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THEORY AND PRACTICE IN RESTORATIVE DENTISTRY

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CHAPTER 1

Dental Anxiety: A Contemporary Perspective from Aetiology to Clinical Management

Suzan Cangül [1]

Anxiety regarding dental treatment is a condition that often arises during childhood and adolescence and can influence the attitudes individuals develop towards the dental environment during this period. Dental anxiety observed in children does not present a homogeneous pattern; whilst some children experience a sense of unease stemming from the general dental clinic environment, others may only experience anxiety when confronted with specific dental stimuli such as needles, drills or similar (Porritt, Buchanan, Hall, Gilchrist, & Marshman, 2013). Dental anxiety can reduce children's compliance with dental treatment and complicate the clinical management process. Research indicates that dental anxiety is low or moderate in the majority of children, whilst high levels of dental anxiety are observed in approximately 10–20% of the paediatric population (Taani, El-Qaderi, & Abu Alhaija, 2005; Dogan, Seydaoglu, Uguz, & Inanc, 2006).

Prevalence of Dental Anxiety

Studies conducted in Turkey indicate that the prevalence of dental anxiety ranges from approximately 5.1% to 42.1% (Saba & Katırcı, 2023). A review of the literature indicates that dental fear and anxiety are more prevalent among adolescents compared to adults (Pekkan, Kılıçoğlu, & Hatipoğlu, 2011; Lahti, Vehkalahti, Nordblad, & Hausen, 2007). Findings presented by Milgrom and colleagues indicate that anxiety levels among individuals in the younger age group (under 40 years old) are significantly higher than those of older individuals, with this difference reaching approximately 1.5 times the level (Milgrom, Fiset, Melnick, & Weinstein, 1988). The literature indicates that women tend to report higher levels of anxiety compared to men. However, it is also reported that women are more likely to attend regular dental check-ups (Bernson, Elfström, & Hakeberg, 2013).

Causes of Dental Anxiety

Dental anxiety is a complex and multidimensional condition that cannot be attributed to a single cause; rather, it arises from the interaction of multiple

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factors. Factors contributing to this process may include individual characteristics, sensitivity to pain and fear, negative dental experiences—particularly those from childhood— the transmission of anxiety from family members or friends onto the individual, lack of trust in the dentist, feelings of embarrassment, fear of injections, and concerns about infection transmission (Scandurra et al., 2021).

Dental anxiety ranks among the most common specific phobias worldwide and can significantly impact individuals' ability to access oral and dental health services. Therefore, it is of great importance for dentists to manage the patient care process through effective communication, individualized approaches, and appropriate clinical strategies (Muneer et al., 2022).

Restorative dental treatments are among the dental procedures commonly associated with dental anxiety; in particular, visual, auditory, and vibrational stimuli caused by rotary instruments, along with local anesthesia injections, can lead to significant anxiety in patients.

Therefore, in the management of individuals with dental anxiety, the "4S" approach—aimed at reducing stress-inducing stimuli (control of visual, auditory, tactile, and olfactory stimuli)—emerges as a key strategy. In this context, alternative approaches such as atraumatic restorative methods, low-speed preparation techniques, the use of polymer burs, chemomechanical caries removal, air abrasion, and laser-assisted procedures may be preferred to enhance patient comfort. Furthermore, patients' expectations that they will experience pain, injury, or a gag reflex during treatment can also increase anxiety levels; effectively addressing such perceptions is of great importance for the success of treatment (Hmuda & Walsh, 2009).

Individuals with higher levels of education generally experience lower anxiety during dental treatments; this can be attributed to their greater knowledge and awareness regarding the treatment process. However, in some cases, conducting extensive research about the treatment may increase an individual's anxiety, whereas individuals with more limited knowledge of dental treatment modalities have been reported to be less likely to experience treatment-related anxiety (Malvania & Ajithkrishnan, 2011).

Financial status is among the factors influencing the development of dental anxiety. In particular, it has been observed that anxiety regarding the payment process increases among individuals who perceive treatment costs as high. In this context, it has been reported that individuals with better economic means tend to develop lower levels of anxiety and fear toward dental treatments (Sukumaran, Taylor, & Thomson, 2021; Singh, Ahmuhin, Alghamdi, & Alasaf, 2021).

It is noteworthy that individuals with dental anxiety tend to postpone scheduling dental appointments and cancel existing ones. (Haugejorden & Klock, 2000). The neglect of treatments due to fear leads to deteriorating oral hygiene and the development of feelings of shame toward the dentist in the patient. In their study comparing the oral health status of individuals with varying levels of dental anxiety, Zinke et al. found that among those with high levels of dental anxiety, oral care habits are generally neglected, and this negatively impacts oral health (Zinke, Hannig, & Berth, 2018). In a related study, Yakar et al. evaluated the relationship between previous treatment experiences and anxiety and fear levels. The research findings indicated that anxiety levels were higher among individuals who had previously experienced painful or negative dental experiences (Yakar, Kaygusuz, & Pirinçci, 2019).

Symptoms of Dental Anxiety

Dental anxiety, defined as fear and anxiety regarding dental treatment, is a problem that can affect both an individual's psychological state and physiological responses and is widely observed across various segments of society. These individuals often clearly reflect high levels of anxiety through their behavior and body language from the moment they enter the clinic. Many patients tend to avoid dental procedures performed while conscious and may prefer treatment under general anesthesia (Şimşek & İspir, 2018).

