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Endodontic filling materials under extreme conditions: Analysis of their resistance in extreme climates

Materiais de obturação endodôntica sob condições extremas: Análise de sua resistência em climas extremos

Materiales de obturación endodóntica bajo condiciones extremas: Análisis de su resistencia en climas extremos

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Abstract
Endodontics is a specialized dental field focused on diagnosing and treating diseases affecting the dental pulp. A fundamental aspect of successful endodontic therapy is root canal obturation, which aims to seal the canals and prevent reinfection. The choice of obturation materials is critical, requiring biocompatibility, durability, and effective sealing ability, especially in humid environments where moisture can compromise material performance and lead to treatment failure. Common materials include gutta-percha and various sealing materials, such as resin-based and bioceramic sealers, which offer improved adhesion, sealing, and mechanical resistance. Recent advancements have introduced innovative materials and obturation techniques, such as thermoplasticized gutta-percha systems (e.g., Thermafil) and synthetic alternatives like Resilon, which create a monoblock effect for enhanced sealing. Hydraulic cement sealers have gained popularity due to their antimicrobial properties and interaction with moisture during setting. Research highlights the importance of selecting appropriate materials and methods to optimize sealing quality, reduce microleakage, and enhance the mechanical integrity of obturations. Complex root canal anatomies, including oval-shaped canals and anomalies like dens invaginatus, pose challenges that require advanced imaging techniques such as cone beam computed tomography (CBCT) for accurate diagnosis and treatment planning. Future directions in endodontic obturation focus on bioactive and antimicrobial materials, nanotechnology, and 3D printing to improve material performance, longevity, and biological integration. These innovations aim to facilitate regenerative, minimally invasive treatments that promote tissue healing and long-term tooth preservation.
Keywords: Endodontic filling materials; Extreme conditions; Resistance; Extreme climates.

Resumo
A endodontia é uma especialidade odontológica focada no diagnóstico e tratamento de doenças que afetam a polpa dentária. Um aspecto fundamental do sucesso na terapia endodôntica é a obturação do canal radicular, que tem como objetivo selar os canais e prevenir a reinfecção. A escolha dos materiais de obturação é crítica, exigindo biocompatibilidade, durabilidade e capacidade eficaz de vedação, especialmente em ambientes úmidos onde a umidade

pode comprometer o desempenho do material e levar à falha do tratamento. Os materiais comuns incluem a guta-percha e diversos seladores, como seladores à base de resina e biocerâmicos, que oferecem melhor adesão, vedação e resistência mecânica. Avanços recentes introduziram materiais e técnicas inovadoras de obturação, como sistemas de guta-percha termoplástica (por exemplo, Thermafil) e alternativas sintéticas como Resilon, que criam um efeito monobloco para melhorar a vedação. Os seladores de cimento hidráulico ganharam popularidade devido às suas propriedades antimicrobianas e à interação com a umidade durante o endurecimento. Pesquisas destacam a importância de selecionar materiais e métodos apropriados para otimizar a qualidade da vedação, reduzir a microinfiltração e aprimorar a integridade mecânica das obturações. Anatomias complexas do canal radicular, incluindo canais ovalados e anomalias como dens invaginatus, apresentam desafios que requerem técnicas avançadas de imagem, como a tomografia computadorizada de feixe cônico (CBCT), para diagnóstico e planejamento do tratamento precisos. As direções futuras na obturação endodôntica focam em materiais bioativos e antimicrobianos, nanotecnologia e impressão 3D para melhorar o desempenho, a durabilidade e a integração biológica dos materiais. Essas inovações buscam facilitar tratamentos regenerativos e minimamente invasivos que promovam a cicatrização dos tecidos e a preservação dentária a longo prazo.
Palavras-chave: Materiais de obturação endodôntica; Condições extremas; Resistência; Climas extremos.

