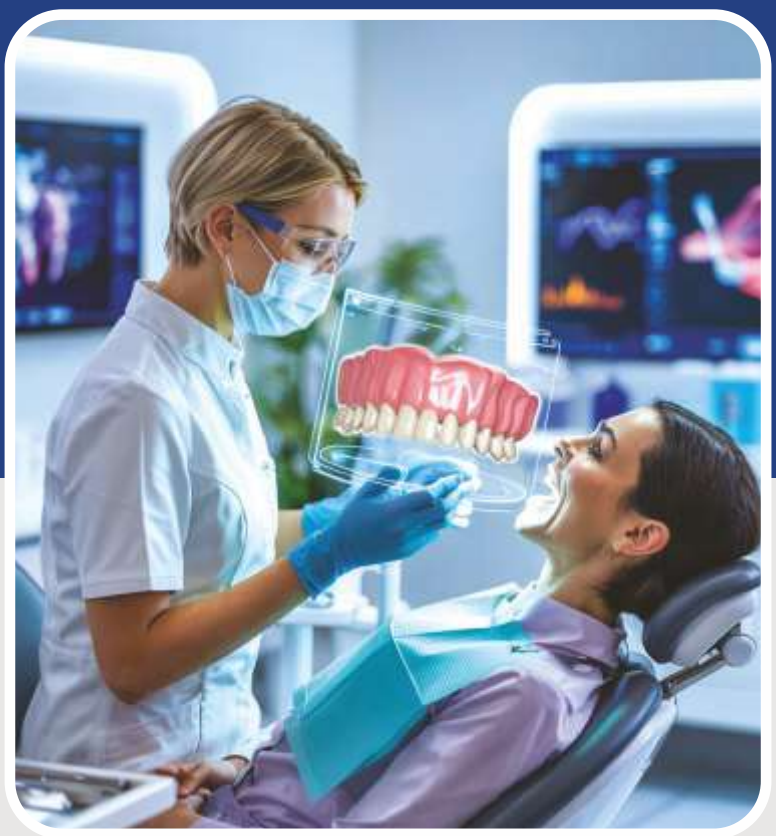
JIDAK

JOURNAL OF INDIAN DENTAL ASSOCIATION - KOCHI



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JIDAK

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PRESIDENT'S MESSAGE

It gives me immense pleasure and a deep sense of pride to present this final issue of JIDAK, Volume 8, Issue 3, marking the culmination of a memorable term for IDA Kochi Branch.

JIDAK for IDA Kochi is a reflection of the knowledge, commitment, creativity and collective spirit of our professional community. Throughout this term, JIDAK has upheld these values with remarkable consistency, emerging as a publication that we can truly be proud of.

My heartfelt congratulations and sincere appreciation go to the entire editorial team for their unwavering dedication, meticulous planning and exemplary execution. The consistent quality of the journal, coupled with the timely release of every issue, speaks volumes about their professionalism, discipline and commitment to excellence. Maintaining such high standards while adhering to timelines is no small achievement, and the team deserves special recognition for making it possible.

I also extend my gratitude to every contributor whose valuable insights, academic work and thoughtful perspectives have enriched these pages. My appreciation equally goes to the reviewers, whose time, expertise and constructive inputs have played an indispensable role in upholding the quality and credibility of the publication. Every individual who has contributed to this endeavour has helped strengthen the academic and professional fabric of IDA Kochi.

As we bring this term to a close, JIDAK stands as a testament to what can be achieved through teamwork, shared purpose and a commitment to quality. It has been a privilege to witness the journal's continued growth and to see it reflect the vibrant intellectual spirit of our branch.

I wish the entire JIDAK team continued inspiration, greater milestones and many more accolades in the years ahead. May the journal continue to flourish as a respected platform for knowledge sharing, academic excellence and professional advancement, bringing pride and recognition to IDA Kochi Branch.

With pride in what we have achieved together, and with optimism for all that lies ahead, I wish JIDAK a future filled with greater accomplishments and well-deserved recognition.

Warm regards,



Dr. Meera Gopalakrishnan
President, IDA Kochi

SECRETARY'S MESSAGE

Dear Esteemed Members, Colleagues, and Readers,

It gives me immense pride and satisfaction to present to you the third issue of the Journal of IDA Kochi Branch for the year 2026. As we flip through the pages of this edition, it stands as a testament to the thriving academic spirit, clinical rigor, and vibrant professional exchange that define our branch.

I would like to extend my heartfelt compliments and profound appreciation to our Editor, Dr. Pooja M. Latti, for her outstanding dedication and exemplary leadership over the past two years. Her unwavering commitment to excellence has elevated the standard of our publication, establishing it as a respected forum for intellectual discourse and clinical practice.

This journey of editorial success has been powered by a collaborative team effort. My sincere thanks go to this year's dedicated editorial team, admirably assisted by Dr. Surya Suprabhan, as well as our Honorary Treasurer, Dr. Subramaniam R., whose tireless behind-the-scenes effort ensured the timely release of our issues.

Looking at the contents of this issue, the growth in our publication quality is unmistakably clear. We have witnessed a notable surge in original research articles, robust evidence-based studies, and high-value clinical reports. This enriching mix of content not only reflects the inquisitive minds within our community but also serves as an invaluable practical reference for everyday dental practice.

As this issue goes to print, it carries a particularly poignant meaning for me. This marks the final issue of the journal released during my tenure as Honorary Secretary of IDA Kochi Branch. Serving this dynamic branch alongside such an exceptional team and engaged fraternity has been an absolute honor and a deeply rewarding privilege. I extend my sincere gratitude to each and every member for your steadfast trust, cooperation, and encouragement throughout my term.



While my official role as Secretary draws to a close, my commitment to the ideals and growth of IDA Kochi remains unchanged. I am confident that our journal and branch will continue to reach new heights of success and scholarly achievement in the years ahead.

I wish you all an insightful and inspiring reading experience.

Warm regards,

Dr. Vivek Narayan
Hon. Secretary, IDA Kochi Branch

CHIEF EDITOR'S MESSAGE

Dear Readers,

It gives me immense pleasure to present this issue of the IDA Kochi Scientific Journal, a platform dedicated to fostering scientific curiosity, and promoting evidence-based practice. Dentistry is evolving at an unprecedented pace, shaped by technological advancements, innovative biomaterials, and emerging treatment modalities. As dental professionals, staying abreast of these developments is an essential responsibility towards delivering ethical, safe, and patient-centred care.

The editorial explores the growing role of Artificial Intelligence in clinical dentistry, examining its potential to transform diagnosis, treatment planning, and patient care while highlighting the importance of responsible and judicious implementation.

The review articles offer valuable insights into several relevant areas, including the medicolegal implications for clinicians, the emerging role of calcium silicate cements, the applications and complications of lasers in oral surgical procedures, advances in regenerative dentistry, oral health considerations in swimmers, the mouth as a mirror of systemic health, and the applications of lasers in aesthetic dentistry.

The case reports further enrich this issue by presenting the conservative esthetic management of a non-vital central incisor and a case of pleomorphic adenoma of the submandibular salivary gland.

As I present this issue, I do so with a deep sense of gratitude and fulfilment, marking the completion of my two-year term as Editor of IDA Kochi Publications. It has been a privilege and an honour to serve the Indian Dental Association, Kochi Branch, through this role. Every issue has reinforced my belief that scientific publishing is far more than the dissemination of information; it is a means of nurturing inquiry, strengthening professional connections, and advancing the collective knowledge of our fraternity. I am deeply thankful to the office bearers of IDA Kochi, the editorial board, the authors, reviewers, and all those who have supported and encouraged me throughout this tenure.

I leave with cherished memories, valuable lessons, and sincere wishes for the journal to scale greater heights in the years ahead. May we continue to learn, question, innovate, and uphold the highest standards of our profession.

With gratitude and warm regards,



Dr. Pooja Latti, MDS, PGDMLE
Chief Editor, JIDAK

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EDITORIAL

ARTIFICIAL INTELLIGENCE IN CLINICAL DENTISTRY: A POWERFUL ASSISTANT, NEVER THE FINAL AUTHORITY

Author:

Dr. Subramaniam R
Treasurer, IDA Kochi

Professor and Head
Department of Public Health Dentistry
Indira Gandhi Institute of Dental Sciences
Nellikuzhi, Kothamangalam, Kerala

Artificial intelligence: A new partner in the dental operatory

Imagine examining a bitewing radiograph when a digital system highlights a suspicious interproximal radiolucency. Within seconds, another application generates a preliminary treatment plan, summarises relevant clinical information and prepares postoperative instructions for the patient. Such scenarios illustrate how artificial intelligence (AI) is becoming increasingly relevant to contemporary dental practice. From radiographic interpretation to treatment planning and patient communication, AI-based applications are beginning to influence the way dental professionals deliver care.[1,2]

For the practising dental surgeon, this technological transition presents both an opportunity and a challenge. AI may improve efficiency, support diagnostic consistency and reduce repetitive tasks. However, dentistry is not simply a process of identifying patterns or following algorithm-generated recommendations. Every patient presents with a unique combination of clinical findings, medical history, expectations, financial circumstances and personal preferences. These factors demand clinical reasoning, professional judgement and effective communication.

The critical question, therefore, is not whether AI can perform certain dental tasks, but how it can be integrated into clinical practice without compromising patient safety or professional responsibility. The appropriate approach is to view AI as a tool that augments the capabilities of the dentist rather than a substitute for clinical expertise.[1,3]

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Where can AI assist the practising dentist?

1. Diagnosis: an additional set of eyes

Dental radiology is one of the most extensively explored applications of AI. Machine learning and deep learning systems have been developed to assist in detecting dental caries, periapical lesions, periodontal bone loss and other abnormalities on dental images. They can also support tooth identification, anatomical segmentation and selected orthodontic measurements.[1,4]

Consider a patient attending a private dental clinic for a routine examination. An AI-assisted radiographic system identifies a possible proximal carious lesion that is not immediately apparent on initial inspection. This prompts the dentist to examine the region more closely, correlate the radiographic finding with clinical examination and assess whether further investigation or intervention is warranted. In this situation, AI serves as a diagnostic aid, encouraging a more systematic assessment.

However, a computer-generated highlight is not a confirmed diagnosis. Radiographic findings must be interpreted in the context of clinical symptoms, lesion activity, previous images, disease risk and other relevant findings. A suspicious radiolucency does not automatically justify operative treatment, just as the absence of an AI-generated alert does not exclude disease.

Systematic reviews of AI applications in dentomaxillofacial imaging have identified promising developments, but also considerable variation in the applications studied, validation methods and reported performance.[4] Research into AI-based caries detection further illustrates that an algorithm's usefulness depends on the quality of its training data and the clinical relevance of its predictions.[5]

Dentists must therefore distinguish between diagnostic assistance and diagnostic certainty. An algorithm that performs well in a controlled research environment may not deliver the same results in a busy clinical setting involving different imaging equipment, patient populations and disease presentations.

2. Treatment planning: individualising care beyond the algorithm

AI has potential applications in orthodontic treatment planning, implant dentistry, endodontics and restorative procedures. It can assist with cephalometric landmark identification, anatomical visualisation, image analysis and the organisation of clinical information. These capabilities may reduce repetitive work and support consistency in selected clinical tasks.[1,2]

Nevertheless, treatment planning involves much more than identifying a technically feasible procedure. The dentist must consider the patient's systemic health, oral hygiene, periodontal condition, remaining tooth structure, prognosis, financial resources, treatment preferences and capacity to attend follow-up appointments.

For example, a digital system may suggest multiple restorative options for a compromised tooth. Selecting the most appropriate option requires consideration of restorability, pulpal and periodontal status, long-term prognosis, cost and the patient's expectations. Similarly, an AI-generated orthodontic simulation may illustrate a predicted outcome, but it cannot guarantee that the anticipated tooth movement or final occlusion will be achieved.

The same principle applies to implant planning. Digital analysis may help identify anatomical structures and support the assessment of available bone, but the final decision must incorporate clinical examination, prosthetic requirements, patient-related risk factors and the clinician's assessment of surgical feasibility.

AI-generated recommendations should consequently be treated as inputs into clinical reasoning, not as instructions that determine treatment. The dentist must retain the ability to question, modify or reject an algorithm's suggestion when it does not align with the patient's needs or the available evidence.

3. Patient communication: efficiency without losing the human connection

Effective communication is essential to informed consent, adherence to treatment and patient satisfaction. Generative AI and large language models can assist in preparing patient education materials, simplifying technical explanations, translating general oral health information and drafting postoperative instructions.[6]

For a busy practitioner, such tools may help prepare an initial explanation of root canal treatment, periodontal therapy or postoperative care following extraction. The dentist can then review and adapt the material to reflect the actual procedure, the patient's medical history and any specific precautions.

The risk arises when generated information is accepted without verification. AI-generated content may contain incorrect clinical advice, omit important warning signs or recommend actions unsuitable for a patient's medical circumstances. A response that sounds convincing is not necessarily scientifically accurate.

Patient communication must also remain personal. An anxious patient may require reassurance, clarification and an opportunity to express concerns that cannot be adequately addressed by standardised text. AI can help prepare the explanation, but empathy, shared decision-making and informed consent remain responsibilities of the treating clinician.

4. Clinical documentation and workflow management

AI may also support selected administrative tasks, including drafting clinical notes, organising patient information, preparing referral letters and generating preliminary treatment summaries. When appropriately implemented, these applications could reduce documentation time and allow dentists to devote more attention to clinical care.

However, automated documentation can introduce errors by omitting relevant findings, misinterpreting speech or including information that was not established during the consultation. A clinical record must accurately reflect the examination, diagnosis, treatment performed, advice given and decisions made.

Dentists should therefore review AI-generated notes before incorporating them into the patient's record. The convenience of automated documentation must not compromise accuracy, confidentiality or continuity of care.

The limitations that demand clinical vigilance

1. Accuracy does not guarantee reliability

AI systems learn patterns from the data on which they are trained. Their performance may change when they encounter images, patient characteristics or clinical conditions that differ from those represented in the development dataset. Differences in imaging equipment, image quality, disease prevalence and patient demographics can affect their reliability.

Another concern is automation bias the tendency to place excessive confidence in computer-generated recommendations. A dentist may accept a highlighted lesion without adequate verification or overlook a clinically significant finding because the software has not flagged it. Conversely, repeated false alerts may lead to alert fatigue and reduced attention.

Trustworthy clinical AI requires appropriate validation, transparent reporting, assessment in relevant patient populations and continued monitoring after implementation. The importance of explainability and reliable evaluation has been emphasised in research on trustworthy AI in dentistry.[7]

For the practising dentist, the message is straightforward: every AI finding must be interpreted within the clinical context. A high accuracy figure reported in a publication is not a guarantee of equivalent performance in every patient or practice.

2. Patient privacy and professional accountability

Dental records contain sensitive information, including medical histories, radiographs, clinical photographs and treatment details.

Uploading identifiable patient information to an external AI platform without appropriate safeguards can expose confidential data.

Before adopting an AI application, practitioners should understand how patient information is collected, processed, stored and potentially reused. Identifiable clinical data should not be entered into unapproved public platforms. Appropriate consent, authorised systems, access controls and data-protection procedures are essential, subject to applicable legal and professional requirements.

Accountability is equally important. If an AI system contributes to an incorrect diagnosis or unsuitable treatment recommendation, the presence of the technology does not remove the dentist's professional obligations. Clinicians must exercise reasonable judgement, verify clinically significant outputs and act in the patient's best interests.[7]

Where AI materially influences a clinical decision, practitioners should consider documenting its contribution and the reasoning behind the final decision when appropriate. Patients should also receive suitable information about the use of AI when it is relevant to their care.

3. Avoiding unnecessary treatment and technological dependence

AI can support the detection of abnormalities, but increased detection does not automatically translate into better health outcomes. An algorithm may identify findings of uncertain clinical significance, potentially leading to unnecessary investigations, patient anxiety or over treatment if its output is interpreted uncritically.

The dentist must distinguish between detecting an abnormality and determining whether that abnormality requires intervention. Treatment decisions should be based on clinical relevance, established evidence, patient preferences and a careful assessment of benefits and harms.

Financial considerations also deserve attention. AI-enabled equipment and software may involve substantial costs, subscriptions and training requirements. Adoption should be guided by demonstrable clinical value rather than the assumption that newer technology is necessarily superior to established methods.

The objective should be better care, not technology for its own sake.

A practical framework for AI-assisted dental practice

Responsible integration of AI into everyday dentistry requires a structured approach

First, identify a genuine clinical need. Determine whether the proposed application addresses a specific problem, such as improving radiographic review, reducing documentation burden or supporting patient communication.

Second, examine the evidence. Review the intended use, validation studies, limitations and suitability for the patients and clinical setting in which the tool will be used.

Third, protect patient information. Use appropriate, approved platforms and safeguards, and comply with relevant confidentiality and data-protection requirements.

Fourth, verify clinically important outputs. AI-generated diagnoses, treatment recommendations, medication-related information and post-operative instructions should be reviewed against reliable evidence and the individual patient's circumstances.

Fifth, preserve independent clinical judgement. The dentist must remain willing to disagree with the algorithm and explain the rationale for the final decision.

Finally, evaluate the actual benefit. Consider whether the technology improves clinical quality, workflow, patient experience or safety. Its value should be assessed against its costs, limitations and potential risks. 1,7

These principles are applicable to both small private practices and larger institutional settings. Responsible adoption does not require every dentist to become an AI specialist, but it does require a working understanding of the

technology's intended use, strengths and limitations.

The way forward: the dentist remains central

The future of clinical dentistry will likely involve increasing collaboration between human expertise and computational tools. AI may improve the speed with which information is processed, help identify patterns and support selected clinical tasks. The dentist contributes contextual understanding, ethical reasoning, empathy, communication and responsibility for treatment decisions.

Professional organisations such as the Indian Dental Association can help practitioners navigate this transition through continuing dental education, discussions on clinical validation and patient confidentiality, and guidance on the responsible use of emerging technologies. Such initiatives can enable dentists to evaluate new applications critically rather than relying exclusively on commercial claims or demonstrations.

Ultimately, AI should be assessed by the improvements it delivers to patients. A system that supports accurate diagnosis, reduces avoidable administrative work or improves communication may provide genuine value. A system that encourages overconfidence, compromises privacy or promotes unnecessary intervention requires caution, regardless of its technological sophistication.

Conclusion

Artificial intelligence is creating new opportunities in clinical dentistry, particularly in diagnostic imaging, treatment planning, patient communication and workflow management. However, its usefulness depends on the quality of its evidence, the context in which it is applied and the judgement of the professional using it.

The modern dental surgeon must develop the ability to evaluate AI critically, recognise its limitations and incorporate its outputs appropriately into clinical decision-making. Neither unquestioning acceptance nor outright rejection serves the interests of patients. What is needed is informed adoption, supported by scientific evidence, professional ethics and continuing vigilance.

AI may help us identify more, process information faster and work more efficiently. It cannot independently assume the full responsibility of understanding a patient's circumstances, balancing competing treatment considerations and making ethically sound decisions. These remain central to the practice of dentistry.

The appropriate goal is not to replace the dental surgeon with an algorithm, but to combine computational capability with clinical expertise to improve patient care. This approach is consistent with the concept of augmented intelligence, in which technology strengthens rather than displaces human decision-making.

The future belongs not to dentists who blindly follow algorithms, nor to those who reject technological progress, but to clinicians who know when to use AI, when to question it and when their professional judgement must prevail. Artificial intelligence should be a powerful assistant in the dental operatory never the final authority.

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REVIEW ARTICLE

WHEN CARE IS CHALLENGED: UNDERSTANDING LITIGATION IN DENTISTRY

ABSTRACT

The practice of dentistry in India is increasingly influenced by heightened patient awareness, consumer rights, and the growing incidence of medicolegal disputes. Dental professionals must therefore understand the legal framework governing their practice to ensure patient safety and protect their professional integrity. This review article examines the principal legal concepts, types of dental negligence, liabilities, compensation mechanisms, landmark judicial decisions, and preventive strategies relevant to dental practice in India.

Negligence in dentistry may arise from errors in diagnosis, inappropriate investigations, inadequate sterilization, procedural shortcomings, improper drug management, and failure to obtain valid informed consent. Dental practitioners may face tortious, contractual, criminal, and statutory liabilities, depending on the nature and severity of the alleged negligence. Judicial decisions, including Jacob Mathew v. State of Punjab and Samira Kohli v. Dr. Prabha Manchanda, have contributed significantly to clarifying standards of care and emphasizing the importance of informed consent. Consumer forums provide mechanisms for seeking compensation for economic and non-economic losses resulting from established negligence.

Effective risk mitigation requires comprehensive clinical documentation, appropriate consent procedures, adherence to evidence-based clinical protocols, judicious referral, professional indemnity insurance, and regular continuing professional education. Equally important are transparent communication, empathetic patient interactions, and shared decision-making. A preventive approach grounded in ethical conduct, clinical competence, and accountability can reduce the likelihood of litigation while strengthening patient trust. Ultimately, understanding medicolegal responsibilities is essential for contemporary dental practitioners to deliver safe, ethical, and legally responsible care while safeguarding patient welfare and professional credibility.

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Author:

Pooja Latti
MDS (Public Health Dentistry)
PGDMLE (Post Graduate Diploma in Medical Law and Ethics)

Professor & Head
Department of Public Health Dentistry
Annoor Dental College & Hospital,
Muvattupuzha, Kerala
Kerala University of Health Sciences

Editor
Journal of Indian Dental Association, Kochi

Medicine is of all the arts the most noble; but, owing to the ignorance of those who practise it, and of those who, inconsiderately, form a judgment of them, it is at present far behind all the other arts.

Hippocrates

INTRODUCTION

The practice of dentistry in India has undergone a profound transformation in recent decades. Once regarded primarily as a noble profession grounded in trust and clinical judgment, it now operates in an environment marked by heightened patient awareness, assertive consumer rights, and increasing litigation. Dentists face growing exposure to civil claims, disciplinary proceedings, and, in rare instances, criminal liability. India's evolving legal landscape has brought dental practice under increasing scrutiny, making medicolegal literacy essential for general dental practitioners.[1]

This review article examines the medicolegal landscape governing dental practice in India, the principal sources of litigation, the judicial standards courts apply, and practical measures to mitigate risk.

LEGAL FRAMEWORK AND THE KEY CONCEPTS

Negligence:

According to the 'Law of Torts', "Negligence is the breach of duty caused by omission to do something which a reasonable man guided by those considerations which ordinarily regulate the conduct of human affairs would do or do something which a prudent and reasonable man would not do".[2]

For an act to be considered negligent, the following aspects must be present:

1. Doctor owned a certain standard of care.
2. Doctor did not maintain that standard.
3. An injury resulting from the lack of care.
4. A connection (proximity) between the negligent act and the resultant injury.[3]

When is it not Negligence?

A review of consumer cases, show that some of the situations mentioned below, do not come under medical negligence, e.g.

- Inability to obtain consent form in an emergency.
- Patient's dissatisfaction with progress of treatment.
- Inability to get desired relief.
- Precedence of one patient over the other based on priority.
- Charging an amount that the patient thinks is exorbitant[3].

Test for negligence: The Bolam Test

India adopted the practice of employing the Bolam test for adjudication of medical negligence cases from the United Kingdom. It is a settled proposition that it is the court and not the medical experts that would be determining whether a particular doctor's conduct is negligent. But, judges and lawyers lack technical expertise to determine what standards to be applied in any given medical negligence case. Therefore, they must rely on the knowledge of medical experts. The Bolam v. Friern HMC (1957) case posited that a doctor must not be held liable if the treatment or course of action carried out by them is considered proper in the opinion of trained medical professionals.[2]

Standard of Care:

The standard of care is the benchmark against which a dentist's conduct is measured. It is determined based on the skill and diligence expected from an average, prudent practitioner. The Supreme Court of India in Jacob Mathew v. State of Punjab clarified that mere error of judgment is not negligence unless it results from gross incompetence or reckless disregard for patient safety.[1]

TYPES OF DENTAL NEGLIGENCE

Negligence in Diagnosis:

- Failure in recording proper case history, and overlooking any other finding or event related to the patient may lead to negligence in making a diagnosis that is responsible for the course of treatment or nontreatment which ultimately results in damages to the patient especially if a correct diagnosis would have resulted in a different course of treatment with a more favorable result to the patient.[2]

Negligence in Investigation:

- Investigation without proper justification may lead to negligence. For example, a radiographic examination involving a higher radiation dose should be considered only when it is needed and necessary.

- In contrast, when an investigation procedure is genuinely required, then it should not be avoided. For example, blood investigation before any surgical intervention.
- In addition, it might occasionally occur that a patient refuses to undergo an investigation, for example, an X-ray examination. In such cases, the best advice is to terminate the dentist–patient relationship or if the dentist elects to continue the treatment without X-ray films, he/she should take certain precautions for protection against any future claims made by the patient for malpractice. A dentist should prepare a statement fully disclosing to the patient the risks associated with the treatment if X-ray films are not taken and have the patient sign it.[2]

Negligence in Sterilization:

- Failure to maintain the desired level of sterilization might lead to the spread of infections and cross-contamination from one person to another/others, which is considered one of the serious cases of dental negligence.[4]

Procedural Negligence:

- The first and foremost step before any dental treatment is to take the patient's informed consent. A lack of informed consent is a cause of malpractice action, and without it, battery (unlawful touching) can be alleged.[4]

• Basic Elements of a consent[5]:

o The patient's name
o The name of the hospital or healthcare practice
o The patient's diagnosis
o The name and a description of the proposed procedure and an explanation of its purpose (information should be provided in both medical and layman's terms)
o The names of all practitioners who will be involved in the procedure and the significant tasks of each
o A statement that the procedure was explained to the patient (or patient's guardian)
o The name and signature of the person who explained the procedure to the patient (or patient's guardian)
o The important risks and benefits of the procedure (e.g., common risks, risks/benefits that the patient might consider important, and risks/benefits that might affect the patient's decision to accept or reject the recommendation)
o Alternatives to the proposed procedure, including doing nothing
o The estimated recovery time based on the procedure and the patient's status as well as the importance of adhering to any recommended follow-up therapies and appointments
o The patient's signature memorializing understanding and providing consent
o The date and time consent is obtained
o A witness signature

Negligence in Drug management:

- Failure to prescribe an appropriate drug due to incomplete medical history and knowledge of pharmacokinetics and pharma codynamics may lead to negligence.
- In some cases, where patients suffer from systemic disease and take medications for the same, then drug interactions need to be considered before giving any prescription.
- Before dental extraction, a few medication doses need to be altered to achieve the desired healthy state of the patient. For example, patients on an antiplatelet drug like aspirin or steroids would require the medication/course of treatment to be stopped or altered 2-7 days prior to consultation with their physician. Failure to do so may lead to serious health complications and would be considered negligence.
- When the patient gives a history of drug allergy, it must be accepted as a fact until proven otherwise. To doubt such a history may invite serious trouble. If the patient is absolutely certain of the offending drug, a drug of a different chemical derivation should be used. However, if the patient gives a definite allergic history to a drug and does not know the exact drug, it is better to have the patient tested before proceeding at random with any drug.[2]

LIABILITY OF DOCTORS

How are Doctors Liable for Negligence?

Doctors are liable under four heads.

1. Tortuous liability
2. Contractual liability
3. Criminal liability
4. Statutory liability

Tortuous Liability (Civil Liability)

The term 'tort' is French in origin which is synonym to 'wrong' in English version. The concept of tort appears when a breach of some duty is caused which is independent of implied contract giving rise to a civil cause of action and for which compensation can be claimed and a damage is recoverable.[6]

Tortuous liability may be of two types:[2]

1. **Primary tortious liability**- When a dentist is directly liable for an act of negligence in his/her clinic or hospital, it is classified as a primary tortious liability. Most dental negligence cases would fall under this category. The remedy for breach of this type of tortious liability is unliquidated damages as awarded by the judge; it is usually in the form of compensation by cash.
2. **Vicarious tortious liability** - A dentist who is employed by a hospital or institution is often not primarily responsible for negligence. They may be said to have vicarious tortious liability through the hospital. The hospital has the primary tortious liability for the negligence of an employee. However, if the patient is admitted by a dentist in his personal capacity, then the dentist will be personally liable.