Various physiological and neurovegetative symptoms may arise during dental anxiety. These may include cold sweating and trembling in the hands, face, and throughout the body, difficulty breathing, dry mouth, blurred vision, dizziness, and fainting spells. Additionally, symptoms such as frequent urination, increased heart rate, muscle tension and spasms, heightened sensory sensitivity, paresthesia, and a drop in blood pressure may also accompany the condition (Appukuttan, 2016).

Methods for Assessing Dental Anxiety

Questionnaires have long been widely used to assess patients' levels of dental anxiety. While not all of these scales fully reflect patients' anxiety, some are easy and practical to use (Şimşek & İspir, 2018). It has also been reported that administering such scales prior to treatment does not have a negative effect on patients' levels of anxiety and fear (Humphris, Clarke, & Freeman, 2006). Therefore, the use of these measurement tools makes significant contributions to both the improvement of clinical practice and the advancement of scientific research (Şimşek & İspir, 2018).

Standardized questionnaires are frequently used in research and clinical evaluations to determine levels of dental anxiety. Among these, the most commonly used are:

1. Corah's Dental Anxiety Scale (DAS),
2. Modified Dental Anxiety Scale (MDAS),

3. Dental Fear Scale (DFS),

4. Photo Anxiety Questionnaire (PAQ), Dental Anxiety Question (DAQ),

5. Gatchel's 10-Point Fear Scale (GFS),

6. Short-Dental Anxiety Inventory (S-DAI),

7. Spielberger's State-Trait Anxiety Inventory (STAI),

8. Visual Analog Scale (VAS) (Ciğerim & Çınarsoy Ciğerim, 2017; Armfield, 2010).

The primary scales commonly used to measure anxiety in medical research are the State-Trait Anxiety Inventory (STAI), the Corah Dental Anxiety Scale (DAS), and the Visual Analog Scale (VAS). The STAI is an assessment tool consisting of two subscales. The State Anxiety subscale measures the level of anxiety an individual experiences at a specific moment or over a short period of time, while the Trait Anxiety subscale aims to identify the individual's general tendency toward anxiety in daily life.

Management of Dental Anxiety

In the treatment of patients experiencing dental anxiety, various methods are employed to help individuals manage their fear levels. In this context, dentistry relies not only on medication-based approaches but also on behavioral techniques aimed at enhancing the patient's psychological comfort. In practice, alongside sedative medications administered orally, intravenously, intramuscularly, and via inhalation, non-pharmacological techniques that provide communication-based and psychological support are also frequently used.

Two distinct approaches primarily stand out in the management of anxious patients. The first approach involves the use of psychosedatives and behavioral guidance techniques alongside iatro-sedation. The second approach consists of pharmacological treatment methods. While pharmacological approaches can be effective in controlling anxiety in the short term, they may carry certain risks, such as adverse drug effects and the development of dependence. In contrast, non-pharmacological methods offer a more comprehensive approach focused on the psychological dimensions of anxiety and pain and can generally be applied without causing systemic side effects. However, for these methods to provide clinically significant benefits, they often require longer-term application and patient compliance (Murillo-Benítez et al., 2020).

It has been reported that combining these two methods yields more successful outcomes, particularly in individuals with severe dental anxiety (Köroğlu & Durkan, 2010). In particular, combining methods such as relaxation exercises or Cognitive Behavioral Therapy (CBT) with low-dose sedative agents can help patients manage their stress levels during dental procedures. Additionally, it has been reported that non-pharmacological interventions may not only reduce anxiety during the procedure but also contribute to managing dental fear in the long term. Current evidence also highlight the importance of a patient-centered approach and recommend that treatment strategies be tailored to the individual's experiences, anxiety level, and clinical needs (Muneer et al., 2022).

Communication-Based Anxiety Management and Non-Pharmacological Psychosedative Approaches

One of the methods used to reduce dental anxiety involves non-pharmacological psychosedative approaches. Iatro-sedation, one of these methods, is based on the trust relationship and effective communication established between the dentist and the patient. As the patient's trust in the dentist increases, cooperation during dental procedures becomes easier, and feelings of fear can be significantly controlled (Friedman, Landesman, & Wexler, 1988).

Maintaining constant eye contact with the patient, supported by a soft and calm tone of voice, can enhance the individual's adaptation to the treatment environment. Additionally, explaining the procedures step by step in simple terms the patient can understand and clearly sharing potential scenarios related to treatment helps reduce anxiety stemming from uncertainty. Recent studies suggest that digital communication-based applications may also be beneficial in managing dental anxiety. It has been reported that these communication support systems, when integrated into the treatment process, can help patients express themselves more comfortably, thereby reducing feelings of loss of control and uncertainty (Nalci, Alaçam, & Altunkaynak, 2022).

Non-pharmacological methods used to reduce dental fear are not limited to communication techniques alone. Hypnosis, acupuncture, electronic dental anesthesia, transcutaneous electrical nerve stimulation (TENS), music-assisted analgesia, and biofeedback methods are also among the alternative approaches used for this purpose (Kong, Liu, Zhang, Wang, & Chen, 2024). The primary goal of these techniques is to create a more comfortable treatment environment by reducing the patient's perception of pain and negative emotions toward treatment.

