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PERFORMANCE OF GIOMERS AS A RESTAURATIVE MATERIAL IN TEMPORARY TEETH: A SYSTEMATIC REVIEW

[Desempenho de giómeros como material restaurador em dentes temporários: revisão sistemática]

Dissertação de Mestrado

Mestrado Integrado em Medicina Dentária

Yann Laxenaire

Orientador:

Doutora Cristina Lopes Cardoso da Silva

Setembro 2024

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To my parents, my sister and my niece, for their unfailing support and constant love, and to my friends, for their unfailing encouragement and patience throughout this adventure. This thesis is also dedicated to you.

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I'd also like to say a special thank you to my mum, Nadia, and my sister, Elsie, for their constant presence and unwavering support. You've been there every step of the way, in moments of doubt, stress and sadness, but also in moments of joy. Your encouragement, comforting words and understanding have kept me focused and motivated throughout this journey. But also a big kiss to my little niece who has brightened up our family. Thank you so much for your love and unfailing support.

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Resumo

Objetivo: O objetivo da presente revisão sistemática foi analisar de forma abrangente o desempenho, tanto em contexto laboratorial como clínico, do material GIOMERO na restauração de dentes temporários. Além disso, pretendeu-se compará-lo com outros materiais restauradores convencionais amplamente utilizados em odontopediatria. **Metodologia:** Para responder aos objetivos propostos, foi realizada uma pesquisa bibliográfica detalhada nas principais bases de dados científicas, incluindo PubMed, Web of Science, Scopus, Scielo e Biblioteca Cochrane. Não foram aplicados limites temporais nem restrições linguísticas, permitindo uma ampla pesquisa. Adicionalmente, foram também efetuadas pesquisas na literatura cinzenta a fim de identificar estudos relevantes não publicados em fontes tradicionais. A revisão incluiu artigos científicos sob a forma de ensaios clínicos randomizados, bem como estudos laboratoriais (*in vitro*). A pesquisa, seleção e interpretação dos artigos foi realizada de modo independente por dois investigadores. Em caso de divergências nas decisões, um terceiro investigador foi consultado. Com base nas referidas pesquisas bibliográficas foram identificados 68 artigos potencialmente elegíveis. Aplicando os critérios de inclusão e exclusão, foi efetuada e leitura, inicialmente pelo título, depois pelo resumo e, numa fase final, pela leitura do texto completo. No final, foram incluídos 8 artigos na presente revisão sistemática. **Resultados:** a presente revisão sistemática demonstrou que os GIOMEROS são uma opção promissora para a restauração de dentes temporários, oferecendo um bom equilíbrio entre estética, biocompatibilidade e propriedades mecânicas, tornando-os uma opção promissora para a restauração de dentes temporários. A sua capacidade de libertação de flúor ajuda a prevenir lesões de cárie secundárias. Limitações clínicas: Apesar destas vantagens, os GIOMEROS têm um desempenho clínico inferior em termos de durabilidade e resistência à microinfiltração, em comparação com outros materiais bioactivos como o ACTIVA BioACTIVE e os compósitos híbridos. Os materiais bioactivos, como o ACTIVA BioACTIVE e os compósitos híbridos, demonstraram uma melhor integridade marginal e resistência em ambientes clínicos exigentes. Por exemplo, o Ormocer® demonstrou uma melhor capacidade de selamento marginal, reduzindo o risco de infiltração bacteriana: Para aumentar a durabilidade dos GIOMEROS, são necessárias melhorias na formulação, particularmente para reduzir a microinfiltração e o desgaste em condições orais complexas. **Conslusões**: Os GIOMEROS são particularmente adequados para situações em que a estética é uma prioridade, mas requerem uma técnica de aplicação rigorosa para minimizar o risco de microinfiltração. É essencial continuar a investigação para melhorar a resistência à microinfiltração e ao desgaste, para garantir uma utilização óptima numa variedade de condições clínicas.

Palavras-chave: “GIOMER”, “restorative materials”, “temporary teeth”

Abstract

Aim: The aim of this systematic review was to comprehensively analyse the performance of the GIOMERO material in restoring temporary teeth in both laboratory and clinical settings. It also aimed to compare it with other conventional restorative materials widely used in paediatric dentistry. **Methodology:** To meet the proposed objectives, a detailed bibliographic search was carried out in the main scientific databases, including PubMed, Web of Science, Scopus, Scielo and the Cochrane Library. No time limits or language restrictions were applied, allowing for a broad search. In addition, grey literature searches were also carried out in order to identify relevant studies not published in traditional sources. The review included scientific articles in the form of randomised clinical trials as well as laboratory studies (*in vitro*). The search, selection and interpretation of articles was carried out independently by two researchers. In the event of divergent decisions, a third researcher was consulted. Based on these bibliographic searches, 68 potentially eligible articles were identified. Applying the inclusion and exclusion criteria, they were initially read by title, then by abstract and, in the final stage, by reading the full text. In the end, 8 articles were included in this systematic review. **Results:** This systematic review has shown that GIOMEROS are a promising option for restoring temporary teeth, offering a good balance between aesthetics, biocompatibility and mechanical properties, making them a promising option for restoring temporary teeth. Their ability to release fluoride helps prevent secondary caries lesions . Clinical limitations: Despite these advantages, GIOMEROSs have inferior clinical performance in terms of durability and resistance to microleakage compared to other bioactive materials such as ACTIVA BioACTIVE and hybrid composites. Bioactive materials, such as ACTIVA BioACTIVE and hybrid composites, have demonstrated better marginal integrity and strength in demanding clinical environments. For example, Ormocer® has demonstrated improved marginal sealing ability, reducing the risk of bacterial infiltration: To increase the durability of GIOMEROS, formulation improvements are needed, particularly to reduce microleakage and wear in complex oral conditions. **Conslusões**: Os GIOMEROS são particularmente adequados para situações em que a estética é uma prioridade, mas requerem uma técnica de aplicação rigorosa para minimizar o risco de microinfiltração. É essencial continuar a investigação para melhorar a resistência à microinfiltração e ao desgaste, para garantir uma utilização óptima numa variedade de condições clínicas.

Keywords: 'GIOMER', 'restorative materials', 'temporary teeth'

General index

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Lists of Abbreviations, Acronyms or Symbols

ART - Atraumatic Restorative Treatment

CAD/CAM - Computer-Aided Design and Computer-Aided Manufacturing

GIC - Cimento de ionomero de vidro

FEA - Finite element analysis

GIC - Glass ionomer cement

HCR - Hybrid composite resin

RMGIC - Resin-modified glass ionomer cement

S-PRG - Surface-pre-reacted glass ionomer

I. Introduction

The application of restorative materials in our clinical practice extends beyond routine procedures. When tooth substance is lost due to carious, non-carious, or traumatic lesions, restoration becomes imperative. The pursuit of effective dental restauration solutions is driven by considerations of ease of use, availability, and physico-chemical properties of materials. In dentistry, restorative materials must endure the substantial mechanical stresses imposed by repeated masticatory cycles, necessitating the developement of highly durable materials. Dental restorations are subjected to variable stresses which can, over time, lead to the formation of cracks or even fractures in the restorative materials (Ilie et al., 2009). Therefore, the selection of appropriate materials is critical to ensuring the longevity and durability of dental restorations.

In paediatric dentistry, the specificities of care necessitate distinct selection criteria and options for obturation materials compared to those used in adults. In fact, the unique characteristics of temporary teeth, along with the varying levels of cooperation and comprehension in children, introduce factors that must be considered when selecting restorative materials (Anagha Chonat, 2023).

Dental composites are organomineral biomaterials designed to closely mimic the properties of dental tissues, namely enamel and dentine which they aim to replace. These materials must fulfil essential criteria to create functional and aesthetic restorations that closely resemble natural dental morphology. Additionally, they play a crucial role preventing and minimising the risk of recurrent lesions, particularly those of carious origin, and in preserving healthy dental structures (Neves et al., 2011).

Several types of materials are available on the market, ut they can be broadly categorized into two main families. The first family includes conventional restorative materials, such as composite resin, Activa Bioactive, glass ionomer, and resin-modified glass ionomer. The second family consists of innovative composites, such as GIOMERs. GIOMERs are dental materials that combine the benefits of traditional composites with those of glass ionomers, resulting in a unique hybrid combination. This hybrid offers numerous advantages, including improved wear resistance and biocompatibility (Jyothi et al., 2011).

Therefore, the present research question was: What is the laboratorial and clinical performance of GIOMER restorative composites on temporary teeth compared to conventional restorative materials?

II. Methodology

2. 1. Study design

The clinical question formulated for this systematic review was based on the PICO strategy (Population, Intervention, Comparison, Outcome): Population: temporary teeth; Intervention: restorations with GIOMER restorative composites; Comparison: restorations with conventional restorative materials (composite resin, Activa Bioactive, glass ionomer, and resin-modified glass ionomer); Outcome: laboratory and clinical performance. To address this question, a systematic review of the literature was performed.

2. 2. Selection and characteristics of the studies

The instructions of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses were followed to performe the present systematic review. (Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G., 2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097).

Table 1.