Contractual liability:

In a doctor–patient relationship, an implied contract is established when a dentist accepts a patient for treatment. A breach of any aspect of this implied contract, where the dentist is under a duty to treat the patient with care as well as a continuing duty to keep treating the patient and not terminate until the patient is cured or the patient discontinues treatment, may be considered a contractual liability. However, in most instances, if there is no written contract, their liability will essentially lie within the realm of tortious liability.[2]

Criminal Liability:[2]

Criminal negligence is considered to be a crime that has been committed against the society and not just the aggrieved party. Criminal liability is a penal offence, and it is provided under the Indian Penal Code of 1860/ Bharatiya Nyaya Sanhita (BNS), 2023. It entails punishment in the form of imprisonment or fine, or both. For negligence to amount to an offence, the element of mens rea must be shown to exist. For an act to amount to criminal negligence, the degree of negligence should be much higher, i.e., gross or of a very high degree.

In order to prosecute a medical professional for negligence under criminal law, it must be shown that the accused did something or failed to do something, which in the given facts and circumstances, no medical professional in his ordinary senses and prudence would have done or failed to do.

The important offenses, provided under IPC/BNS, inviting criminal liability with respect to negligence are as follows:

- Section 304A of Indian Penal Code/Section 106 of the BNS: Negligent homicide - A rash or negligent act resulting in death. For example, death on the dental chair.
- Section 336 of Indian Penal Code/Section 125 of the BNS - An act endangering the life of a person (even if there is no injury). For example, invasive dental procedure on a patient with valvular heart disease without antibiotic prophylaxis against endocarditis (even if he does not develop endocarditis).
- Section 337 of Indian Penal Code/Section 125(a) of the BNS - A rash or negligent act causing simple injury. For example, pain and swelling after root canal due to negligent treatment.
- Section 338 of Indian Penal Code/Section 125(b) of the BNS - A rash or negligent act resulting in grievous injury. For example, fracture of jaw during extraction due to excessive or improper force.

It is important for the dentist to be aware of these liabilities. It is also important for him/her to understand his/her rights. For example, bail

is a matter of right in the above situations and it is to be given by the police officer effectuating the arrest based on the surety given by a colleague. He/she can be given surety on his/her own reputation. The burden of reason for refusing bail rests on the police officer and they will have to provide convincing reasons for not granting bail.[2]

Statutory liability:

A dentist is liable if there is any infringement of the statutes. Thereafter, they become accountable to a statutory body. The liability depends on the kind of refinement and the provisions in the statute to deal with. Dentists may also be liable to other statutory bodies such as the Pollution Control Board.

TYPES OF COMPENSATION IN MEDICAL NEGLIGENCE[7]:

1. Pecuniary (Economic) Damages:

These cover actual financial losses that can be quantified:

- **Medical expenses** - all costs incurred for treatment of the injury caused by the negligence, including future treatment costs
- **Loss of earnings** - income lost due to the injury, calculated from the date of harm to the expected retirement age
- **Cost of care** - if the patient requires ongoing nursing, physiotherapy, or assisted living
- **Transportation and incidental** costs related to the injury

2. Non-Pecuniary (Non-Economic) Damages:

These are harder to quantify but are regularly awarded:

- **Pain and suffering** - physical and mental anguish caused by the negligent act
- **Loss of amenity** - reduction in quality of life or inability to pursue hobbies and activities
- **Mental agony** - particularly relevant in cases of disfigurement, disability, or loss of a family member
- **Loss of consortium** - impact on the spouse or dependants

3. Punitive Damages: Awarded in rare cases of gross negligence, willful misconduct, or extreme dereliction of duty to punish the provider and deter future lapses.

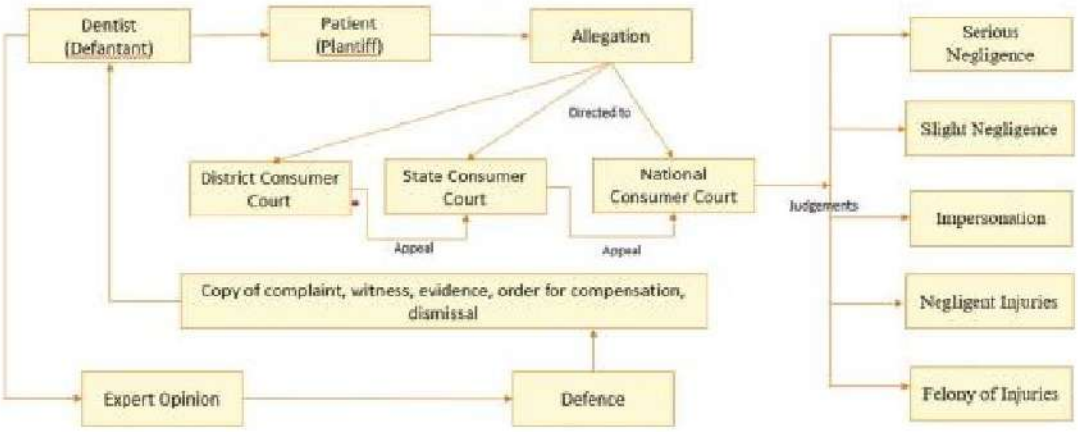
How Consumer Forums Calculate Compensation[7]

Consumer forums under the Consumer Protection Act, 2019 are the most commonly used route for medical negligence claims in India. They follow a broad principle of **"just and reasonable" compensation** not a mathematical formula.

Key factors that influence the award include:

- The age and income of the victim at the time of injury
- The degree of permanent disability, if any
- The number of dependants
- The severity and nature of the negligent act
- The conduct of the hospital or doctor (for example, whether they destroyed records or showed callous disregard)

REDRESSAL MECHANISMS FOR HANDLING THE LAWSUITS IN INDIA[8]:



LANDMARK JUDGMENTS SHAPING DENTAL JURISPRUDENCE:

Case	Court	Key Principle
Indian Medical Association v. V.P. Shantha (1995)	Supreme Court	Brought healthcare services under the Consumer Protection Act
Jacob Mathew v. State of Punjab (2005)	Supreme Court	Distinguished civil and criminal negligence; gross negligence required for criminal liability
Martin F. D'Souza v. Mohd. Ishfaq (2009)	Supreme Court	Recommended expert opinion before proceeding with negligence claims
Samira Kohli v. Dr. Prabha Manchanda (2008)	Supreme Court	Specific informed consent is mandatory
Kusum Sharma v. Batra Hospital (2010)	Supreme Court	Error of judgment not negligence if done in good faith
V. Kishan Rao v. Nikhil Super Speciality Hospital (2010)	Supreme Court	Expert evidence not mandatory in clear cases

Table 1: Summary of the Landmark Judicial decisions and their clinical implications[1]

RISK MITIGATION AND BEST PRACTICES:

- Comprehensive Documentation: Maintain detailed records of patient history, diagnosis, treatment plans, informed consent, and follow-ups. Courts rely heavily on written documentation.
- Informed Consent Protocols: Use procedure-specific consent forms explained in the patient's native language. Have them signed and witnessed8.
- Adherence to Protocols: Follow guidelines by DCI/NDC and IDA. Attend continuing education programs to stay updated with current practices.
- Judicious Referral: Refer complex cases to specialists when beyond your scope of training. It demonstrates prudence rather than inadequacy.
- Professional Indemnity Insurance: Essential financial protection. Choose coverage that includes legal consultation and appropriate claim limits.
- Clinic Preparedness and Staff Training: Equip the clinic with emergency drugs, sterilization logs, and trained staff for managing complications.
- Patient Rapport and Communication: Establish trust, explain risks, and encourage shared decision-making. Empathy can prevent many lawsuits.[1]

CONCLUSION

The rising incidence of medicolegal disputes in dentistry highlights the need to shift from a defensive approach to a preventive culture grounded in ethical, transparent, and patient-centred practice. Following key principles can prevent most litigation: obtaining valid informed consent, keeping complete and accurate clinical records, explaining treatment options and potential complications, adhering to evidence-based protocols, and communicating clearly with patients. Dentists should also recognise the importance of professional indemnity insurance, attending continuing professional education programs, and understanding relevant legal and regulatory requirements.

Ultimately, the strongest defence against litigation is not simply legal preparedness, but responsible clinical practice rooted in competence, compassion, communication, and accountability. By placing patient welfare at the centre of every clinical decision, dental professionals can protect their patients' rights and their own professional integrity while strengthening public trust in the dental profession.

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REVIEW ARTICLE

REDEFINING ENDODONTIC THERAPY: THE EMERGING ROLE OF CALCIUM SILICATE CEMENTS

Authors:

Ardhra B S[1]
Anjali E U[2]
Anjali K S[3]
Anusha Anand[4]
A.M Neeba Nafeesa[5]
Chinuu Mary Jose[6]

House Surgeon[1,2,3,4,5]
Department of Conservative Dentistry and Endodontics
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala 686 691

Senior Lecturer[6]
Department of Conservative Dentistry and Endodontics
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala 686 691

Corresponding Author
Ardhra B S
House surgeon
Department of Conservative Dentistry and Endodontics
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala 686 691

E mail: drardhrabs28gmail.com

ABSTRACT

Calcium silicate-based cements (CSCs) have emerged as important biomaterials in modern endodontics owing to their favourable biocompatibility, bioactivity, sealing ability, and potential to promote hard-tissue regeneration. Endodontic therapy has advanced significantly with the development of these materials from early calcium-based formulations to mineral trioxide aggregate (MTA), Biodentine, BioAggregate, and modern bio ceramic sealers. The development of calcium silicate cements is studied in this narrative review, with an emphasis on their material properties, hydration processes, biological properties, clinical applications, limitations, and new advances. Mineral trioxide aggregate, particularly ProRoot MTA, established the foundation for hydraulic calcium silicate-based materials and demonstrated favourable biological and sealing properties in challenging clinical environments. Subsequent formulations such as Biodentine were developed to improve handling, setting characteristics, and aesthetic performance while maintaining bioactivity. CSCs have demonstrated applications in pulp capping, pulpotomy, apexification, root-end filling, perforation repair, resorption management, and regenerative endodontic procedures. Their ability to release calcium and hydroxyl ions and interact with tissue fluids contributes to mineral deposition and biological repair. Overall, calcium silicate-based cements represent a rapidly evolving class of bioactive materials with considerable potential to further transform endodontic therapy from conventional repair towards biologically driven and regenerative treatment approaches.

Keywords: Calcium Silicates; Biocompatible Materials; Root Canal sealers.

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INTRODUCTION

Apical periodontitis is a common condition worldwide, and endodontic therapy is the best method to promote wound healing, depending on the choice of therapeutic approaches and associated materials, according to various surveys[1].

Recent advances have sparked a lot of interest in regenerative dentistry, especially endodontics, which aims to improve or repair the maxillofacial system's function during illness. Calcium silicate-based cements, also known as mineral trioxide aggregate (MTA) or MTA-like materials, are among the inorganic biomaterials that have recently drawn a lot of attention in regenerative medicine[2]. These biocompatible materials support cell attachment and proliferation and induce mineralization, making them ideal for pulp capping, root-end filling, apexification procedures, and other regenerative endodontic procedures[3].

Endodontics has seen the introduction of a variety of bio ceramic formulations, including premixed and powder-liquid forms. CSCs are designed to aid in tissue regeneration by the deposition of mineralized tissue. These compounds have immunomodulatory qualities in addition to precipitating into calcium and phosphate, which encourages the remineralization of hard tissues. Bio ceramic sealers' anti-inflammatory and modulatory properties, which are essential for maintaining bone homeostasis and promoting the regeneration of damaged tissues, have thus been strongly linked to their therapeutic efficacy[4]. CSCs nevertheless face some drawbacks despite their benefits, such as tooth discoloration, lengthy setting times, and poor clinical stability. Due to discoloration, these problems are most noticeable in MTA-based cements, which use bismuth oxide as a radiopacifier. Although formulations like Endo Sequence Root Repair Material and Bio dentine provide better cosmetic qualities with less staining potential, these materials are still being criticized for their handling and setting times in specific clinical situations[5].

This narrative review aims to critically explore the evolution of calcium silicate cements in endodontics, with particular emphasis on their material characteristics, mechanisms of bioactivity, clinical applications, current evidence, limitations and emerging directions toward regenerative and personalized endodontic therapy.



Figure 1: Evolution of calcium silicate cements from sealing to healing, illustrating the chronological progression from early 1st-generation formulations to 6th-generation next-generation bioceramics.[5]

EARLY CALCIUM SILICATE FORMULATIONS

Early calcium-based cements represent a major shift toward biomimetic and osteogenic materials in restorative dentistry and endodontics. Beginning with the introduction of calcium hydroxide $Ca(OH)_2$ paste in 1920, calcium cements evolved from simple antibacterial pulp-capping agents into hydraulic tricalcium silicates (Mineral Trioxide Aggregate) and bioactive calcium phosphate cements (CPCs). Mineral Trioxide Aggregate (MTA) products are based on calcium silicate-based cement. Many brands are available and are widely used in repair procedures in endodontics and are regarded as the gold standard repair material with promising clinical outcomes[6].

Subsequently commercialized as ProRoot MTA, it became one of the most extensively investigated hydraulic calcium silicate cements and established the foundation for the development of several generations of bioceramic materials. In contrast to conventional endodontic repair materials, MTA demonstrated the ability to set in the presence of moisture while exhibiting favourable biological and sealing properties, making it particularly suitable for the challenging moist environment of the root canal system and periradicular tissues[7].

Composition of ProRoot MTA

ProRoot MTA is primarily composed of calcium silicate phases, predominantly tricalcium silicate and dicalcium silicate, together with other cement clinker phases and a radiopacifying agent. The original formulation incorporated bismuth oxide to provide adequate radiopacity and permit radiographic identification of the material. The powder is mixed with water before clinical application, initiating a hydration reaction. The composition and hydration characteristics of MTA are closely related to those of Portland cement, although dental formulations are specifically manufactured and modified for endodontic applications. The calcium silicate components play a major role in determining the setting behaviour, mechanical characteristics and biological activity of the cement[7].

Hydration Reaction and Bioactivity

The setting of ProRoot MTA occurs through a hydration reaction between the calcium silicate phases and water. This reaction results primarily in the formation of calcium silicate hydrate gel and calcium hydroxide. The calcium silicate hydrate phase contributes to the development of the cement matrix, whereas the formation and subsequent dissociation of calcium hydroxide result in the release of calcium and hydroxyl ions. Consequently, MTA produces an alkaline environment that contributes to its antimicrobial activity and biological response. Calcium-ion release also facilitates interaction with tissue fluids and promotes the formation of calcium phosphate-rich deposits at the cement–tissue interface. This ability to interact with the surrounding biological environment and promote mineral deposition is an important characteristic of calcium silicate-based materials and forms the basis of their classification as bioactive hydraulic cements[8].

Biological Properties

ProRoot MTA's favourable biological characteristics played a major role in its extensive use in endodontics. In comparison to MTA Angelus, Petrovic et al.'s experimental studies revealed a higher grade of biocompatibility with relatively favourable responses from pulpal and periarticular tissues. At the material–tissue interface, MTA has also been linked to the development of mineralized tissue, including cementum-like tissue. These biological reactions are thought to be significantly influenced by its high pH, calcium-ion release, and surface bioactivity. Compared to a number of conventional repair agents, MTA's capacity to promote hard-tissue development and aid in biological sealing marked a significant advancement. Its use in procedures other than root-end surgery was subsequently encouraged by these qualities[8].

Clinical Applications

Although MTA was initially developed primarily for root-end filling and root perforation repair, its clinical indications gradually expanded with increasing evidence regarding

its biological properties. ProRoot MTA has been used for apexification, apexogenesis, direct pulp capping, pulpotomy, repair of internal and external root resorption, and regenerative endodontic procedures. Its ability to set in the presence of moisture, combined with its sealing capacity and biological activity, made it particularly useful in situations involving open apices, perforations and communication with periradicular tissues. The successful clinical application of MTA in these procedures contributed to the broader acceptance of calcium silicate-based materials in both surgical and nonsurgical endodontics[9].

Physicochemical Properties

ProRoot MTA possesses several favourable physicochemical characteristics, including relatively good sealing ability, dimensional stability, moisture tolerance and alkaline pH. The hydration process and subsequent formation of calcium silicate hydrate contribute to the development of a solid matrix. In addition, the release of calcium ions and interaction with tissue fluids can result in the formation of mineral deposits on the material surface. However, the physicochemical properties of MTA are influenced by factors such as powder-to-liquid ratio, mixing procedure, environmental moisture and formulation. These factors can affect its setting characteristics, mechanical strength and handling during clinical application[10].

Colour stability

Colour is the most significant feature of observation during dental procedures. The aesthetic appeal of a tooth is harmed by discolouration. One of the main causes of tooth discoloration is the intricate reaction between filling materials and the coronal dentine of the pulp chamber, which alters the appearance of the crown. Initially, when developed, MTA had a grey colour owing to the presence of tetra Ca aluminoferrite, making it unsuitable for its application on anterior teeth. Therefore, this led to the establishment of white MTA which is devoid of iron to prevent the discoloration of the tooth[7,10].

The composition of white MTA includes C2S and C3S silicate with 20% of bismuth oxide. The amount of bismuth oxide added to MTA to boost its radio-opacity was reported to be just 8.4% in the set material as compared with 21.6% in the unset material. The colour of the cement and adjacent tooth structure changes as bismuth oxide is reduced and comes into contact with the tooth structure. The loss of stability of the bismuth oxide molecules, which happens when they come into close contact with a strong oxidizing agent, has been found to be the cause of the colour shift. Therefore, it is proposed that changing the radiopacifier agent could help prevent tooth discolouration[8,10].

Consistency

Davis et al (2012) in his studies showed that there is a difference in opinion regarding the consistency of MTA. The ratio of powder to water is essential as increasing the quantity of water reduces radiopacity. The particle size is vital here as the newer advances in silicate types of cement have been developed using nanoparticles of Ca silicate (CS)[7].

Newer preparations

The advances which lead to enhanced flow ability comprise MTA HP, MTA Flow, Biodentine (Septodont, France), and ones having ceramic complexes incorporated with Biodentine, Endo Sequence (Brasseler, Savannah, GA, USA), and BioAggregate (Verio Dental Co. Ltd., Vancouver, Canada)[7].

BIODENTINE

Biodentine™ (Septodont, Saint-Maur-des-Fosses, France), a calcium silicate-based material, was introduced to the dental market in 2009 as a "dentine substitute" and has gained significant attention from researchers and clinicians due to its major advantages such as easier handling, shorter setting time, and reduced discoloration compared to MTA. Biodentine has a wide range of applications including endodontic repair (root perforations, apexification, resorptive lesions, and retrograde filling material in endodontic surgery) and pulp capping and can be used as a dentine replacement material in restorative dentistry (Septodont, Paris, France).[10]

Composition:

Based on Biodentine's product file, tricalcium silicate, dicalcium silicate, calcium carbonate and oxide filler, iron oxide shade, and zirconium oxide constitute the material's powder component. Zirconium oxide acts as a radiopacifier, whereas tricalcium silicate and dicalcium silicate are designated as the primary and secondary core components, respectively. The liquid comprises a hydro soluble polymer that acts as a water- reducing agent and calcium chloride as an accelerator.(Journal of endodntics vol. 39, 2013.)

Biodentine as a Vital Pulp Treatment Material:

Willig et al (2012) based on his studies recommended the use of biodentine in pulpotomy, another crucial pulp therapy technique. This technique, which is frequently used in paediatric dentistry, involves amputating the pulp chamber and applying a substance to maintain the life of the radicular pulp tissue. When direct pulp capping is not a possibility and the coronal pulp tissue is irritated, this treatment is especially helpful and desired[10].

The first study to demonstrate the induction of effective dentinal repair was the one by Tran et al. where the material was applied directly on mechanically exposed rat pulps. In their study where Biodentine was compared to MTA and calcium hydroxide interms of reparative dentine bridge formation, they noted that the structure induced by Ca(OH)2 contained several cell inclusions[10].

Clinical application of calcium silicate-based cements

The biocompatibility, bioactivity, and mechanical qualities of calcium silicate-based cements (CSCs) make them popular in a variety of clinical endodontic applications. Apexification, pulp capping, root-end filling, and root canal sealants are a few of the most popular applications[5,11].

Varanasi P et al (2024) in their comparative stereomicroscopic study evaluated that calcium silicate-based cements (CSCs), especially Mineral Trioxide Aggregate (MTA) and Bio dentine, have become popular choices for both direct and indirect pulp capping because of their biocompatibility, bioactivity, and sealing capacity. Even though they are frequently regarded as desirable materials because of their bioactive qualities, favourable outcomes still depend on factors like proper case selection, the level of pulpal inflammation at the time of treatment, and the quality of the finished coronal seal. Clinical criteria relating to working time, handling preferences, and aesthetic factors must guide the selection of particular CSCs[5,12].

In the event that conventional obturation techniques fail, a permanent hermetic seal must be specified in every apical surgery case that requires a root-end filling. The problems caused by missing apical obturations can be reduced using the appropriate root-end fill material. As a way to prevent periapical inflammation, root-end filling materials create a tight seal, enhance biogenic apical healing, and are reasonably biocompatible. Among the materials that have been proposed and used are amalgam, glass ionomer cement (GIC), zinc oxide-eugenol cements, intermediate restorative material (IRM), Super-EBA, composite resins, mineral trioxide aggregate (MTA), and biodentine. Both MTA and Biodentine have comparable biocompatibility and sealing capabilities, yet in some cases, Biodentine works better than MTA, especially in the early stages of healing[7,13].

Angkasuvan V et al (2022) in his study have shown, calcium silicate-based sealers, critically evaluated in laboratory and clinical studies, have thoroughly met the ISO criteria on flow, setting time, and radiopacity, and have demonstrated exceptional bio compatibility and bioactivity. It's interesting to note that sealers based on calcium silicate appear to accelerate the healing of periapical tissues and the sealing of related lesions, especially in retreatment situations following unsuccessful root canal treatments. Increased antibacterial activity and decreased solubility have been shown when silver and hydroxyapatite nanoparticles are added to bioceramic sealers, improving bond strength while maintaining the sealers' mechanical qualities. In conclu-

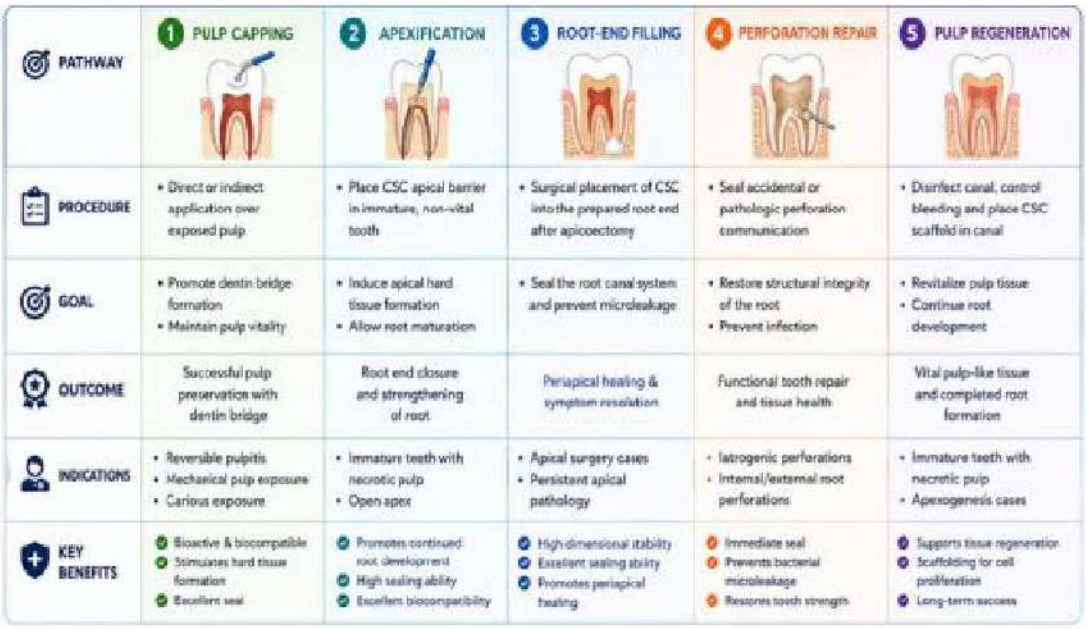


Figure 2: Summary of clinical indications, procedures, and therapeutic outcomes of calcium silicate cements (CSCs) in endodontic treatments.[4,14]

sion, calcium silicate-based sealers have the potential to significantly replace earlier resin-based sealers due to their biocompatibility, bioactivity, and competent sealing qualities[4,14].

LIMITATIONS

Despite their favourable biological properties and clinical potential, calcium silicate cements (CSCs) are associated with several limitations that may influence their clinical application. The prolonged setting time of some formulations remains a concern, as it may increase susceptibility to material displacement, dissolution, or contamination before complete maturation. Their handling characteristics can also be challenging, particularly for conventional powder-liquid formulations, which may require precise manipulation and appropriate moisture control. Biocompatibility and bioactivity are relevant properties that can lead the material to be the first choice for reparative and regenerative endodontic treatments[4,15].

Variations in material composition:

Rashed et al (2025) in his studies have shown the diverse compositions of different CSC products may generate inconsistent outcomes, both in the laboratory and in the clinic. For instance, the addition of varying radiopacifiers and modifiers, such as zirconium oxide and bismuth oxide, alters the radiopacity, setting time, and the mechanical characteristics of the final product in different ways. Such differences may complicate the selection of the most appropriate material in accordance with the specific clinical indications[5,15].

Discoloration and aesthetic issues:

As highlighted by Uslu ys 2026, the biological properties of calcium silicate-based cements like MTA and Biodentine are remarkable. However, they are prone to discoloration, especially if used in the anterior region of the mouth. This becomes compromised in anterior cases where aesthetic considerations are highly important[8,16].

FUTURE DIRECTIONS

The field of calcium silicate-based cements (CSCs) is evolving to address current clinical limitations specifically setting time and discoloration while expanding their role in regenerative endodontics. The following areas represent the most significant avenues for future investigation:

Development of responsive and nano-modified CSCs

Cruz hondares et al (2024), in his study showed that future research is increasingly focused on "smart" materials capable of responding to the local clinical environment, which includes the development of cements that respond to pH shifts brought on by infection or inflammation, potentially leading to the targeted release of medicinal substances[16].

The integration of nanotechnology remains a primary strategy for enhancing material performance (Fig.3). Incorporating nanoparticles such as nano-hydroxyapatite (nHA) and nano-silica can improve mechanical strength and reduce setting times. Furthermore, nanotechnology provides a solution to aesthetic challenges; replacing traditional radiopacifiers like bismuth oxide (Bi_2O_3) with zirconium oxide or nano-silica can mitigate tooth discoloration while maintaining necessary radiopacity and bioactivity[17].

Regenerative endodontics: Stem cells and growth factors:

Putzeys E et al (2018) suggested that recent advancements have focused on the development of calcium silicate-based cements and sealers, which are designed to exhibit bioactive properties. This is achieved by the release of calcium and hydroxide ions that contribute to the formation of hydroxyapatite, thereby facilitating periapical tissue repair. Combining CSCs with mesenchymal stem cells (MSCs) or induced pluripotent stem cells (iPSCs) shows promise in enhancing dentin-pulp complex regeneration. Additionally, the incorporation of signalling molecules, such as Bone Morphogenetic Protein 2 (BMP-2), may further accelerate mineralized tissue formation and pulp healing[18].

CONCLUSION

In this review, the clinical application of calcium silicate-based bioceramics, including MTA, Biodentine in endodontic treatment was summarized. Firstly, the characteristics of calcium silicate-based bioceramics were emphasized in terms of their biocompatibility, sealing ability, bioactivity, and other related aspects. Second, it has been discussed how the use of nanotechnology and innovative powder synthesis techniques has improved the qualities of calcium silicate cements, as well as their limitations and future prospects.