Resumen

La endodoncia es una especialidad dental enfocada en el diagnóstico y tratamiento de enfermedades que afectan la pulpa dental. Un aspecto fundamental del éxito en la terapia endodóntica es la obturación del conducto radicular, cuyo objetivo es sellar los conductos y prevenir la reinfección. La elección de los materiales de obturación es crítica, requiriendo biocompatibilidad, durabilidad y una capacidad de sellado efectiva, especialmente en ambientes húmedos donde la humedad puede comprometer el desempeño del material y conducir al fracaso del tratamiento. Los materiales comunes incluyen la gutapercha y diversos selladores, como los selladores a base de resina y biocerámicos, que ofrecen mejor adhesión, sellado y resistencia mecánica. Los avances recientes han introducido materiales y técnicas innovadoras de obturación, como los sistemas de gutapercha termoplástica (por ejemplo, Thermafil) y alternativas sintéticas como Resilon, que crean un efecto monobloque para mejorar el sellado. Los selladores de cemento hidráulico han ganado popularidad debido a sus propiedades antimicrobianas y su interacción con la humedad durante el fraguado. Las investigaciones destacan la importancia de seleccionar materiales y métodos adecuados para optimizar la calidad del sellado, reducir la microfiltración y mejorar la integridad mecánica de las obturaciones. Las anatomías complejas de los conductos radiculares, incluyendo conductos ovalados y anomalías como el dens invaginatus, presentan desafíos que requieren técnicas avanzadas de imagen, como la tomografía computarizada de haz cónico (CBCT), para un diagnóstico y planificación del tratamiento precisos. Las futuras direcciones en obturación endodóntica se centran en materiales bioactivos y antimicrobianos, nanotecnología e impresión 3D para mejorar el desempeño, la durabilidad y la integración biológica de los materiales. Estas innovaciones buscan facilitar tratamientos regenerativos y mínimamente invasivos que promuevan la cicatrización tisular y la preservación dental a largo longo prazo.
Palavras-chave: Materiales de obturación endodóntica; Condiciones extremas; Resistencia; Climas extremos.

1. Introduction

Endodontics is a dental specialty that focuses on the diagnosis and treatment of diseases and injuries affecting the dental pulp. One of the key aspects of endodontic procedures is root canal obturation, a technique aimed at sealing the canals to prevent reinfection and ensure the long-term health of the treated tooth. The choice of obturation materials is crucial, as they must be biocompatible, durable, and effective in sealing the root canal (Zan et al.,2021; Pineda et al., 2021).

The term "extreme conditions" refers to environments characterized by high relative humidity (above 85%), thermal fluctuations exceeding ±10 °C within short time intervals, atypical atmospheric pressures, and continuous exposure to oral fluids or intermittent mechanical stress. Such conditions are commonly encountered in tropical regions, high-altitude areas, or in patients with parafunctional habits. Studies such as that by (Winkler et al., 2023) have demonstrated that the combination of humidity and thermal variation can compromise the adhesion of materials to radicular dentin.

The resistance and durability of endodontic obturation materials in humid environments are of particular interest, given that moisture can interfere with the mechanical and chemical properties of sealers and materials used in treatments, potentially leading to endodontic treatment failures. In this context, it becomes essential to analyze and understand the behavior of these materials under such conditions to guarantee their efficacy and longevity in patients living in humid climates (Pineda et al., 2021; Winckler et al,2023).

In clinical practice, there are several types of obturation materials commonly used in endodontics, among which gutta-

percha and resin-based sealers stand out. Gutta-percha is one of the most widely used due to its excellent adaptability and sealing ability, although it is often combined with sealers to enhance its effectiveness. However, these materials face significant challenges under extreme conditions (Zan et al.,2021, Winckler et al.,2023).

In recent years, endodontics has experienced numerous significant advances, largely thanks to new discoveries in obturation materials and techniques. These discoveries include the evolution from traditional methods, such as vertical condensation, to more current techniques like injection and thermocompaction. These advances have not only improved the quality of root canal sealing but have also reduced postoperative complications. Additionally, the use of irrigation systems with sonic and ultrasonic activation has optimized canal cleaning, ensuring greater treatment efficacy (Al-Haddad et al.,2016).

Among the most interesting technologies are microencapsulated obturation materials, designed to release therapeutic agents in a controlled manner. This approach has allowed for maintaining constant levels of these agents in surrounding tissues, reducing the need for high medication doses and minimizing side effects. These developments represent an important step toward more effective and safer treatments in endodontics (Winckler et al.,2023; Al-Haddad et al.,2016).

The objective of this research is to search for endodontic filling materials that present resistance in extreme climates through bibliographic review.