Bibliographical research strategy

Database	Search terms	Articulation of search terms	Number of articles found
Pubmed	GIOMER, restorative materials, temporary teeth	"GIOMER AND restorative materials OR temporary teeth" "GIOMER AND temporary teeth OR restorative material" "Restorative materials OR temporary teeth AND GIOMER"	19 articles
Cochrane	GIOMER, restorative materials, temporary teeth	"Restorative materials AND temporary teeth OR GIOMER" "GIOMER AND restorative materials OR temporary teeth" "GIOMER OR temporary teeth AND restorative materials"	27 articles
Scielo	GIOMER, restorative materials, temporary teeth	"Restorative materials AND GIOMER OR temporary teeth" "Temporary teeth AND GIOMER OR restorative materials" "GIOMER OR restorative materials AND temporary teeth"	22 articles

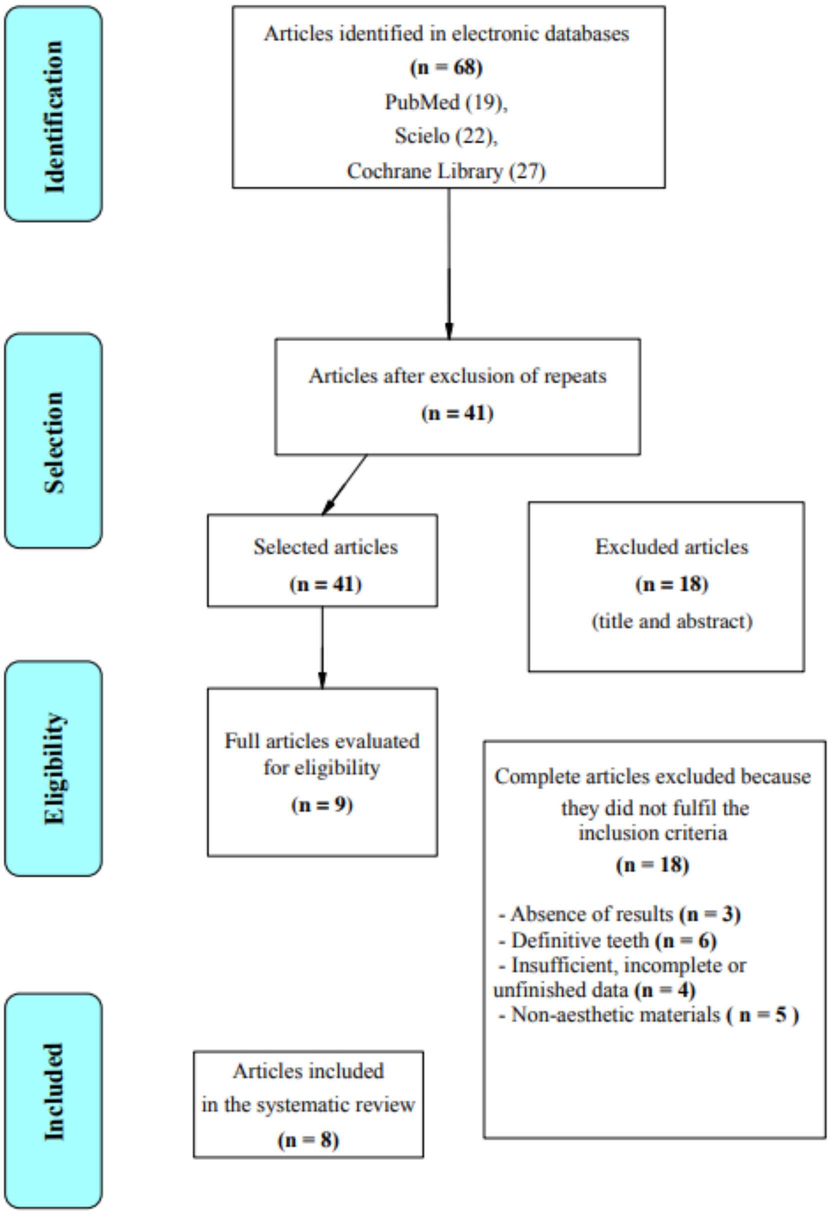
The initial search of electronic databases yielded a total of 68 potentially relevant articles. (Pub Med: 19 articles; Cochrane: 27 articles and Scielo: 22 articles). After eliminating duplicate publications (n=41), the titles and abstracts of 27 articles were evaluated. After eliminating publications by title and then by abstract (n=18), 9 articles were analysed for a complete reading. Once the analysis was complete, 1 article was eliminated as it did not correspond to the eligibility criteria.

In summary, this systematic review included 8 articles reporting on the performance of GIOMER restorative composites in temporary teeth and comparing them with other conventional restorative materials.

Regarding the type of studies, were selected 3 randomised clinical studys (Deepika UK et al., 2022; Pássaro et al., 2021; Sengul F et al., 2015) and 5 in-vitro studys (Abdulhamid Al Ghwainem & Adel S. Alqarni, 2024; Ibrahim et al., 2023; Yutaro Nakase et al., 2022; Sengul et al., 2014; Yadav G et al., 2012).

Figure 1.

PRISMA flow diagram with information on the different phases of the selection of the articles.



2. 3. Search strategy

The systematic literature search was conducted exhaustively using the electronic databases, renowned for their high-quality scientific content, PubMed, Web of Science, Scopus, Scielo and Cochrane Library. In addition, a search of the grey literature was also carried out to ensure that no relevant unpublished or hard-to-access studies were missed.

The search strategy was carefully designed, using Boolean operators such as "AND" and "OR" to combine search terms efficiently. The specific search terms included were: "GIOMER", "restorative materials" and "temporary teeth". No time limits or language barriers were considered in this literature search, allowing us to include the most comprehensive and diverse literature possible.

This rigorous literature selection process ensures a broad and thorough coverage of the subject, ensuring that the data and analyses presented in this thesis are based on a solid and comprehensive evidence base.

2. 4. Eligibility criteria

The following inclusion criteria were used to select the studies:

- Parallel randomised clinical trial with crossover control, prospective, non-blinded, parallel group clinical studies with a balanced randomised block design, finite element analysis (FEA) studies, clinical evaluation and case control studies
- Studies of temporary teeth
- Studies of children and adolescents up to and including puberty with restorable dental cavities
- Studies in which a direct comparison was made between different materials, establishing control groups
- Studies with a sample size of more than 5 participants
- Studies in which outcome was assessed
- Studies comparing the following aesthetic materials with GIOMER: ACTIVA bioactive restorative material (Pulpdent, Watertown, MA, USA), Bulk-fill composite, Flowable composite, Hybrid composite resin (HCR), Ion-releasing bioactive composites, Ormoceran, Nanohybrid resin composites and the Resin-modified glass ionomers

The following exclusion criteria were used to select studies:

- Studies investigating non-aesthetic materials such as amalgams or metallic materials
- Studies with absent results
- Studies of definitive teeth

- Studies with insufficient, incomplete or unfinished data.
- Opinion articles, editorials, letters to the editor and conference abstracts without complete data.

2. 5. Selection of articles and extraction of information

The selection process for articles and the extraction of relevant information were conducted using a rigorous and systematic approach to ensure the reliability and validity of the review. Two independent examiners, Y. L. and C.A., reviewed the titles of all retrieved articles based on the predefined inclusion and exclusion criteria. Articles that did not meet the criteria were excluded and the abstracts of the remaining articles were analized, excluding articles that did not meet the referred criteria from further review. The full texts of the remaining articles were then assessed independently by both examiners. In instances where there was disagreement between examiners regarding the inclusion of an article, a third examiner (C.C.S.) was consulted. The third examiner reviewed the articles in question and provided a final decision to resolve the disagreement.

The data extraction strategy was pre-established and defined according to the characteristics of the sample: authors name, year, study design, length of follow-up, procedures performed, age of patients, eligibility criteria, study objectives and final results. The extracted data from both examiners were compared to ensure consistency and accuracy. Any discrepancies in the extracted data were discussed between examiner Y.L. and examiner C.A., and if consensus could not be reached, examiner C.C.S. was involved to resolve the discrepancies. By employing this methodical approach, the review aimed to minimize bias and enhance the reliability of the findings, ensuring that the selection of articles and extraction of information were conducted in a thorough and systematic manner.

2. 6. Risk of bias

To assess the risk of bias of the articles included in this systemic review (Abdulhamid Al Ghwainem & Adel S. Alqarni, 2024; Deepika UK et al., 2022; Ibrahim et al., 2023; Yutaro Nakase et al., 2022; Pássaro et al., 2021; Sengul F et al., 2015; Sengul et al., 2014; Yadav G et al., 2012), two types of studies were applied: one to assess clinical studies and the other to assess in vitro studies. For each type of study, specific criteria and questions were developed according to current standards, in particular those used by the Joanna Briggs Institute (JBI), which adopts a systematic approach to assessing the risk of bias in different types of study. The evaluation of clinical studies was assessed using a set of 13 questions, allowing responses in four distinct options: Yes, No, Unclear, and NA (Not Applicable). Selection parameters at the end of each assessment included: Include, Exclude, and Seek further info.

Each clinical study could score up to 13 points, with each Yes answer worth one point, and No, Unclear, and NA answers worth zero points.

Clinical studies were scored as follows:

- A maximum score of 13 points.

- Studies with a score above the median (score > 7) were considered to be of high quality.

In vitro studies were assessed using 11 questions, with possible answers in two statements: Yes or No. Each Yes answer worth one point, allowing a score of up to 11 points.