Another approach commonly used in the management of dental anxiety is cognitive and behavioral therapy (Kömerik & Muğlalı, 2005). In these methods, it is acknowledged that an individual's thought patterns, past experiences, and the way they evaluate events play a significant role in the development of anxiety. Misconceptions or exaggerated fears stemming from negative experiences can lead the patient to develop more intense anxiety toward treatment. Cognitive therapy applications aim to help the individual evaluate these thought patterns more realistically, thereby facilitating the control of anxiety.

In addition to cognitive approaches, various behaviour management strategies are also utilised in the management of dental anxiety. These methods include the ‘tell-show-do’ approach, which is based on explaining the procedure to the patient in stages; play-based approaches; techniques based on the use of role models; trust-based communication practices; visual support materials; distraction techniques; virtual reality systems; and mindfulness-based awareness exercises (Yağız & Erten Can, 2025). Studies have reported that cognitive and behavioral approaches can yield effective results, particularly in individuals with high levels of dental anxiety, and in some cases can serve as an alternative to pharmacological methods (Aartman, de Jongh, Makkes, & Hoogstraten, 2000; Berggren & Linde, 1984; Wilson & Davies, 2001).

Pharmacological Methods

The choice of sedation methods for the pharmacological management of dental anxiety may vary depending on the patient’s anxiety level, behavioral characteristics, systemic condition, and the scope of the dental procedure to be performed. While the clinician’s individual experience was previously the primary factor in sedation practices, today greater emphasis is placed on evaluating the patient’s needs in a more objective manner. Evaluation systems developed for this purpose contribute to determining a more appropriate and patient-centered pharmacological approach by considering both the patient’s anxiety level and the complexity of the treatment (Coulthard, 2018).

Pharmacological approaches are used to reduce anxiety in patients experiencing high levels of dental anxiety, to help the patient feel more comfortable during treatment, and to ensure that clinical procedures can be performed safely. Oral sedation, intravenous sedation, nitrous oxide/oxygen inhalation sedation, and general anesthesia are among the most commonly preferred methods for managing dental anxiety. In particular, conscious sedation is considered one of the most frequently used options in clinical practice because it allows the patient to maintain communication and retain protective reflexes (Bean & Aruede, 2023; Coulthard, 2018).

Conscious Sedation

Conscious sedation is a sedation method in which central nervous system activity is controlled through the use of one or more sedative agents, yet the patient remains able to communicate with their surroundings. During this procedure, the individual can respond to verbal commands, retain protective reflexes, and maintain an open airway without losing consciousness. The primary objective of the medications and techniques used is to ensure adequate sedation while maintaining safety parameters and minimizing the risk of loss of consciousness (Inter-Collegiate Advisory Committee for Sedation in Dentistry [IACSD], 2020).

Today, intravenous midazolam administered via titration combined with nitrous oxide/oxygen inhalation sedation is recognized as one of the methods with a high safety profile. It has been reported that when combined with effective local anesthesia, conscious sedation can serve as an alternative to general anesthesia for many patients and contribute to the ability to perform dental treatments on a broader range of patients within primary care settings (NHS England, 2023).

General Anesthesia

General anesthesia is one of the advanced pharmacological methods used, particularly for patients with severe dental phobia, those who are uncooperative, or those requiring extensive dental treatment (Geddis-Regan et al., 2022). However, it is recommended that more conservative anxiety management options, such as behavioral approaches and conscious sedation, be carefully evaluated before deciding on general anesthesia. During general anesthesia procedures, the patient loses consciousness, and control of the airway and vital functions is entirely managed by the healthcare team. Therefore, the procedure must be performed in centers equipped with appropriate facilities and by experienced teams. Additionally, the treatment plan to be implemented should be determined through a multidisciplinary approach, taking into account the patient's medical condition, dental needs, and the complexity of the procedure (Geddis-Regan et al., 2022).

Conclusion

Dental anxiety is a significant and multifaceted clinical problem that affects individuals' compliance with dental treatment and their oral health behaviors. Past negative dental experiences, fear of pain, individual psychological characteristics, and environmental factors play a significant role in the development of dental anxiety. This condition can lead individuals to avoid dental treatment and negatively impact their oral health.

Today, effective communication, behavioral guidance techniques, non-pharmacological approaches, and pharmacological methods can be used together in the management of dental anxiety. Accurately assessing patients' anxiety levels and developing individualized treatment plans are of great importance for successful clinical management. In conclusion, adopting patient-centered and multidisciplinary approaches will contribute to controlling dental anxiety and creating more positive dental experiences.

REFERENCES

Aartman, I. H., de Jongh, A., Makkes, P. C., & Hoogstraten, J. (2000). Dental anxiety reduction and dental attendance after treatment in a dental fear clinic: A follow-up study. *Community Dentistry and Oral Epidemiology, 28*(6), 435–442

Appukuttan, D. P. (2016). Strategies to manage patients with dental anxiety and dental phobia: Literature review. Clinical, Cosmetic and Investigational Dentistry, 8, 35–50.

Armfield, J. M. (2010). How do we measure dental fear and what are we measuring anyway. Oral Health & Preventive Dentistry, 8(2), 107–115.

Bean, T., & Aruede, G. (2023). Conscious sedation in dentistry. In StatPearls. Treasure Island, FL: StatPearls Publishing. Retrieved from NCBI Bookshelf

Berggren, U., & Linde, A. (1984). Dental fear and avoidance: A comparison of two modes of treatment. *Journal of Dental Research, 63*(10), 1223–1227.