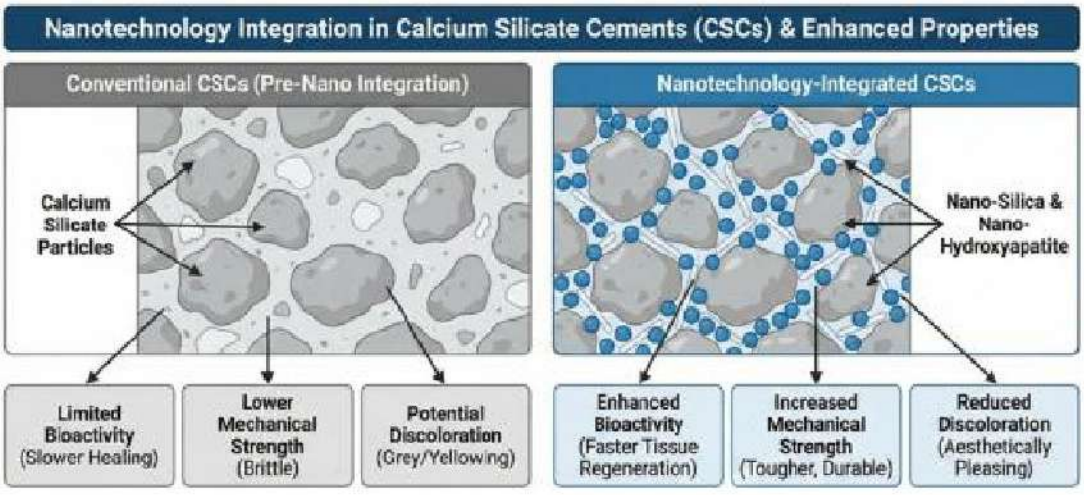


Figure 3: Comparative schematic of conventional versus nanotechnology-integrated calcium silicate cements (CSCs) and their enhanced properties. (17).

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REVIEW ARTICLE

A NARRATIVE REVIEW OF LASER USE AND ASSOCIATED COMPLICATIONS IN ORAL SURGICAL PROCEDURES

ABSTRACT

Modern oral surgery is highly dependent on lasers with benefits like hemostasis, accuracy, and less post-operative disorder. Nonetheless, the implementation of these materials can bring about dangers which are not always well-documented in the literature. This narrative review aimed to assess the complications associated with the use of lasers in oral surgery, looking closely at causes, responses in different tissues and the risk profile of different wavelengths. A literature search was done from PubMed, Scopus, Web of Science and Google Scholar which included published studies from January 2000 to April 2026 reporting complications with CO2, Nd:YAG, Er:YAG and diode lasers in human oral surgery. There was a thematic analysis of them. The research suggests that most adverse events occur due to laser physics, tissue biology, and operator skills. Safety issues, which mainly depend on both the indications and the skill of the practitioner, are numerous and various. The danger level of something can be widely assessed through wavelength and application. Er:YAG lasers resulted in less morbidity, while Nd:YAG presence had higher swelling and nerve damage risks. With proper device selection, cooling, and structured operator training, many complications are avoidable. The conclusion of the review is that safe laser use in oral surgery requires an understanding of the laser-tissue interaction and standardisation of protocols along with realistic counselling of the patients. We need more high-quality RCTs with adverse events as the primary outcome.

Keywords: Laser surgery, oral surgery, complications, adverse effects, thermal damage, postoperative pain.

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Authors:

[1]Shaiba P P
[2]Prijitha Alex
[3]Bharath Sekhar Nayanar
[4]Pallavi Ammu Thomas

[1]Intern
Department of Public Health Dentistry
Al Azhar Dental College, Thodupuzha, Kerala
Mail ID: shaibamoidheen@gmail.com

[2]Professor & HOD
Department of Public Health Dentistry
Al Azhar Dental College, Thodupuzha, Kerala
Mail ID: prijithaalex@gmail.com

[3]Reader
Department of Public Health Dentistry
Al Azhar Dental College, Thodupuzha, Kerala
Mail ID: bharathsnayanar1 @gmail.com

[4]Senior Lecturer
Department of Public Health Dentistry
Al Azhar Dental College, Thodupuzha, Kerala
Mail ID: patreigns@gmail.com

Corresponding Author:
Shaiba P P
Intern
Department of Public Health Dentistry
Al Azhar Dental College, Thodupuzha, Kerala
Mail ID: shaibamoidheen@gmail.com

INTRODUCTION

Since their initial application in dentistry in the 1970s, lasers have become a standard adjunct for many oral surgical procedures. Over 40% of oral and maxillofacial practices in developed countries are estimated to use at least one type of surgical laser; the most popular types are diode, CO2, Er:YAG, and Nd:YAG systems[1].

Due to recent technological developments like pulsed delivery modes, integrated cooling systems, and fiber-optic delivery, the laser usage now include soft tissue excisions, osseous surgery, frenectomies, and vascular lesion management. Better hemostasis, less bacteremia, more accurate tissue contact, and biostimulatory effects that may encourage wound healing and lower inflammation are some of the advantages lasers provide over conventional scalpel techniques[1,2].

Despite these benefits, complications do occur. The dangers of employing of a Nd: YAG laser for vascular abnormalities differs greatly from that of an Er: YAG laser for osteotomy[3,4].

The available consolidated data specifically addressing adverse events related to different laser types and oral procedures remains significantly limited, even though systematic reviews have focused on effectiveness outcomes such as pain relief[5].

A narrative review approach is appropriate considering the diversity of laser systems and the operator-dependent nature of the issues involved. In situations where there is a scarcity of randomized data on adverse events, narrative reviews allow for thematic synthesis and expert analysis of various types of studies. Therefore, this review aims to classify different types of side effects, explore their underlying causes, and assess the risk profiles associated with different laser wavelengths in oral surgical procedures.

1. METHODOLOGY

A narrative review was carried out in accordance with the guidelines for transparent reporting of narrative syntheses in the health sciences since this method enables a thorough, qualitative synthesis of the evidence from different types of study designs, especially in cases where the existing literature on a given subject involves a variety of methodologies and where a meta-analysis is not possible due to clinical and methodological heterogeneity.

2.1 Search Strategy

In April 2026, a systematic and comprehensive literature search was performed across four major electronic databases: PubMed (MEDLINE), Scopus, Web of Science, and Google Scholar. These databases were chosen to ensure broad coverage of both medical and dental literature, including peer-reviewed journals and high-quality systematic reviews. The search was restricted to articles published between January 2000 and April 2026 to capture contemporary evidence while acknowledging the evolution of laser technology over the past two decades. No language restrictions were applied during the initial search; however, only English-language articles were considered for full-text review due to resource constraints for translation.

The following exact search string was employed, combining terms related to laser types, oral surgical procedures, and complications using Boolean operators:

("laser surgery" OR "diode laser" OR "Er:YAG laser" OR "CO2 laser" OR "Nd:YAG laser") AND ("oral surgery" OR "third molar" OR "frenectomy" OR "biopsy" OR "osseous surgery") AND ("complications" OR "adverse effects" OR "thermal damage" OR "postoperative pain" OR "nerve injury")

The search strategy was developed iteratively, with preliminary scoping searches used to refine the terms and ensure sensitivity. Reference lists of included articles and relevant systematic reviews were also hand-searched to identify any additional studies that may have been missed by the electronic database searches.

2.2 Study Selection

The initial electronic searches yielded a total of 412 records: PubMed n=142, Scopus n=118, Web of Science n=96, and Google Scholar n=56. After

the removal of duplicate records using reference management software (EndNote), 298 unique records remained for screening.

Two reviewers independently screened the titles and abstracts of all retrieved records against a predefined set of eligibility criteria. Any disagreements between reviewers were resolved through discussion and consensus, with a third reviewer consulted when necessary. Following the initial screening, the full texts of potentially relevant articles were retrieved and assessed in detail.

The inclusion criteria were established a priori as follows:

- **Study design:** Systematic reviews, meta-analyses, randomized controlled trials (RCTs), or cohort studies. These designs were prioritized because they provide the highest level of evidence for evaluating both efficacy and adverse events.
- **Population:** Human participants undergoing oral surgical procedures, including but not limited to third molar extractions, frenectomies, biopsies, osteotomies, and treatment of vascular lesions.
- **Intervention:** Use of any surgical laser (CO2, Nd:YAG, Er:YAG, diode, or combinations thereof) as part of the surgical procedure.
- **Outcome**: Explicit reporting of complications or adverse effects associated with laser use, including but not limited to thermal injury, pain, swelling, delayed healing, scarring, and nerve damage.
- **Publication date:** January 2000 to April 2026.
- **Language:** English.

The exclusion criteria were as follows:

- Opinion pieces, editorials, letters to the editor, and conference abstracts without full data.
- In vitro or animal studies, as tissue responses may not accurately reflect human clinical outcomes.
- Case reports or case series with fewer than three patients, due to limited generalizability.
- Studies without full-text availability.
- Studies that did not report adverse events as a distinct outcome or provided insufficient data to extract complication rates.

At the full-text review stage, articles were excluded for the following specific reasons: no complication data reported (n=18), wrong intervention (i.e., laser therapy not used surgically or not in oral surgery) (n=7), and insufficient data for qualitative synthesis (n=5).

2.3 Data Synthesis

Following the full-text assessment, 15 studies met all eligibility criteria and were included in the final narrative synthesis. Due to the heterogeneity of the included studies in terms of laser types, surgical procedures, outcome measures, and follow-up durations, a formal meta-analysis was not feasible. Instead, a thematic synthesis approach was adopted.

Data extraction was performed using a standardized data extraction form that captured the following information for each study: first author and year, laser type and parameters, surgical procedure performed, study design, sample size, specific complications reported, complication rates or frequencies, and key conclusions. The extracted data were then organized thematically around the major complication categories (soft tissue problems, hard tissue and nerve damage) and risk profiles of different wavelengths.

To ensure analytical rigor, the following prioritization criteria were applied during synthesis:

1. Recent high-quality RCTs and systematic reviews were given greater weight in informing conclusions.
2. Studies with clearly defined, objective complication outcomes were prioritized over those relying solely on subjective assessments.
3. Papers that allowed direct or indirect comparison across at least two laser wavelengths were considered particularly valuable for understanding differential risk profiles.

Study	Laser Type	Procedure	Key Complication Reported	Study Design
Malcangi et al.(1)	All types	Generaloral surgery	Operator error, thermal injury	Systematic Review
Maiti N et al.(3)	Er:YAG	Thirdmolar surgery	Reduced pain, post operative Trismus, Prolonged operative time	Prospective RCTs
Pellegrini M et al.(4)	Nd:YAG	Vascular lesion	Recurrence in deeper lesions, Require multiple sessions	Systematic Review
Romeo et al.(6)	Various	Bone cutting	Temperature elevation	In Vitro
Pandurić et al.(7)	Er:YAG	Osteotomy	Thermal damage zone	Experimental
Aoki et al.(8)	CO2, Diode	Periodontal/peri-implant	Delayed healing	Systematic Review
Tiwari et al.(9)	Diode 650nm	Third molar surgery	Pain vs triamcinolone	RCT
Sun et al.(10)	CO2	Scar management	Post-inflammatory dyspigmentation	Systematic Review

Table 1. Summary of Included Studies and Their Focus on Complications

3. LASER COMPLICATIONS: CLASSIFICATION AND CAUSES

Complications can be broadly categorized into device-related issues, operator-related factors, and tissue-specific responses.

3.1 Device-related problems

The absorption properties of water, hemoglobin, and hydroxyapatite depend on wavelength. Common mistakes include choosing the wrong wavelength for tissue, incorrect power output or pulse duration, and malfunctioning cooling systems leading to acute heat injury[1,6].

3.2 Operator-related problems

Operator factors are the most important and avoidable category. Lack of training is linked to more complications[1]. Common errors: holding tip still causing localized heat buildup, wrong focal distance, poor sweeping motion, incorrect ablation depth assessment, and not knowing cooling needs[1,2].

3.3 Tissue-specific reactions

Vascular anomalies, alveolar bone, and nerve bundles exhibit distinct responses. Bone has poor heat dissipation; insufficient water cooling during laser osteotomy can cause thermal necrosis and delayed healing[6,7]. Nd:YAG laser treatment of vascular lesions requires multiple sessions in case of larger lesions[4].

3.4 Clinical significance

Safe laser surgery requires:

1. Choosing the right device for procedure and tissue.
2. Extensive training in laser physics.

3. Knowing tissue vulnerabilities[1,2].

4. SOFT TISSUE PROBLEMS: FROM PAIN TO SCARRING

4.1 Background

Diode and CO2 lasers are widely preferred for soft tissue procedures due to their excellent hemostatic properties, which provide a clear surgical field and reduce intraoperative bleeding. However, these wavelengths are strongly absorbed by water and hemoglobin, and if excessive energy is delivered or proper technique is not followed, they can generate significant collateral thermal damage to adjacent tissues. This unintended heat spread may manifest clinically as increased postoperative pain, delayed wound healing, or undesirable scar formation, potentially offsetting the initial benefits of reduced bleeding[2,8].

4.2 Key findings

Burning, swelling, and pain are most common. Er:YAG laser treated patients shows reduced intra operative and post operative pain in third molar surgery[3]. Nd:YAG for vascular lesions showed mild postoperative pain and requirement of multiple sessions for larger lesions[4]. Triamcinolone was more effective than 650 nm diode for pain in one study[9].

4.3 Clinical significance

Wavelength must match desired outcome. Diode lasers are useful for frenectomy but risk lateral thermal spread[2]. For cosmetic procedures, patients should be counseled on swelling, erythema, and texture changes[10].

5. DAMAGE TO NERVOUS SYSTEM AND HARD TISSUE

5.1 Background

Er: YAG lasers are valued for their precise bone ablation capabilities, as their wavelength is strongly absorbed by water and hydroxyapatite, allowing for controlled tissue removal with minimal mechanical vibration. However, cortical bone is relatively avascular and has poor thermal conductivity, making it highly susceptible to heat-induced injury when laser energy is applied without adequate cooling. Furthermore, surgical sites such as the posterior mandible and maxilla are anatomically close to critical structures like the inferior alveolar nerve and maxillary sinus, increasing the potential for irreversible damage if thermal or mechanical injury extends beyond the intended field[6,7].

5.2 Key findings

Heat damage can cause irreversible pulpitis. Er:YAG with poor cooling caused larger thermal damage zones than burs[7]. Insufficient cooling can elevate temperature above bone viability threshold _ osteocyte death[6,7].

5.3 Clinical significance

Proper water cooling is not merely an accessory but an essential requirement for safe laser osteotomy, as it dissipates heat and prevents the bone temperature from exceeding the critical threshold of 47°C, above which irreversible osteocyte necrosis occurs. The use of lasers on hard tissue demands a steeper learning curve than soft tissue applications, primarily because the consequences of error such as osteonecrosis, or tooth devitalization are more severe and often irreversible. Therefore, clinicians must exercise heightened caution, adhere strictly to manufacturer-recommended parameters, and ensure continuous irrigation when performing any laser-assisted osseous procedure[6,7].

6. RISK PROFILES OF DIFFERENT LASER WAVELENGTHS

6.1 Background

The extent of laser-tissue interaction and the resulting biological effects are primarily governed by the wavelength of the laser, which determines its primary chromophore (target molecule) and depth of penetration into the tissue. Wavelengths that are strongly absorbed by water, such as Er: YAG, have very shallow penetration depths and produce minimal lateral thermal spread, making them safer for precise ablative work. Conversely, wavelengths like Nd:YAG that are poorly absorbed by water but readily absorbed by pigments such as hemoglobin and melanin penetrate deeply,

offering advantages for vascular and pigmented lesions but carrying a higher risk of unintended deep tissue damage and collateral effects[1,2,4].

6.2 CO2 (10,600 nm)

The CO2 laser emits a wavelength that is highly absorbed by water, resulting in very shallow tissue penetration and making it ideal for precise, superficial soft tissue ablation, excisions, and vaporization with excellent hemostasis. However, the intense heat generated at the tissue surface creates a zone of thermal coagulation that can impede healing and lead to complications such as delayed wound closure and post-inflammatory dyspigmentation, particularly in patients with darker skin types or when treating cosmetically sensitive areas[8,10].

6.3 Nd:YAG (1064 nm)

The Nd:YAG laser penetrates deeply into tissue due to its low absorption by water and high affinity for hemoglobin and melanin, which makes it highly effective for treating deep vascular lesions, hemangiomas, and pigmented pathologies. According to the literature, treatment using the Nd:YAG laser for VMs is highly recommended due to its ability to generate heat during the procedure and this allows for it to selectively destroy the targeted tissue without damaging the adjacent areas. However, this deep penetration also poses significant risks, including incidence of postoperative pain, discomfort and require multiple sessions in larger lesions, Recurrence (8%) and minimal side effects[4].

6.4 Er:YAG (2940 nm)

With a wavelength that coincides with the peak absorption peak of water, the Er:YAG laser exhibits the shallowest penetration and minimal lateral thermal damage among surgical lasers, making it exceptionally safe for both hard and soft tissue ablation with reduced postoperative pain and swelling. These properties have made it the preferred choice for osseous surgery and third molar extractions, as evidenced by RCT showing significantly lower post operative and intra operative pain and swelling compared to conventional rotary instruments. Nonetheless, the Er:YAG laser is not devoid of risk; inadequate water cooling or prolonged exposure can still induce thermal necrosis in bone, emphasizing that its safety is highly dependent on proper technique and irrigation, and prolonged use leads to post operative Trismus, and it requires double the cutting time of a bur[3,6,7].

6.5 Diode (810-980 nm)

Diode lasers are widely utilized in oral surgery for soft tissue procedures such as frenectomies, gingivectomies, and hemostasis due to their portability, affordability, and effective absorption by hemoglobin and melanin. However, their longer wavelength allows for deeper tissue penetration and can produce significant lateral heat if the fiber tip is held stationary or if energy settings are too high. This lateral thermal spread can result in delayed wound healing, excessive scarring, and even thermal necrosis, making it essential to employ a continuous sweeping motion and adhere to recommended power outputs to minimize collateral damage[2,8].

6.6 Summary

In summary, no single laser wavelength is universally suitable for all oral surgical applications, and the choice of device must be carefully tailored to the specific tissue type, lesion depth, and desired clinical outcome. While Er:YAG lasers are generally associated with the lowest morbidity for hard tissue and third molar surgeries, and diode or CO2 lasers are effective for soft tissue hemostasis, each wavelength carries a distinct and predictable risk profile that clinicians must understand. Ultimately, operator proficiency and adherence to safety protocols remain the most critical factors in preventing complications, regardless of the laser system being used[1,2,4].

LASER	WAVELENGTH	Primary Chromophore	Clinical Use	Main Complications
DIODE	810-980 nm	Hemoglobin, Melanin	Soft tissue hemostasis	Lateral thermal damage, delayed healing[2,8]
Nd:YAG	1064 nm	Hemoglobin, deep penetration	Vascular lesions	Pain, Discomfort, Minimal side effects, Recurrence (8%)[4]
Er:YAG	2940 nm	Water, Hydroxyapatite	Bone, soft tissue	Thermal necrosis if no cooling[6,7]
CO2	10,600 nm	Water	Soft tissue ablation	Delayed healing, dyspigmentation[10]

Table 2. Risk Profile of Common Surgical Lasers in Oral Surgery

7. WAYS TO MANAGE AND PREVENT

7.1 Patient selection: A thorough preoperative assessment is essential to identify patients who may be at increased risk for laser-related complications. Individuals with a history of photosensitivity disorders or those currently taking photosensitizing medications (such as tetracyclines, non-steroidal anti-inflammatory drugs, or certain diuretics) should be carefully evaluated, as they may experience exaggerated tissue reactions or photoreactions. Additionally, patients with compromised immune function, uncontrolled diabetes, or a history of keloid formation should be counseled about their elevated risk of delayed healing and scarring, and alternative treatment modalities should be considered when appropriate[1].

7.2 Training: Structured training programs that encompass both theoretical knowledge of laser physics and tissue interactions, as well as extensive hands-on supervised practice, are fundamental to ensuring safe and effective laser use. Novice operators should begin with low-risk procedures under proctorship until they demonstrate competence in parameters such as focal distance, sweeping technique, and energy titration. Continuing education and regular skills assessment are also vital, as the rapid evolution of laser technology and the operator-dependent nature of complications demand that practitioners remain current with best practices[1].

7.3 Protocol: The development and strict adherence to standardized, written protocols for each laser device and procedure type are critical for minimizing variability and preventing errors. These protocols should specify the optimal wavelength, power output, pulse duration, repetition rate, and cooling requirements based on the manufacturer's recommendations and the specific tissue being treated. Regular calibration and maintenance of laser equipment, along with routine checks of cooling systems and fiber-optic integrity, are also essential components of a comprehensive safety protocol[1,2].

7.4 Safety: Comprehensive safety measures are non-negotiable in any laser surgical environment and must address the risks to both the patient and the surgical team. Wavelength-specific protective eyewear must be worn by everyone in the treatment room, and non-reflective surgical instruments should be used to prevent accidental beam reflection. In addition, proper technique, such as maintaining a sweeping motion to prevent static heat buildup, using adequate cooling and smoke evacuation systems, and ensuring proper tip maintenance, are essential to minimize thermal injury to adjacent tissues and prevent airborne contamination[1].

CATEGORY	STRATEGY	RATIONALE
PATIENT	Screen for photosensitivity, medications	Reduce risk of adverse photoreactions[1]
OPERATOR	Competency-based training, proctorship	Most complications are operator-dependent[1]
DEVICE	Correct wavelength selection, parameter standardization	Match laser to tissue chromophore[1,2]
TECHNIQUE	Sweeping motion, adequate cooling, eye protection	Prevent thermal buildup and collateral damage[1,7]
PROTOCOL	Informed consent with laser-specific risks	Improve patient counselling and expectations[10]

Table 3. Strategies for Prevention and Management of Laser Complications

8. DISCUSSION

8.1 Key Findings and Critical Synthesis

This narrative review demonstrates that complications in laser oral surgery are not random device failures, but rather predictable outcomes of the interaction between laser physics, tissue biology, and operator proficiency[1]. This aligns with Panduric et al., who demonstrated smaller thermal damage zones with Er:YAG under adequate irrigation[7]. The most consistently reported adverse events were thermal necrosis, postoperative pain, delayed healing, discomfort, recurrence, side effects.[2,7,8]

Across studies, a clear pattern emerges: ablative lasers with high water absorption, such as Er:YAG, are associated with lower morbidity. The Randomized Control trial by Maiti N et al. showed significantly reduced swelling, pain and bleeding after third molar surgery with Er:YAG compared to rotary instruments[3].

In contrast, deep-penetrating wavelengths like Nd:YAG carry a distinct risk profile. In study conducted by Pellegrini M et al ., Shows that the lesions treated with Nd:YAG had a recurrence rate of 8% ± 0.9% Nd:YAG, which means that patients required additional treatment sessions[4].

8.2 Comparison and Conflicting Evidence

The literature presents some apparent contradictions that warrant explanation. Parker noted that despite excellent hemostasis, diode and CO2 lasers can produce significant lateral thermal damage if used improperly, leading to delayed healing that may offset early benefits[5]. While lasers are widely promoted for superior hemostasis and reduced postoperative pain, direct comparisons do not always support this.

These discrepancies likely reflect 3 factors:

- **Operator experience:** Malcangi et al. emphasized that most thermal injuries stemmed from static tip use, incorrect focal distance, and inadequate cooling - variables rarely standardized across trials[1].
- **Outcome measurement:** Studies reporting "delayed healing" used histologic or 2-week follow-up data[7,8]. while those reporting "less pain" often used VAS at 24-48h[9].
- **Wavelength and parameter heterogeneity:** "Diode laser" studies varied from 810-980 nm to 650 nm LLLT, with vastly different tissue interactions[9].

Thus, the conflicting evidence does not invalidate laser use, but highlights that efficacy is highly context-dependent. Nd:YAG should be reserved for vascular lesions with careful risk-

benefit analysis[3].whereas Er:YAG appears favorable for hard tissue and third molar surgery[4]. Tiwari et al. found that triamcinolone acetonide was more effective than a 650 nm diode laser for pain control after third molar surgery[9].

8.3 Clinical Implications

The data support abandoning a "one laser for all" approach. Clinicians must match wavelength to chromophore and tissue depth[1]. Institutional protocols should mandate: wavelength-specific eye protection, standardized cooling, and competency-based training before independent use[1].

For bone, Er:YAG with copious cooling is safer[7]. For soft tissue with bleeding risk, diode or CO2 may be appropriate but require sweeping motion and strict energy limits[2,8]. Informed consent must specifically mention laser-related risks such as dyspigmentation after CO2, as noted by Sun et al. in scar management[10].

8.4 Limitations of Current Evidence

Several limitations affect interpretation. First, heterogeneity in laser settings, outcome measures, and follow-up periods precluded RCTs[1,3]. Second, most studies had small samples and short follow-up, potentially missing late complications like Recurrence, Pain[4,9].Third, publication bias likely favors positive efficacy outcomes over adverse events[5].Finally, only 15 studies met inclusion criteria, indicating a need for more RCTs with adverse events as primary endpoints.

8.5 Future Directions

Future research should prioritize:

- Standardized reporting frameworks for laser complications
- RCTs powered to detect adverse events, not just efficacy
- Comparative effectiveness studies between laser types for the same procedure
- Evaluation o f structured training programs on complication rates

9. CONCLUSION

Laser technology has significant positive outcomes in oral surgery, including enhanced precision and haemostasis. However, this review confirms that safety is not innate to the technology. Most complications are preventable and arise from inappropriate device selection, inadequate cooling, and insufficient operator training . Safe operation requires a thorough understanding of laser-tissue interactions, adherence to standardized protocols, and transparent patient counselling. Further high-quality research is needed to define best practices and minimize complications.

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REVIEW ARTICLE

REGENERATIVE DENTISTRY: CURRENT ADVANCES IN STEM CELLS, BIOMATERIALS AND BIOACTIVE STRATEGIES FOR ORAL TISSUE REPAIR

ABSTRACT

Regenerative dentistry is an emerging field that harnesses stem cells, biomaterials, bioactive molecules, tissue engineering concepts, and innovative manufacturing techniques to restore the structure and function of damaged oral and maxillofacial tissues. Conventional restorative and surgical approaches typically replace lost tissues, whereas regenerative medicine seeks to rebuild, repair, or influence biological processes to recreate tissue formation and repair. Dental-derived stem cells, including dental pulp stem cells, stem cells from human exfoliated deciduous teeth, periodontal ligament stem cells, and stem cells from the apical papilla have been investigated extensively for their potential to regenerate oral tissues. Biomaterials and scaffolds provide an appropriate microenvironment for cell seeding, attachment, proliferation, differentiation, and extracellular matrix deposition. Moreover, bioactive materials can further support tissue repair by releasing ions, growth factors, or other molecules. Recent advances in hydrogels, extracellular vesicles, cell-free approaches, and three-dimensional bioprinting have provided new opportunities for personalized regenerative treatments. Nevertheless, several challenges related to vascularization, immunological barriers, scaffold degradation, cell survival, manufacturing, costs, regulations, and clinical outcome prediction still hinder the widespread clinical adoption of these innovative technologies. This narrative review discusses recent advances in stem cell–based therapies, biomaterials, bioactive materials, hydrogels, extracellular vesicles, and three-dimensional bioprinting for the regeneration of dental pulp, dentin, periodontal tissues, and alveolar bone, highlighting their potential impact on the future of clinical dentistry.

Keywords: Regenerative dentistry; dental stem cells; biomaterials; bioactive materials; tissue engineering; dental pulp regeneration; periodontal regeneration; bioprinting.