The in vitro studies were scored as follows:

- A maximum score of 11 points.

- Studies with a score above the median (score > 6) were considered to be of high quality.

For each study evaluated, the study quality determination and scoring process was applied, and the number of points was tallied to establish the individual score for each study. Specific steps included: compilation of responses (the answers to the questions were compiled and the total points for each study were calculated); scores analysis (the scores were analysed to determine the quality of each study, by comparing the scores obtained with the established median).

This rigorous methodology makes it possible to systematically and objectively assess the lifetime risk of articles using well-defined criteria recognised by international standards. By clearly distinguishing between high-quality studies, ensures that only the most robust and reliable studies are considered in the final analysis, thereby reinforcing the validity and reliability of the conclusions of this systemic review.

Table 2.

Risk of bias assessment - in vitro study

	Article 1	Article 2	Article 3	Article 4	Article 5
Q1	Yes	Yes	Yes	Yes	Yes
Q2	Yes	Yes	Yes	Yes	Yes
Q3	Yes	Yes	Yes	Yes	Yes
Q4	Yes	Yes	Yes	Yes	Yes
Q5	Yes	Yes	Yes	Yes	Yes
Q6	No	No	No	Yes	Yes
Q7	No	No	No	No	No
Q8	Yes	Yes	Yes	Yes	Yes
Q9	Yes	Yes	Yes	Yes	Yes
Q10	Yes	Yes	Yes	Yes	Yes
Q11	No	No	No	No	No
Q12	No	No	No	No	No
Total :	8	8	8	9	9

Legends in relation:

The articles:

Article 1: (Abdulhamid Al Ghwainem & Adel S. Alqarni, 2024)

Article 2: (Ibrahim et al., 2023)

Article 3: (Yutaro Nakase et al., 2022)

Article 4: (Sengul et al., 2014)

Article 5: (Yadav G et al., 2012)

The questions Q*n*:

Q1 - Clear Objectives: Does the study have clearly defined objectives?

Q2 - Study Design: Is the study design appropriate for answering the research questions?

Q3 - Control of Variables: Have the controlled variables been clearly defined and kept constant?

Q4 - Control Group: Is there a suitable control group for comparison?

Q5 - Reproducibility: Are the methods described in sufficient detail to allow replication of the study?

Q6 - Randomisation: Was the allocation of treatments randomised?

Q7 - Blinding: Were the researchers blinded to the treatments?

Q8 - Sample size: Is the sample size sufficient to detect a statistically significant difference?

Q9 - Statistical Analysis: Are the statistical analyses appropriate and well described?

Q10 - Reporting of Results: Are the results presented clearly and completely, including negative and positive data?

Q11 - Potential Confounders: Have potential confounding factors been identified and controlled?

Q12 - Conflict of Interest: Have potential conflicts of interest been declared and managed?

Table 3.

Assessment of the risk of bias - Clinical Study

	Article 1	Article 2	Article 3
Q1	Yes	Yes	Yes
Q2	Yes	Yes	NA
Q3	Yes	Yes	Yes
Q4	Yes	No	Na
Q5	Yes	No	Na
Q6	Yes	No	Na
Q7	Yes	Yes	Yes
Q8	Yes	Yes	Na
Q9	Yes	Yes	Yes
Q10	Yes	Yes	Yes
Q11	Yes	Yes	Yes
Q12	Yes	Yes	Yes
Q13	Yes	Yes	Yes
Total :	13	10	8

Legends in relation:

The Articles:

Article1: (Deepika UK et al., 2022)

Article 2: (Pássaro et al., 2021)

Article 3: (Sengul F et al., 2015)

The Questions Q*n*:

Q1 - Was true randomization used for assignment of participants to treatment groups?

Q2 - Was allocation to treatment groups concealed?

Q3 - Were treatment groups similar at the baseline?

Q4 - Were participants blind to treatment assignment?

Q5 - Were those delivering treatment blind to treatment assignment?

Q6 - Were outcomes assessors blind to treatment assignment?

Q7 - Were treatment groups treated identically other than the intervention of interest?

Q8 - Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?

Q9 - Were participants analyzed in the groups to which they were randomized?

Q10 - Were outcomes measured in the same way for treatment groups?

Q11 - Were outcomes measured in a reliable way?

Q12 - Was appropriate statistical analysis used?

Q13 - Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?

III. Developement

The need to restore temporary teeth is essential for maintaining children's oral health. Temporary teeth play a major role not only in speech, but also in the positioning and movement of the tongue, chewing, the developement of orofacial muscles, alignment and the maintenance of the space necessary for the eruption of permanent teeth (Zimmerman et al., 2023).

Healthy temporary teeth are essential to ensure the proper developement of permanent tooth germs under the adjacent teeth. Alterations to the temporary teeth can lead to numerous complications, such as premature loss or degradation of the teeth, which can cause infections and pain (Lourenço et al., 2013). A healthy oral environment allows the dental germ to encrust in the best possible conditions and to maintain the balance of the oral sphere as much as possible (Yirsaw et al., 2024).

This is why, in the course of the evolution of paediatric dentistry, numerous restorative materials have appeared, making it possible to develop, improve and increase the effectiveness and durability of paediatric dental care, including the following materials:

3. 1. Composite Resins

Composite resins are indispensable in modern dentistry, providing both aesthetic and functional solutions for dental restorations. These materials consist of an organic matrix that is reinforced with fillers and bonded using a silane-based bonding agent. Composite resins do not harden independently, necessitating the use of an adhesive for proper application (Chaput & Faure, 2019).

3. 1. 1. Composition

Composite resins are categorized into several types, including microhybrids, macro fillers and nanocomposites (Ferdani Adrien, 2023).

The resin matrix primarily consists of monomers like BIS-GMA (Bisphenol A glycol dimethacrylate) or polyurethanes, forming the unpolymerized resin matrix (Devillard R et al., 2021). Additionally, a mixture of inorganic filler particles, such as glass or quartz, is incorporated to enhance the mechanical strength and aesthetic properties of the resins. These fillers are critical in improving the overall performance of the composite.

Furthermore, the composition includes components for viscosity control and the polymerization mechanism (Leprince et al., 2010).

3. 1. 2. Reaction principle

The exposure of the monomer chains to a light source, achieved through photopolymerization, or via a chemical process, initiates a reaction that leads to the formation of polymer chains (Borges et al., 2021). However, dental composites are prone to significant shrinkage during polymerization, which can subsequently result in issues such as inadequate sealing, poor fit, and/or microleakage. The severity of these problems can vary depending on the extent of polymerization shrinkage (El-Damanhoury et al., 2014).

In the short term, patients may experience postoperative pain. In the medium term, marginal discoloration can occur, and in the longer term, the recurrence of caries is a significant concern, often being the primary cause of clinical failure. This shrinkage and the associated complications highlight the importance of careful handling and application of composite resins to minimize adverse outcomes (Leprince et al., 2010).

3. 1. 3. Properties

Composite resins possess a remarkable ability to mimic the natural colors of teeth, making them highly suitable for aesthetic restorations, including both direct and indirect applications such as onlays and inlays (Fan et al., 2021).

However, these composite resins are not without their drawbacks, particularly concerning their susceptibility to degradation within the oral cavity. The degradation of composite resins can be broadly classified into two main types: the thermal fluctuations and the hydric degradation.

The dimensional changes caused by this degradation are due to thermal fluctuations within the oral cavity. Intra-oral thermal expansions and contractions can cause microfractures in the composite material, thereby compromising its durability and functionality (Pinto-Sinai et al., 2018).

Hydric degradation is a form of degradation that occurs as a result of hydrolysis and chemical decomposition. The integrity of the resin can be further compromised by the proliferation of intra-oral bacterial agents, which exacerbate the process (Miyazaki et al., 2010).

These degradation mechanisms highlight the challenges associated with maintaining the long-term stability and performance of composite resin restorations in the dynamic environment of the oral cavity (Devillard R et al., 2021).

3. 2. Glass ionomer cement

The developement of glass ionomer cements (GICs) is the result of extensive experimentation with silicate cements. GICs are restorative materials introduced by Wilson and Kent (Christophe Magnien, 2020). These cements have a special capacity for intrinsic adhesion to dental tissue, thanks to two processes:

1. Ionic bonding between hydroxyapatite calcium and carboxyl groups;

2. Interdiffusion into the collagen network.

3. 2. 1. Composition

GICs consists of a powder and a liquid to be mixed. The powder consists of fluoro-alumino-silicate glass with the following chemical composition: Al_2O_3-SiO_2-CaF_2 (alumina, silica, fluorite). The liquid is an aqueous solution of polyalkenoic acid, also containing copolymers of acrylic acid, itaconic acid and tartaric acid. During mixing, an acid-base reaction occurs, with the liquid being the acid and the powder the base (Cécile Gebhard, 2016). The components of this cement give it the ability to release fluoride ions even in an acidic environment.

3. 2. 2. Reaction principle

During the reaction between polyalkenoic acid and glass, the release of fluoride ions is exponential for the first 24 hours after the material is applied. According to Karantakis, the release of fluoride ions peaks in the first four hours, then gradually decreases between 24 and 72 hours, stabilising for 10 to 20 days, before slowly decreasing over months or even years (Karantakis et al., 2000).

