equivalent to histologically confirmed radicular cysts. This issue is particularly relevant when interpreting reports of nonsurgical endodontic treatment and should be considered when comparing endodontic and surgical treatment outcomes.

Another limitation is the variation in radiographic methods used to assess lesion reduction and bone regeneration. Conventional radiography, CBCT, and other imaging approaches may provide different levels of anatomical information, while criteria for defining radiographic healing are not uniform across studies. Standardized three-dimensional imaging and clearly defined radiographic endpoints would improve the comparability of future research. The evidence for several emerging technologies is also limited. Endoscopic-assisted surgery, digital surgical planning, three-dimensional printing, artificial intelligence-assisted workflows, and laser-assisted procedures are not supported by the same volume of cyst-specific clinical evidence as decompression and marsupialization. Their potential advantages should therefore be interpreted as emerging findings rather than established clinical standards.

Finally, the literature includes studies addressing different objectives within the same treatment pathway. Some investigations focus on cyst reduction, others on surgical access, bone regeneration, preservation of teeth, or subsequent implant rehabilitation. These different endpoints make direct quantitative comparison difficult. The findings of this scoping review should consequently be interpreted as an evidence map describing the range of available approaches and their reported clinical applications rather than as a ranking of treatment effectiveness.

CONCLUSION

The present scoping review demonstrates that the management of odontogenic cysts is increasingly characterized by conservative, tissue-preserving, regenerative, and technology-assisted treatment concepts. The available literature does not indicate that minimally invasive treatment should replace conventional surgery in all patients. Rather, it demonstrates that different minimally invasive approaches may be incorporated selectively according to lesion characteristics, anatomical relationships, treatment objectives, and the requirements for subsequent rehabilitation. Decompression and marsupialization remain important conservative approaches, particularly for large lesions in which immediate extensive surgery may place adjacent teeth, nerves, sinus structures, or other anatomical tissues at risk. Their principal advantages are reduction of lesion size and preservation of surrounding structures, although prolonged treatment and the possibility of subsequent surgery remain important considerations. Nonsurgical endodontic treatment provides a tooth-preserving option for selected inflammatory periapical lesions when adequate control of the intracanal infection can be achieved. Calcium hydroxide and contemporary bioceramic materials have established biological applications in endodontic treatment, but nonsurgical management should not be considered a universal alternative to surgical treatment of histologically confirmed or persistent odontogenic cysts. Endoscopic-assisted and piezoelectric techniques provide additional methods for reducing surgical access and improving operative control in selected anatomically difficult cases. Their value is principally related to visualization, precision, and tissue preservation rather than to independent biological treatment of the cyst. Regenerative procedures, including bone-graft materials, guided bone regeneration, collagen membranes, and platelet-rich fibrin, have expanded the objectives of cyst management beyond elimination of pathology toward

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restoration of the residual osseous defect. These approaches are particularly relevant when preservation or reconstruction of alveolar bone is important for subsequent functional or implant-supported rehabilitation. CBCT and digital planning contribute primarily to diagnosis, anatomical assessment, and individualized preoperative planning. Virtual surgical planning and three-dimensional printing represent further developments in this field, while artificial intelligence-assisted workflows remain at an early stage of clinical validation. These technologies should therefore be regarded as adjuncts to clinical decision-making rather than independent treatment modalities. Overall, minimally invasive management of odontogenic cysts represents a shift from a purely lesion-removal model toward a broader treatment philosophy that seeks to control the pathological process while preserving teeth, bone, and surrounding anatomical structures and, when necessary, restoring lost tissue. The appropriate approach remains dependent on the individual lesion and patient. Future prospective studies using standardized diagnostic criteria, treatment protocols, radiographic assessment, and long-term clinical outcomes are required to establish more predictable evidence-based treatment pathways.

DECLARATIONS

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Ethical Approval

Ethical approval was not required because this study was a scoping review of previously published literature and did not involve the collection or analysis of new patient data.

Conflict of Interest

The authors declare no conflict of interest related to this manuscript.

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