Bernson, J. M., Elfström, M. L., & Hakeberg, M. (2013). Dental coping strategies, general anxiety, and depression among adult patients with dental anxiety but with different dental-attendance patterns. *European Journal of Oral Sciences, 121(*3), 270–276.

Ciğerim, L., & Çınarsoy Ciğerim, S. (2017). Dental İmplant Cerrahisinde Anksiyete: Literatür Derlemesi. Van Tıp Derg, 24(4), 415-419.

Coulthard, P. (2018). Medical management of dental anxiety. *Primary Dental Journal, 7*(4), 40–44.

Dogan, M. C., Seydaoglu, G., Uguz, S., & Inanc, B. Y. (2006). The effect of age, gender and socio-economic factors on perceived dental anxiety determined by a modified scale in children. *Oral Health & Preventive Dentistry, 4*(4), 235–241.

Geddis-Regan, A. R., Gray, D., Buckingham, S., Misra, U., Boyle, C., & British Society for Disability and Oral Health. (2022). The use of general anaesthesia in special care dentistry: A clinical guideline from the British Society for Disability and Oral Health. *Special Care in Dentistry,* 42(1), 3–32.

Haugejorden, O., & Klock, K. S. (2000). Avoidance of dental visits: The predictive validity of three dental anxiety scales. *Acta Odontologica Scandinavica, 58*(6), 255–259.

Hmuda, R., & Walsh, L. J. (2009). Dental anxiety: Causes, complications and management approaches. *Journal of Minimum Intervention in Dentistry, 2*(1), 67–78.

Humphris, G., Clarke, H., & Freeman, R. (2006). Does completing a dental anxiety questionnaire increase anxiety? A randomised controlled trial with adults in general dental practice. *British Dental Journal*, 201(1), 33–35.

Inter-Collegiate Advisory Committee for Sedation in Dentistry. (2020). *Standards for conscious sedation in the provision of dental care: Report of the Inter-Collegiate Advisory Committee for Sedation in Dentistry*. Retrieved from Inter-Collegiate Advisory Committee for Sedation in Dentistry.

Kong, X., Liu, Y., Zhang, H., Wang, J., & Chen, L. (2024). Non-pharmacological interventions for reducing dental anxiety: A systematic review and network meta-analysis. *BMC Oral Health, 24*(1), 1123. https://doi.org/10.1186/s12903-024-04973-0

Kömerik, N., & Muğlalı, M. (2005). Ağız cerrahisinde anksiyete kontrolü: Hastaların bilgilendirilmesi. *Atatürk Üniversitesi Diş Hekimliği Fakültesi Dergisi, 15*(3), 25–33.

Köroğlu, A., & Durkan, R. (2010). Diş hekimliği uygulamalarında karşılaşılan dental anksiyete sendromunun etiyolojisinin ve tedavi yöntemlerinin değerlendirilmesi. Atatürk Üniversitesi Diş Hekimliği Fakültesi Dergisi, 20(3), 205–212.

Lahti, S., Vehkalahti, M. M., Nordblad, A., & Hausen, H. (2007). Dental fear among population aged 30 years and older in Finland. *Acta Odontologica Scandinavica, 65*(2), 97–102.

Malvania, E. A., & Ajithkrishnan, C. G. (2011). Prevalence and socio-demographic correlates of dental anxiety among a group of adult patients attending a dental institution in Vadodara city, Gujarat, India. *Indian Journal of Dental Research, 22*(2), 195–199.

Milgrom, P., Fiset, L., Melnick, S., & Weinstein, P. (1988). The prevalence and practice management consequences of dental fear in a major US city. *Journal of the American Dental Association, 116*(6), 641–647.

Muneer, M. U., Ismail, F., Munir, N., Shakoor, A., Das, G., Ahmed, A. R., & Ahmed, M. A. (2022). Dental anxiety and influencing factors in adults. Healthcare, 10(12), 2352. https://doi.org/10.3390/healthcare10122352.

Murillo-Benítez, M., Martín-González, J., Jiménez-Sánchez, M. C., Cabanillas-Balsera, D., Velasco-Ortega, E., & Segura-Egea, J. J. (2020). Association between dental anxiety and intraoperative pain during root canal treatment: A cross-sectional study. *International Endodontic Journal, 53*(4), 447–454. https://doi.org/10.1111/iej.13256

Nalci, G., Alaçam, T., & Altunkaynak, B. (2022). Evaluation of the effectiveness of a mobile application in the management of dental anxiety: A randomised controlled trial. Journal of Oral Rehabilitation, 49(5), 535–540. https://doi.org/10.1111/joor.13311

NHS England. (2023). *Clinical standards for dental anxiety management*.

Pekkan, G., Kılıçoğlu, A., & Hatipoğlu, H. (2011). Relationship between dental anxiety, general anxiety level and depression in patients attending a university hospital dental clinic in Turkey. *Community Dental Health, 28*(2), 149–153.

Porritt, J., Buchanan, H., Hall, M., Gilchrist, F., & Marshman, Z. (2013). Assessing children's dental anxiety: A systematic review of current measures. *Community Dentistry and Oral Epidemiology, 41*(2), 130–142.

Saba, Z., & Katırcı, G. (2023). Relationship between dental anxiety levels and oral health among dental patients in Turkey: A cross-sectional study. *BMC Oral Health, 23*, 328. doi:10.1186/s12903-023-03041-8.