Although the release of fluoride ions decreases over time, the material is able to recharge when it comes into contact with fluoride solutions. It also demonstrates good sealing capacity. These advantages promote remineralisation of dental tissue and have a cariostatic and antibacterial effect (Devillard R et al., 2021). This characteristic makes GICs particularly useful for patients at high caries risk.

Spontaneous adhesion to hard tissue is due to ionic exchanges with dental tissue. However, the use of polyacrylic acid can improve this adhesion (Devillard R et al., 2021).

3. 2. 3. Mechanical properties

Several factors influence the mechanical performance of GICs (Xie et al., 2000). In particular, the structure of the glass (De Caluwe et al., 2014), the structure of the polyacid, such as the composition in relation to the molecular weight, but also the powder/liquid ratio (Fleming et al., 2003). Numerous studies demonstrate this influence (Molina et al., 2013).

Various properties can be studied, such as wear resistance, which demonstrates the GICs resistance and ability to withstand surface degradation due to friction forces. According to Xie et al. (2000), GICs have high wear resistance, especially resin-modified versions, which can be comparable to resin composites. The wear resistance of GICs is often considered to be good but can vary depending on the specific formulation of the material.

The adhesion of GICs to enamel and dentin is a crucial property that determines the durability and effectiveness of dental restorations. The bond strengths of GICs typically range from 3 to 10 MPa. Mount and Hume (2005) highlighted the chemical adhesion of GICs to tooth structure as a significant advantage, enabling effective marginal sealing and reducing microleakage, which improves the longevity of restorations.

Compressive strength is an essential measure for assessing the durability of GICs under masticatory forces. This property, which indicates the material's ability to resist compressive forces, is crucial to ensuring the longevity of dental restorations. Typically, the compressive strength of GICs varies between 100 and 300 MPa. According to Nicholson (2016), modern GICs have improved in compressive strength due to changes in chemical composition and more advanced preparation techniques.

The modulus of elasticity, or Young's modulus, measures the stiffness of a material, with a higher modulus indicating greater stiffness. For GICs, this modulus generally varies between 4 and 10 GPa. According to the study of Yap et al. (2003), resin-modified GICs have a higher modulus of elasticity than conventional GICs, which improves their performance under occlusal stress.

Tensile strength, a measure of a material's ability to resist stretching or tearing forces, is relatively low for GICs, typically between 5 and 15 MPa. This weakness is a notable drawback of GICs, as highlighted by Sidhu and Nicholson (2016), limiting their use in areas subject to high tensile forces.

3. 2. 4. Chemical properties

GICs are innovative dental materials widely used in modern dentistry, due to their distinct chemical properties. The chemical composition of these cements is based mainly on a fluoro-alumino-silicate glass matrix combined with polycarboxylic acids (Wilson & Kent, 1972). During their use, an acid-base reaction is initiated between the polycarboxylic acids and the calcium and aluminium ions released by the glass, which leads to the formation of a rigid gel structure ensuring the cohesion of the material (Mount & Hume, 1998).

This chemical reaction plays an essential role not only in the cement hardening process, but also in the establishment of strong chemical bonds with dental tissues. Indeed, GICs benefit from a natural adhesion to enamel and dentin, facilitated by ionic interdiffusion and micromechanical interactions at the interface between cement and dental tissue. This unique chemical characteristic helps to considerably reduce the risk of carious infiltration under restorations, thus providing enhanced, long-lasting protection for dental structures (Smith, 1998).

In addition, one of the most valued properties of GICs is their ability to release fluoride ions, an aspect which not only helps to strengthen the surrounding tooth structure, but also provides ongoing protection against the formation of new carious lesions. The controlled release of fluoride, combined with the possibility of recharge from the oral environment, makes GICs an essential bioactive material for the prevention of caries recurrence (Croll et al., 2001).

3. 2. 5. Optical Properties

GICs have specific optical properties that play a crucial role in their application, particularly in aesthetic restorations. These materials are particularly effective at reproducing the appearance of natural teeth under various types of lighting, due to their distinctive optical characteristics. Among these, fluorescence is a key property. According to Hse et al (2009), the fluorescence of GICs contributes significantly to improving their aesthetics, both in natural and artificial light, by allowing better visual integration into the oral environment. This ability to mimic the nuances and reflections of natural teeth under different light conditions reinforces the effectiveness of GICs in dental aesthetic applications.

They are distinguished by their ability to reproduce the natural translucency of dental tissue, due to their fluoro-aluminous glass silicate composition. This formulation allows light diffusion comparable to that of enamel and dentin, ensuring perfect aesthetic integration with the surrounding dental structures (Sidhu & Nicholson, 2016).

GICs have a controlled opacity that limits light permeability and enhances their ability to mask underlying sub-layers. This characteristic is particularly advantageous for ensuring the visual consistency of dental restorations, improving overall aesthetics while maintaining excellent adaptation to natural dental tissues (Peutzfeldt, 1997).

3. 3. Resin-modified glass ionomer

In response to faults in GICs, researchers decided to add resin, which increased their mechanical properties and extended their range of indications while retaining the advantages of ahdesion and fluoride release **(**Devillard R et al., 2021).

3. 3. 1. Composition

Resin-modified glass ionomer cements (RMGICs) consist of a powder and a mixing liquid. The powder contains calcium fluoroaluminosilicate glass. The liquid is an aqueous solution of polyalkenoic acid, hydroxyethyl methacrylate (HEMA), soluble initiators such as camphoroquinone and photosensitive activators (Cécile Gebhard, 2016). The aim of this resin modification was to reinforce the acid-base matrix with a resinous matrix.

3. 3. 2. Reaction principle

Two reactions occur: an acid-base reaction, similar to that of conventional GICs, but slower because some of the aqueous solution is replaced by hydroxyethyl methacrylate (Wilson, 1990); and a polymerisation reaction, which can be light-cured or self-cured (Sidhu, 2011).

3. 3. 3. Properties

RMGICs adhere to dental tissue in the same way as GICs, relying on ion exchange at the surface. RMGICs also act as fluorine reservoirs, with the ability to release and recharge fluorine.

The mechanical properties of RMGICs are superior to those of conventional GICs. However, their mechanical performance remains inferior to that of composite resins. Consequently, their use is contraindicated in areas subject to heavy occlusal loads (Cécile Gebhard, 2016).

3. 4. GIOMER

GIOMER materials are a major innovation in restorative dentistry. By combining the advantages of GICs and resin composites, they offer optimised dental restorative solutions (Kishore G et al., 2010). To fully understand the nature of GIOMERs and their clinical applications, it is crucial to examine their composition, their distinctive properties and the advantages they offer over other dental materials.

The term "GIOMER" is an acronym formed from the words "Glass Ionomer" and "Composite Resin". GIOMER materials are resin composites reinforced with glass ionomer fillers that have been pre-treated. This pre-treatment consists of a reaction of polyacrylic acid with the glass ionomer, producing a surface-modified glass ionomer filler (Ikemura K & Tay FR, 2004). This filler is then incorporated into a resin matrix, giving GIOMERs their distinctive properties.

GIOMERs are characterised by their ability to release fluoride, comparable to that of GICs (Mousavinasab et al., 2009). This continuous release of fluoride helps to prevent enamel demineralisation and strengthen dental structures. In addition, GIOMERs can be recharged with fluoride from external sources such as fluoridated mouthwashes and toothpastes, prolonging their beneficial effects over time (Chong et al., 2014).

The use and clinical application of GIOMERs is diverse and varied. They range from fissure sealants to direct restorations of posterior and anterior teeth, encompassing Black class I, II, III, IV and V cavities. The versatile use of GIOMERs is attributed to their wide range of beneficial properties (Kishore G et al., 2010). These materials are highly biocompatible with both dental and gingival tissues, which minimizes the risk of significant adverse reactions when in contact with oral tissues (Rajavardhan K et al., 2014). Additionally, their mechanical strength is comparable to that of resin composites, enabling them to withstand the forces of mastication and wear. This makes them particularly suitable for high-stress areas in the oral cavity, such as the restoration of posterior teeth.

GIOMERs have great aesthetic properties which give them good translucency, and they can be polished to obtain a shiny, smooth surface. This property is particularly crucial for restorations of anterior teeth, where aesthetics is essential **(**Devillard R et al., 2021**).**

IV. Results

A - Clinical Performance and Monitoring of Restorative Materials

1. Clinical Evaluation and Comparison of the ACTIVA™ BioACTIVE and the GIOMER

Restorative materials have been shown to possess unique mechanical and physical properties. A study by Deepika UK, et al. (2022) focus on the comparison of the bioactive material ACTIVA™ BioACTIVE and the GIOMER. In this study ACTIVA™ BioACTIVE Restorative is a brand name for a dental restorative material belonging to the bioactive resin modified glass ionomer family and Beautifil Flow Plus is also a brand name for a dental restorative material developed by Shofu, which belongs to the GIOMER family.

ACTIVA™ BioACTIVE is an innovative dental restorative material that combines the properties of composites and glass ionomers. The material was designed to be bioactive, which means that it mimics the physical properties of natural teeth and promotes remineralisation of dental tissue.