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Authors:

[1]Prithvijith
[2]Niveditha S S
[3]Sherin
[4] Pooja Latti

[1,2,3]House Surgeon
Department of Public Health Dentistry
Annoor Dental College & Hospital
Muvattupuzha, Kerala

[4]Professor and Head
Department of Public Health Dentistry
Annoor Dental College & Hospital
Muvattupuzha, Kerala

Corresponding Author
Prithvijith
House Surgeon
Department of Public Health Dentistry
Annoor Dental College & Hospital
Muvattupuzha, Kerala
Mail ID: officialprithvi1234@gmail.com

INTRODUCTION

Regenerative dentistry is an interdisciplinary area of research, which involves the fields of medicine, biology, stem cell biology, biomaterials and tissue engineering, molecular biology and bioengineering. The main goal of regenerative dentistry is not only to replace the missing parts of the dental system, but also to reconstitute its structure and functionality by stimulating and/or replacing its natural regeneration processes[1].

Conventional restorative procedures such as fillings, crown, bridges and root canals are an integral part of modern dentistry, but they primarily involve restoration of damaged tissues. Regenerative approaches to tissue repair aim to restore fully function of all dental tissues including pulp, dentin, periodontal ligament, cementum, and alveolar bone. The aim of this review is to analyze the latest scientific literature on the topic and provide a summary of the current state of regenerative endodontics and its therapeutic potential bone[1].

The development of dental stem-cell research has greatly contributed to the understanding of regenerative approaches. Dental pulp stem cells (DPSCs), stem cells from human exfoliated deciduous teeth (SHED), periodontal ligament stem cells (PDLSCs), stem cells from the apical papilla (SCAP), and other mesenchymal stem-cell populations have shown self-renewal, multilineage differentiation, immuno modulatory, and trophic properties relevant to tissue repair[2].

At the same time, advances in biomaterials have provided increasingly sophisticated scaffolds and matrices capable of supporting cell survival and directing tissue formation. Hydrogels, natural and synthetic polymers, ceramics, nanocomposites, and bioactive materials can be engineered to reproduce aspects of the extracellular micro environment[3].

More recently, extracellular vesicles, cell-free regenerative strategies, and three-dimensional bioprinting have introduced additional approaches for controlling tissue regeneration and creating anatomically complex constructs[4].

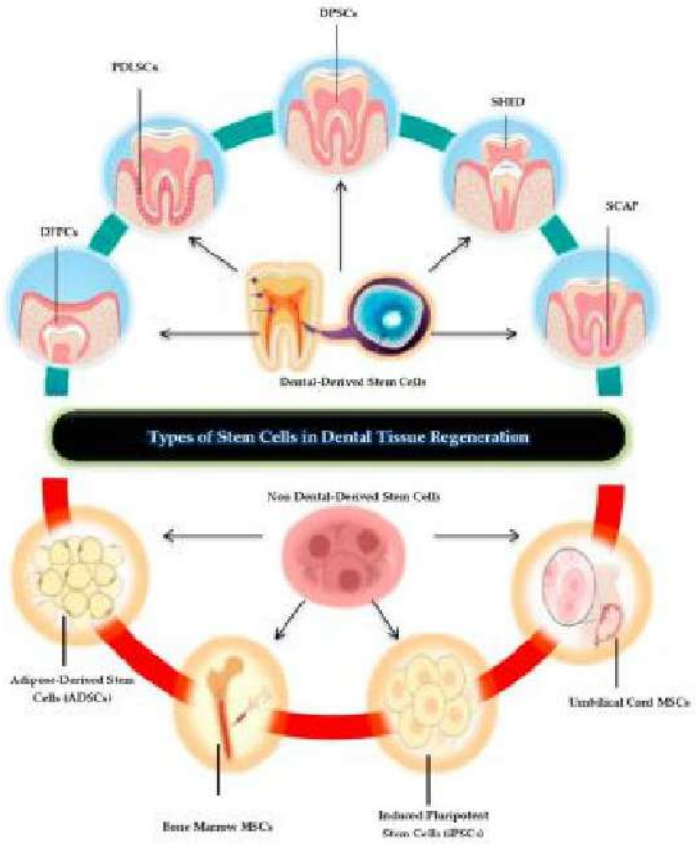


Figure 1.

Overview of regenerative dentistry. Schematic/figure illustrating the integration of stem cells, biomaterials, bioactive signals, and tissue-engineering approaches in regeneration of dental and supporting tissues.[1]

2. DENTAL STEM CELLS

Stem cells are a distinct class of cells that possess the unique ability of self-renewal and the capability to differentiate into specialized cell types. Dental-derived stem cells are particularly promising in regenerative dentistry since they can be isolated from tissues associated with the oral cavity and exhibit characteristics pertinent to odontogenic, periodontal, and osteogenic functions regeneration[2].

Major dental stem-cell populations include DPSCs, SHED, PDLSCs, SCAP, dental follicle progenitor cells and gingival-derived mesenchymal stem cells. Non-dental mesenchymal stem cells from bone marrow, adipose tissue and umbilical tissue have also been investigated[2].

2.1 Dental Pulp Stem Cells

Dental Pulp Stem Cells were initially identified within adult dental pulp and have demonstrated considerable proliferative and differentiation capacity. They can differentiate toward odontoblast-like, osteogenic, chondrogenic, and other mesenchymal lineages under appropriate conditions[2].

Their ability to participate in dentin-pulp complex regeneration makes dental pulp stem cells one of the most extensively investigated cell populations in regenerative endodontics. However, successful pulp regeneration requires more than the presence of stem cells. Appropriate vascularization, innervation, extracellular matrix organization, signaling molecules, and a suitable scaffold are also necessary[5].

2.2 Stem Cells from Human Exfoliated Deciduous Teeth

Stem Cells from Human Exfoliated Deciduous Teeth are derived from naturally exfoliating deciduous teeth and possess high proliferative capacity. Their accessibility and biological properties make them promising candidates for regenerative medicine applications, including dentin, pulp, and bone regeneration, as well as for other purposes tissues[6].

cells can differentiate into odontoblast-like cells and participate in the formation of dentin and other dental tissues. Besides, they can regenerate pulp tissue, initiate dentin formation, and repair processes of damaged teeth, due to their regenerative properties and abilities to influence the surrounding cells by signaling molecules.[7]

2.3 Periodontal Ligament Stem Cells

Periodontal Ligament Stem Cells are located in the periodontal ligament and have potential to regenerate periodontal tissues including periodontal ligament, cementum, and alveolar bone. Their response to the periodontal environment makes them attractive candidates for periodontal regenerative therapies therapies[2].

They are mesenchymal stem cells with the ability to self-renew and differentiate into cells that contribute to periodontal tissues. They can promote the regeneration of periodontal ligament, cementum, and alveolar bone in damaged periodontal sites.[8]

2.4 Stem Cells from the Apical Papilla

Stem Cells from the Apical Papilla are associated with developing permanent teeth and have been investigated particularly for root development and pulp-dentin regeneration. Their biological characteristics have generated interest in regenerative endodontic procedures and tissue-engineering strategies[9].

They help the apexogenesis, dentin form, angiogenesis, blood vessels revascularization in permanent younger teeth. Also, they might contribute to the release of different bioactive molecules or exosomes that activate the environment cells and support dentin – pulp complex regeneration[10].

2.5 Other Mesenchymal Stem Cells

Bone marrow-derived, adipose-derived, umbilical cord-derived, and other mesenchymal stem cells have been considered for tissue regeneration in the oral cavity and skull, offering potential advantages in several applications, but necessitating careful

evaluation of cell source, safety, standardization, and other factors in order to achieve clinically meaningful outcomes[6].

3. MECHANISMS OF STEM-CELL-MEDIATED REGENERATION

Stem-cell-mediated regeneration involves several interconnected mechanisms, including proliferation, differentiation, migration, paracrine signaling, extracellular-vesicle release, immunomodulation, and interaction with the surrounding extracellular matrix[2].

Following tissue injury may activate local signaling pathways conducive to recruitment of endogenous progenitor cells or modulation of transplanted stem cells. growth factors and cytokines regulate cellular proliferation and differentiation, and extracellular matrix components provide biochemical and biomechanical cues that influence cell fate[2].

Stem cells may contribute directly to tissue formation through differentiation into specialized cell types. However, their regenerative effects may also occur through paracrine mechanisms involving secretion of growth factors, cytokines, and extracellular vesicles[11].

4. BIOMATERIALS AND SCAFFOLDS

Biomaterials provide structural and biochemical support for tissue regeneration. An ideal scaffold should provide appropriate porosity, mechanical properties, degradation behavior, biocompatibility, cell-adhesion characteristics, and capacity for controlled delivery of bioactive molecules[3].

4.1 Natural Biomaterials

Natural polymers such as collagen, gelatin, chitosan, alginate, hyaluronic acid, and fibrin have been investigated because of their

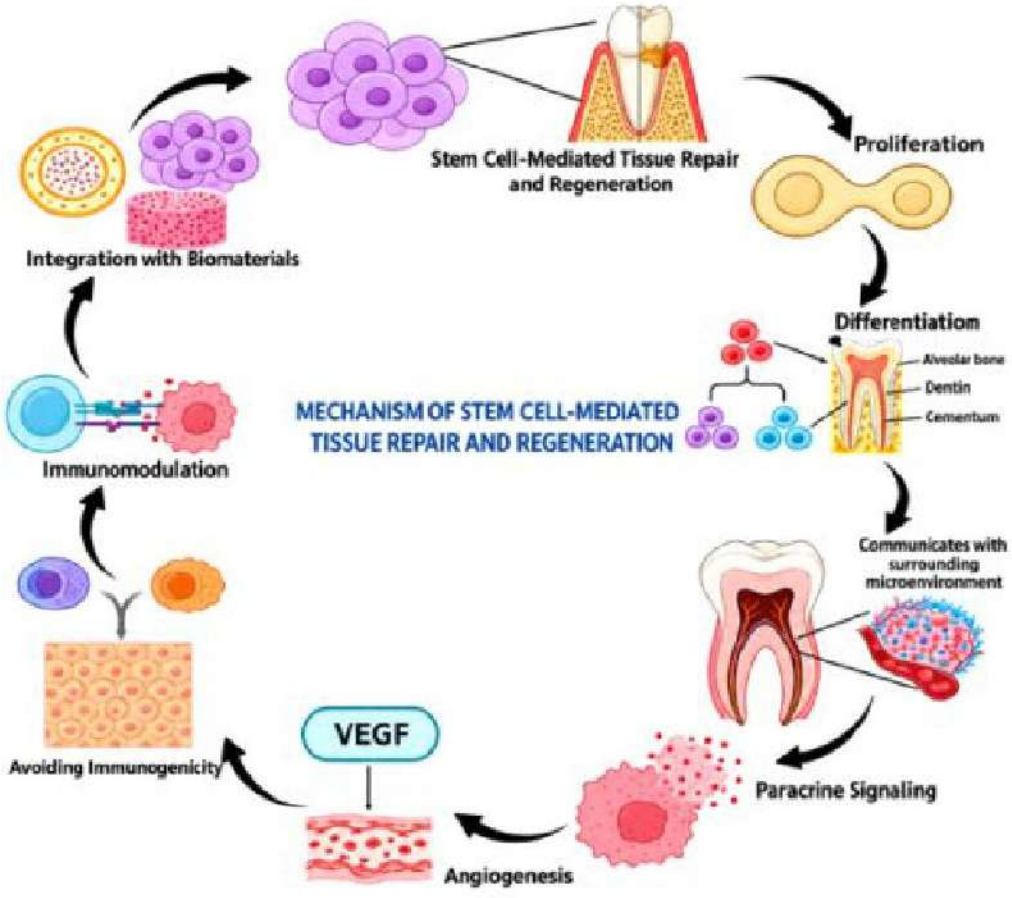


Figure 3. Mechanisms of stem-cell-mediated dental tissue regeneration. Adapted from Umapathy et al., illustrating stem-cell proliferation, migration, differentiation, and formation of dental-specific cells.[1]

biocompatibility and similarities to components of the extracellular matrix[12].

4.2 Synthetic Biomaterials

Synthetic polymers such as polycaprolactone, polylactic acid, polyglycolic acid, and related copolymers offer greater control over mechanical properties and degradation kinetics[13].

4.3 Ceramic and Mineral-Based Materials

Hydroxyapatite, β-tricalcium phosphate, bioactive glass, and related calcium-phosphate materials have demonstrated particular relevance to hard-tissue regeneration because of their similarity to the mineral phase of bone and dental tissues[14].

4.4 Composite Scaffolds

Combining polymers with ceramic or bioactive components can provide complementary mechanical and biological properties. Such composite systems are being explored for periodontal and alveolar bone regeneration[15].

5. BIOACTIVE MATERIALS

Bioactive materials are designed not only to provide structural support but also to actively influence cellular behavior and tissue formation. Their effects may occur through ion release, surface interactions, growth-factor delivery, or modulation of cellular signaling pathways[16].

Material Class	Examples	Key Properties	Primary Dental Application
Calcium Silicate Cements (CSCs)	MTA, Biodentine, EndoSequence	Bioactive, releases Ca^{2+}/OH^- ions, high pH (alkaline), forms apatite layer	Direct pulp capping, vital pulp therapy, apical plugs, perforation repair
Bioactive Glasses (BGs)	45S5 Bioglass, Mesoporous Glass, Nanoglass	Controlled ion release (Si, Ca, P), antibacterial, strong bonding to soft/hard tissue	Bone grafting, dentin remineralization, periodontal defect filling
Natural Hydrogels	Collagen, Hyaluronic Acid, Chitosan, Fibrin	High biocompatibility, native cell-binding motifs (RGD), high porosity	Pulp tissue engineering, soft tissue regeneration, drug delivery
Synthetic Polymers	PLLA, PLGA, PCL, PEG	Tunable mechanical properties and degradation rates, printable	3D bioprinted scaffolds, Guided Bone Regeneration (GBR) membranes
Platelet Concentrates	PRP, PRF, i-PRF, PRGF	Autologous source, rich in growth factors (PDGF, VEGF, TGF-β)	Revascularization protocols, periodontal wound healing acceleration
Decellularized Matrices (dECM)	Dental pulp dECM, Bone dECM	Preserves native tissue architecture and biochemical signaling cues	Organoid culture, bio-instructive biological pulp regeneration

Table 1 Recent biomaterials used in dentistry[1]

Bioactive glass, calcium-silicate materials, calcium-phosphate materials, and ion-releasing restorative materials have been investigated for their potential to stimulate mineralization and improve tissue repair[16].

The incorporation of therapeutic molecules into scaffolds may further enhance regeneration. Controlled delivery systems can regulate the temporal and spatial presentation of growth factors and other signalling molecules, potentially improving cellular differentiation and tissue maturation[12].

6. DENTAL PULP AND DENTIN REGENERATION

Dental pulp regeneration represents one of the most extensively investigated applications of regenerative dentistry. The objective is to restore a functional pulp-like tissue capable of supporting dentin formation, vascularization, and potentially neural function[5].

Current approaches generally combine three fundamental components:

Cells or endogenous progenitor cells

Scaffolds or biomaterials

Bioactive signals

Hydrogels are particularly attractive because their water-rich three-dimensional structure can support cellular survival while permitting incorporation of growth factors and other signaling molecules[12].

Polymeric scaffolds have also been investigated for pulp tissue engineering. Scaffold architecture, degradation, mechanical properties, and vascularization remain important determinants of regenerative success[12].

Although promising preclinical findings have been reported, complete regeneration of a functional pulp-dentin complex remains challenging because the tissue requires coordinated formation of blood vessels, nerves, odontoblast-like cells, and extracellular matrix[9].

Adapted from Fukushima et al. and related pulp-regeneration reviews, showing the interaction between cells, scaffolds, and bioactive cues.[12]

7. PERIODONTAL REGENERATION

Periodontal regeneration aims to restore the complex architecture of cementum, periodontal ligament, and alveolar bone rather than simply repairing the periodontal defect[9].

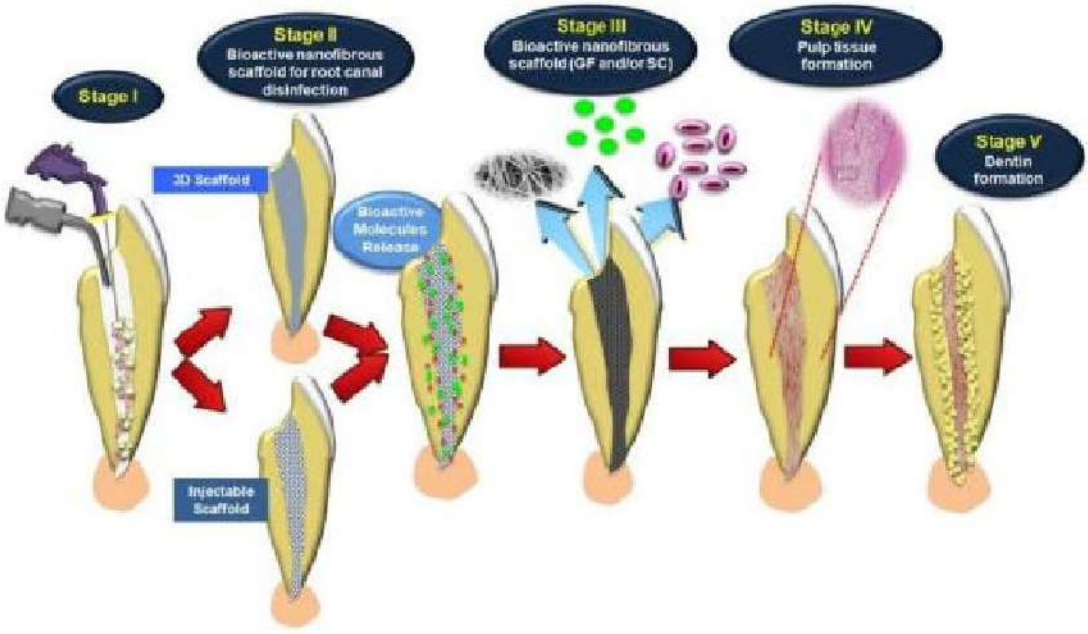


Figure 5. Tissue-engineering strategies for dental pulp regeneration.

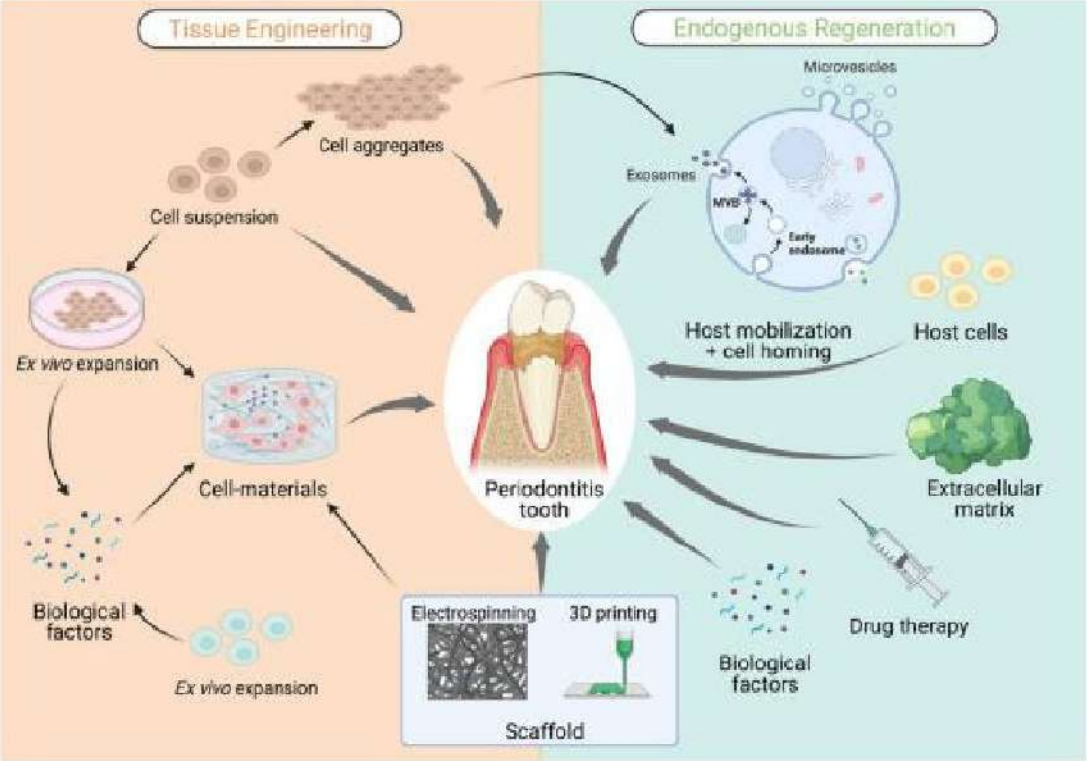


Figure 6. Stem-cell and biomaterial strategies for periodontal regeneration. Adapted from Bartold and Ivanovski and other systematic reviews of periodontal regenerative approaches (9).

PDLSCs and other mesenchymal stem-cell populations have demonstrated regenerative potential in preclinical models. Biomaterial scaffolds can provide structural support while growth factors and cellular therapies may influence tissue formation[2].

Systematic reviews and meta-analyses of clinical studies suggest that stem-cell-based approaches may have potential benefits; however, variations in cell source, scaffold composition, treatment protocols, defect characteristics, and outcome measures limit direct comparison among studies[3].

8. ALVEOLAR BONE REGENERATION

Alveolar bone regeneration is important in periodontal therapy, implant dentistry, oral surgery, and craniofacial reconstruction. Bone regeneration strategies commonly involve osteogenic cells, osteoconductive scaffolds, and bioactive signalling molecules[15].

Hydroxyapatite, β-tricalcium phosphate, bioactive glass, polymeric scaffolds, and composite biomaterials have been investigated for bone regeneration. Mesenchymal stem cells may further contribute through osteogenic differentiation and paracrine mechanisms[16].

Three-dimensional bioprinting provides an opportunity to fabricate patient-specific structures with controlled architecture and spatial distribution of cells and biomaterials[17].

9. HYDROGELS AND ADVANCED SCAFFOLDS

Hydrogels are three-dimensional polymeric networks containing substantial amounts of water. Their ability to mimic aspects of the extracellular matrix makes them particularly useful for soft-tissue regeneration and delivery of cells or bioactive molecules.[12]

Advanced scaffold systems increasingly incorporate multiple functional components. These may include nanoparticles, growth factors, extracellular vesicles, antimicrobial agents, and controlled-release systems.[18]

Smart biomaterials capable of responding to

pH, temperature, enzymes, mechanical forces, or other biological signals represent a further development in tissue engineering[19].

10. EXTRACELLULAR VESICLES AND CELL-FREE STRATEGIES

Although conventional regenerative medicine frequently relies on transplantation of living cells, cell-free strategies have attracted increasing interest.

Extracellular Vesicles (EVs) such as exosomes carry a cargo of proteins, lipids, and RNA (including messenger RNA, microRNA, and other biologically active molecules) that are capable of modulating target cells. They are less likely to cause problems as might occur with transplanting whole cells, and they offer additional advantages, such as being easier to store and handle and having potential as components of bioengineered scaffolds for tissue repair.[15]

11. THREE-DIMENSIONAL BIOPRINTING

Three-dimensional bioprinting combines computer-aided design with controlled deposition of biomaterials, cells, and bioactive components. The technique offers the possibility of creating complex structures with controlled spatial organization[17].

Use an appropriately licensed/adapted figure from an open-access review. Ostrovidov et al. describe extrusion-based, inkjet, and laser-assisted techniques in detail.[15]

12. CLINICAL TRANSLATION AND CURRENT LIMITATIONS

Despite considerable advances, translation of regenerative strategies from laboratory studies to routine clinical dentistry remains challenging.

12.1 Cell Survival and Vascularization

The survival of transplanted cells within engineered constructs can be limited by inadequate vascularization. Large tissue constructs require rapid establishment of blood supply to maintain cell viability.[20]

12.2 Immune and Inflammatory Responses

Although many dental stem cells demonstrate immunomodulatory properties, immune

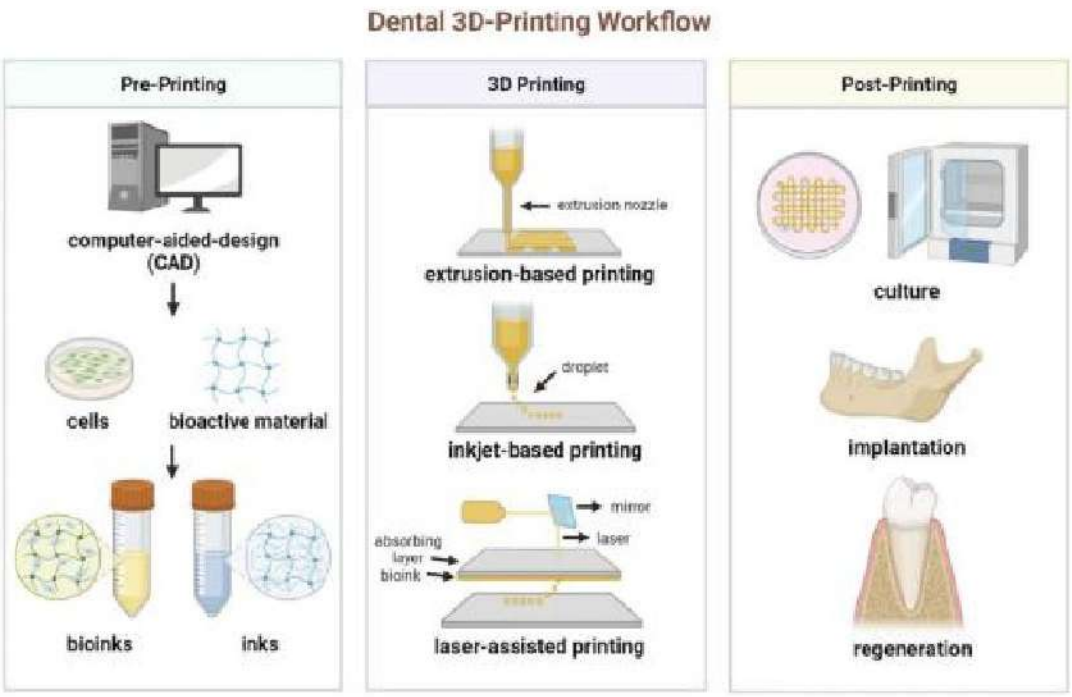


Figure 7. Major three-dimensional bioprinting approaches used in dental tissue engineering.

responses to cells, scaffolds, degradation products, and bioactive molecules must be carefully evaluated.[9]

12.3 Scaffold Degradation

The degradation rate of a scaffold must correspond appropriately with the rate of new tissue formation. Premature degradation may result in loss of structural support, whereas excessively slow degradation may interfere with tissue remodeling.[11]

12.4 Standardization

Variations in cell isolation, culture conditions, scaffold composition, manufacturing processes, and outcome measurements make comparison between studies difficult.[13]

12.5 Regulatory and Economic Considerations

Cell-based and advanced biomaterial therapies involve complex manufacturing and regulatory requirements. Cost, accessibility, quality control, and long-term safety will strongly influence their clinical adoption.[15]

13. FUTURE PERSPECTIVES

The future of regenerative dentistry is likely to involve increasing integration of stem-cell biology, biomaterials science, artificial intelligence, digital dentistry, nanotechnology, extracellular-vesicle biology, and three-dimensional bioprinting.[21]

Personalized regenerative treatment may become possible through patient-specific imaging, digital design, customized scaffolds, and individualized cell or bioactive-material therapies.[16]

Combination approaches may be particularly promising. Instead of relying on a single component, future therapies may combine endogenous stem-cell recruitment, bioactive molecules, smart scaffolds, controlled-release systems, and bioprinting.[3]

14. CONCLUSION

Regenerative dentistry has evolved from concept to advanced tissue-engineering processes using dental-derived stem cells and biomaterials, and has embraced bioactive materials; hydrogels; extracellular vesicles; and three-dimensional bioprinting. Dental-derived stem cells offer intriguing potential for regenerative dentistry, while biomaterials and bioactive products create environments in which cells and tissues can grow.

Pulp-dentin, periodontal, and alveolar bone regeneration have been the focus of promising preclinical and clinical investigations, yet several challenges to their routine clinical application still exist and include vascularization, cell survival, scaffold function and performance, reproducibility, safety, cost, regulatory approval, and long-term clinical efficacy.