Scandurra, C., Gasparro, R., Dolce, P., Bochicchio, V., Muzii, B., Sammartino, G., Marenzi, G., & Maldonato, N. M. (2021). The role of cognitive and non-cognitive factors in dental anxiety: A mediation model. *European Journal of Oral Sciences, 129*(e12793).

Singh, S., Almulhim, B., Alghamdi, S., & Alaasaf, A. (2021). Effect of age, gender and socioeconomic status on perceived dental anxiety. *Revista Argentina de Clínica Psicológica, 30*, 525–530.

Sukumaran, I., Taylor, S., & Thomson, W. M. (2021). The prevalence and impact of dental anxiety among adult New Zealanders. *International Dental Journal, 71*(2), 122–126.

Şimşek, N., & İspir, S. (2018). Diş hekimliğinde anksiyete. *Akdeniz Tıp Dergisi*, *5*(1), 15-20.

Taani, D. Q., El-Qaderi, S. S., & Abu Alhaija, E. S. (2005). Dental anxiety in children and its relationship to dental caries and gingival condition. *International Journal of Dental Hygiene, 3*(2), 83–87.

Tanidir, A. N., Atac, M. S., & Karacelebi, E. (2016). Information given by multimedia: Influence on anxiety about extraction of impacted wisdom teeth. *British Journal of Oral and Maxillofacial Surgery, 54*(6), 652–657.

Wilson, K. I., & Davies, J. G. (2001). A joint approach to treating dental phobics between community dental services and specialist psychotherapy services: A single case report. *British Dental Journal, 190*(8), 431–432.

Yağız, G., & Erten Can, S. H. (2025). Dental anksiyete yönetiminde nonfarmakolojik güncel yaklaşımlar. In B. Özkara (Ed.), Sağlık Bilimleri Değerlendirmeleri (136–159). Yaz Yayınları.

Yakar, B., Kaygusuz, T. O., & Pirinçci, E. (2019). Evaluation of dental anxiety and fear in patients who admitted to the Faculty of Dentistry: Which patients are more risky in terms of dental anxiety. *Ethiopian Journal of Health Sciences, 29*(6), 719–726.

Zinke, A., Hannig, C., & Berth, H. (2018). Comparing oral health in patients with different levels of dental anxiety. *Head & Face Medicine,* 14, 25.

CHAPTER 2

Bioactive Materials in Restorative Dentistry: Claims, Mechanisms, and Clinical Evidence

Özge Duman Özbilgi[1]

1. Introduction

The concept of bioactive materials has gained considerable momentum in dentistry in recent years. Dental materials used in restorative procedures are expected not only to exhibit basic biocompatibility but also to possess properties that can induce biological responses. This review aims to discuss the historical development of bioactive materials, their mechanisms of biological interaction, their clinical applications in restorative systems, and the performance data available in the current literature.

1.1. Bioactivity and the Development of Bioactive Materials

The management of dental hard-tissue loss has historically relied on restorative materials such as dental amalgam, glass ionomer cements, and resin composites. Materials that function in harmony with living tissues without causing adverse biological effects are generally referred to as biomaterials (Park & Lakes, 2007; Özcan, Garcia, & Volpato, 2021).

Bioactivity is the ability of a biomaterial to elicit a biological response through chemical interactions with living tissues upon contact, even when the biomaterial is biocompatible (Özcan et al., 2021). In tissue engineering and the medical sciences, the term bioactivity encompasses the cellular effects induced by biologically active ions and molecules released from biomaterials, such as bioactive glasses, used in both hard and soft tissue applications. Therefore, in the medical sciences, bioactivity broadly refers to all biological interactions between materials and living cells and tissues, including the pharmacological effects of drugs (Vallittu, Boccaccini, Hupa, & Watts, 2018).

The term *bioactive* is derived from the Greek word *bios* (life) and the Latin word *activus* (active), and literally means "biologically active." Accordingly, a bioactive compound is a substance that exhibits biological activity (Abdelkarim, Soumaya, Naima, Mohammed, & Abdellah, 2014).

The term bioactive was first introduced into the scientific literature in the 1970s by L. L. Hench with the development of bioactive glasses, also referred to as "bioactive ceramics" (Hench, Splinter, Allen, & Greenlee, 1971). Hench's

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bioactive glasses were reported to bond rapidly to bone and stimulate bone growth. Their ability to form an apatite-like layer on their surfaces when immersed in simulated body fluid marked a major milestone in the field of bioactive ceramics and paved the way for the development of new calcium phosphate-based materials, such as synthetic hydroxyapatite (HAp). Since their original formulation in the 1970s, Hench's bioactive glasses have undergone numerous modifications in composition, particle size, and structural characteristics (LeGeros, 2002). The definition of bioactive materials was adapted to dental applications by Steven Jefferies in 2014. According to Jefferies, bioactive materials should be capable of forming an apatite-like surface layer in the presence of inorganic phosphate-containing solutions. In addition, these materials are expected to exhibit bactericidal and/or bacteriostatic effects, stimulate dentin formation, and contribute to the preservation of pulp vitality (Jefferies, 2014).

Several definitions of bioactive materials have been proposed. Whitlow et al. defined bioactive materials as "materials capable of eliciting specific and predictable cellular and tissue responses" (Whitlow, Paul, & Polini, 2016). Vallittu et al. addressed bioactivity in the context of biomineralization and suggested that the term bioactive be restricted to materials or material combinations that release sufficient ions to support biomineralization (Vallittu, 2018).