ACTIVA™ BioACTIVE has several notable features. Firstly, it is bioactive, which means that it releases and recharges fluoride, calcium and phosphate ions. These ions are essential for remineralising enamel and preventing caries. Secondly, this material adheres chemically and micromechanically to dental tissue, providing excellent bonding to enamel and dentin. Thirdly, ACTIVA™ BioACTIVE absorbs and distributes chewing forces, reducing the risk of fractures thanks to its flexibility and resilience. In addition, the material has an aesthetic appearance close to natural tooth, with shade options to match tooth colour. It's also easy to handle, with a self-mixing syringe for precise, even application. Finally, ACTIVA™ BioACTIVE has good wear resistance, making it suitable for areas subject to high chewing forces (Glazer, 2016).

GIOMER is a dental restorative material that combines the advantages of composites and glass ionomers. GIOMER are particularly valued for their ability to release fluoride and their excellent aesthetic properties.

GIOMER has several important characteristics. Like glass ionomers, this GIOMER releases fluoride, helping to prevent secondary caries. It uses an adhesive system that creates a strong bond with enamel and dentin, ensuring a durable restoration. Aesthetically, GIOMER offers an excellent appearance with polishing properties that result in a smooth, shiny surface close to the natural tooth. The material is available in a range of viscosities to suit different clinical applications, including occlusal and interproximal restorations. It is also easy to handle, thanks to a layered application that allows the shape of the restoration to be sculpted and adjusted. Finally, GIOMER has excellent wear resistance, making it suitable for high-stress areas such as molars.

Deepika et al. (2022) conducted a study to compare these two materials in terms of clinical performance in restoring temporary decayed molars with Class I cavities. Both materials were evaluated for their ability to resist wear, adhesion, esthetics and ability to prevent secondary caries over a 12-month period.

2. Assessment of Restorative Longevity

Assessing the longevity of dental restorations is crucial to ensuring the durability of materials in complex oral environments. In the study by Ibrahim et al. (2023), the performance of four resin composite materials used in Class II restorations was compared: Z350 XT Filtek™ Universal Restorative, Filtek™ Bulk Fill Flowable Restorative, Beautifil-Bulk Flowable and Tetric™ N-Flow. The materials were subjected to various tests, including flexural strength, modulus of elasticity and microleakage resistance, to assess their ability to maintain durable restorations. The results showed that Beautifil-Bulk Flowable exhibited the highest flexural strength (86.24 ± 7.41 MPa), a key indicator of its ability to withstand repetitive masticatory forces, which are crucial to the longevity of restorations under clinical conditions. At the same time, Beautifil-Bulk Flowable also showed the highest modulus of elasticity, indicating greater resistance to deformation under stress, which is particularly important for Class II restorations. In addition, Filtek™ Bulk Fill Flowable Restorative demonstrated excellent resistance to microleakage after 20,000 thermocycling cycles, simulating two years in the mouth, with 70% of samples free of dye penetration, suggesting uniform polymerisation even in thicker layers.

The study by Pássaro et al. (2021) also highlighted the durability of the ART technique using GIC or GIOMER for occlusoproximal restorations of temporary molars. This is a two-arm randomised parallel clinical trial conducted in a school setting in Cerquilho, Brazil, in which 182 children aged 4 to 8 were randomly assigned to two groups. One group was treated with GIC and the second with GIOMER. Throughout the study, restorations were carried out by a paediatric dentist in a school setting and were assessed at 3, 6, 12, 18 and 24 months. Equia Forte™, a high-viscosity encapsulated GIC, proved to be durable over a 24-month period, due to its bioactive properties, such as the release of fluoride, calcium and phosphate ions, which contribute to the remineralisation of enamel and the prevention of caries. After 24 months, restoration survival was 58.1% for GIC and 49.1% for GIOMER. The Intention-to-Treat analysis showed success rates of 61.1% for the GIC and 52.2% for the GIOMER.

In the study by Ghwainem and Alqarni (2024), Ormocer® underwent extensive testing to demonstrate its superior ability to seal the margins of dental restorations, since a good dental seal ensures better durability of the treatment over time by reducing the risk of bacterial infiltration. It also proved that Ormocer® performed better than RMGIC and GIOMER, with or without reducing marginal microleakage. This superiority was demonstrated by rigorous tests involving the preparation of class V cavities on a sample of 75 non-carious temporary molars, extracted for reasons close to exfoliation or orthodontic, followed by 500 cycles of thermocycling alternating baths at 5°C and 55°C to simulate intra-oral temperature variations. The samples were then immersed in a dye (methylene blue) to assess dye penetration, which is an indicator of micro-infiltration. The more the dye penetrates, the more infiltration there is. Following this procedure, the results showed that Ormocer® showed the lowest marginal micro-infiltration (1.22 ± 0.01), followed by RMGIC (1.31 ± 0.07) and GIOMER (1.78 ± 0.03).

3. Long-Term Monitoring of Restoration Materials

Sengul et al. (2015) conducted a clinical study over a 24-month period to evaluate the success of 4 restorative materials: hybrid composite resin, resin modified glass ionomer cement, compomer and GIOMER composite resin, for Class II lesions in temporary molars. The study sample consisted of 146 molars from 41 children aged between 5 and 7 years, all of whom were at high risk of caries. The restorations were rigorously evaluated according to the criteria of the World Dental Federation, which take into account aesthetic, functional and biological aspects, each of which is rated on a five-level scale. Children were selected after a behavioural assessment of 3 or 4 on the Frankl scale, in the presence of radiographically confirmed class II caries lesions. The teeth were then restored following specific protocols recommended by the manufacturers of the materials used. The tests gave a failure rate of 33% for compomer, 28.1% for RMGIC, 22.5% for HCR and 21.1% for GIOMER composite resin. Valux^{TM} Plus (3M Dental Products), a hybrid composite resin, stood out for its excellent mechanical and wear resistance, as well as its ability to adhere effectively to enamel and dentine, particularly when combined with appropriate adhesive systems. RMGIC, in particular GC Fuji II LC (GC Corporation), has been shown to be effective in the continuous release of fluoride, offering protection against secondary caries, although it is less aesthetically pleasing than composites. Dyract AP compomer (Dentsply/De Trey) showed good workability and anti-cariogenic protection, while Beautifil GIOMER (Shofu Inc.) combined outstanding aesthetic properties with the anti-cariogenic benefits of glass ionomers.

As part of the long-term monitoring of restorative materials, Nakase et al. (2022), conducted several tests to evaluate the physical properties and wear resistance of composite resin blocks over time. The test included experimental CAD/CAM composite resin blocks containing S-PRG filler which were designated by the letters EB in the study, a commercial CAD/CAM block which were designated by the letters HC, two temporary dental composites (BEAUTIFIL Kids Paste and BEAUTIFIL Kids Zero flow), and a permanent dental composite (BEAUTIFIL II).

These tests included Vickers hardness, which measured indentation resistance, and the three-point bending test, which assessed fracture resistance under load. Fracture strength was analysed to assess crack propagation as a function of time, a key indicator of long-term durability. In addition, the water absorption test quantified the amount of water absorbed, which is essential for understanding the behaviour of materials in a moist oral environment, while the wear test simulated abrasion by antagonistic teeth over time in order to assess the strength of the materials under realistic clinical conditions. The results showed that for Vickers hardness the EB block showed a lower Vickers hardness than the HC block, but there was no significant difference between BEAUTIFIL Kids Zero flow, BEAUTIFIL Kids Paste, and BEAUTIFIL II. EB had a higher fracture toughness than the other materials tested, a lower water absorption than HC, BEAUTIFIL Kids Zero flow, and BEAUTIFIL Kids Paste, but higher than BEAUTIFIL II As for wear resistance, EB showed significantly lower counter wear than HC and BEAUTIFIL II, but higher than BEAUTIFIL Kids Zero flow.

In the same year, a study by Deepika et al. (2022) evaluated the clinical performance of two restorative materials over a 12-month period: a bioactive resin-modified glass ionomer (ACTIVA BioACTIVE Restorative) and a GIOMER hybrid composite (Beautifil Flow Plus). This randomised controlled trial, using a split-mouth design, was carried out on a sample of 50 children aged between 5 and 9, each with at least two occlusal caries lesions on the upper or lower molars, for a total of 100 temporary molars. Participants were divided into two groups: Group I (Control, n = 50), treated with GIOMER (Beautifil Flow Plus F00), and Group II (Experimental, n = 50), treated with bioactive resin-modified glass ionomer cement (ACTIVA BioACTIVE Restorative).

The restorations were assessed immediately after placement, then at 6 and 12 months, using modified United States Public Health Service criteria, covering parameters such as marginal integrity, anatomical shape and retention. At 12 months, the group using bioactive resin-modified glass ionomer cement showed superior marginal integrity compared with GIOMER, with a statistically significant difference ($p < 0.001$). In addition, this group also demonstrated better retention and increased preservation of anatomical shape compared with GIOMER, with a significant difference observed ($p = 0.02$).

B - <u>Physical and Mechanical Properties of Restorative Materials</u>

1. <u>Marginal Microleakage</u>

The issue of marginal microleakage in dental restorations is crucial to ensuring the durability of the materials used in clinical practice. To assess this phenomenon, Al Ghwainem and Alqarni (2024) conducted a comparative study of several dental materials, including Resin-Modified Glass Ionomer Cement, Ormocer®, and GIOMERs. Resin-Modified Glass Ionomer Cement, which is known for its good adhesion and fluorine release, has an increased sensitivity to moisture and a tendency to crack during polymerisation, which may increase the risk of microleakage. Ormocer®, although technically more complex and costly, are characterised by low contraction during polymerisation and excellent biocompatibility. GIOMERs, on the other hand, combine the advantages of composites and Glass Ionomers, but are subject to some shrinkage during polymerisation, thus influencing their effectiveness in preventing microleakage.