Future progress will depend on multi disciplinary integration of biology, materials science, digital technologies, and clinical dentistry. With appropriate validation and standardization, regenerative strategies may increasingly complement or transform conventional approaches to oral tissue repair.

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REVIEW ARTICLE

ORAL HEALTH IN SWIMMERS: A COMPREHENSIVE REVIEW

Authors:

Yadav M P[1]
Aiswarya Asokan[2]
Vishna N[3]
Subramaniam R[4]
Jesline Merly James[5]
Priya Babu[6]

House Surgeon[1,2,3]
Department of Public Health Dentistry,
Indira Gandhi Institute of Dental Sciences,
Kothamangalam, Kerala

Professor & Head[4]
Department of Public Health Dentistry
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala

Reader[5,6]
Department of Public Health Dentistry
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala

Corresponding author:
Yadav M P
House Surgeon
Department of Public Health Dentistry
Indira Gandhi Institute of Dental Sciences
Kothamangalam, Kerala -686691

Email:
yadavviswambaran544@gmail.com

ABSTRACT

Sports practices on a routine basis expose athletes to the onset of several diseases, especially swimming where the individuals are frequently exposed to chemically treated water for long durations. Prolonged exposure to chlorinated pool environments among professional swimmers can lead to significant oral health concerns, The aim of this review is to narrate the impacts of swimming on oral health, with a focus on identifying key patterns, underlying mechanisms, and clinical implications.

Keywords: Swimming, chlorine, water, oral health, oral diseases.

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INTRODUCTION

Oral health is a key indicator of overall health, encompassing the well-being of teeth, gums, and the entire mouth, enabling essential functions like eating and speaking.[1] It is largely maintained through daily brushing, flossing, and regular dental checkups, which prevent common diseases like cavities, periodontal (gum) disease, and tooth loss.[1,2]

Swimming, a widely practiced recreational and competitive activity, involves repeated exposure to chlorinated water and specific lifestyle habits that may influence oral conditions. Swimmers, especially those who train regularly, are exposed to chemically treated water for long durations. Such exposure has been associated with potential risks including dental erosion and dental Caries, along with other changes affecting the teeth and oral tissues. Apart from its negative impacts, swimming also offers additional health benefits, as regular swimmers can improve their cardiovascular fitness and lung function and maintain overall physical fitness.[3] There are various factors that protect the tooth surface from developing Dental Caries. Secretory IgA is the main immunoglobulin found in saliva and is considered the first line of the host defense mechanism. It serves as an important indicator of mucosal immunity and helps prevent the entry of microbial pathogens into the body. Several studies have demonstrated that certain sports activities, particularly competitive swimming, may lead to decreased IgA levels, thereby increasing the risk of upper respiratory tract infections.[4] However, existing studies on this topic are limited and show inconsistent findings. The available evidence is scattered, making it difficult to draw clear conclusions. Therefore, a narrative review is needed to compile and interpret current literature, provide a comprehensive understanding of oral health issues in swimmers, and identify gaps for future research. The aim of this review is to critically examine and integrate existing evidence on the relationship between swimming and oral health, with a focus on identifying key patterns, underlying mechanisms, and clinical implications.

Swimming as a sport

Swimming is a widely practiced physical activity that serves both recreational and competitive purposes, contributing significantly to overall fitness and well-being.[5]

Recreational swimming is performed for relaxation, fitness, and leisure activities. It is usually practiced occasionally and involves less intensive exposure to pool water, thereby posing minimal health risks .[6]

Competitive swimmers are individuals who engage in swimming at a professional or high-performance level, involving frequent and prolonged exposure to chlorinated pool water. They spend at least two hours per session, five times per week, engaging in vigorous exercise.9 This repeated exposure, along with intense training schedules, may influence their oral health, particularly increasing the risk of dental erosion and other related conditions. Proper preventive care and monitoring are essential to maintain their overall and oral health.[7]

Professional swimmers tend to spend several hours in swimming pools, consequently being exposed to high levels of chlorine-based chemicals present in the water. Chlorine, which is primarily used for disinfecting pools, may have adverse effects with prolonged exposure, leading to problems affecting the hair, skin, and teeth.[8]

Prolonged exposure to chlorinated pool environments among professional swimmers can lead to significant oral health concerns, often referred to as “swimmer’s mouth.” This condition should be taken seriously, as continuous exposure may adversely affect the oral cavity. Hence, it is vital to take into account such risks when establishing and maintaining standards for proper pool upkeep.[4,9]

Pool water chemistry

The American Public Health Association recommends strict monitoring of swimming pool water, including checking chlorine levels and pH three times daily. The pH should be maintained between 7.2 and 8.0, with a free chlorine level of 1-3ppm and any change must be corrected immediately. Proper maintenance

helps prevent "swimmer's erosion," a painful and irreversible dental condition caused by poorly regulated chlorinated pools.[5]

Improperly treated pool water, particularly when it has a low pH due to inadequate buffering, can have detrimental effects on swimmers. When the pH falls significantly, prolonged exposure to such chlorinated water may lead to dental erosion. This condition makes swimmers' teeth vulnerable to enamel damage, due to acidic environment that promotes the dissolution of hydroxyapatite crystals, resulting in the release of calcium ions from the tooth surface.[8]

ORAL HEALTH RISK IN SWIMMERS

Oral health is an important aspect of overall well-being and can be influenced by environmental and lifestyle factors. Swimming, especially at a competitive level, involves repeated exposure to chlorinated water, which may increase the risk of conditions such as dental erosion, dental caries, gingivitis, dental calculus, and tooth sensitivity.[10] Additional factors like training intensity and reduced salivary flow may further compromise oral health. Therefore, understanding these risks is essential for effective prevention and maintenance of oral health in swimmers.[5]

Dental erosion

Dental erosion is one of the most imperceptible problems often overlooked by dental professionals. Dental erosion is defined as the loss of tooth substance by a chemical process that does not involve bacteria. It is an irreversible lesion leading to altered appearance and function and eventually results in tooth loss. Sports drinks, acidic diet, and swimming are found to be the most common reasons for erosion of enamel. Professional (competitive) swimmers typically engage in prolonged training sessions in swimming pools, which may predispose them to acid-mediated enamel degradation. Dental erosion, often termed "swimmer's erosion," is an irreversible condition associated with significant clinical and economic implications, primarily linked to exposure to inadequately maintained gas-chlorinated pool water.[11] When the pH of pool water decreases below that of saliva, enamel erosion may occur.[4]

Chlorine gas is increasingly used for pool disinfection due to its low cost compared to traditional methods. However, its interaction with water forms hydrochloric and hypochlorous acids, resulting in a highly acidic environment that can significantly lower pool pH. Such acidic conditions have been associated with a higher prevalence of Dental erosion among competitive swimmers. Studies report that approximately 39-48% of swimmers exhibit signs of erosion, with severity increasing in proportion to the duration of pool exposure.[4,9]

Awareness regarding the detrimental effects of excessive chlorination of pool water among pool maintenance personnel and facility employees must be significantly enhanced through structured education and regulatory monitoring, as overchlorination can create an acidic aquatic environment that is strongly associated with dental erosion among frequent swimmers. In this regard, oral health professionals play a pivotal role in prevention by promoting targeted interventions, including the use of customized, professionally fabricated mouthguards for competitive swimmers who are exposed to chlorinated water for prolonged periods, thereby minimizing direct contact between acidic water and tooth surfaces. It is also important to note that enamel remineralization and repair mechanisms typically commence within approximately two hours following an acidic exposure; however, during this period, the enamel surface remains softened and highly susceptible to mechanical damage.

Consequently, immediate tooth brushing after swimming is not recommended, as it may exacerbate enamel wear. Instead, swimmers should be encouraged to rinse the oral cavity thoroughly with water, sodium bicarbonate solutions, or fluoride-containing mouthwashes to help neutralize residual acids and promote remineralization, along with the use of a soft-bristled toothbrush to reduce abrasive effects during routine oral hygiene practices. Collectively, these preventive strategies,

coupled with increased awareness and interdisciplinary collaboration, can significantly reduce the risk of chlorine-induced dental erosion among swimmers.[10]

Dental caries

Dental caries is a lifelong disease influenced by various biological factors present in saliva and dental plaque. The dental plaque biofilm provides a favorable environment for the proliferation of cariogenic microorganisms, particularly mutans streptococci and Lactobacillus species, which possess the ability to rapidly ferment dietary carbohydrates and produce acids. This acid production leads to a decrease in pH to levels that promote the demineralization of tooth structure. Furthermore, the concentration and activity of these cariogenic bacteria within saliva and plaque play a critical role in determining an individual's susceptibility to the development and progression of dental caries.[4]

Chlorine exhibits an antibacterial effect that can reduce plaque formation on tooth surfaces. Since dental plaque is a primary factor in enamel demineralization, its reduction limits the activity of cariogenic bacteria. Consequently, the antimicrobial action of chlorine may inhibit the formation of plaque biofilm, thereby contributing to a lower risk of dental caries among swimmers. A cross-sectional study conducted by Barbara Sophie Gaugeler et al. compared elite swimmers with athletes participating in other sports, and concluded that competitive swimmers exhibited a lower incidence of dental caries and plaque levels compared to high-performing athletes engaged in other sporting activities.[3] A cross-sectional study conducted by Barbara Sophie Gaugeler et al. compared elite swimmers with athletes participating in other sports, and concluded that competitive swimmers exhibited a lower incidence of dental caries and plaque levels compared to high-performing athletes engaged in other sporting activities.[3] A study conducted by Iwona Grzesiak-Gasek et al. included adolescents aged 12-15 years, comprising competitive swimmers and control participants, and assessed dental caries experience using the Decayed, Missing, and Filled Teeth (DMFT) index. Swimmers reported significantly higher consumption of chocolate bars, energy drinks, water, and sweet carbonated beverages compared to the control group. Overall, the findings indicated that swimmers exhibited a significantly higher DMFT score than controls, suggesting a greater experience of dental caries despite differences in dietary habits.[12]

Swimmer's calculus

Calculus is defined as a hard deposit which is formed by mineralization of dental plaque on the surface of natural teeth and dental prosthesis, usually covered by a layer of unmineralized plaque. Dental calculus is primarily composed of inorganic mineral salts, with calcium phosphate accounting for about 70-80% of its structure, mainly in the form of hydroxyapatite, brushite, whitlockite, and octacalcium phosphate. The remaining portion consists of organic components such as proteins, lipids, and desquamated epithelial cells. This mineralized mass forms through the calcification of dental plaque, resulting in a hard deposit that firmly adheres to the tooth surface.[14]

Swimmer's calculus, also referred to as swimmer's stain, is a condition characterized by the presence of hard, brown tartar deposits, most commonly observed on the anterior teeth. This staining occurs on the acquired enamel pellicle a thin layer of proteins and peptides approximately 1µm thick that forms on the enamel surface. The discoloration results from the interaction between salivary proteins and antimicrobial agents present in pool water, which typically has a higher pH than saliva. These agents can denature and degrade salivary proteins, leading to the formation of organic deposits on the tooth surface. Competitive swimmers are particularly at risk, as they are frequently exposed to chemically treated pool water for extended periods, often exceeding six hours per week.[13]

Dental staining

Swim staining, also referred to as "swimmer's stain," is a form of tooth discoloration that occurs due to prolonged exposure to chlori-

nated pool water. The discoloration may appear in shades such as yellow, brown, or green, and its severity can vary from mild to pronounced. This condition is frequently observed in competitive swimmers, as well as in recreational swimmers who spend extended periods in swimming pools.

Chlorine plays a vital role in maintaining pool hygiene; however, it can reduce the pH of the water, making it more acidic. Such acidic conditions increase the risk of enamel erosion, thereby allowing pigments and staining substances to penetrate the tooth surface more easily. Additionally, pool water may contain metals like copper and iron, which are commonly present in algaecides and other treatment chemicals. These metals can adhere to the enamel, resulting in greenish or brownish stains, especially in pools with inadequate filtration or poor maintenance. Furthermore, swimmers who frequently breathe through their mouth may experience reduced salivary flow, leading to dry mouth. Since saliva provides a protective effect by neutralizing acids and aiding remineralization, its reduction increases the susceptibility of enamel to damage. Although staining is the most noticeable effect, affected teeth may also lose their natural shine, appear dull, and develop a rough surface texture due to enamel wear.[4,7,13,16-18]

Dental staining is thought to result from interactions between disinfectants and pool chemicals, such as chlorine, which induce the denaturation of salivary proteins. This process promotes the formation of deposits on tooth surfaces composed of both organic and inorganic components, including calcium phosphate compounds.[16]

Competitive swimmers with longer pool exposure are reported to have higher incidence of dental staining and trauma compared to non-competitive athletes.[4]

PREVENTIVE MEASURES

Fluoride prevents demineralization and dental erosion by reducing acidogenic bacterial activity and forming fluorapatite, which is more resistant to acidic conditions than hydroxyapatite. Likewise, synthetic hydroxyapatite promotes remineralization by releasing calcium and phosphate ions and aiding in enamel surface repair. Weekly application of high-concentration fluoride for 5 minutes effectively protects against tooth erosion. Similarly, remineralizing agents like F-APC, used daily for 2 minutes and weekly for 4 minutes, help protect tooth surfaces from erosive tooth wear (ETW).[7]

Routine dental cleanings and regular checkups alone may not be sufficient to prevent staining in competitive swimmers. Additional measures, such as regular fluoride treatments, using fluoride toothpaste before and after swimming, and wearing fluoride-lined mouthguards during swimming, are recommended. However, fluoride use should be carefully monitored by dental professionals to avoid overexposure.[18]

Chewing gum containing xylitol may help swimmers reduce caries risk associated with dental erosion; for effective prevention, 5-6g should be consumed at least three times daily. In addition to personalized home care, increased professional dental visits can help reduce staining, erosion, and calculus. The application of fluoride varnish further enhances remineralization, decreases enamel solubility, and lowers the risk of caries.[4,9]

CONCLUSION

Swimming is a highly beneficial physical activity that promotes overall health and fitness; however, prolonged exposure to chlorinated pool water presents specific challenges to oral health. This review highlights that competitive swimmers, due to frequent and extended exposure, are at an increased risk of developing conditions such as dental erosion, swimmer's calculus, and extrinsic staining. The role of pool water chemistry, particularly pH imbalance and excessive chlorination, is a critical factor influencing these oral changes. Although certain protective effects, such as reduced plaque accumulation due to the antimicrobial action of chlorine, have been observed, the overall impact on oral tissues can be detrimen-

tal when preventive measures are neglected. Additional factors, including reduced salivary flow, dietary habits, and training intensity, further contribute to the complexity of oral health outcomes in swimmers.

Effective prevention requires a multi disciplinary approach involving swimmers, dental professionals, and pool maintenance authorities. Regular monitoring of pool water quality, maintenance of optimal pH levels, and the implementation of appropriate oral hygiene practices such as fluoride use, rinsing after swimming, and routine dental checkups are essential in minimizing risks. In conclusion, while swimming remains a valuable and health-promoting activity, increased awareness and preventive strategies are necessary to protect swimmers from potential oral health problems. Further research is needed to establish standardized guidelines and strengthen evidence-based preventive protocols in this field.

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REVIEW ARTICLE

THE MOUTH AS A MIRROR: REFLECTING SYSTEMIC HEALTH THROUGH SALIVARY BIOMARKERS

Authors:

[1]Kadeeja Ajimi
[2]Habira Misna
[3]Jiji R Chandran
[4]Gopika Ramesh

[1,2,3,4]House surgeon
Department of Public Health Dentistry
Annoor Dental College
Muvattupuzha, Kerala

Corresponding Author
Kadeeja Ajimi
House surgeon,
Department of Public Health Dentistry
Annoor Dental College
Muvattupuzha, Kerala

Mail ID: ajimikadeeja@gmail.com

ABSTRACT

Saliva is a complex biological fluid that reflects both normal and abnormal systemic conditions, making it a promising medium for non-invasive detection and monitoring of diseases. Recent progress in salivary diagnostics has revealed a broad range of biomarkers such as proteins, enzymes, cytokines, metabolites, hormones, nucleic acids, and microbial patterns linked to neurological conditions like Alzheimer's disease and dementia, metabolic disorders such as diabetes mellitus, mental health issues including depression, and long-term inflammatory conditions. In the field of oncology, salivary biomarkers demonstrate significant potential for diagnosing and predicting the course of oral, breast, and pancreatic cancers, due to changes in the expression of proteins and microRNAs associated with tumors. Systemic conditions like chronic kidney disease, cardiovascular issues, and periodontitis display unique salivary biomarker patterns that indicate inflammation, oxidative stress, and immune system dysfunction. During the COVID-19 pandemic, saliva became a dependable sample for detecting the virus and evaluating immune responses. Moreover, saliva is important in forensic medicine, assisting with personal identification, toxicological testing, and genetic studies. This review compiles existing evidence regarding the clinical significance, diagnostic precision, and potential for application of salivary biomarkers in various disease conditions. Although there are challenges concerning biomarker standardization and analytical inconsistencies, salivary diagnostics offer a promising area for early detection, disease tracking, and tailored medical treatments.

Keywords: salivary diagnostics, non-invasive detection, Alzheimer's disease, cardiovascular disease, Periodontitis, Oral cancer, Breast cancer, Depression, Forensic medicine, Diabetes mellitus, Dementia, Chronic kidney disease, chronic inflammation, COVID.

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INTRODUCTION

Saliva is the easily obtainable biological fluid found in the mouth. It is secreted by three main pairs of glands along with numerous smaller ones. The three primary glands involved in saliva production are the parotid, submandibular, and sublingual glands, which correspond to the classification of parotid saliva, submandibular saliva, and sublingual saliva. The secretion of saliva can be further classified depending on whether or not stimuli are present that trigger its production. More specifically, when at rest, un-stimulated saliva is mainly produced by the submandibular glands, accounting for nearly 70% of the total, while stimulated saliva, triggered by factors such as smell, taste, or medications, is primarily secreted by the parotid glands.[1]

In recent decades, saliva has become an important biological fluid with notable applications in the field of medicine. It is becoming more widely acknowledged as a dependable method for detecting diseases, monitoring their progression, and guiding treatment decisions. Salivary diagnostics holds significant potential for detecting a range of systemic conditions, including various types of cancer, among its many applications.[2]

One of the major strengths of saliva-based testing is its non-invasive nature. Sample collection is simple, painless, and does not require any complex instruments or highly specialized training. Saliva can be collected easily in both in-home and clinical settings, improving patient comfort and compliance.[2]

Moreover, salivary diagnostics helps make it possible to detect diseases at an earlier stage. Biomarkers found in saliva could signal the early presence of cancer, when treatment results are typically more positive. Early detection using saliva testing may help improve survival rates and decrease the need for more intensive treatments.[2]

Oral saliva has been shown to contain a high concentration of viruses, indicating that salivary glands are active sites for viral replication. In addition, dry mouth and a reduced sense of taste may be linked to the dysfunction of salivary glands caused by COVID-19.[3]

The application of saliva-based mi-RNA diagnostics in clinical practice has the potential to significantly transform the treatment of oral cancer. These diagnostics have the potential to enhance patient outcomes by allowing for earlier identification and more accurate predictions, thus shifting the healthcare approach from reactive to proactive.[4]

Chronic inflammation and microbial imbalance linked to periodontal disease might play a role in the neurodegenerative changes observed in Alzheimer's disease. Saliva and gingival crevicular fluid are becoming increasingly recognized as valuable non-invasive sources for detecting biomarkers associated with both oral health and neurodegenerative diseases.[5]

Periodontitis

Recent research underscores saliva as a promising, non-invasive tool for diagnosing periodontal disease, providing benefits compared to traditional clinical and radiographic evaluations. Certain salivary biomarkers indicate the inflammatory, immune, and tissue-damaging mechanisms that contribute to periodontitis. Changes in exosome-related tetraspanins, such as CD9 and CD81, have been associated with the presence and severity of diseases, indicating their possible role as markers for periodontal condition. In addition, higher concentrations of soluble urokinase plasminogen activator receptor (suPAR) and galectin-1 in oral fluids seem to be linked to periodontal inflammation, suggesting their potential utility in the early identification of the disease.[6]

Proteolytic enzymes and inflammatory mediators have also demonstrated significant diagnostic importance. Higher levels of matrix metalloproteinase-9 (MMP-9) and S100A8 in saliva are associated with clinical indicators like probing depth and attachment loss, indicating continuous degradation of connective tissue. Elevated levels of lactate dehydrogenase (LDH) and aspartate

aminotransferase (AST) suggest cell injury and the advancement of the disease. Pro-inflammatory cytokines such as interleukin-1β, interleukin-6, and tumor necrosis factor-α regularly show significant links to the severity of periodontal disease, highlighting their importance in assessing the level of inflammation.[6]

Crucially, using several biomarkers together can enhance diagnostic accuracy, especially when distinguishing between gingivitis and existing periodontitis. In addition to diagnosis, specific biomarkers may be useful in assessing treatment effectiveness and forecasting disease progression, promoting a move toward individualized periodontal care.[6]

Stress, Anxiety and Depression

Present methods for evaluating stress, anxiety, and depression primarily rely on clinical interviews and behavioral observations, which lack the objectivity provided by laboratory-based research. Saliva has become a practical alternative for diagnostic testing due to its low cost, stability, and the fact that it can be collected without invasion, even by patients at home. Multiple salivary biomarkers show detectable variations when exposed to psychological stress. Cortisol is the most common indicator; acute stress increases salivary cortisol levels, while chronic stress can lead to a diminished or unexpectedly lower response. During acute stress, the sympathetic nervous system becomes active, causing a quick increase in salivary alpha-amylase (sAA), which makes it a reliable indicator of immediate stress responses. Chromogranin A (CgA) also rises quickly in response to psychosomatic stressors like exams or public speaking, and, aside from an initial morning peak, remains fairly consistent throughout the day.[7]

Other elements in saliva offer insights into mood disorders and immune system changes linked to long-term stress. Melatonin is closely linked to depression and somewhat connected to anxiety, indicating issues with the regulation of the circadian rhythm. Secretory immunoglobulin A (s-IgA) and lysozyme, which are markers of immune function, usually decrease during extended periods of stress, possibly increasing the risk of infections. Fibroblast growth factor-2 (FGF-2), which plays a role in nerve regeneration, could be an indicator of resilience, as lower levels may signal a higher susceptibility to anxiety. In a clinical context, cortisol, lysozyme, sAA, and CgA are regarded as important markers for assessing stress, whereas evaluating both cortisol and melatonin together can help differentiate depression from typical stress conditions. These biomarkers also have the potential to track the effectiveness of treatments. However, interpretation must be approached with care, as the composition of saliva is affected by factors such as age, gender, diet, smoking habits, and daily fluctuations, highlighting the importance of standardized collection procedures.[7]

Diabetes Mellitus

Salivary glucose, the most thoroughly researched and promising biomarker, has repeatedly shown a strong association with blood glucose levels in both Type 1 and Type 2 diabetes. Other potential biomarkers, including 1,5-anhydroglucitol, alpha-amylase, asprosin, resistin, and fructosamine, have also been reported to have diagnostic value, while cystatin SA demonstrated limited reliability because of its stronger link to periodontal condition rather than blood sugar control.[8]

Saliva provides multiple clinical benefits, such as painless sampling, lower infection risk, simple handling, and the potential for earlier detection when compared to urine testing. Nevertheless, the primary challenges that currently hinder routine clinical use, especially the absence of standardized protocols for saliva collection, processing, and storage, along with differences in study populations and reporting approaches. Although salivary glucose and alpha-amylase show great potential for monitoring diabetes, extensive, well-standardized research is necessary before these salivary diagnostics can be reliably incorporated into clinical practice.[8]

Chronic inflammation

Persistent, mild inflammation frequently occurs before the development of serious

conditions such as type 2 diabetes, obesity, heart disease, and cancer. Saliva is simple to collect, noninvasive, and economical. A variety of inflammatory substances, such as cytokines, chemo-kines, and acute phase proteins, pass into saliva from the bloodstream via passive diffusion or active transport. Some indicators, such as Interleukin-6 (IL-6) and cortisol, demonstrate notable associations between salivary and serum levels.[9]

Several factors, including age, gender, lifestyle, genetics and epigenetics, can influence inflammatory biomarkers. Aging is linked to elevated levels of cytokines such as IL-6 and TNFα. Gender also influences responses, with males exhibiting higher levels of certain cytokines. Obesity and smoking are both contributing factors to ongoing chronic inflammation. On the other hand, physical activity has been demonstrated to lower indicators such as C-reactive protein (CRP). Genetic variations and microRNA (mi-RNA) expression levels significantly influence an individual's susceptibility to inflammatory conditions.[9]

Passive drool is regarded as the preferred method for sample collection. Other approaches involve chewing (suggested for detecting CRP) and swab-based techniques, although cotton swabs might lead to variations in marker levels. Standard tests such as ELISA are commonly used but typically necessitate the use of centralized lab facilities. There is a growing trend toward creating biosensors such as electrochemical, optical, and acoustic types for real-time, point-of-care monitoring. Examples include wireless mouth guards that are integrated for monitoring uric acid or glucose. Machine learning models are being created to examine intricate datasets and detect particular "signatures" of circulating biomarkers, thereby enhancing diagnostic precision.[9]

The absence of standardized reference ranges and collection procedures continues to pose a challenge for clinical implementation. Local oral conditions, such as periodontal disease, may affect salivary markers and could obscure systemic signals. Future advancements rely on developing biosensors that can simultaneously detect multiple biomarkers to more accurately

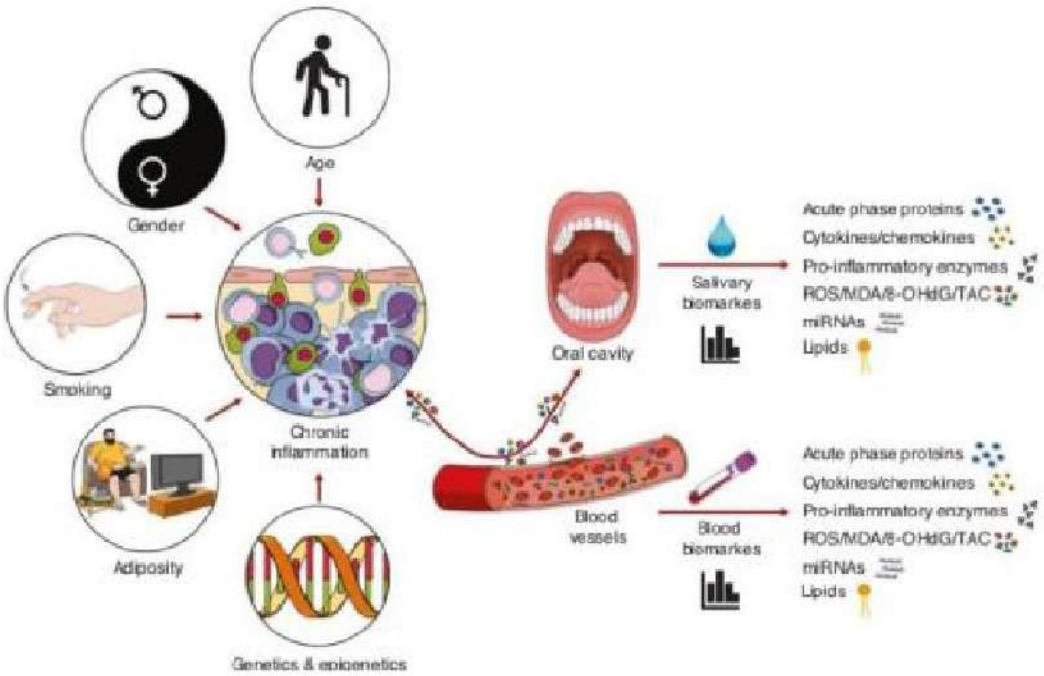


FIGURE 1: Schematic representation of possible indicators of chronic inflammation, compounds enchanged between blood and oral cavity, and dosable compounds in biological fluid.[9]

identify specific diseases.[9]