2. Methodology

In this section, please write this beginning paragraph: “A qualitative research (Pereira et al., 2018) from literature review (Snyder, 2019) of the specific type of narrative review (Casarin et al., 2020; Rother, 2007) was carried out. The electronic databases PubMed, ScienceDirect, Scopus, and EBSCO were used, and the search words: endodontic filling materials, extreme conditions, resistance, and extreme climates

3. Results and Discussion

3.1 Fundamentals of Endodontic Obturation

The professional’s goal when performing endodontic treatment is to provide a three-dimensional seal of the root canals. A complete obturation of the canals is considered the foundation for a successful endodontic treatment, as it helps prevent microleakage and bacterial invasion between the root canals and periradicular tissues. Therefore, a good three-dimensional seal, both apical and coronal, would ensure maximum preservation of these canals against microorganisms (Loiacono et al.,2024; Zan et al.,2021).

To achieve excellent treatment results, it is necessary to correctly choose the obturation technique according to the anatomical variations of the root canal systems present in the tooth. Quality obturation materials that meet certain standards are also required, such as biocompatibility, good filling of the apical and coronal root canal spaces, anatomical compatibility (i.e., adapting well to the walls in three dimensions), radiographic visibility, and ease of removal when necessary (Zan et al., 2021; De la Fuente et al., 2022).

Generally, the canal filling consists of a core material (gutta-percha) and a sealer, which after adequate chemomechanical preparation, seal the dentinal tubules, ramifications, and accessory root canals. Since most sealers are soluble in liquids, causing dimensional changes during setting, their amount should ideally be as low as possible (Winckler et al.,2023).

3.2 Fundamental Properties of Endodontic Obturation Materials

These properties are crucial to guarantee the effectiveness and success of root canal treatment. They ensure that the materials used to fill the root canals are effective at eliminating bacteria, preventing their reentry, and promoting healing. One

of the most essential properties is biocompatibility, which refers to the material's ability to coexist without causing adverse effects on surrounding biological tissues. A biocompatible material should not cause inflammation, irritation, or allergic reactions in periapical tissues or adjacent structures. The most used materials, such as gutta-percha and bioceramics, are highly biocompatible, facilitating tissue regeneration without compromising patient health (Estrela et al.,2023; Zamparini., 2024).

Adhesion and sealing are other fundamental properties that directly influence the success of endodontic treatment. Materials must effectively adhere to the root canal walls and provide a hermetic seal. Adequate sealing prevents bacterial and fluid leakage, which avoids reinfection and improves the likelihood of proper tissue healing. Resin-based sealers and bioceramics are known for their excellent adhesive capacity and ability to form a durable seal, significantly reducing treatment failure risk and contributing to long-term stability (Cardinali et al., 2023; Estrela et al., 2023).

Fracture and compression resistance are important to ensure the integrity of the material inside the root canal. Obturation materials must withstand compressive forces and masticatory loads without fracturing or deforming. Fracture resistance is crucial to avoid material breakage or cracking during normal use, which could compromise the obturation and generate potential infection foci. Similarly, compression resistance ensures the material remains stable under internal pressures, offering good performance even under chewing forces. Bioceramic materials and gutta-percha combined with resin sealers have shown excellent resistance to both fracture and compression (Estrela et al., 2023; Baumann., 2024).

Dimensional stability is another critical property for obturation materials. A material that does not maintain its original shape may undergo volume changes, such as expansion or contraction, creating voids within the root canal. These spaces can allow bacterial infiltration, affecting the sealing quality and ultimately the treatment's success. Obturation materials should maintain dimensional stability over time, ensuring the root canal remains effectively sealed. For example, gutta-percha exhibits minimal expansion, ensuring no significant volume changes after placement (Zamparini.,2024; Baumann., 2024).

Finally, wear and abrasion resistance are fundamental to ensure the longevity of the obturation material inside the root canal. During mastication, the material is exposed to abrasive forces that may cause wear over time. A worn material can compromise the seal, allowing bacterial and fluid infiltration, and thus the possibility of reinfection. Bioceramic materials, for example, have excellent wear resistance, allowing them to maintain integrity for long periods. This property is especially important in cases where the restored tooth must withstand substantial masticatory loads (Zamparini.,2024; Khanvilkar., 2023)

3.3 Innovations in Obturation Materials

The Thermafil gutta-percha system has evolved and currently demonstrates its efficacy, as successful studies conducted worldwide have shown. It has become established as an easy and fast thermoplastic obturation method. It consists of a plastic carrier coated with gutta-percha, and to ensure good adaptation to the canals, several studies mention that effective removal of the dentinal smear layer should be performed (Alberdi et al., 2023).