To assess marginal microleakage, samples of these materials were subjected to 500 thermocycling cycles, mimicking intra-oral temperature variations between 5°C and 55°C. After immersion in methylene blue dye for 24 hours, the samples were sectioned and examined under a stereoscopic microscope to determine the extent of marginal infiltration. The results revealed significant differences between materials. Hybrid composites, for example, although endowed with superior mechanical and aesthetic properties, showed a susceptibility to microleakage, requiring a precise placement technique. Compomers, which also release fluorine, showed lower resistance than traditional composites, due to greater contraction during polymerisation.

These observations are supported by the work of Ibrahim et al. (2023), who also assessed the microleakage resistance of various materials after 20,000 thermocycling cycles, simulating two years of exposure in the mouth. Their rigorous protocol highlighted those materials such as Filtek Bulk Fill Flowable showed better resistance, with 70% of samples showing no microleakage, while others, such as Tetric N-Flow, showed significant signs of microleakage. Tests showed that Filtek Bulk Fill Flowable had the best resistance to microleakage, with 70% of samples showing no dye penetration, indicating excellent marginal integrity. In contrast, other materials such as Tetric N-Flow and Z350 XT showed significant dye penetration, indicating increased susceptibility to microleakage.

Finally, Sengul et al. (2014) investigated the impact of margin stress levels on microleakage in temporary molar restorations. Their study, involving 146 molars from 41 children, revealed that flowable composite resin generated the highest marginal stress levels, increasing susceptibility to microleakage, while materials such as compomer and amalgam, with lower stress levels, showed better marginal adaptation.

2. Properties of CAD/CAM Composite Resin Blocks

A study by Nakase et al. (2022) focused on the developement and evaluation of composite resin blocks for temporary molar restorations, with particular emphasis on those incorporating a Surface-reacted Glass Ionomer (S-PRG) filler. The materials tested included experimental CAD/CAM composite resin blocks containing S-PRG (EB), a commercial CAD/CAM block (HC), as well as two composites for temporary teeth (BEAUTYFIL Kids Paste Shofu and, BEAUTYFIL Kids Zero flow) and a composite for permanent teeth (BEAUTYFIL II).

The incorporation of S-PRG filler into CAD/CAM resin composites was tested to see whether their overall performance improved, more specifically in the reduction of antagonist wear and fracture resistance. This is essential for the long-term maintenance of restorations in children.

Vickers hardness tests showed that the experimental CAD/CAM resine composite block material had a lower hardness than Shofu block HC, but comparable to that of BEAUTYFIL Kids Paste Shofu and BEAUTYFIL Kids Zero flow composites for temporary teeth. Shofu Block HC was found to be harder than the experimental CAD/CAM resine composite block, while BEAUTYFIL Kids Paste Shofu, BEAUTYFIL Kids Zero flow and the BEAUTYFIL II showed no significant differences in hardness between them.

After one week of immersion in water, the experimental CAD/CAM resine composite block and Shofu Block HC showed greater flexural strength in comparisons to the other materials. However, all materials except BEAUTYFIL II showed a decrease in flexural strength after this immersion period, indicating some sensitivity to water absorption.

The experimental CAD/CAM resine composite block EB demonstrated higher fracture toughness than other materials. This property is particularly advantageous for restoring thinner temporary teeth, where increased fracture toughness is essential.

Water absorption tests revealed that the experimental CAD/CAM resine composite block absorbed less water than Shofu Block HC, BEAUTYFIL Kids Zero flow, and BEAUTYFIL Kids Paste Shofu, but more than BEAUTYFYL II. Lower water absorption is beneficial for the durability and dimensional stability of restorative materials.

When evaluating antagonist wear, this was significantly lower for the experimental CAD/CAM resine composite block compared to Shofu Block HC and BEAUTYFIL II but higher than for BEAUTYFIL Kids Zero flow. Furthermore, after wear testing, the experimental CAD/CAM resine composite block and BEAUTYFIL Kids Zero flow showed a smooth surface, while Shofu Block HC showed cracks and a rough surface, which may affect the longevity and effectiveness of the restorations.

3. Comparison of Bulk-Fill and Incremental Composites

Comparison of Bulk-Fill and incrementally applied composites reveals significant differences in their physical and mechanical properties, which influence their clinical performance. In the study by Ibrahim et al. 2023, the evaluation of materials such as

Filtek™ Bulk Fill Flowable Restorative, Z350 XT Filtek™ Universal Restorative, Beautifil-Bulk Flowable, and Tetric™ N-Flow, highlighted notable variations in terms of microhardness, flexural strength, surface roughness and modulus of elasticity.

Although Filtek™ Bulk Fill Flowable had the lowest microhardness of all the materials tested, which may limit its use in areas subject to high stress, it also had very low surface roughness, which helps to reduce plaque build-up. Its flexural strength and modulus of elasticity are moderate, making it suitable for restorations requiring a degree of flexibility. In contrast, Z350 XT Filtek™ Universal Restorative offers the highest microhardness, medium surface roughness, high flexural strength and moderate modulus of elasticity, contributing to good resistance to deformation.

Beautifil-Bulk Flowable, formulated with Surface Pre-Reacted Glass-Ionomer fillers, has a high microhardness, ensuring good resistance to wear and scratching. Despite its high surface roughness, its bioactive properties compensate for this disadvantage. In addition, Beautifil-Bulk Flowable showed the best performance in terms of flexural strength and a high modulus of elasticity, making it a mechanically robust material. Tetric™ N-Flow, on the other hand, has average microhardness and the highest surface roughness, with the lowest flexural strength of the materials tested, which may limit its use in high-stress areas. Its lowest modulus of elasticity indicates greater flexibility, but lower resistance to deformation.

Nakase et al. (2022) extended these analyses by comparing Bulk-Fill composites formulated with Surface Pre-Reacted Glass-Ionomer fillers with conventional composites. They demonstrated that Bulk-Fill composites allow sufficient deep polymerisation, thereby significantly reducing operating time, a significant advantage in clinical practice. Rigorous testing, including Vickers hardness, flexural strength, fracture toughness, water absorption and wear, revealed that Bulk-Fill composites offer physical performance comparable to or better than traditional incremental composites. However, assessment of their ability to minimise microleakage remains essential, as insufficient polymerisation could compromise marginal integrity and affect the longevity of dental restorations.

4. <u>Marginal Leaks</u>

Marginal leaks are a recurring problem in dental restorations, potentially compromising the integrity of the restoration and promoting secondary caries. Yadav et al. (2012)

classified various restorative materials according to their susceptibility to microleakage, noting that coloured compomer, although aesthetically pleasing and valued for its fluoride release, is sensitive to placement technique and prone to leakage. In the same vein, Ormocer® stood out for its low microleakage, attributable to its three-dimensional polymerised structure, despite its complex handling and high cost. GIOMER, which combines the advantages of glass ionomer cements and composite resins, showed greater microleakage, suggesting the need for further studies to validate its clinical performance.

Al Ghwainem and Alqarni (2024) confirmed these observations in a rigorous study of Class V cavities, using a methodology involving 500 cycles of thermocycling and immersion in methylene blue dye to assess marginal leakage. The results revealed that Ormocer® had the lowest microleakage of the materials tested, outperforming both RMGIC and GIOMER, and indicating a superior ability to seal the margins of restorations.

Meanwhile, Ibrahim et al. (2023) compared conventional and Bulk-Fill composites in terms of resistance to marginal leakage after 20,000 thermocycling cycles. They demonstrated that Filtek Bulk Fill Flowable, a Bulk-Fill composite, outperformed conventional composites such as Z350 XT Filtek™ in preventing marginal leakage, due to more uniform curing in thick layers, reducing the risk of microcracks.

Nakase et al. (2022) also contributed to this analysis by evaluating CAD/CAM materials containing S-PRG fillers, which showed excellent adaptation to cavity walls and low polymerisation shrinkage, both key factors in minimising marginal leakage. Additional tests, including Vickers hardness, three-point bending, fracture toughness and water absorption, confirmed that these composites offer superior marginal sealing performance, reducing the risk of secondary caries and prolonging the durability of dental restorations.

5. Finite Element Analysis

In the study conducted by Sengul et al. (2014), the main objective was to evaluate and compare the stress distribution within restored primary molars, depending on the material used. To do this, the authors used finite element analysis (FEA), a method recognised for its ability to simulate and analyse mechanical stresses in dental structures.

Three-dimensional modelling of the maxillary and mandibular primary molars was carried out using CT images of a six-year-old girl. These models were created using

MIMICS 10.01 software and then imported into ANSYS Workbench for FEA analysis. The models were organised into three distinct groups: Model 1, representing intact control teeth; Model 2, corresponding to a restored mandibular molar; and Model 3, representing a restored maxillary molar. Six restorative materials commonly used in paediatric dentistry were analysed in the study: amalgam, hybrid composite resin, resin-modified glass ionomer cement, compomer, flowable composite resin and GIOMER. A vertical force of 100 N was applied to the models to simulate the force of mastication, making it possible to assess the strength of the materials and the distribution of the stresses they generate in the dental structures.