During an international conference in 2018, it was proposed that dental restorative materials may be considered bioactive if, in addition to their primary function of repairing or replacing lost tooth structure, they actively stimulate or direct specific cellular and/or tissue responses or are capable of modulating interactions with microbial species (Price & Roulet, 2020).

Bioactivity has also been defined in several ISO standards, though these definitions primarily apply to surgical implants. For example, ISO 23317:2014 defines bioactivity as "the property of a material that elicits a specific biological response at the interface of the material, resulting in the formation of a bond between the tissue and the material." Likewise, ISO 19090:2018 states that bioceramics should be capable of forming direct bonds with bone when implanted into a bone defect. These examples illustrate the diversity of definitions proposed for bioactivity (International Organization for Standardization [ISO], 2014; ISO, 2018).

As evidenced by the definitions above, there is currently no consensus on the definition of bioactive materials. In restorative dentistry, bioactive materials are generally regarded as materials that promote the formation of hydroxyapatite crystals on tooth surfaces. In addition, dental caries develops through a multistep process involving biofilm formation, bacterial adhesion, microcolony development, biofilm maturation, and biofilm dispersion. Therefore, a bioactive material intended for caries control should be capable of disrupting one or more stages of biofilm formation and progression (Ferracane et al., 2023; Zhang et al., 2023).

In 2023, the Fédération Dentaire Internationale (FDI) published a policy statement on bioactive dental materials. According to the statement, the principal effect of bioactive materials is to induce the formation of dentin or dentin-like tissues and to promote pulpal healing. However, the statement emphasized that the primary function of materials used to restore dental tissues is to replace lost tissue and, therefore, such materials should not generally be classified as bioactive interventions. Nevertheless, the statement acknowledged that fluoride ions released from materials such as glass ionomer cements may exert secondary bioactive effects. In contrast, for materials incorporating pharmaceutical agents or biologically active molecules, such as bone morphogenetic proteins (BMPs), bioactivity should be regarded as the material's primary function (Schmalz, Hickel, Price, & Platt, 2023).

1.2 Interactions Between Bioactive Materials and Dental Tissues

One of the major causes of long-term failure of dental restorations is the development of secondary carious lesions adjacent to restorative materials. Although secondary caries is a multifactorial condition primarily associated with cariogenic biofilms, bioactive materials have been proposed to protect the remaining tooth structure from marginal secondary caries by preventing or arresting lesion progression. However, definitive evidence supporting this claim remains limited (de Carvalho et al., 2025; Gonulol, Ozer, & Tunc, 2015).

Bioactive materials may interact with dental tissues, including enamel, dentin, and pulp, through various mechanisms. These interactions may be biological, biological and chemical, or purely chemical in nature (Schmalz et al., 2023).

Mechanisms of Bioactive Interaction with Enamel

Enamel is the hardest and most highly mineralized tissue in the human body. Its inorganic component consists predominantly of hydroxyapatite crystals arranged in a hexagonal structure, accounting for approximately 95–96% of the tissue. The remaining composition comprises approximately 1% organic matrix and 3% water (Salinovic, Schauperl, Marcius, & Miletic, 2021). Enamel is secreted by ameloblasts, and once full thickness is achieved, the secretory process ceases, rendering enamel incapable of self-regeneration.

However, bioactive materials and incorporated bioactive glasses may promote the precipitation of calcium and phosphate ions on the enamel surface, thereby facilitating the formation of an apatite-like layer. This ion-rich layer can penetrate deeper into demineralized enamel and enhance remineralization (Ramadoss, Padmanaban, & Subramanian, 2022).

Mechanisms of Bioactive Interaction with Dentin

Unlike enamel, dentin contains approximately 20% organic matrix, most of which is collagen. This organic matrix makes dentin remineralization more complex. Dentin remineralization requires the coordinated restoration of collagen and inorganic apatite structures, ultimately resulting in intrafibrillar mineralization of collagen fibrils (Šalinović, Schwendicke, Askar, Yassine, & Miletić, 2023).

In this context, dentin remineralization mediated by bioactive materials should not be viewed merely as the chemical deposition of apatite. Other components of dentin, particularly collagen fibrils, also contribute to the process. For example, agents such as tannic acid can chemically interact with collagen fibrils by promoting cross-linking, thereby enhancing remineralization. In addition, restorative materials containing calcium hydroxide may stimulate the formation of tertiary dentin (Schmalz et al., 2023).

Mechanisms of Bioactive Interaction with the Pulp

The pulp tissue plays a dual role in promoting or delaying tissue repair and regeneration and in enhancing the tooth's resistance to infection. Furthermore, odontoblasts in the pulp tissue can produce reparative dentin in response to external stimuli, thereby helping protect the dental pulp. Two principal approaches have been proposed for pulp regeneration. The first is revascularization, whereas the second involves placing stem cells, scaffold-forming materials, and growth factors into the root canal system to establish a functional pulp–dentin complex (Li, Fan, & Fan, 2024).

1.3 Bioactive Restorative Materials

Contemporary approaches to caries removal have shifted toward tissue-preserving strategies grounded in minimally invasive dentistry, with the goal of maximizing the preservation of biological tissues. This tissue-friendly approach advocates retaining partially demineralized dentin, which may allow residual microorganisms to persist. Consequently, preventing bacterial colonization and secondary caries requires restorative materials with enhanced antibacterial and bioactive properties (Imazato, Kuramoto, Takahashi, Ebisu, & Peters, 2006).