Chronic kidney disease

Creatinine and urea levels demonstrate strong and consistent positive correlations, frequently surpassing 0.8, with serum concentrations, particularly when obtained through the spitting method, indicating a high level of accuracy in diagnosing and monitoring CKD. Calcium and Parathyroid Hormone (PTH) show significantly weaker and less consistent relationships with blood levels. This is because of physiological barriers, such as PTH's large molecular size and its tendency to break down due to enzymes in the mouth. The spitting and un-stimulated techniques are typically regarded as the most accurate for reflecting systemic concentrations, while "oral rinse" methods frequently produce inconsistent and diluted outcomes.[10]

Using saliva as a diagnostic method minimizes the discomfort, stress, and infection risk typically linked to regular blood tests (phlebotomy). Saliva collection is simple to perform, needs less trained staff, and is more affordable, making it well-suited for areas with limited resources, outpatient monitoring, and community screening programs. Unlike urine testing, saliva collection does not need privacy and can be used with patients who are anuric or oliguric, such as those undergoing dialysis.[10]

At present, there is no standardized method for collecting or analyzing saliva, resulting in inconsistent findings factors like salivary flow rate, oral health, hydration levels, and circadian rhythms can all influence biomarker levels. There needs to be larger, standardized clinical trials at every stage of CKD (not only in advanced stages) to define clear reference ranges and confirm their clinical usefulness.[10]

Cardiovascular disease

When assessing salivary equivalents of well-established serum cardiac biomarkers. Among these, creatine-kinase myocardial band (CK-MB), C-reactive protein (CRP), troponin I (TnI), and myoglobin showed the greatest and most reliable diagnostic value. Increases in these markers in saliva during acute cardiac events, showing positive correlations with serum levels. Importantly, salivary CRP demonstrated significant links to inflammation, atherosclerosis, and vascular disease, and proved to be one of the most dependable salivary markers for AMI. While Troponin I is highly specific in serum, its diagnostic effectiveness in saliva varies, highlighting difficulties associated with low levels in saliva and assay sensitivity.[11]

Other biomarkers, such as myeloperoxidase, brain natriuretic peptide, matrix metalloproteinases, oxidative stress indicators (malondialdehyde,8-hydroxy deoxyguanosine), and metabolic proteins like adiponectin and irisin, produced inconsistent or conflicting results.[11]

COVID-19

Saliva has become a very promising diagnostic fluid because of the non-invasive, straightforward, and economical way it can be collected, which makes it especially well-suited for widespread screening and ongoing monitoring. Containing a variety of biologically active components such as proteins, enzymes, hormones, antibodies, nucleic acids, and metabolites, saliva indicates both local oral conditions and systemic physiological changes. These molecules enter saliva via processes like passive diffusion, active transport, and ultrafiltration from the bloodstream, allowing for the identification of systemic diseases.[3]

The main diagnostic technique employed for saliva analysis was RT-PCR, although other methods such as RT-LAMP and immunoassays (ELISA) were also assessed. Saliva shows high sensitivity and specificity in detecting SARS-CoV-2, especially during the early stages of infection and even in people without symptoms. Saliva showed similar effectiveness to nasopharyngeal swabs, with both methods demonstrating high consistency. Importantly, saliva shows high sensitivity during the initial phases of infection and in people without symptoms, reinforcing its value in reducing the spread of the virus. In some instances, viral RNA can still be detected in saliva for multiple weeks following the appearance of symptoms, even when respiratory swab tests have come back negative. In addition to molecular

detection, saliva can be used to identify specific antibodies like IgG, IgM, and IgA, indicating its possible use in tracking both short- and long-term antibody-based immune responses. The option to collect items oneself and receive telemedicine support further lowers the risk of infection and enhances access. Saliva has shown particular usefulness in detecting infectious diseases, especially for viral pathogens, where both viral genetic material and host antibodies can be identified with diagnostic accuracy similar to that of traditional samples.[12]

ALZHEIMER'S DISEASE AND PERIODONTITIS

New research using multi-omics approaches suggests a strong link between periodontal dysbiosis and Alzheimer's disease (AD), emphasizing the oral brain connection as a possible mechanism and diagnostic route. Changes in the microbiome and metabolome of saliva and gingival crevicular fluid (GCF) have regularly been found in patients with Alzheimer's disease (AD) and mild cognitive impairment (MCI). Notably, a higher presence of periodontal pathogens like Porphyromonas gingivalis and Veillonella parvula has been associated with cognitive decline, systemic inflammation, and the severity of the disease. These changes in microbial composition are associated with increased levels of pro-inflammatory cytokines (IL-1β, IL-6, TNF-α), indicating that long-term periodontal inflammation might play a role in neuro-inflammatory processes involved in the development of Alzheimer's disease.[5]

Figure2: Relationship between Alzheimer's disease and periodontitis via the oral brain axis in which the arrows indicates proposed mechanism that connects the periodontal inflammation to neuro-degeneration: periodontal disease leads to systemic inflammation (IL-1β, IL-6, TNF-α), which contributes to blood-brain barrier disruption and promotes microglial activation and accumulation of amyloid-β and pTau181 in the brain, leading to cognitive decline. Bidirectional arrows highlight the diagnostic potential of salivary and gingival crevicular fluid biomarkers (e.g., ApoE, PgAgD), as well as the interplay between oral and neurological health.[5]

Metabolomics studies also reveal disruptions in salivary metabolites, such as L-tyrosine, galactinol, mannitol, taurine, and 3-hydroxybutyric acid, several of which are linked to oxidative stress, changes in energy metabolism, and immune system activation. Crucially, specific salivary proteins like stratifin (14-3-3σ) exhibit strong links with well-

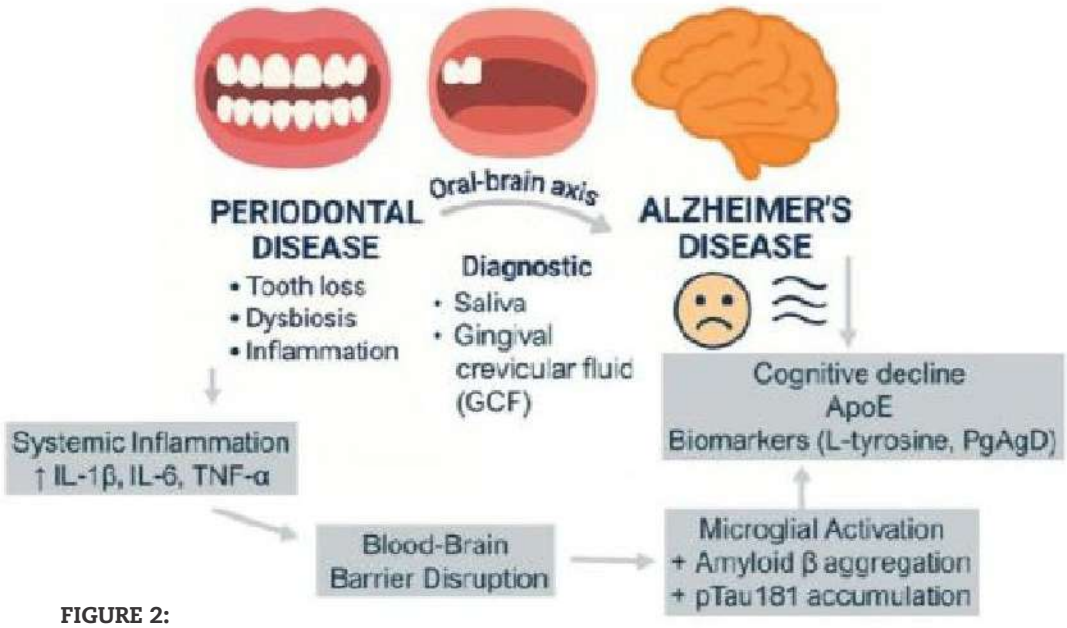


FIGURE 2:

established plasma biomarkers for Alzheimer's disease, such as phosphorylated tau (pTau181), suggesting that oral biofluids could mirror central nervous system pathological processes.[5]

Additionally, functional changes in the microbiome have been observed, including variations in the expression of bacterial virulence factors and metabolic enzymes, implying that oral pathogens might actively affect host immune responses and the integrity of the blood brain barrier. Moreover, longitudinal data suggest that periodontitis is linked to faster cognitive decline, reinforcing the idea that periodontal disease could be a changeable risk factor in the progression of Alzheimer's disease.[5]

Changes in microbial makeup and the body's immune responses are being recognized more and more as factors that influence neurodegeneration. Certain periodontal pathogens, particularly Porphyromonas gingivalis, are known to initiate systemic inflammatory responses and generate virulence factors that can access neural tissues. Bacterial elements, including lipopolysaccharides, can increase oxidative stress, the release of cytokines, and harm to neurons. Prolonged exposure to these inflammatory triggers could worsen synaptic impairment and accelerate cognitive deterioration.[13]

In addition to microbial factors, disruptions in metabolic and immune pathways such as changes in cytokine signalling, reduced removal of amyloid peptides ,and mitochondrial issues seem to interact within a complex disease mechanism. The two-way connection between systemic inflammation and neurodegeneration indicates that treatable peripheral conditions, such as periodontal disease, could serve as possible targets for therapy or prevention.[13]

FORENSIC MEDICINE

Saliva, commonly found at crime scenes as bite marks, lip prints, cigarette butts, and food residue, is a dependable source of DNA and biochemical markers that can connect individuals to criminal acts. Salivary α-amylase serves as a crucial indicator for saliva detection, with the discussion covering a range of preliminary and confirmatory tests, including starch-iodine diffusion, the Phadebas test, RSID-Saliva, and SERATEC amylase assays. Advanced detection techniques, such as alternative light sources, forensic lighting, and fluorescent spectroscopy that rely on tryptophan emission, improve the visibility and recognition of dried saliva stains. The text emphasizes the importance of using proper collection techniques, especially the double-swab method, to enhance DNA recovery. Saliva has also been demonstrated to be helpful in determining blood groups, detecting drug and alcohol use, assessing cigarette consumption by measuring thio-cyanate levels, and analyzing bite marks.[14]

NEURODEGENERATIVE DEMENTIA

Various metabolites linked to neuro degenerative disorders. In Alzheimer's disease, there are increased levels of amyloid-β42, t-tau, and serotonin. In contrast, Alzheimer's patients frequently exhibited lower levels of lactoferrin and taurine. Mild Cognitive Impairment (MCI) is characterized by specific changes, such as variations in taurine, cholesterol, and lactoferrin levels. Vascular Dementia (VaD) was characterized by elevated levels of histamine and propionate, along with reduced levels of taurine and succinate. The two main spectroscopic techniques used to analyze the complex salivary metabolome are Nuclear Magnetic Resonance (NMR) Spectroscopy, which is useful for detecting small molecules through their unique resonance frequencies, and Mass Spectrometry (MS), which is frequently combined with chromatography to offer a detailed insight into metabolic changes.[15]

Certain metabolites, such as propionate, are also elevated in oral diseases (eg. periodontitis), making it challenging to ascertain whether they are specific to dementia or are instead indicative of poor oral health. There is a significant absence of standardized procedures for collecting and storing samples; therefore, using stimulated saliva helps guarantee sufficient sample quantities. Larger, multicenter longitudinal studies should be con-

ducted to validate these biomarkers for clinical use, and review calls should be made to facilitate this.[15]

CANCER

Saliva is becoming more widely acknowledged as a useful, non-invasive biological fluid for identifying a range of systemic conditions, including various types of cancer such as breast, oral, and pancreatic cancer. The following will explain how various cancers can be detected using saliva.

a) Breast cancer

Saliva-oncoomics is an emerging specialized field that utilizes "omics" technologies to identify and track breast cancer via the analysis of saliva. The authors suggest that saliva serves as a highly effective diagnostic tool since the salivary and mammary glands originate from the same embryonic tissue and possess comparable biological receptors. This biological connection enables the identification of breast cancer-specific biomarkers, such as BRCA1/2 mutations in genomics, HER2 proteins in proteomics, and certain metabolic byproducts like lactic acid, making saliva a feasible "liquid biopsy" that is completely non-invasive and simple to collect.[2]

However, despite this potential, current research is frequently disjointed and lacks the standardization required for clinical application. To address this gap, suggest a move towards "interact-omics," an approach that focuses on examining the intricate interactions across various molecular levels, such as the impact of genetic mutations on protein expression in saliva. Spectral-omics employs vibrational spectroscopy to detect distinctive "fingerprints" of cancer in saliva. Saliva-oncoomics has the potential to transform early detection by offering a painless and easily accessible option compared to conventional imaging methods such as mammography.[2]

b) Oral cancer

Oral squamous cell carcinoma (OSCC) is a significant global health concern and is among the most common cancers worldwide, with patient survival rates strongly influenced by the stage at which the cancer is diagnosed. Early detection is essential because stage I disease has a five-year survival rate of about 80%, while survival rates can drop to nearly 20% in stage III or IV cases. In this context, saliva has become a promising diagnostic tool due to its non-invasive nature, ease of collection, affordability, and safety for healthcare professionals. Saliva directly surrounds oral tumors, acting as a biological "window" to their molecular microenvironment. Among the many salivary biomarkers being studied,

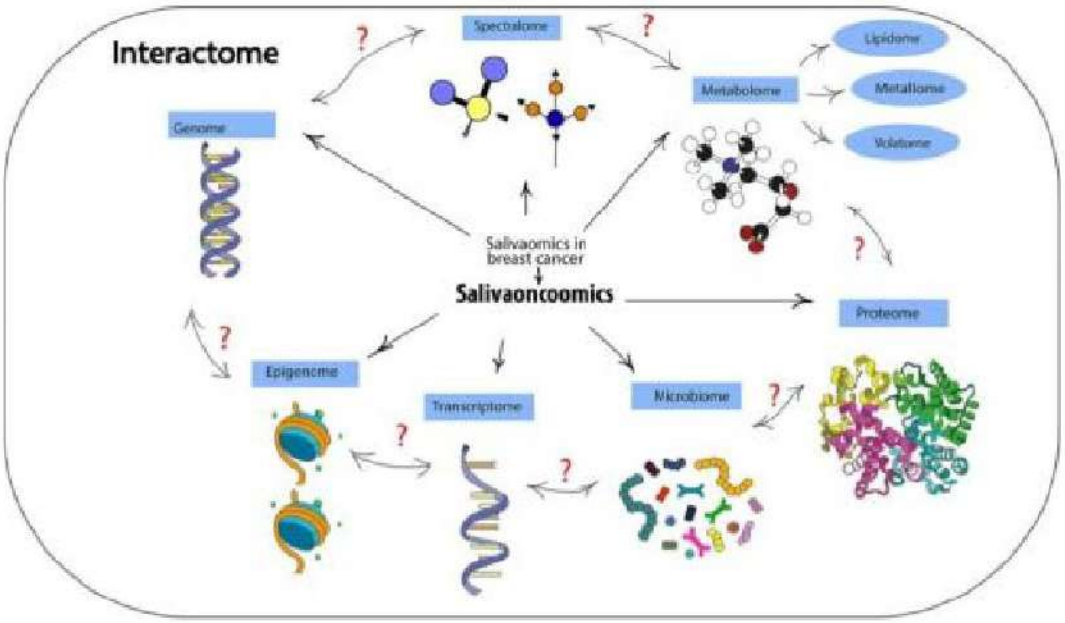


FIGURE 3: Basic structural components of salivonkoomics[2]

microRNAs (mi-RNAs)small, non-coding RNA molecules that control gene expression have attracted significant interest. In OSCC, mi-RNAs can act as either oncogenes or tumor suppressors, thus affecting crucial processes like cell growth, programmed cell death, invasion, and metastasis. Oncogenic mi-RNAs, such as miR-21, support tumor cell survival by suppressing tumor suppressor genes like PTEN, miR-31 increases the potential for invasion and metastasis by regulating epithelial-mesenchymal transition (EMT), and miR-184 is associated with greater tumor aggressiveness and progression. On the contrary, tumor suppressor mi-RNAs like miR-375 are often decreased in later stages, miR-125a restricts cell growth and its reduction speeds up disease progression, while miR-200a is essential in preventing metastasis by inhibiting EMT.[4]

Although they show promise for diagnosis and prognosis, several challenges hinder the regular use of salivary mi-RNAs in OSCC clinical practice. A significant challenge is the lack of standardized procedures for collecting, processing, and analyzing saliva, which leads to inconsistencies between studies. Moreover, salivary mi-RNA profiles can be affected by various confounding factors, including diet, oral hygiene habits, tobacco use, alcohol intake, and changes related to the body's daily rhythms. Tumor heterogeneity adds another layer of complexity to biomarker development, since molecular profiles vary significantly among patients, making it challenging to identify universally applicable markers. Although mi-RNAs can be broken down by RNAses in saliva, their stability is somewhat maintained when they are enclosed in

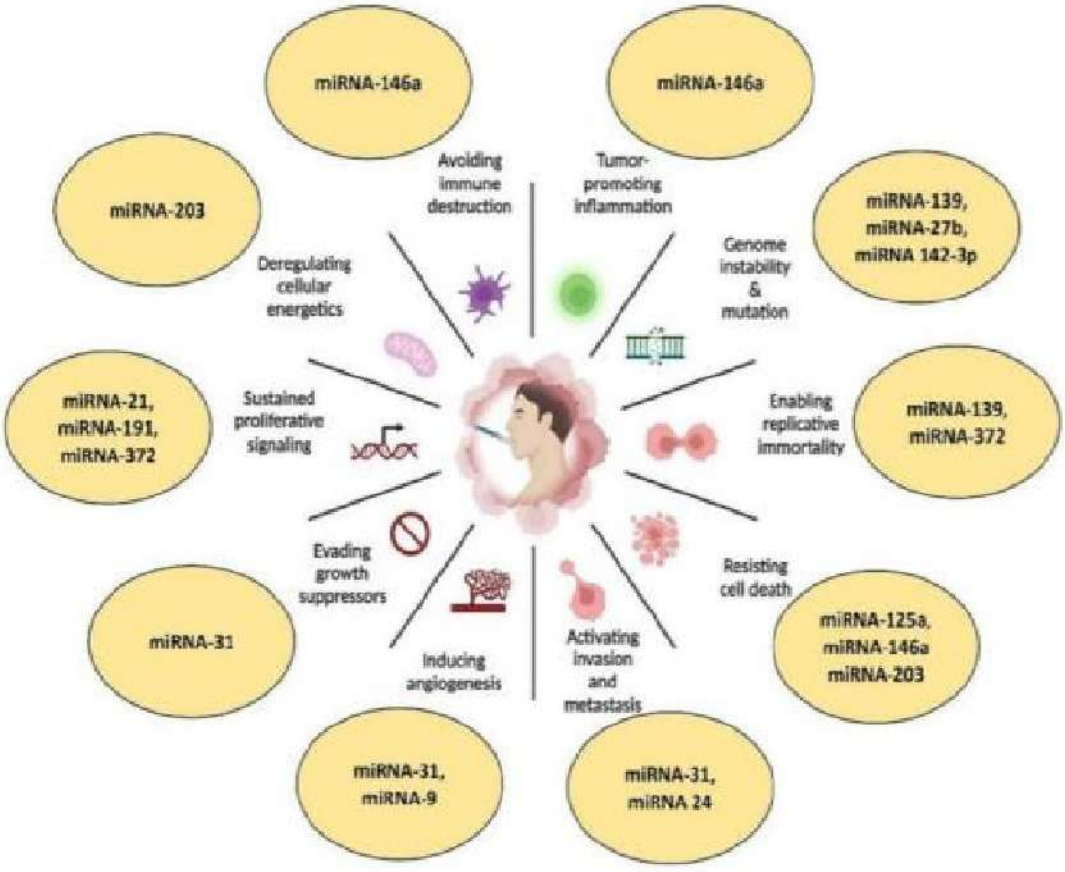


FIGURE 4:
Schematic illustration of salivary mi-RNA associated with hallmarks of cancer in OSCC.(4)

extracellular vesicles like exosomes. Future outlooks highlight the importance of combining salivary mi-RNA profiling with other omics methods, such as proteomics and metabolomics, to enhance diagnostic accuracy. In addition, mi-RNAs are being investigated as potential therapeutic targets, with current preclinical studies evaluating mi-RNA mimics and inhibitors designed to hinder tumor growth and development.[4]

CONCLUSION

Saliva has transitioned from being seen simply as an oral secretion to a clinically significant diagnostic fluid with wide-ranging applications in both medicine and dentistry. Growing evidence shows that salivary biomarkers effectively indicate both local oral diseases and broader systemic physiological and pathological conditions.

The primary benefits of salivary diagnostics include the non-invasive, pain-free, and affordable method of collection, the ability to perform repeated sampling, and the practicality of conducting large-scale screenings and home monitoring. Recent progress in molecular biology, omics technologies, and analytical tools has made it possible to detect intricate biomarker patterns that include proteins, enzymes, cytokines, metabolites, nucleic acids, microRNAs, and microbial characteristics. These advancements encourage a shift in approach from responding to illnesses after they occur to focusing on early identification, continuous tracking, and tailored medical care.

Although it shows great potential, several challenges need to be resolved before it can be widely used in clinical settings. Variations in saliva composition, the absence of standardized procedures for collection and analysis, low levels of biomarkers, and the impact of confounding factors like circadian rhythms, diet, smoking, and oral health continue to represent major challenges. To overcome these challenges, strict standardization, validation via extensive multi-center studies, and the combination of multiple biomarker and multi-omics methods will be necessary.

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LASERS IN ESTHETIC DENTISTRY

Authors:
Apsara Subramanian[1]
Bibina Basheer[2]
Fathima P A[3]

House Surgeon[1,2,3]
Department of Public Health Dentistry
Annoor Dental College & Hospital
Muvattupuzha, Kerala

Corresponding Author
Apsara Subramanian
House Surgeon
Department of Public Health Dentistry
Annoor Dental College & Hospital
Muvattupuzha, Kerala

Mail:
apsarasubramanian2001@gmail.com

ABSTRACT

Laser technology has emerged as an important adjunct to contemporary dentistry because it enables precise, minimally invasive management of both soft- and hard-tissue procedures. This narrative review evaluates the role of lasers in dentistry, with particular emphasis on their applications in aesthetic dental practice. Relevant literature available through Google Scholar was reviewed to summarize the principles, clinical uses, advantages, limitations, and future potential of laser-assisted procedures. Different laser systems, including diode, erbium, Nd:YAG, and CO_2 lasers, interact differently with oral tissues; therefore, appropriate wavelength selection, power settings, and clinical technique are essential for safe and predictable outcomes.

In aesthetic dentistry, lasers are widely used for gingival contouring, gingivectomy, crown lengthening, depigmentation, frenectomy, exposure of unerupted teeth, treatment of inflammatory gingival enlargement, and optimization of the gingival smile line. They also have applications in tooth whitening, management of dentinal hypersensitivity, periodontal therapy, disinfection during endodontic treatment, photodynamic therapy, and photobiomodulation to support healing and reduce postoperative discomfort. Compared with conventional techniques, laser-assisted treatment may provide improved hemostasis, reduced bacterial load, less postoperative pain and edema, reduced need for sutures and local anesthesia in selected cases, faster healing, and enhanced patient acceptance. These advantages are particularly valuable in aesthetic procedures, where preservation of healthy tissue and accurate gingival architecture are essential.

However, lasers are not a universal replacement for conventional dental instruments. Their effectiveness depends on the procedure, laser wavelength, clinician experience, correct safety protocols, and case selection. High equipment costs, the need for training, possible thermal tissue damage from incorrect use, and limited suitability of certain lasers for hard-tissue procedures remain important limitations. Overall, lasers represent a valuable addition to modern aesthetic and general dental practice, offering the potential for more precise, comfortable, and minimally invasive care when used according to evidence-based protocols.

Keywords: Lasers; aesthetic dentistry; gingival depigmentation; teeth whitening; minimally invasive dentistry.

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INTRODUCTION

Since the 1960s, lasers have become a valuable tool in dentistry, offering precise, efficient, and minimally invasive treatment options for both hard and soft oral tissues. Over the decades, their use has expanded from detecting small cavities to assisting in the management of serious conditions like oral cancers. Among the various types, diode lasers are the most commonly used for soft-tissue procedures such as gum reshaping, frenectomy, and removal of oral lesions. In the 1970s, researchers also established the effectiveness of carbon dioxide (CO_2) and Nd:YAG lasers for treating oral soft tissues, further broadening the clinical applications of laser technology in dental care. To increase interaction with dental hard tissues, the first pulsed "Nd: YAG laser" was released in 1900. Surgical and non-surgical dental lasers, low-level laser therapy, laser doppler flowmetry, PAD, laser-based curing light, and other treatments are available[1].

LASER stands for Light Amplification by Stimulated Emission of Radiation. First introduced to dentistry by Goldman et al. in the 1960s, early lasers caused excessive heat damage and were not clinically viable. Pioneering work by Pick (1985 gingivectomy study) and the development of the helium-neon laser (Bennett & Herriott, 1961) laid the foundation for modern therapeutic use. Lasers emit focused electromagnetic energy across UV, visible, and infrared spectra, with specific wavelengths absorbed by tissue chromophores (melanin, hemoglobin, hydroxyapatite, water), enabling precise, sterile, and comfortable aesthetic procedures.[2]

Laser technology has transformed dentistry by enabling precise treatment of hard and soft tissues with reduced discomfort, bleeding, and healing time. Since its introduction into dental practice in the 1990s, lasers have been used in periodontal therapy, cavity preparation, caries removal, root canal treatment, implantology, photobiomodulation, and tooth whitening. Common dental lasers include CO_2, diode, and erbium lasers. Their effects depend on the wavelength and tissue targeted, allowing them to cut, vaporize, coagulate, or decontaminate tissue. Lasers may also reduce the need for anesthesia and help control infection. However, laser treatment has limitations, including high equipment and training costs. In many procedures, lasers complement rather than replace conventional instruments such as dental burs. Continued advances may improve their effectiveness, affordability, and integration into routine dental care.[3]

LASER stands for Light Amplification by Stimulated Emission of Radiation. Dental lasers have become valuable tools in cosmetic and soft-tissue dentistry because they can improve treatment precision, patient comfort, hemostasis, and healing. Although lasers were introduced into medicine and dentistry in the 1960s, early devices caused excessive thermal damage. Advances in wavelength selection and power control have since made lasers suitable for several clinical applications.[2]

Laser energy interacts with tissue through chromophores such as melanin, hemoglobin, water, and hydroxyapatite. Depending on the wavelength and power, this interaction can produce coagulation, vaporization, ablation, carbonization, or tissue denaturation.[2]

Clinicians in this field help patients achieve good-looking smiles and oral health and gain tremendous clinical advantages like sterile procedures and increased patient comfort. Advances in equipment technology have transformed modern dentistry, replacing conventional belt-driven motors with air rotors, air-abrasion devices, digital radiography, and laser systems. Among these innovations, lasers have attracted particular interest because of their precision and wide range of clinical applications. Although introduced into dentistry several decades ago, laser technology has gained increasing prominence in recent years and continues to expand the possibilities of modern dental treatment.

Modern dental lasers are used for both soft- and hard-tissue procedures. Their safe and effective use depends on three key principles:

- matching the laser wavelength to the target tissue chromophores (hemoglobin, melanin, and water in soft tissue; water and hydroxyapatite in hard tissue),
- understanding depth of penetration, which is shallow for water-absorbed wavelengths and deeper for visible/near-infrared light,

- recognizing whether the dominant photo effect is photothermal or photoacoustic to guide cooling and relaxation intervals. Visible and near-infrared wavelengths, poorly absorbed by water, penetrate deeper and are suited mainly to soft tissue and photobiomodulation, whereas near- and mid-infrared wavelengths, strongly absorbed by water, act more superficially and are appropriate for both soft- and hard-tissue applications.[5]

Classification of Lasers Used in Dentistry

Classification of lasers according to the lasing medium, tissue applicability, wavelength, and output power.