The specific mechanical properties of each material were taken into account in the analysis. The authors concluded that fluid composite resin, with a modulus of elasticity of 5,300 MPa, is characterised by its excellent adaptation to cavities and its low viscosity, making it easy to apply. Compomer, with a modulus of elasticity of 10,700 MPa, is recognised for its fluorine release and aesthetic properties, positioning it as an intermediate between composite and glass ionomer. GIOMER, with a modulus of elasticity of 11,300 MPa, offers a compressive strength of 400 MPa, demonstrating its robustness in dental restorations. Resin-modified glass ionomer cement, although less rigid with a modulus of elasticity of 10.860 MPa, offers clinical advantages due to its ability to release fluoride. Amalgam, with a modulus of elasticity of 20,000 MPa, remains a preferred choice for its durability despite aesthetic concerns. Finally, hybrid composite resin, with a modulus of elasticity of 19,700 MPa, combines compressive strength and flexibility, making it a versatile material for restorations.

V. Discussion

GIOMERs, as a dental restorative material, have attracted increasing interest due to their ability to combine the advantages of composites and Glass Ionomer Cements. Studies included in this systematic review, such as that conducted by Deepika et al (2022), showed that GIOMERs, including Beautifil Flow Plus, have remarkable mechanical and aesthetic characteristics. This material is distinguished by its ability to release fluoride, thereby helping to prevent secondary caries, while offering a high-quality aesthetic appearance (Ikemura K & Tay FR, 2004). However, it should be noted that these results must be interpreted in the light of the potential limitations of the included studies, such as the relatively short duration of clinical follow-up and variations in the application techniques used by practitioners.

In comparison, ACTIVA BioACTIVE, an innovative resin-modified material, showed significant superiority in terms of marginal integrity and long-term retention (Glazer, 2016). This difference in performance could be attributed to ACTIVA BioACTIVE's unique combination of mechanical and bioactive properties, which more closely mimic the natural properties of dental tissue. The material's chemical and micromechanical adhesion to dental tissue, as well as its ability to release and recharge essential ions, could explain its better clinical performance, particularly in complex oral environments where masticatory forces and pH variations can compromise restorations (Glazer, 2016).

However, although ACTIVA BioACTIVE outperforms GIOMERs in terms of certain clinical properties, it is important to recognise the specific advantages of GIOMERs, particularly their superior aesthetics and ease of handling. These characteristics make GIOMERs a viable choice in settings where aesthetics is a priority, although their use may require technical adjustments to minimise the risk of microleakage and maximise the durability of restorations (Deepika et al., 2022).

The durability of dental restorations is a critical factor for clinical success, especially in children's temporary teeth, which are subject to considerable wear. The results of the review indicate that the durability of restorations with GIOMERs is influenced by several factors, including the placement technique, intra-oral conditions, and the intrinsic characteristics of the material. The study by Pássaro et al. (2021) found that restorations using GIOMERs had slightly lower survival after 24 months compared to GICs, suggesting a potential limitation of GIOMERs in environments where active remineralisation of dental tissue is crucial.

The continuous release of fluoride, calcium and phosphate from GICs appears to play a key role in enamel remineralisation, which may explain their better performance in terms of restoration longevity (Pássaro et al., 2021). Despite their ability to release fluoride, GIOMERs appear to be less effective in promoting remineralisation, which could be due to their chemical composition and ion release mechanism being less effective than that of GICs. These results underline the importance of choosing the restorative material not only based on aesthetics and handling, but also taking into account the specific needs of the patient, particularly in children at high risk of caries (Mousavinasab & Meyers, 2009).

In addition, the study by Ibrahim et al. (2023) compared several composite materials, including GIOMERs, in terms of flexural strength, modulus of elasticity and resistance to microleakage. The results showed that Beautifil-Bulk Flowable exhibited high flexural strength and modulus of elasticity, which is crucial for the durability of restorations under real clinical conditions. However, the contraction of GIOMERs during polymerisation remains a major concern. This contraction can lead to microleakage, compromising the integrity of restorations and increasing the risk of secondary caries (Ibrahim et al., 2023).. These results suggest that, although GIOMERs may offer adequate durability under specific conditions, they may not be the best choice for all clinical situations, particularly in areas subject to high chewing forces or increased risk of microleakage.

The physical and mechanical properties of restorative materials are essential to ensure the longevity and effectiveness of dental restorations. According to the studies reviewed, GIOMERs offer an interesting compromise between hybrid composites and GICs in terms of mechanical strength and aesthetics. For example, the study by Sengul et al. (2015) showed that GIOMERs, such as Beautifil Flow Plus, have good flexural strength and superior aesthetics, as well as being able to release fluoride to prevent secondary caries (Mousavinasab & Meyers, 2009).

However, despite these advantages, GIOMERs also present challenges, not least their susceptibility to marginal microleakage. Microleakage is of particular concern as it can lead to bacterial infiltration, compromising the integrity of the restoration and leading to secondary caries. The study by Nakase et al. (2022) showed that, although the incorporation of S-PRG fillers into composites can improve certain properties, GIOMERs could still benefit from further optimisation to reduce microleakage and improve wear resistance. This could include chemical modifications or the addition of nanotechnology components to improve the physical properties of GIOMERs and reduce their susceptibility to shrinkage during polymerisation.

In addition, wear resistance tests, such as those conducted by Nakase et al. (2022), have shown that GIOMERs, while having good initial strength, can be susceptible to wear over time, particularly in moist oral environments. This sensitivity could be linked to the chemical composition of GIOMERs and their interaction with the oral environment. This highlights the need for long-term monitoring of restorations made with GIOMERs to ensure that they maintain their structural and aesthetic integrity over time. Further research into the degradation mechanisms of GIOMERs under real clinical conditions would be beneficial in understanding and potentially improving their performance (Nakase et al., 2022).

Although GIOMERs are versatile and aesthetic materials, they do not systematically outperform conventional composites or bioactive materials in all aspects. For example, the study by Sengul et al, (2014) found that hybrid composites, such Valux™ Plus, offered better mechanical strength and more reliable marginal adaptation than GIOMERs. Valux™ Plus stood out for its ability to adhere effectively to enamel and dentin, particularly when combined with appropriate adhesive systems, which is crucial for the durability of restorations in complex oral environments.

Although more complex and expensive, Ormocer® have been shown to have a better ability to seal the margins of restorations, reducing the risk of bacterial infiltration and secondary caries. This superior ability of Ormocer® can be attributed to their three-dimensional polymerised structure, which minimises contraction during polymerisation and improves the dimensional stability of the material. In comparison, GIOMERs, while offering good aesthetics and fluoride release, show an increased susceptibility to microleakage, which may limit their effectiveness in certain clinical situations (Al Ghwainem & Alqarni, 2024).

In addition, the study by Al Ghwainem and Alqarni (2024) confirmed these observations by showing that Ormocer® outperform GIOMERs in terms of their ability to seal the margins of restorations, which is crucial for the long-term durability of dental restrations. This superiority of Ormocer®, combined with their low shrinkage during polymerisation and excellent biocompatibility, makes them a preferable choice for restorations requiring maximum strength and protection against microleakage.

Finally, the study by Nakase et al. (2022) evaluated the properties of CAD/CAM composite resin blocks containing S-PRG fillers. The results showed that these composites offer physical performance comparable or even superior to that of traditional composites, particularly in terms of hardness, flexural strength and wear resistance. However, the ability of these composites to minimise microleakage remains an essential aspect to be assessed to ensure the durability of dental restorations. The application of these results in clinical practice could lead to significant improvements in the selection of restorative materials, particularly for temporary teeth, where the prevention of secondary caries and long-term durability are major concerns (Nakase et al., 2022).

VI. Conclusion

In conclusion, the present systematic review has shown that GIOMERs are a promising option for the restoration of temporary teeth, offering a good balance between aesthetics, biocompatibility and mechanical properties.

GIOMERs offer a good balance between aesthetics, biocompatibility and mechanical properties, making them a promising option for the restoration of temporary teeth. Their ability to release fluoride helps prevent secondary caries.

Despite these advantages, GIOMERs have inferior clinical performance in terms of durability and resistance to microinfiltration, compared with other bioactive materials such as ACTIVA™ BioACTIVE and hybrid composites.

Bioactive materials such as ACTIVA™ BioACTIVE and hybrid composites have demonstrated improved marginal integrity and resistance in demanding clinical environments. For example, Ormocer® has shown improved marginal sealing capacity, reducing the risk of bacterial infiltration.

To increase the durability of GIOMERs, formulation improvements are needed, particularly to reduce microinfiltration and wear in complex oral conditions.

GIOMERs are particularly suited to situations where aesthetics are a priority, but require a rigorous application technique to minimise the risk of microleakage. Further research is essential to improve resistance to micro-leakage and wear, to ensure optimal use in a variety of clinical conditions.