Another successful material is Resilon, which is the first obturation system capable of creating a "monoblock" between the obturation material and the canal walls. It is synthetic and thermoplastic, based on polymers, containing bioactive glass and radiopaque filler particles. Its handling and properties are similar to gutta-percha; it is also available as a cartridge for use with the Obtura gun system and as a capsule and cannula ready for the Elements Obturation Unit device (Terauchi et al., 2023).

Additionally, ActiV GP™ is a new glass ionomer (GI)-based obturation system that, according to the manufacturer, offers longer working time, radiopacity, and improved handling characteristics. It consists of gutta-percha structures coated externally with GI. To establish a connection between the master cone and the dentin in the root canal walls, these cones are used with a GI sealer to produce a single cone (Terauchi et al., 2023).

It is worth mentioning that the use of hydraulic cement sealers for obturation has recently gained popularity due to their antimicrobial properties and interaction with the clinical environment in which they are placed. These are available in syringe

and auto-mix formats. The difference between the two lies in the availability of active components: the former requires moisture from the environment to set, while the latter contains all components in separate compartments that are mixed and extruded via a cannula (Sabeti et al., 2024).

3.4 Research and Clinical Studies on the Resistance of Root Canal Filling Materials

Various recent studies have evaluated the resistance and clinical performance of root canal filling materials, providing significant evidence for the optimal selection of techniques and materials in endodontic treatment, Alberdi et al. (2023) evaluated the effect of heat generated during thermoplastic obturation techniques on the adhesion of bioceramic materials to root dentin in the apical third of extracted human lower premolars. Their results indicated that heat does not significantly affect the adhesion of the bioceramic to the dentin wall, confirming the stability of these materials under the thermal procedures used (Jasrasaria et al.,2023) However, although the study by (Alberdi et al.,2013) provides valuable information on the thermal adhesion of bioceramics, its exclusively in vitro approach limits clinical extrapolation. Furthermore, the lack of control over biological variables such as donor tooth age and health reduces the external validity of the findings.

On the other hand, Terauchi et al. investigated the impact of the filling level with Mineral Trioxide Aggregate (MTA) on the success of endodontic retreatment. They concluded that obturation with MTA is a viable option for teeth that have not healed after initial treatment. However, insufficient filling with MTA increases the likelihood of healing failure, while overfilling or flush fillings do not negatively affect outcomes (Santos et al., 2020). Regarding obturation technique, Sabeti et al. demonstrated in a systematic review that the single-cone technique with a calcium silicate-based bioceramic sealer produces comparable results to other methods in promoting healing in apical periodontitis cases (Wang et al., 2019).

Jasrasaria et al., using micro-computed tomography, evaluated the porosity, dissolution, and apical extrusion of AH Plus, MTA Fillapex, and EndoSequence BC sealers after immersion in phosphate-buffered saline (PBS). Their findings showed that none of these sealers achieved a completely hermetic three-dimensional seal, presenting varying degrees of porosity and dissolution both immediately after obturation and after seven days in PBS (López Castillo et al.,2019).

Advances in materials have also favored the growing popularity of bioceramic sealers. Recent studies have shown that these sealers present better sealing ability and less microleakage compared to conventional sealers, suggesting improved long-term outcomes in endodontic treatment (Al-Hiyasat et al., 2023).

Additionally, biocompatibility is a key factor for the integration of materials with periapical tissues. According to research available on PubMed, calcium silicate-based sealers generate less inflammation and promote hydroxyapatite formation, favoring better integration with dentin (Iqbal et al., 2023). Likewise, a 2021 study indicates that these materials facilitate tissue regeneration in cases of extensive periapical lesions (Zhang et al., 2021).

Regarding fracture resistance, recent articles from EBSCO report that thermoplastic techniques distribute forces more evenly within the root canal, reducing the risk of vertical fractures, especially in teeth with weakened walls. This highlights the importance of selecting appropriate materials and techniques to enhance the longevity of the treated tooth (Arora et al., 2022; Mamat et al., 2023).

Although these studies provide valuable data on material performance, they present methodological limitations that must be considered. For example, some rely solely on in vitro models, which do not always replicate real clinical conditions. Additionally, not all works include details on sample size, age distribution, or control of variables such as tooth type. In the systematic review by (Sabeti et al.,2024), considerable variations were observed in confidence intervals and analysis methodology, suggesting that although the results are promising, greater homogeneity in protocols is needed to draw more robust conclusions. A critical appraisal of these aspects allows the reader to better contextualize the findings and their clinical applicability.