Nevertheless, Ferracane emphasized that, given the complexity of the chemistries, products, and biological effects involved, it is nearly impossible to clearly define the fundamental characteristics that qualify a material as bioactive. He further noted that, from a clinician's perspective, determining whether a product claiming bioactivity is clinically superior and whether its use is truly warranted remains challenging (Ferracane et al., 2023).

Four major approaches have emerged in designing bioactive dental restorative materials. Antibacterial activity can be achieved by incorporating quaternary ammonium monomers (QAMs), metallic nanoparticles (e.g., silver, zinc oxide, and copper), and antimicrobial peptides, thereby reducing biofilm formation and the risk of secondary caries. Strategies aimed at remineralization promote hydroxyapatite formation through ion-releasing systems, such as amorphous calcium phosphate, tricalcium phosphate, and bioactive glass, thereby supporting the remineralization of enamel and dentin. In addition, biomolecule delivery systems facilitate tissue regeneration by providing controlled release of agents such as matrix metalloproteinase (MMP) inhibitors and growth factors. Finally, combined strategies integrate these mechanisms within a single material, providing antibacterial, remineralizing, and regenerative properties simultaneously (Melo et al., 2023).

Collectively, these approaches transform restorative materials from passive substitutes that merely replace lost tooth structure into biologically active systems that control biofilm formation, promote tissue repair, and contribute to the biological success of restorative treatment.

1.3.1 Classification of Bioactive Restorative Materials

Glass Ionomer Cements (GICs)

Glass ionomer cements (GICs), first developed by Wilson and Kent in 1969 by combining fluoroaluminosilicate glass particles with polyacrylic acid, have been widely used in dentistry for their favorable properties, including biocompatibility, bioactivity, and sustained fluoride release. However, their relatively poor mechanical properties and low resistance to wear and erosion have limited their use as long-term restorative materials in permanent dentition (Nicholson, 1998; Menezes-Silva et al., 2019).

A conventional GIC consists of three principal components: a water-soluble polymeric acid, ion-releasing glass fillers, and water. The polymeric components commonly used in GICs are homopolymeric polyacrylic acid or polyalkenoic acids, which are copolymers of acrylic and maleic acids in a 2:1 ratio. The setting reaction is an acid–base reaction between the basic glass particles and the polymeric acids, forming a salt-based matrix. Although various glass compositions may theoretically support this reaction, fluoride- and phosphate-containing aluminosilicate glasses have been shown to satisfy these chemical requirements most effectively in clinical applications (Sidhu & Nicholson, 2016). Water acts as a solvent for the polymeric acid and facilitates proton release, thereby enabling the acid–base reaction and playing an essential role in the setting process (Nicholson, 1998).

GICs are restorative materials that release fluoride ions in an initial burst, followed by sustained, diffusion-controlled release. An important advantage of these materials is their ability to be recharged with fluoride after topical fluoride application, thereby maintaining their biological activity (Hill, 2022). Through fluoride release, GICs lower the critical pH at which hydroxyapatite crystals begin to dissolve (approximately 5.5) to around 4.5 by promoting the formation of fluorapatite. Consequently, they facilitate enamel remineralization by promoting the incorporation of calcium and phosphate ions and contribute to the formation of a more acid-resistant fluorapatite-rich structure (Hamdy, 2018). In some formulations, silver or silver alloys have been incorporated into GICs to enhance their antibacterial properties (Schmalz et al., 2023).

Resin-Modified Glass Ionomer Cements (RMGICs)

Although RMGICs exhibit superior flexural strength compared with conventional and high-viscosity GICs, their wear resistance remains limited. Furthermore, the resin matrix results in lower overall fluoride release than conventional GICs, despite an initially high fluoride release. Nevertheless, RMGICs may be considered bioactive due to their fluoride-releasing capability and potential to promote dentin remineralization. Clinically, they have been successfully used in selected indications, including cervical lesions, restorations in primary teeth, and as an intermediate layer in the sandwich technique (Francois, Fouquet, Attal, & Dursun, 2020).

Reinforced Glass Hybrids

Introduced in 2007, a new material system for long-term glass ionomer restorations combined a fast-setting, reinforced glass ionomer cement with a nano-filled resin coating system. In 2007, the manufacturer reintroduced it as the EQUIA Restorative System (GC) and indicated its use in load-bearing Class I and small Class II cavities. An improved version based on glass-hybrid technology, EQUIA Forte (GC), was launched in 2015. EQUIA Forte consists of a highly viscous glass-hybrid restorative material (EQUIA Forte Fil) and a resin-based coating agent (EQUIA Forte Coat) (Miletić et al., 2020). Incorporating specially designed glass particles, the material exhibits enhanced reactivity and improved aesthetics. EQUIA Forte Coat is a nanoparticle-containing adhesive resin that protects the restoration, improves marginal sealing, and enhances surface gloss. According to the manufacturer, EQUIA Forte demonstrates superior mechanical properties compared with its predecessor, the EQUIA Restorative System (Kütük, Ozturk, Soleimani, Yalcin, & Gurgan, 2018; Miletić et al., 2024).