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VIII. Annexes

Table 4

Article summaries

Author	Year	Types of study	Objective	Main Results	Conclusion
Deepika et al.	2022	Clinical evaluation, a randomized, parallel-group, and split-mouth controlled clinical study	Evaluate and compare the clinical performance of a GIC modified by bioactive resin (ACTIVA™ BioACTIVE) and glass-ionomer hybrid composite, a GIOMER (Beautifil® Flow Plus) in the restoration of class I decayed temporary molars.	After 6 months there were no differences between groups in marginal discolouration, marginal integrity, anatomical shape and retention; Statistically significant differences were found in these parameters after 12 months, and 66 teeth presented a wear rate of 33%. At 12 months, there was no post-operative sensitivity in either group. Colour matching between the groups was not statistically significant at all intervals.	Both materials presented colour change and marginal discolouration from ideal to acceptable; ACTIVA™ BioACTIVE showed better marginal integrity due to its sealing capacity, provided a better anatomical shape and retention compared to Beautifil® Flow Plus; As a hydrophilic restorative material, ACTIVA™ BioACTIVE can be used as an effective restorative material, especially in children with excessive salivation, where isolation is a problem.
Pássaro et al.	2021	Randomised clinical study	Assess the longevity of occlusoproximal restorations in temporary molars carried out with the ART technique, using GIC (Equia Forte®) and GIOMER (Beautifil Bulk Restorative® et BeautiBond®), over 24 months.	Restoration survival after 24 months was: GIC = 58.1% and GCR = 49.1%. The Intention to Treat analysis showed successful restorations of: GIC = 61.1% and GCR = 52.2% (RR = 1.17; CI = 0.91-1.52). The hypothesis of superiority was not proven in both analyses ($p > 0.05$).	GCR does not exhibit greater longevity than GIC in occlusoproximal ART of primary molars.
Sengul and Gurbuz	2015	Clinical Evaluation , prospective, non-blinded, parallel-group study with a randomized block design	Evaluate the clinical success of restoring class II lesions in temporary teeth with different restorative materials: Hybrid Composite Resin (HCR), Resin-Modified Glass Ionomer Cement (RMGIC), Compomer (Compomer) and GIOMER Composite Resin (GCR), over a 24-month period.	The failure rates of the restorative materials were as follows: compomer - 33.3%, RMGIC - 28.1%, HCR- 22.5% and GCR 21.1%.	Functional failure was identified as the most important factor to consider in restorative material failure. RMGIC was the material that showed the greatest success in terms of its biological performance, while GCR was the material that showed the highest survival rate. Resin-based restorative materials showed favourable performance in class II temporary molar cavities. At 24-month follow-up, failures appeared mainly in the functional, aesthetic and biological criteria.

Table 5 (cont.)

Article summaries

Author	Year	Types of study	Objective	Main Results	Conclusion
Abdulhamid Al Ghwainem, Adel S Alqarni.	2024	In vitro study	Assess the marginal microleakage of various aesthetic restorative materials (RMGIC) - Vitremer (3M Dental Products, USA) Ormocer® - Admira Flow (Voco, Cuxhaven, Allemagne) GIOMER - Beautifil (Shofu Inc., Kyoto, Japon)) applied to deciduous teeth.	The lowest marginal microleakage was found in the Ormocer® group (1.22 ± 0.01 MPa), followed by the resin-modified glass ionomer cement group (1.31 ± 0.07 MPa) and the GIOMER group (1.78 ± 0.01 MPa). (1.31 ± 0.07) and the GIOMER group (1.78 ± 0.03). There was a very high statistically significant difference found between the resin-modified glass ionomer cement group and Ormocer® group, the resin-modified glass ionomer cement group and the GIOMER group. No statistically significant difference was found between the Ormocer® group and the GIOMER group.	There was some microleakage in deciduous teeth in all the restorative materials studied. However, the marginal sealing capacity of the Ormocer® restorative material was greater than that of resin-modified glass ionomer cement and GIOMER.
Ibrahim M., *et al.*	2023	In vitro study	The aim of the study was to compare the mechanical and physical properties of four composite materials (Z350 XT Filtek™ Universal Restorative (ZXT) - Product of 3M (Saint Paul, MN, USA). Filtek™ Bulk Fill Flowable Restorative (FBF) - Product of 3M (Saint Paul, MN, USA). Beautifil-Bulk Flowable (BBF) - Product of Shofu INC (Kyoto, Japan). Tetric™ N-Flow (TNF) - Product of Ivoclar Vivadent (Schaan, Liechtenstein) used for class II cavity restorations in primary and permanent teeth	The study found that BBF (86.24 ± 7.41 MPa) and ZXT (64.45 ± 11.52 MPa) had greater flexural strength than FBF (50.89 ± 8.44 MPa) and TNF (50.67 ± 9.40 MPa), while both exhibited the highest surface roughness values. The modulus of elasticity was higher in BBF, which was not statistically significant for FBF or ZXT ($p > 0.05$). ZXT (109.7 ± 7.83 VH) had the highest microhardness value, which was statistically significant compared to the other three materials ($p < 0.0001$). Microleakage was assessed after 20,000 thermocycling cycles in order to mimic the wear inherent in two years of the restorative material's presence in the patient's mouth. FBF (70%) showed greater resistance to microleakage.	The different types of CBR restorations have different characteristics. It is up to the dentist to choose the most suitable restorative material based on the different clinical scenarios of each of their patients.

Table 6 (cont.)

Article summaries

Author	Year	Types of study	Objective	Main Results	Conclusion
Nakase Y., *et al.*	2022	In vitro study	This study aimed to design, via CAD-CAM, composite resin blocks incorporated with S-PRG for use in first molars. It also aimed to evaluate the physical properties and strength of this innovative material. (Experimental CAD/CAM blocks with S-PRG (EB) - Product of Shofu Inc (Kyoto, Japan). Shofu Block HC (HC) - Product of Shofu Inc (Kyoto, Japan). Beautifil Kids Paste (BKP) - Product of Shofu Inc (Kyoto, Japan). Beautifil Kids Zero Flow (BKZ) - Product of Shofu Inc (Kyoto, Japan). Beautifil II (BII) - Product of Shofu Inc (Kyoto, Japan).	The Vickers hardness of the EB experimental material was lower than that of the HC material but there was no statistically significant difference between BKZ, BKP and BII. After 1 week of immersion in water, EB and HC showed good flexural strength when compared to the other materials ($p<0.05$). EB showed better fracture resistance compared to the other materials ($p<0.05$). The water absorption shown by EB was lower than that shown by HC, BKZ and BKP ($p<0.05$) and higher than that shown by BII ($p<0.05$). Antagonist wear was significantly lower in EB than in HC and BII ($p<0.05$), and significantly higher than in BKZ ($p<0.05$).	The present study concluded CAD/CAM RCBs containing S-PRG as a filling material (the experimental material developed in this study) for use in deciduous molars showed adequate physical properties and wear performance, suggesting that this material is suitable for restoring deciduous molar teeth and that it can function as a substitute for conventional metal crowns - SSCs. In addition, the experimental material could protect deciduous teeth from demineralisation processes.
F. Sengul, T. Gurbuz, S. Sengul.	2014	Finite element analysis (FEA)	Evaluate and compare the stress distributions in deciduous molars and restorative materials according to the material used.	The highest von Mises stress values were calculated in the enamel and restoration of restored tooth 84. Based on these results, all the materials were classified in terms of enamel stress as: flowable composite resin (FCR) > compomer > resin-modified glass ionomer cement (RMGIC) > gyromeric composite resin (GCR) > hybrid composite resin (HCR) > amalgam. In addition, the classification of the materials in terms of the stress shown by the restoration was FCR < compomer < RMGIC < GCR < amalgam < HCR.	Within the inherent limitations of finite element analysis, different and innovative computerised models can be progressively used in biomechanical applications in dentistry. Furthermore, finite element analysis represents an ideal test environment for research and developement of new dental materials. Clinical and laboratory research will create a more reliable approach to verifying the validity of computerised studies. In this sense, a restorative material with an appropriate modulus of elasticity, capable of balancing the stress concentrations that occur, should be used to increase the survival rate of both the hard tissue of the tooth and the restorative material.

Table 7 (cont.)

Article summaries

Author	Year	Types of study	Objective	Main Results	Conclusion
Yadav G., Rehani, U., Rana, V.	2012	In vitro study	The objectives of this study were: (1) To evaluate and compare the marginal leakage of more recent restorative materials such as coloured compomer, Ormocer®, GIOMER and RMGIC in the class I restoration of deciduous molars. (2) To compare the microleakage *scores* between the groups of: coloured compomer and Ormocer®, GIOMER and RMGIC, Ormocer® with GIOMER and RMGIC, GIOMER with RMGIC. the materials used are: Colored compomer - MagicFil (Zenith/DMG, Englewood, NJ, USA). . Ormocer® - Ceram X (Dentsply) GIOMER - Beautifil (Shofu Inc, Kyoto, Japon). Resin-modified glass ionomer cement (RMGIC) and Vitremer (3M Dental Products, USA)	No significant difference was observed when coloured compomer was compared to Ormocer®, GIOMER and RMGIC. Ormocer showed significantly less microleakage when compared to GIOMER. However, no significant difference was observed when Ormocer® was compared to RMGIC. No significant difference was found between GIOMER and RMGIC.	The present study concluded that Ormocer® proved to be an excellent restorative material as it showed the least microleakage, followed by coloured compomer, GIOMER and RMGIC - in ascending order.