Basis of classification	Category	Examples	Main dental applications or characteristics
Lasing medium	Gas lasers	Carbon dioxide (CO_2), argon, helium–neon (He–Ne)	Used mainly for soft-tissue surgery, coagulation, photobiomodulation, and selected dental procedures.
	Liquid lasers	Dye lasers	Use different dye solutions as the active medium; mainly used in specialized applications.
	Solid-state lasers	Nd:YAG, Er:YAG, Er,Cr:YSGG	Used for soft-tissue procedures, periodontal therapy, caries removal, cavity preparation, and hard-tissue applications. Nd:YAG Lasers have strong coagulation that provides a bloodless field and faster healing, but settings must be carefully controlled to avoid thermal damage to bone and surrounding tissue.
	Semiconductor lasers	Diode lasers	Commonly used for soft-tissue surgery, periodontal procedures, gingival contouring, bleaching, and photobiomodulation. This selective absorption enables precise cutting with excellent coagulation and minimal damage to hard tissues.
	Excimer lasers	Argon fluoride, krypton fluoride, xenon chloride	Mainly used in specialized and experimental applications
Tissue applicability	Soft-tissue lasers	Diode, CO_2, Nd:YAG, argon, He–Ne	Gingivectomy, frenectomy, gingival recontouring, periodontal treatment, biopsy, coagulation, and photobiomodulation
	Hard-tissue lasers	Er:YAG, Er,Cr:YSGG	Caries removal, enamel and dentin preparation, cavity preparation, etching, and removal of restorative materials

	Both hard- and soft-tissue lasers	Nd:YAG, Er:YAG, CO_2	May be used for both tissue types depending on wavelength, energy settings, and clinical indications
Output power	Low-power or soft lasers	He–Ne and low-power diode lasers	Used mainly for therapeutic effects, pain reduction, wound healing, and stimulation of cellular activity
	High-power or hard lasers	CO_2, Nd:YAG, Er:YAG, Er,Cr:YSGG	Used for cutting, vaporization, ablation, coagulation, and surgical procedures
Wavelength range	Ultraviolet lasers	Excimer lasers	Specialized applications involving precise tissue interaction
	Visible-light lasers	Argon and He–Ne lasers	Used in selected soft-tissue, diagnostic, and therapeutic applications
	Infrared lasers	Diode, Nd:YAG, Er:YAG, and CO_2 lasers	Widely used in soft-tissue surgery, periodontal therapy, caries management, and hard-tissue procedures

Table no:1 classification of Lasers[4,6]

Laser parameters and factors influencing clinical outcomes:

- Wavelength: Determines tissue penetration and absorption by chromophores such as water, haemoglobin, and melanin, affecting treatment precision and thermal damage.
- Power output: Controls the amount of energy delivered per unit time, influencing cutting, coagulation, and tissue damage.
- Pulse duration: Affects heat transfer and tissue ablation; shorter pulses generally reduce collateral thermal injury.
- Energy density (fluence): Energy delivered per unit area, determining the extent of ablation or biostimulation.
- Spot size: Smaller spots concentrate energy for precise cutting, while larger spots treat broader areas with lower energy density.
- Continuous or pulsed mode: Continuous mode supports rapid cutting, whereas pulsed mode allows tissue cooling and reduces thermal damage.
- Tissue chromophores: Water, haemoglobin, and melanin absorb laser energy selectively and determine tissue penetration and clinical effects.[6]

LASER APPLICATIONS IN DENTISTRY:

Lasers are used in dentistry to treat both hard and soft tissues with greater precision than traditional methods. They minimize damage to surrounding tissues, reduce bleeding, inflammation, and postoperative discomfort, and may lessen the need for local anesthesia. Because lasers produce less noise and vibration than dental burs, they improve patient comfort. They also provide a clearer, relatively sterile treatment area, which may reduce infection risk and support faster healing. Common applications include periodontal treatment, cavity preparation, soft-tissue surgery, root canal therapy, and tooth whitening.[3]

Lasers are special beams of light used in many dental treatments. They can be used as an alternative or an additional method to normal dental instruments in selected cases. In gum treatment, lasers can remove infected or

damaged gum tissue, reduce bacteria, control bleeding, and support healing. In root-canal treatment, lasers may help disinfect the canals after normal cleaning and shaping. In tooth whitening, laser light may activate the bleaching gel and help break down stains on teeth.Lasers are also useful in implant dentistry, soft-tissue surgery, gum reshaping, frenectomy, operculectomy, and treatment of some oral lesions. They may also be used around implants to help clean infected areas. Different lasers are used for different tissues. Er:YAG and Er,Cr:YSGG lasers can be used on both hard tissues, such as teeth and bone, and soft tissues, such as gums. Diode and CO_2 lasers are mainly used for soft-tissue procedures. Low-level laser therapy uses gentle laser energy without cutting tissue. It may reduce inflammation, pain, and swelling and can promote healing after dental treatment. Overall, lasers can make many dental procedures more comfortable and accurate. However, they should be used by trained dentists and usually work best along with conventional dental treatment.[7]

Lasers are widely used in esthetic dentistry to reshape gums, remove dark pigmentation, and improve smile balance with minimal bleeding and faster healing.[8]

Periodontics

Dental lasers are widely used in periodontal therapy as part of a multistep protocol:

- Scaling and root planing to debride and disinfect the sulcular epithelium (Nd:YAG, diode)
- Removal of calculus and smear layer from root surfaces (Er:YAG)
- Promotion of fibrin clot formation and coagulation (Nd:YAG, diode) to support epithelial reattachment.

Nd:YAG and diode lasers are poorly absorbed by water, allowing deeper penetration and efficient targeting of hemoglobin and melanin in diseased epithelium, while Er:YAG-induced shock waves in water ai calculus removal and smear-layer elimination. With Nd:YAG, longer pulse durations (~650µs) favour fibrin clot formation, providing a scaffold for new tissue growth after debridement of the pocket lining.[4]

Lasers are used for bacterial reduction, subgingival calculus removal (Er:YAG), pocket epithelium removal, root conditioning, and enhancement of periodontal regeneration.

- **Removal of pocket epithelium:** Nd:YAG and CO_2 lasers effectively de-epithelialize periodontal pockets, often more completely than curettes.
- **Laser root conditioning:** Defocused, pulsed CO_2 lasers produce smooth root surfaces that promote fibroblast attachment and cellular proliferation.
- **Bacterial reduction:** Diode lasers used with ultrasonic scaling significantly reduce bacteremia and bacterial load in periodontal pockets[4].

Gingival depigmentation

Dark gums are caused by excess melanin. Lasers target melanin (and hemoglobin) because these chromophores absorb specific laser wavelengths. The absorbed light turns into heat, vaporizing pigmented cells in a controlled way (ablation). This gives a lighter, more uniform gum color. Diode lasers (around 810-980 nm) are commonly used; they can be run in continuous or pulsed mode depending on the case.[8]

Benefits: Less pain, no sutures or dressings, quicker recovery, and often better esthetics than scalpel or electrosurgery.[9]

Gingival aesthetic reshaping

Lasers help correct uneven gum lines, adjust crown height, and improve tooth proportions for a balanced smile. Diode lasers are often used at about 0.8-1.2 W in continuous mode with fine tips to precisely trim and shape soft tissue while sealing blood vessels.Ideal gum contours show symmetry, with matching gingival zeniths (highest points) around front teeth for a natural look.[8]

Gingival Cosmetic Re-sculpting

Lasers refine gum shape and symmetry to improve smile aesthetics:

Corrects uneven gum heights and tooth proportions.

Enhances gingival form (curve of gum margin) and contour (3D gum topography, including papillae).

Technique tip: The laser ablates tissue with focused photons drag the fiber gently along the planned path instead of pressing.

Visible improvement typically seen within~3 weeks post-procedure.[9]

Crown lengthening for esthetics (fixing "gummy smile"):

Crown lengthening exposes more tooth by removing excess gum (and sometimes bone) to reduce a gummy smile or prepare for restorations. Laser-assisted gingivectomy can reshape gums with less bleeding and discomfort than traditional surgery; in some cases it's combined with flap techniques or minor bone work. Because diode lasers interact little with enamel and bone at proper settings, they're safe and predictable for soft-tissue crown lengthening.[8]

Goals: Expose more tooth, balance gum-to-tooth ratios, and prepare for crowns/veneers.[9]

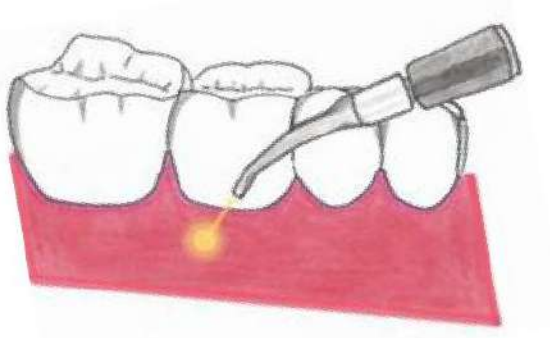


Fig. 1: Use of a laser in dentistry as an accurate, non-invasive method with predictable results.[7]

Restorative Dentistry

Lasers have multiple applications in restorative dentistry, including caries prevention, cavity preparation, enamel and dentin etching, composite curing, desensitization, and bleaching.

Prevention of caries: Nd:YAG and CO_2 lasers can help prevent dental caries by increasing the resistance of enamel to acid demineralization. Laser irradiation modifies the enamel crystal structure and reduces its solubility, making the tooth surface less vulnerable to acid attacks produced by cariogenic bacteria. This is especially beneficial in aesthetic dentistry, where maintaining intact, healthy enamel is important for preserving the natural shade, translucency, and surface gloss of the teeth.

Lasers can also be used to remove incipient carious lesions and debride pits and fissures before the application of pit-and-fissure sealants. By cleaning and preparing these susceptible areas, the laser improves the adaptation of the sealant and helps protect the enamel from future demineralization. This preventive approach is particularly useful for young patients, patients with high caries risk, and individuals undergoing aesthetic treatments where preservation of natural tooth structure is a priority.

Nd:YAG and CO_2 lasers increase enamel resistance to acid demineralization by modifying the crystal structure and reducing solubility. Lasers can also remove incipient caries and debride pits and fissures before sealing.[4]

Cavity preparation: Er:YAG (2.94 µm) and Er,Cr:YSGG (2.78–2.97 µm) lasers efficiently ablate enamel, dentin, and bone with minimal pulpal temperature rise and reversible pulpal response, comparable to conventional high-speed drills.[4]

Co_2 and Er:YAG lasers are effective for hard-tissue procedures, including cavity preparations. Unlike rotary burs, lasers are non-contact (typically~10 mm from the tooth), rely on visual rather than tactile feedback, and cut primarily in an end-cutting manner; many preparations, including Class II, can be performed without local anesthesia, which is advantageous for pediatric and anxious patients. Both wavelengths are absorbed by water and hydroxyapatite, but Er:YAG is ~100× more absorbed by water, while CO_2 is ~100× more absorbed by hydroxyapatite. Er:YAG removes tooth structure mainly via a photoacoustic mechanism (micro-explosions in enamel/dentin), whereas CO_2 acts via photothermal ablation/vaporization. Water spray with Er:YAG hydrates and cools the tooth despite minimal heat generation; with CO_2, it limits thermal rise to protect the pulp. Both lasers efficiently remove enamel and dentin, albeit through different physical interactions.[5]



Fig 2. CO2 Laser Class I preparation[5]



Fig 3. CO2 Laser Class II preparation[5]



Fig 4. CO2 Laser Class III preparation[5]

Depigmentation/ De-epithelialization

Among the available systems, Nd:YAG laser has shown superior long-term desensitization compared with diode laser in some studies. Er:YAG laser has also demonstrated effective long-term reduction of dentin hypersensitivity. In aesthetic dentistry, laser desensitization is particularly valuable after bleaching, enamel microabrasion, veneer preparation, or exposure of cervical dentin, as it improves patient comfort while preserving the natural appearance and integrity of the tooth.

Diode, Nd:YAG, erbium, and CO_2 lasers can reduce dentin hypersensitivity, though proposed mechanisms differ: some suggest surface protein coagulation and melting/sealing of tubule openings with a "frozen" smear layer, while others propose intratubular plasma precipitation altering nerve fiber activity. Power settings are typically ~10× lower than surgical levels to avoid irreversible tooth damage. Nd:YAG has shown superior long-term desensitization compared with diode in some studies, while Er:YAG has also demonstrated effective long-term dentin desensitization.[5]

Amalgam tattoos and melanin pigmentation can be removed using diode, Nd:YAG, erbium, and CO_2 lasers. Diode and Nd:YAG energy is absorbed by dark pigments, causing direct tissue ablation, whereas erbium and CO_2 lasers ablate pigmented tissue indirectly via water absorption in soft tissue. Low-energy de-epithelialization produces a superficial photothermal effect that enhances local blood flow and accelerates healing without true ablation or photobiomodulation; this can be achieved with erbium and CO_2 lasers and is useful in managing conditions such as lichen planus and spongiotic gingivitis.[5]

Bleaching: Lasers are used to accelerate bleaching of both vital and non-vital teeth. In dental bleaching, lasers act through a photothermal and photochemical process by directing light energy at bleaching agents like hydrogen peroxide. The absorbed energy converts into heat that accelerates the decomposition of the bleaching gel into reactive free radicals to oxidize and remove organic stains.[4]

Pediatric Dentistry

- Frenectomy and ankyloglossia: In an attempt to close a midline diastema, a laser-assisted frenectomy using an Er:YAG laser may be performed when a hyperactive or abnormally attached maxillary labial frenum is present. A thick or low-inserting frenum can pull on the gingival tissues and prevent complete closure of the space between the central incisors. By precisely releasing the abnormal frenum, the Er:YAG laser reduces this traction and supports orthodontic closure while helping to minimize relapse. Its high absorption by water allows controlled tissue removal with minimal thermal damage, reduced bleeding, less discomfort, and often no need for sutures. The Er:YAG laser is also used to manage ankyloglossia, or tongue-tie, in infants and children. A restricted lingual frenum can affect feeding, speech, and oral hygiene; laser frenotomy or frenectomy releases the tissue, improves tongue mobility, and offers a minimally invasive alternative to conventional surgery.
- Exposure of unerupted teeth: Er:YAG, Nd:YAG, and Er,Cr:YSGG lasers can be used to expose an unerupted or partially erupted tooth so that an orthodontic bracket or bondable button can be attached. This is commonly required for impacted canines, premolars, or central incisors that have failed to erupt into the dental arch. The laser removes the overlying soft tissue and, when necessary, a small amount of overlying bone, creating a clean and dry field for immediate bracket or button placement. Compared with conventional surgical exposure, laser-assisted exposure offers better hemostasis, reduced need for sutures, less postoperative swelling and discomfort, and improved patient acceptance. Because the tissue is precisely removed with minimal thermal damage, the exposed enamel surface can be prepared and bonded soon after the procedure, allowing orthodontic traction to begin without delay. This makes lasers a useful adjunct in interdisciplinary orthodontic and surgical management of impacted teeth.
- Prevention of dental caries: In aesthetic dentistry, preserving the natural enamel surface is essential because enamel determines the color, translucency, gloss, and overall appearance of the smile. Erbium and CO_2 lasers can increase the caries resistance of enamel when applied to the surface of a newly erupted tooth. CO_2 lasers operating at wavelengths of 10,600 nm, 9,600 nm, and 9,300 nm, as well as Erbium lasers at 2,940 nm and 2,780 nm, have been reported to produce a similar caries-resistant effect.The laser energy causes controlled heating and microstructural modification of the enamel surface, reducing its permeability and making it less susceptible to acid attack from cariogenic bacteria. This is particularly valuable in aesthetic treatment planning, as it helps protect the visible facial surfaces of anterior teeth while maintaining their natural appearance.[4]

LOW-LEVEL LASER TREATMENT (LLLT)

LLLT uses red (600-700 nm) and near-infrared (770-1200 nm) light at low power to stimulate cellular metabolism without thermal damage. Photons are absorbed by cytochrome c oxidase in mitochondria, boosting ATP, cAMP, ROS, and NO production, which enhances healing, reduces inflammation and pain, and promotes tissue regeneration.

- Treats oral mucositis (approved by MASCC/ISOO), recurrent aphthous ulcers, herpes simplex, trigeminal neuralgia, and xerostomia (increases salivary flow and MUC5B).

Supports periodontal therapy, implant osseointegration, and management of BRONJ/MRONJ when combined with antibiotics.

- Optimal penetration occurs around 810 nm; dosing follows a biphasic response under-oroverdosing reduces efficacy or causes adverse effects.[7]

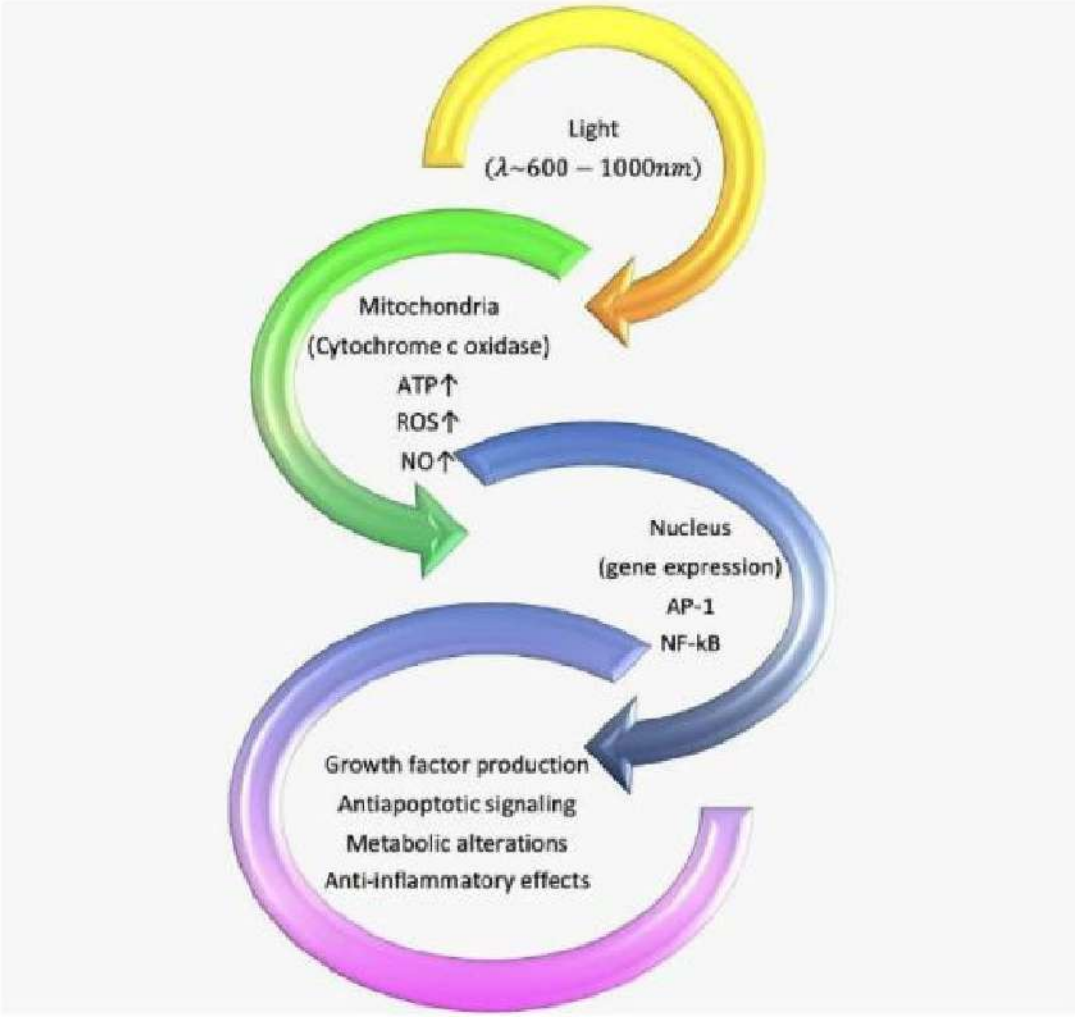


Fig:5 Summary of mechanism of action and direct effect of LLLT(7)

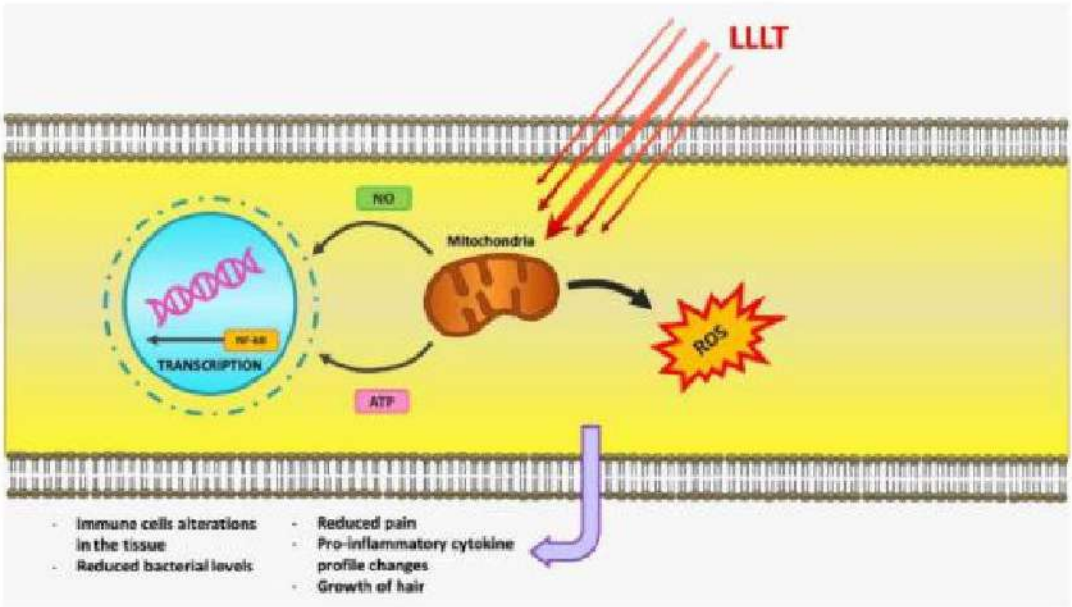


Fig:6 Graphical scheme of the direct effects of LLLT(7)

Photobiomodulation (PBM)

PBM reduces inflammation and promotes healing, with effects dependent on wavelength and energy density. Diode and Nd:YAG lasers, poorly absorbed by water, penetrate deeply to trigger mitochondrial biochemical responses; optimal wavelengths are ~660-1064 nm at doses of 4-8 J/cm². PBM is used to accelerate healing of aphthous ulcers, temporomandibular disorders, extraction sites, and soft-tissue surgical wounds, and to reduce postoperative pain after extractions or implant placement, significantly shortening healing time and pain levels.[5]

DISCUSSION

Soft-Tissue Applications of High-Power Dental Lasers

High-power lasers are widely used for soft-tissue procedures in dentistry. While some systems employ coolant, others operate without it; however, all procedures should use vacuum aspiration to control smoke and aerosol and maintain a clean field. Clinical reports show excellent aesthetic outcomes with minimal scarring in the treatment of vascular lesions such as capillary haemangioma, venous lake, and lip venous malformations.

Experimental work on gingival tissue across 400-1500nm wavelengths indicates that increasing power does not necessarily increase incision depth or thermal damage, highlighting the importance of wavelength and exposure parameters over power alone. In particular, a 635nm laser has been associated with reduced soft-tissue scarring. At the biological level, laser exposure can enhance healing by modulating TGF-β1 signaling and upregulating HBD-2, while low-frequency irradiation may provide additional therapeutic benefits.[3]

Er:YAG and Nd:YAG lasers have been used effectively for degranulation, sterilization, gingival de-epithelialization, clot stabilization, and phototherapy, including successful removal of physiologic gingival hyper pigmentation with superior efficiency compared to cryotherapy.[1]

Hard-Tissue and Adjunctive Laser Applications

Laser osteotomy and hard-tissue conditioning have benefited from wavelength-specific protocols. In one approach, Nd:YAG was used to help distinguish soft from hard tissue, while Er:YAG performed the actual bone excision. Er:YAG has also been applied to clean and assess root surfaces after composite removal in the cervical region. For implant therapy, Nd:YAG and Er:YAG irradiation has been used to modify implant surfaces and increase the area available for bone apposition during osseointegration.[3]

Surface conditioning and bonding have been additional focuses. CO_2 and Er:YAG lasers have been used to demineralize tooth structure around composite restorations; when fluoride varnish is applied before irradiation, enamel hardness and resistance improve, suggesting a synergistic effect. Laser irradiation of zirconia (using CO_2, Er:YAG, or Nd:YAG) has been shown to increase shear bond strength to resin cements, supporting its use as a surface-treatment alternative or adjunct. Studies also indicate that diode, Nd:YAG, and Er:YAG lasers, alone or combined with fluoride, can effectively occlude dentinal tubules, which is relevant for managing dentin hypersensitivity and potentially reducing caries risk. Clinical and laboratory evidence further supports selective laser use in hard- and soft-tissue contexts. For example, Er,Cr:YSGG and CO_2 lasers showed no recurrence of treated lesions over one year in vivo, while different wavelengths were matched to specific indications (e.g., CO_2 for vascular and premalignant /mucosal lesions; diode/Nd:YAG for benign mucosal or vascular lesions; erbium lasers for excision of benign growths). Flapless crown lengthening with Er,Cr:YSGG has achieved adequate tooth exposure without flap reflection, and post-extraction Er:YAG/Nd:YAG protocols have been reported to enhance alveolar bone repair. Low-level diode laser therapy has demonstrated benefits for pain reduction and anxiety management in dental patients, including those with temporo mandibular disorders, with longer wave-

lengths (≈910-1100nm) showing particularly favorable short-term analgesic effects.[3]

Safety considerations remain important. Intracanal laser use can raise temperatures and potentially affect surrounding periodontal tissues, and diode irradiation of primary tooth roots has been studied for its thermal effects on the outer root surface. Overall, contemporary reports indicate that lasers can complement or, in selected steps, replace conventional mechanical methods while offering minimally invasive, efficient tissue interaction.[1]

Future trends in laser dentistry

Laser dentistry is expected to become more precise, accessible, and widely used across dental specialties. Future developments include compact and affordable laser systems, improved wavelength selection, advanced fiber-optic delivery, AI-supported diagnosis, 3D imaging, and computer-assisted surgical planning. These advances may enable more minimally invasive procedures, preserve healthy tissues, improve treatment accuracy, and enhance patient comfort.

Diode lasers are already valuable in oral and maxillofacial surgery because they can provide good haemostasis, reduced postoperative discomfort, improved healing, and antibacterial effects. However, further long-term clinical research, standardized treatment protocols, and proper operator training are needed to ensure safe, predictable, and evidence-based use.[6]

CONCLUSION

Laser technology has undergone significant advancements in clinical dentistry and continues to offer considerable potential for future development. It addresses the increasing demand for minimally invasive, comfortable, and efficient dental treatments, enhancing treatment precision and improving clinical outcomes in both hard-and soft-tissue procedures. By facilitating faster interventions with greater accuracy, reduced tissue damage, and minimal patient discomfort, lasers have made several dental procedures more predictable and less invasive, often with improved bleeding control. Future research should prioritize optimizing thermal effects and improving wavelength selection and control to enhance procedural safety, treatment effectiveness, and overall clinical outcomes.

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CONSERVATIVE ESTHETIC TRANSFORMATION OF A NON-VITAL MAXILLARY CENTRAL INCISOR - A CASE REPORT

Authors:

Anjana Ashok[1]

Praveena G[2]

Post Graduate Student[1]
Department of Conservative Dentistry and Endodontics
Azeezia College of Dental Sciences and Research, Kollam

Professor and Head[2]
Department of Conservative Dentistry and Endodontics
Azeezia College of Dental Sciences and Research, Kollam

CORRESPONDING AUTHOR:
Anjana Ashok
Post Graduate Student
Department of Conservative Dentistry and Endodontics
Azeezia College of Dental Sciences and Research, Kollam

Mail Id: anjanaashok1997@gmail.com

ABSTRACT

Aesthetic dental enhancement has become increasingly relevant, gaining prominence and importance, with symmetry, shape, contour, and especially colour playing a crucial role. Among conservative and minimally invasive treatments, teeth whitening and composite veneering have gained considerable importance.