3.5 Ethical and Biological Reporting Considerations

Some of the studies cited in this work include in vitro analyses and clinical investigations with extracted human teeth. In these cases, it is assumed that such procedures were conducted in accordance with international ethical standards. Indeed, in the investigations by Alberdi et al. and Terauchi et al., the use of informed consent for the collection of human teeth is specified, which constitutes relevant information that helps ensure compliance with ethical principles in biomedical research. However, few studies provide detailed basic information about the samples used. For example, the study by Alberdi et al. specifies the use of human lower premolars. Nevertheless, most investigations do not mention important variables such as age, sex, or health status of donors, which limits the ability to compare results across different populations and clinical contexts (Alberdi et al., 2023; Terauchi et al 2023).

This highlights the need to adopt greater rigor in including differentiated biological data, as proposed by the ARRIVE guidelines and NIH recommendations on the importance of sex as a biological variable in scientific research, in order to improve the validity and applicability of findings in clinical contexts (Arora et al., 2022; Mamat et al., 2023).

3.6 Research and Future of Root Canal Filling Materials

Research in endodontic filling materials has evolved considerably over recent decades, aiming to overcome the limitations of traditional methods and meet the demand for safer, more effective, and biocompatible treatments. Gutta-percha, despite its long history and recognized efficacy, has limitations such as the lack of chemical adhesion to dentin and absence of intrinsic antimicrobial properties, which has driven the search for new materials. Currently, advanced biomaterials like calcium silicate-based cements (MTA, Biodentine) stand out for their bioactive properties, ability to induce tissue regeneration, and high biocompatibility, improving the sealing and repair of root canals (Collado et al., 2023; Poggio et al., 2023). Moreover, materials with intrinsic or controlled-release antimicrobial properties are being developed, which could eliminate residual bacteria and prevent biofilm formation, helping to reduce long-term failure rates (Torres et al., 2022).

The future of root canal obturation is also linked to technological innovations such as nanotechnology, allowing the incorporation of antimicrobial nanoparticles and mechanical reinforcements to improve the materials' resistance and functionality. 3D printing represents another frontier, enabling the creation of customized obturators perfectly adapted to the root canal anatomy, optimizing obturation. These innovations, together with the development of bioactive polymers and smart systems, are steering endodontics toward a more regenerative and less invasive approach, where materials not only act as sealers but also repair and protect dental tissue (Poggio et al., 2023).

3.7 Challenges of Obturation in Canals with Complex Anatomies

For successful endodontic treatment, it is essential to understand the root canal morphology and its anatomical variations. The presence of dens invaginatus (DI) complicates the endodontic treatment of any tooth. Accurate diagnosis of this anatomical condition is very important because variations in the coronal morphology may be present, sometimes exhibiting larger than usual dimensions. Many professionals opt for multiple angled radiographs to obtain an image of the internal anatomy of the affected tooth. However, this technique only provides a two-dimensional image that may present geometric distortions. Currently, cone beam computed tomography (CBCT) surpasses conventional radiography by providing three-dimensional images, allowing precise evaluation of complex canal anatomy. In this study, conventional canal preparation was carried out using the step-back technique, and obturation was completed by a combined technique of lateral condensation and vertical compaction (Khalil et al., 2021)

It is important to remember that the apical portion of root canals has a complex and variable anatomy, which can influence the outcome of endodontic treatment. In the histological study by Ricucci and Langeland, the apical constriction was

located just before the apical foramen; thus, several authors consider this area as the ideal site for instrumentation and obturation of the root canal. Various studies have shown that the distance between the apical foramen and the radiographic apex varies according to age. This has been the subject of investigation, and some authors concluded that microorganisms tend to accumulate in this zone, which is one of the main causes of apical periodontitis after treatment (Neelakantan et al., 2021)