Minimally invasive approach provide satisfactory esthetics and functional outcomes while preserving the maximum remaining tooth structure. Furthermore, direct composite veneering represents a cost-effective restorative option that allows for future modifications or repairs without compromising the integrity of the underlying dental structure. Careful case selection and adherence to proper clinical protocols are essential to minimize the risk of post-treatment complications.

This case report demonstrate the management of a 32-year-old male patient diagnosed with pulp necrosis and symptomatic apical periodontitis in a maxillary central incisor. The treatment protocol consisted of nonsurgical root canal therapy, followed by walking bleach technique and direct composite veneering to restore the aesthetics.

Key Words: walking bleach technique, direct composite veneering, minimally invasive.

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INTRODUCTION

Fractured and discoloured anterior tooth is a significant aesthetic concern that can negatively affect a patient's confidence, psychosocial well-being, and perception of their own appearance.[1] Among the various causes, dental trauma is a leading factor, with most traumatic injuries involving the anterior region, particularly the maxillary central incisors. Post traumatic intra-pulpal haemorrhage, pulp necrosis, and subsequent bacterial invasion contribute to the development of intrinsic discoloration within the tooth structure. Aesthetic treatment options for discoloured teeth are Bleaching, Direct composite veneering, Indirect laminates, Indirect veneers and Crowns.[2] The intervention should include minimal damage to the tooth structure and should not affect future restoration options.

Non-vital bleaching is a simple and conservative method for removing intrinsic stains and lightening discoloured teeth without unnecessary removal of dental tissues.[3] It involves the use of oxidising agents that penetrate the tooth structure and break down organic pigments, thereby improving its colour. Common techniques for bleaching non-vital teeth include the walking bleach technique, inside-outside bleaching, and in-office bleaching.[4] The walking bleach and inside-outside techniques have been reported to produce comparable results; however, the walking bleach technique is often preferred because the access cavity is sealed, eliminating the need for a home bleaching tray. Internal bleaching generally produces more predictable outcomes when discoloration is associated with trauma or pulpal necrosis than when it is caused by restorative materials.[5]

Preservation of the natural tooth structure remains a key consideration. Depending on the clinical circumstances, treatment may involve direct or indirect restorations, or, when feasible, reattachment of the fractured fragment. Direct composite resin restorations are often preferred because they achieve satisfactory aesthetic outcomes while requiring minimal removal of sound dental tissue and providing a more economical alternative to indirect restorations. The treatment plan should be tailored to the patient's clinical condition, functional requirements, and aesthetic expectations.[6]

Based on these considerations, this clinical case presents a conservative treatment approach involving endodontic therapy, non-vital tooth bleaching, and aesthetic rehabilitation using direct composite resin restoration in a maxillary central incisor.

CASE REPORT

A 32-year-old male patient reported to the Department of Conservative Dentistry and Endodontics with a chief complaint of broken and discolored upper front tooth since1 year. The patient reported a history of trauma on the upper front teeth one year back and history of pain and sensitivity present at the time of trauma and presently symptomless. On clinical examination the tooth 11 showed enamel dentin fracture involving the middle third of crown. on palpation slight tenderness was present and Tender on percussion was positive. Intraoral periapical radiographs showed coronal radiolucency involving enamel and dentin suggestive of missing coronal structure with periapical lesion in relation to 11. Cold test and Electric Pulp Test of 11 showed no response compared to adjacent tooth.

DIAGNOSIS

Pulp necrosis with symptomatic apical periodontitis - 11

TREATMENT PLANNING:

Based on the clinical and radiographic findings the following sequence of treatment was planned for tooth 11

- Root canal treatment
- Non vital tooth Bleaching
- Direct composite veneering

PROCEDURE

1. ROOT CANAL TREATMENT

- The tooth 11 was anaesthetised using 2% lidocaine with 1:1,00,000 epinephrine as a local infiltration.
- After rubber dam isolation access cavity was prepared and working length was determined using 15 k file to be 21.5 mm.
- Cleaning and shaping of canal done using

stainless steel k files by step back technique with the master apical preparation upto 55 k file.

- Irrigation was done with 3% NaOCl and normal saline in-between cleaning and shaping of the canals with K files.
- calcium hydroxide medicament (RC CAL)was placed and closed dressing given for one week.
- On the next visit Final irrigation was done using 3% NaOCl , 17% EDTA, 3% NaOCl and finally Normal saline.
- Mastercone was selected -50 2% gutta percha cone.
- Canal obturation was done using gutta percha and zinc oxide eugenol sealer and patient was recalled after 2 weeks.

2. WALKING BLEACH TECHNIQUE

- **Shade Selection:** Preoperative shade was recorded to be 5M-2 using a shade guide (Vita 3D Master Shade Guide).
- **Gutta-Percha Removal:** Gutta-percha was removed 2 mm apical to the cemento-enamel junction (CEJ).
- **Barrier Placement:** A 2mm protective barrier of glass ionomer cement (GIC) was placed over the gutta-percha to prevent apical leakage and external cervical resorption.
- **Bleaching Agent:** A mixture of sodium perborate and distilled water was placed in the pulp chamber.
- **Temporary Seal:** The access cavity was sealed with intermediate restorative material.
- **Follow-Up Appointments:**

o After two sessions of non-vital bleaching, patient was recalled and the tooth showed a marked lightening in shade.(5M-2 to 2M-3).



Fig 1: Preoperative Photograph

o After bleaching the access cavity was irrigated and dried followed by placement of calcium hydroxide in the pulp chamber and restored with temporary filling.

o After 2 weeks post endodontic restoration was done with composite.

3. DIRECT COMPOSITE VENEERING

- On the following visit direct composite veneering was initiated:
- After shade selection using button technique rubber dam isolation was done.
- Infinite bevel was given on the labial aspect of 11 using a straight fissure diamond bur.
- For mesial and distal margins of the teeth, transparent matrix bands were cut, applied and fixed with appropriate wedges.
- Then, 37% phosphoric acid was applied on the enamel surfaces for 15 seconds, rinsed with water spray for 30 seconds and dried .
- Bonding agent was applied in two layers on the prepared tooth surfaces by using a applicator brush and polymerized with a light-curing unit for 20 seconds.
- A2 and A3 shade composite resin was applied incrementally and polymerized each time for 40 seconds.
- After composite buildup fine finishing diamond bur was used for initial refinement followed by shofu disc from coarse to fine grit in a slow-speed micromotor for final polishing.
- Post operative instructions were given.



Fig 2: Preoperative Radiograph



Fig 3: Gutta Percha Removal



Fig 4: Radiograpgh- GIC Barrier Placement



Fig 5: Initial Shade Selection



Fig 6: Shade Matching-2 Week Post Bleaching



Fig 7: Infinite Bevel -Buccal



Fig 8: Infinite Bevel -Palatal



Fig 9: Palatal shelf created



Fig 10: Post-operative View



Fig 11: Post-Operative Smile

DISCUSSION

Bleaching of discoloured nonvital teeth was first reported in the mid-nineteenth century, when chloride of lime was used as the bleaching agent of choice. Other agents subsequently described for bleaching pulpless teeth included aluminium chloride and, initially, oxalic acid. The bleaching effect of hydrogen peroxide was discovered in 1884, leading to its use in tooth bleaching.[7] Spasser first described a bleaching technique involving the placement of a paste composed of sodium perborate and water into the access cavity. In 1963, Nutting and Poe modified this technique by replacing water with hydrogen peroxide. In 2008, Yui investigated the effects of different concentrations of carbamide peroxide and concluded that sodium perborate combined with either 10% or 35% carbamide peroxide was more effective than when combined with distilled water.

The intra-coronal bleaching procedure is widely used in discoloured non vital teeth, because it is efficient, relatively simple, presents low cost and preserves the dental hard tissue compared to the prosthetic treatment. Most commonly used intra-coronal bleaching agents are hydrogen peroxide, carbamide peroxide and sodium perborate.[8]

Various risks associated with non-vital teeth bleaching are penetration of hydrogen peroxide in the dentinal tubules, changes in the dentin structure and permeability, general weakening of the physical properties of dental hard tissues, dental fracture during treatment, over-bleaching, possibility of relapse and the most serious external cervical root resorption. Lado et al presumed that internal bleaching procedure leads to denaturation of dentin in the cervical region. This denatured dentin induces a foreign body reaction. Glass ionomer cement was used as the barrier material. Here in this case 2mm thickness barrier was placed and the shape of the barrier was kept as 'bobsled tunnel' when viewed from facial aspect. The significance of this shape is that it blocks all the dentinal tubules which run from pulp chamber to external tooth surface apical to the level of epithelial attachment so that the bleaching agent stays within the cavity and hence prevents external root resorption.[9]

After the completion of the bleaching procedure, the acidic environment in the tooth cavity should be neutralized by placing calcium hydroxide suspension for 7 days. This duration is necessary for releasing the remaining oxygen and dentin remineralization to stabilize the colour and to provide adequate adhesion to the composite filling material. Direct composite restorations represent the best immediate solution for the patient with fractured teeth in the aesthetic area, especially

when the fractured fragment is missing. Restoration of anterior teeth is regarded as a challenge to most dentists, but following the natural layering concept can be considered the simple approach to obtain lifelike mimicking restorations.[6] Disadvantages of the direct composite veneers include long term colour instability, less wear resistance, which means that they often require repair or replacement.

The use of conservative techniques for the rehabilitation of anterior teeth, as demonstrated in this case, shows that internal bleaching combined with direct composite veneers can be effective. This approach provides aesthetic and functional harmony when executed properly, with careful diagnosis and treatment planning being crucial to achieving satisfactory results.

CLINICAL IMPLICATION

Bleaching of non-vital teeth is a minimally invasive approach for improving the aesthetics of endodontically treated teeth.[10] A well-sealed coronal restoration and a properly placed cervical barrier are essential for minimizing the risk of peroxide leakage into the periodontal tissues. Clinicians should also consider the limitations of direct composite veneers, including long-term colour instability and reduced wear resistance, when selecting the definitive restorative option.

CONCLUSION

Non-vital bleaching is a conservative, cost-effective, and predictable procedure that can achieve satisfactory aesthetic outcomes within a relatively short period.[11] Direct composite resin veneers provide an effective restorative option for improving the shape and colour of discoloured anterior teeth while preserving the remaining tooth structure. Successful treatment depends on careful case selection, meticulous clinical execution, and adherence to sound endodontic principles to minimize the risk of post-treatment complications. This case demonstrates that, when combined with adhesive restorative techniques, non-vital bleaching can provide a reliable and conservative alternative to prosthetic rehabilitation for discoloured non-vital teeth.

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CASE REPORT

AN UNCOMMON PRESENTATION OF PLEOMORPHIC ADENOMA IN THE SUBMANDIBULAR SALIVARY GLAND: A CASE REPORT

ABSTRACT

Background: Pleomorphic adenoma (PA) is the most common benign salivary gland neoplasm and accounts for most benign tumors involving the major salivary glands. Although the parotid gland is the most frequent site of occurrence, involvement of the submandibular gland is uncommon. Patients typically present with a slowly enlarging, painless, mobile swelling that may remain asymptomatic for several years before seeking medical attention. Despite its benign nature, delayed treatment may increase the risk of recurrence and malignant transformation.

Case report: A 36-year-old male presented with a painless, slowly enlarging swelling over the left submandibular region of six months' duration. Clinical examination revealed a well-defined, firm, non-tender swelling measuring approximately 5 × 3 cm with normal overlying skin. The lesion was surgically excised, and histopathological examination demonstrated characteristic epithelial and myoepithelial components within a myxochondroid stroma, confirming the diagnosis of pleomorphic adenoma of the submandibular gland. The postoperative course was uneventful, and the patient was advised regular follow-up because of the potential risk of recurrence.

Management and Outcome: Complete surgical excision of the tumor together with the involved submandibular gland was the treatment of choice in all reviewed cases. Careful preservation of adjacent neurovascular structures resulted in favorable postoperative recovery. Histopathological examination consistently demonstrated epithelial and myoepithelial components within a characteristic chondromyxoid stroma. Long-term follow-up revealed excellent outcomes with minimal recurrence when complete excision was achieved.

Conclusion: This case illustrates the typical presentation of a slowly enlarging, painless, firm submandibular swelling in a 36-year-old male. Histopathological examination confirmed the diagnosis by demonstrating the characteristic admixture of epithelial and myoepithelial elements within a myxochondroid stroma.

Keywords: Pleomorphic adenoma, Submandibular gland, Salivary gland tumor, Fine-needle aspiration cytology, Computed tomography, Surgical excision, Histopathology, Case report.

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Authors:

[1]Sania Anna Varghese
[2]Selwa Muhammed Rasheed
[3]Priya Thomas

[1,2]House Surgeon
Department of Oral and Maxillofacial Pathology
Annoor Dental College,
Muvattupuzha,
Kerala University of Health Sciences

[3]Professor
Department of Oral and Maxillofacial Pathology
Annoor Dental College,
Muvattupuzha,
Kerala University of Health Sciences

Corresponding Author

Sania Anna Varghese
House Surgeon
Department of Oral and Maxillofacial Pathology
Annoor Dental College,
Muvattupuzha,
Kerala University of Health Sciences
Mail:
saniaannavarghese2002@gmail.com

INTRODUCTION

Salivary gland neoplasms constitute a relatively uncommon group of head and neck tumors, accounting for approximately 1-5% of all head and neck neoplasms.[1] Among these, pleomorphic adenoma is the most common benign epithelial tumor and represents the predominant neoplasm affecting the major salivary glands. Although approximately 70–90% of pleomorphic adenomas arise in the parotid gland, only a small proportion occur in the submandibular gland, making this location relatively uncommon.[2] Despite its rarity, pleomorphic adenoma remains the most frequent benign tumor of the submandibular gland and should always be considered in the differential diagnosis of a painless submandibular swelling.[3]

Pleomorphic adenoma is characterized by its slow growth, well-defined margins, and biphasic histological composition consisting of epithelial and myoepithelial cells embedded within a variable chondromyxoid, myxoid, or fibrous stromal background. Clinically, patients usually present with a painless, firm, mobile swelling that may remain unnoticed or untreated for several years because of its indolent nature. Although benign, incomplete excision may result in recurrence, while prolonged duration has been associated with an increased risk of malignant transformation into carcinoma ex pleomorphic adenoma[3]. The patient's vitals structures were preserved during the full surgical resection of the tumor and submandibular gland. The surgical course was unremarkable, and the diagnosis was confirmed by histopathology.[4] Hence, the best management for pleomorphic adenoma is surgery, the tumour tissue must be removed as a whole because the remaining parts of a tumour can easily become recurrent or turn into a malignant tumour.[5]

Ultrasonography can differentiate solid from cystic lesions in the salivary glands. It is also useful in guiding a biopsy (both FNAC and core biopsies). USG can diagnose most of the salivary gland diseases. Pleomorphic adenomas are typically hypoechoic and may show posterior acoustic enhancement. Most salivary gland tumours are investigated by FNAC. The accuracy for the diagnosis of benign or malignant salivary gland tumour by FNAC is around 80-90%.8 FNAC also helps to differentiate between tumours and inflammatory conditions or enlarged lymph nodes. Computerized Tomography (CT) scan or Magnetic Resonance Imaging (MRI) are the gold standard radiological tools for lesion arising from the salivary glands. The final pathologic diagnosis is always established based on the histopathological findings after surgical excision.[6] Surgical removal is the treatment of choice. 3% to 4% is the estimated risk of malignant transformation of PA.[7]

Here we report a case of pleomorphic adenoma presenting within the submandibular region which is relatively uncommon.

CASE REPORT

A 36-year-old male presented with a chief complaint of a painless swelling on the left side of the face that had been progressively increasing in size over a period of six months. The patient first noticed the swelling approximately six months before presentation. The swelling gradually enlarged to its present size without any episodes of rapid growth. There was no associated pain, bleeding, paraesthesia, facial weakness, trauma, fever, weight loss, or constitutional symptoms. The patient's medical, dental, and family histories were non-contributory, and no significant personal habits were reported.

Extraoral examination revealed facial asymmetry due to a solitary swelling located over the left submandibular region. The swelling measured approximately 5 × 3 cm, was well defined, ovoid in shape, and situated near the inferior border of the angle of the mandible. The overlying skin appeared normal without erythema, ulceration, sinus formation, or discharge. (Fig 1)

On palpation, the swelling was non-tender, firm in consistency, compressible, non-fluctuant, and non-pulsatile. The local temperature was not elevated, and the overlying skin remained freely pinchable, suggesting the absence of skin involvement. There was no evidence of fixation to underlying structures. Cervical lymphadenopathy was absent. Based on the clinical findings, a benign salivary gland neoplasm involving the left submandibular gland was considered as the provisional diagnosis.

The lesion was surgically excised in toto. Gross examination demonstrated a well-circumscribed encapsulated mass, tan, brown in colour. The soft tissue was bisected and the cut surface showed a predominantly greyish white to tan-white colour, firm in consistency. (Fig 2) Histopathological examination revealed characteristic features of pleomorphic adenoma, including epithelial duct-like structures interspersed within abundant myxoid and chondromyxoid stroma. (Fig 3) Myoepithelial cells exhibited variable morphology, and no evidence of cellular atypia, increased mitotic activity, necrosis, perineural invasion, or malignant transformation was observed. These microscopic findings confirmed the diagnosis of pleomorphic adenoma of the left submandibular gland.



Fig1: Extra-oral appearance of pleomorphic adenoma in submandibular region



Fig 2 : Gross appearance of pleomorphic adenoma: Lobulated brown colour soft tissue specimen. Bisected cut surface demonstrating a solid, homogeneous, grayish-white variegated appearance with firm and glistening/myxoid regions.

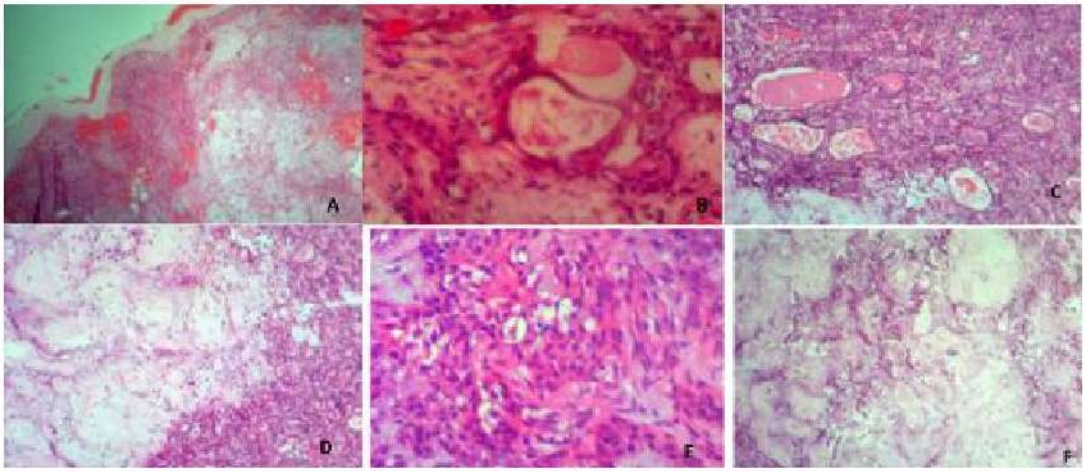


Fig 3: Histopathological photomicrographs of pleomorphic adenoma in submandibular region

(A) Low-power view showing a well-circumscribed tumour with heterogeneous histomorphology surrounded by a capsule. (B) Duct-like structures lined by epithelial cells, containing eosinophilic luminal material. (C) Numerous ductal and tubular structures embedded in a cellular stromal background (D) Prominent chondromyxoid stroma adjacent to cellular epithelial areas. (E) High-power view showing polygonal and plasmacytoid myoepithelial cells with variable nuclear morphology.(F) Abundant myxoid and chondromyxoid stromal areas with tumour cells.

DISCUSSION

Pleomorphic adenoma, also referred to as the benign mixed tumour, is the most common benign neoplasm of the salivary glands. The tumour accounts for approximately 55-75% of all parotid gland tumours, while involvement of the submandibular gland represents approximately 9-10% of cases, making the present case relatively uncommon compared with parotid lesions.[8]

Historically, the lesion was believed to originate from more than one germ layer because of its remarkable histological diversity. However, current evidence demonstrates that pleomorphic adenoma is entirely epithelial in origin, arising primarily from reserve cells of the intercalated duct with differentiation toward ductal epithelial and myoepithelial cells. The extensive morphological diversity observed within the tumour is largely attributed to the ability of myoepithelial cells to produce abundant extracellular matrix, including myxoid, chondroid, hyalinized, fibrous, and occasionally osseous components.

The histogenesis of pleomorphic adenoma has been clarified by molecular studies. Recurrent chromosomal rearrangements involving PLAG1 at 8q12 and HMGA2 at 12q14-15 is recognised as early oncogenic events. These alterations may occur as gene fusions or amplifications and are considered critical in tumour initiation and they may also persist during progression to carcinoma ex pleomorphic adenoma.[9]

Clinically, pleomorphic adenoma usually presents as a painless, slowly enlarging, firm mass that remains asymptomatic for several months or years. The tumour most commonly affects individuals between the third and fifth decades of life and demonstrates a slight female predominance.[10] Facial nerve dysfunction, pain, ulceration, and rapid enlargement are unusual in benign lesions and should raise suspicion for malignant transformation. The present patient exhibited the classical presentation of a benign pleomorphic adenoma with slow enlargement, absence of pain, and a firm, well-defined swelling.

Submandibular gland pleomorphic adenoma generally appears as a well-circumscribed asymptomatic mass beneath the angle of the mandible.[11] The tumour may remain freely mobile during the early stages but can become less mobile with increasing size because of progressive enlargement and surrounding soft tissue compression. The present lesion measured approximately 5 × 3 cm and showed the typical characteristics expected in a benign submandibular gland tumour.

Microscopically, pleomorphic adenoma is characterized by a highly variable admixture of epithelial and stromal components. The epithelial cells form ducts, tubules, nests, sheets, and cords, whereas the myoepithelial cells may appear spindle-shaped, plasmacytoid, angular, or clear. The stromal component demonstrates varying proportions of myxoid, chondroid, hyalinized, and fibrous tissue, accounting for the remarkable histological diversity that gives the tumour its name. The ratio between the components vary between cases.[12] These classic microscopic findings were demonstrated in the present case and confirmed the diagnosis.

The differential diagnosis of a painless submandibular swelling includes chronic sialadenitis, submandibular gland cyst, Warthin tumour, basal cell adenoma, monomorphic adenoma, lymphadenopathy, lipoma, branchial cyst, and low-grade malignant salivary gland tumours such as adenoid cystic carcinoma and mucoepidermoid carcinoma. Clinical examination alone is often insufficient to establish a definitive diagnosis. Radiological imaging, fine-needle aspiration cytology, and histopathological examination remain essential diagnostic modalities. Imaging modalities, including CT and MRI, are commonly utilized to detect PA.[13]

Complete surgical excision with removal of the involved gland remains the treatment of choice for pleomorphic adenoma of the sub mandibular gland. It's considered as one of the safest method of treatment with a low complication rate and high treatment success.[14] Enucleation should be avoided because microscopic pseudopod-like extensions beyond the capsule

can remain within the surgical field, predisposing to recurrence.[10] Long-term follow-up is recommended because recurrence may occur many years after surgery, particularly when tumour spillage or incomplete excision has occurred.

Malignant transformation is uncommon. Carcinoma ex pleomorphic adenoma may develop after a long duration of untreated or recurrent disease, particularly when the original tumour has been incompletely excised. Features include rapid enlargement, pain, fixation, ulceration, facial weakness, and the histological presence of cellular atypia, increased mitotic activity, necrosis, or perineural invasion. Parotid PAs have a long-term recurrence rate of up to 7% over a 20-year follow-up period, whereas recurrence of submandibular PAs is exceptionally rare.[15,16]

The present case demonstrates the classical clinical and histopathological characteristics of pleomorphic adenoma involving the submandibular gland. The absence of pain, neurological deficits, rapid growth, and histological atypia supports its benign nature. Early recognition and complete surgical excision are expected to provide an excellent prognosis with a very low risk of recurrence.

CLINICAL SIGNIFICANCE

Pleomorphic adenoma should always be considered in the differential diagnosis of a painless submandibular swelling. Ultrasonography, computed tomography, and fine-needle aspiration cytology are valuable for preoperative assessment. Histopathological examination remains the gold standard for diagnosis. Complete surgical excision with preservation of vital neurovascular structures provides excellent prognosis. Long-term follow-up is recommended because recurrence and malignant transformation, although uncommon, may occur.

CONCLUSION

Pleomorphic adenoma is the most common benign salivary gland tumour but occurs less frequently in the submandibular gland than in the parotid gland. This case illustrates the typical presentation of a slowly enlarging, painless, firm submandibular swelling in a 36-year-old male. Histopathological examination confirmed the diagnosis by demonstrating the characteristic admixture of epithelial and myoepithelial elements within a myxochondroid stroma. Early diagnosis, accurate histopathological evaluation, and complete surgical excision remain the cornerstones of successful management. Careful long-term follow-up is essential because recurrence and, rarely, malignant transformation may occur if the lesion is inadequately excised.

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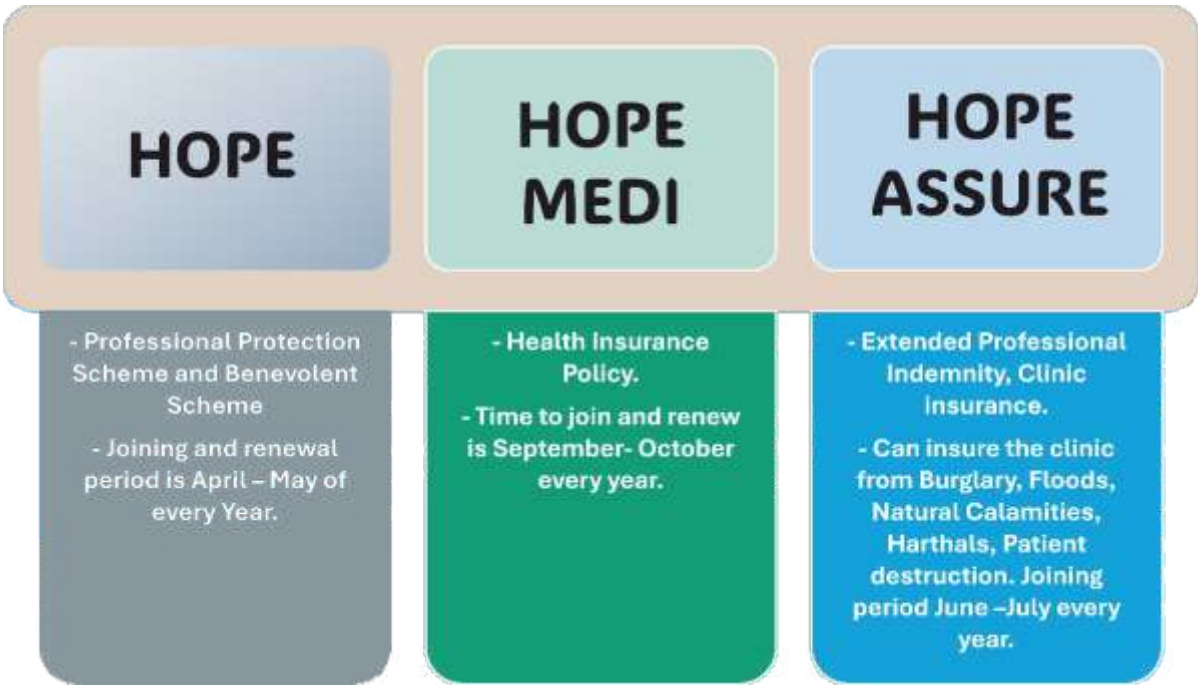
Dr. Pooja Latti
Editor, JIDAK
Professor and Head
Department of Public Health Dentistry
Annoor Dental College & Hospital, Muvattupuzha
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Contact number: 9916260249

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