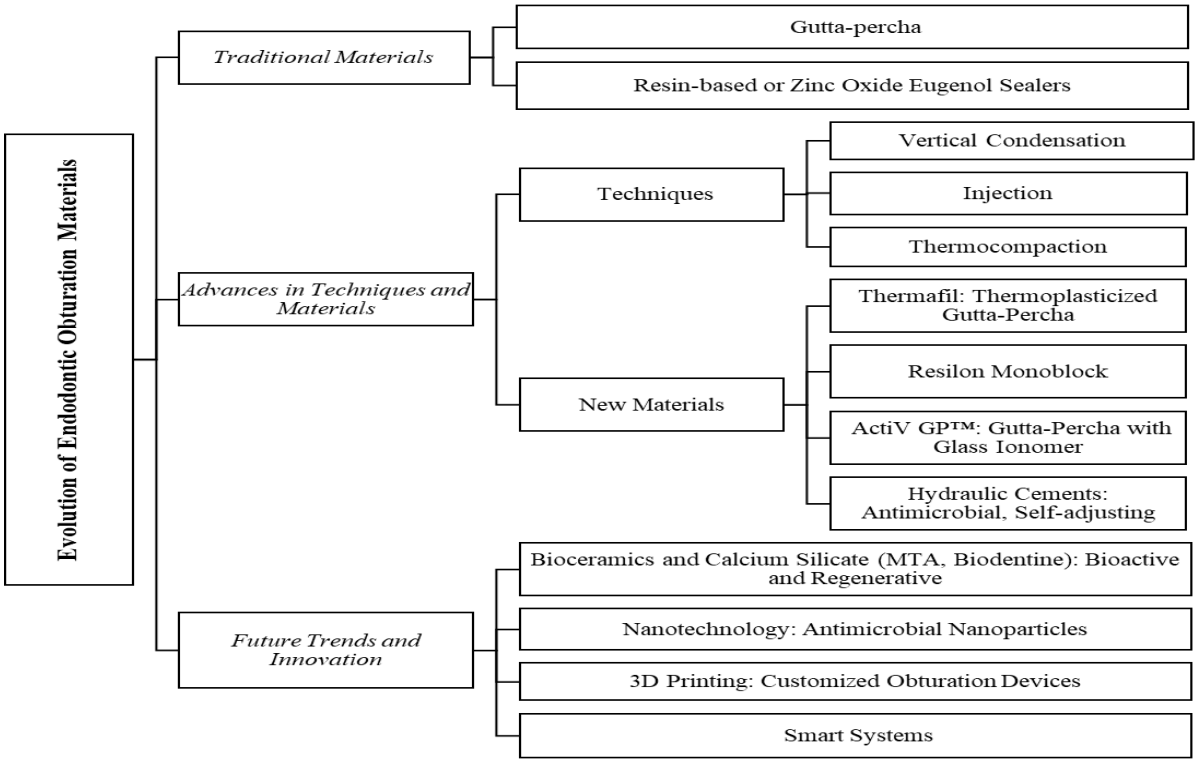
Another point to mention is that root canals present different anatomical configurations, which can be round, oval, flat, or irregular. Research has reported a high prevalence of oval-shaped root canals. It is noted that applying the preparation and cleaning protocol designed for round canals to oval canals may result in incomplete preparation, leaving uninstrumented areas, especially on the buccal and lingual extensions, which complicates subsequent obturation. Several investigations affirm that the sealing ability can be influenced by the root canal shape. Obturation of oval-shaped canals is a challenge for practitioners. Therefore, some authors recommend that to fill the irregularities and achieve a good adaptation of the gutta-percha to the canal walls, the filling material should be used in conjunction with a sealer, taking into account the amount of cement presente (Versiani et al., 2020).

4. Conclusion

Within the framework of modern endodontics, the future of obturation materials points toward multifunctional and bioactive solutions that go beyond simple sealing, integrating nanotechnology, 3D printing, and antimicrobial biomaterials. These advances aim for more effective, durable, and personalized treatments, promoting tissue regeneration and reducing complications. To ensure treatment success, it is essential to understand root canal morphology and its anatomical variations, since precise diagnosis and adequate visualization—through angled radiographs or cone beam tomography—allow the selection of appropriate instrumentation and obturation techniques. Furthermore, the materials used must be capable of withstanding masticatory forces, properly adapting to the canal, and minimizing bacterial infiltration. The quality of the seal will depend on both the material and the complementary sealer. In this context, ongoing research will continue to be fundamental to raising quality standards in endodontic care.

A conceptual map is presented below to synthesize this evolution and provide a structured visualization of the current complexity of endodontic obturation materials. The content of the conceptual map was developed by the authors based on a qualitative synthesis of the most relevant findings drawn from the studies analyzed in this article. To facilitate interpretation, the information was organized into key themes such as innovations in obturation materials, clinical studies on their resistance, and future directions in the development of new compounds. Based on this structure, the materials were grouped according to their chronological evolution and distinguishing characteristics, ranging from traditional gutta-percha to thermoplastic techniques such as Thermafil and Resilon, as well as more recent alternatives like ActiV GP and bioceramic sealers.

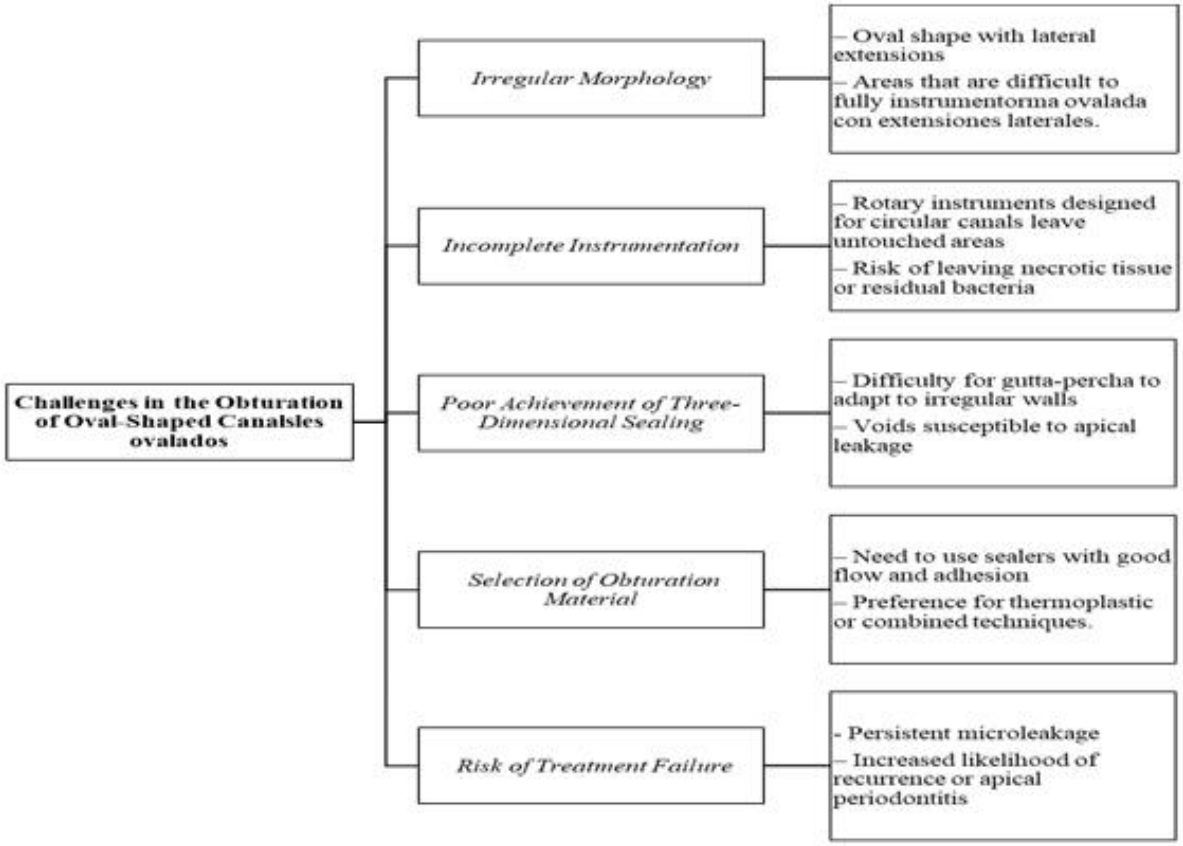
Figura 1 – Evolution of endodontic obturation materials.



Source: Autthors.

A conceptual framework is presented below to summarize the main challenges associated with the obturation of oval-shaped root canals and to provide a clear overview of the complexities involved in achieving effective sealing in these anatomies. This framework was developed by the authors through a qualitative synthesis of key findings from the literature reviewed in this article. To enhance understanding, the information is organized around critical aspects such as irregular canal morphology, limitations of current instrumentation techniques, difficulties in achieving complete three-dimensional obturation, and material selection considerations. The challenges are discussed in terms of their impact on treatment outcomes, including risks of residual bacterial contamination and microleakage, with emphasis on the need for advanced obturation techniques and materials tailored to the unique anatomy of oval canals.

Figura 2 – Challenges in the obturation of oval-shaped canals.



Source: Autthors.

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