The reinforcing mechanism of EQUIA Forte Fil relies on uniformly distributed, highly reactive ultrafine glass particles. These modifications have led to the development of a new class of restorative glass ionomer materials with improved mechanical properties. The manufacturer claims that this material can be used not only for Class I and Class V restorations but also for load-bearing Class II restorations. In addition, improvements in flexural strength and wear resistance have been reported (Moshaverinia et al., 2019).

Multicenter randomized clinical trials have compared the clinical performance of glass-hybrid restorative systems, such as EQUIA Forte, with nanohybrid resin composites in posterior Class II cavities. Miletić et al. evaluated EQUIA Forte and Tetric EvoCeram, reporting two-year survival rates of 93.6% and 94.5%, respectively (Miletić et al., 2020). At five years, the corresponding survival rates were 81.9% for EQUIA Forte and 90.7% for Tetric EvoCeram (Miletić et al., 2024). Similarly, Kütük et al. compared a resin composite (G-ænial Posterior) with EQUIA Forte, reporting two-year survival rates of 100% and 93.7%, respectively. In that study, a limited number of failures, including bulk and proximal fractures, were identified in the EQUIA Forte group (Kütük et al., 2018).

These findings suggest that EQUIA Forte demonstrates clinically acceptable durability and long-term stability. However, its performance may be inferior to that of resin composites in areas subjected to high occlusal stresses.

Giomers

To overcome the relatively poor mechanical properties of conventional glass ionomer cements (GICs), giomers were developed by combining the advantages of glass ionomers with those of resin-based materials. The term giomer was introduced following the development of patented prereacted glass fillers by Roberts et al. in 1999 (Tian et al., 2024). These fillers are produced by pre-reacting fluoroaluminosilicate glass with polyacids to form a glass-ionomer phase, which is then incorporated into a resin matrix. The extensive hydrogel layer that forms around the glass particles plays a critical role in fluoride uptake and rerelease, giving giomers a greater fluoride recharge capacity than conventional resin-based materials. Thus, giomers retain the esthetic properties of resin composites while exhibiting improved clinical handling and physical properties compared with conventional and resin-modified GICs (Itota, Carrick, Yoshiyama, & McCabe, 2004).

Pre-reacted glass fillers can be classified as fully reacted (F-PRG) or surface reacted (S-PRG). In F-PRG fillers, the entire filler particle reacts with polyacrylic acid, resulting in complete reaction of the glass core and the release of large amounts of fluoride. In contrast, only the surface layer reacts in S-PRG fillers, leaving the glass core intact. Consequently, F-PRG fillers degrade more rapidly, whereas S-PRG fillers exhibit superior long-term stability. For this reason, contemporary giomer materials predominantly employ S-PRG filler technology (Ozer et al., 2021).

Introduced by Shofu Inc. in 2000, S-PRG filler technology is a significant advancement in bioactive dental materials and differs fundamentally from conventional fluoride-releasing glass-ionomer hybrid materials. S-PRG fillers consist of three layers: an outer silica coating, a prereacted glass-ionomer (PRG) layer, and a glass core. This structure enables the controlled release of multiple ions, including sodium, aluminum, borate, silicate, fluoride, and strontium (Moreira, Vieira-Junior, Turssi, França, & Basting, 2025). The release of these ions has been associated with long-term anticariogenic properties, remineralization potential, buffering capacity, and reduced dentinal hydraulic conductance. Furthermore, ion release from S-PRG fillers has been reported to inhibit demineralization around restorations (Wu et al., 2024).

In addition, S-PRG fillers have been shown to suppress Streptococcus mutans adhesion and inhibit biofilm formation. The ions released from S-PRG fillers have also demonstrated inhibitory effects against bacteria associated with periodontal disease and have been reported to suppress their pathogenic activities. Specifically, S-PRG fillers have been shown to inhibit the growth of Porphyromonas gingivalis, Fusobacterium nucleatum, and Aggregatibacter actinomycetemcomitans, and to suppress the hemagglutination and gingipain activities of P. gingivalis (Imazato et al., 2023). Nomura et al. suggested that borate (BO_3^{3-}) and fluoride (F^-) ions are primarily responsible for these effects. These ions not only inhibit bacterial growth but also reduce carbohydrate metabolism, acid production, and glucan synthesis, thereby promoting the formation of less dense, structurally weaker biofilms (Nomura, Morita, Matayoshi, & Nakano, 2018).

Fluoride release from giomers occurs via water sorption and does not require acid activation, thanks to reactive S-PRG fillers. However, unlike conventional GICs, giomers do not show an initial burst of fluoride release, and there is currently insufficient evidence that the amount of ions released is adequate to promote clinically relevant remineralization. Although some studies have suggested that the long-term survival of giomers may be inferior to that of resin composites, these materials remain viable alternatives for cervical, occlusal, and pediatric restorations. Concerns remain about their long-term esthetic stability (Francois et al., 2020). For example, Yoshihara et al. reported numerous surface irregularities on S-PRG-containing materials after immersion in lactic acid (pH 4.0) for three days, whereas no surface alterations were observed in conventional resin composites. Such surface degradation has been attributed to the dissolution of S-PRG fillers (Yoshihara et al., 2017).

Beautifil II (Shofu Inc.) is a universal second-generation giomer restorative material designed to combine the favorable characteristics of resin composites and glass ionomer cements. To validate the biological potential of these materials under clinical conditions, several research groups have conducted long-term clinical evaluations. In a three-year prospective study, Özer et al. assessed Beautifil II and Beautifil Flow Plus giomer restorative materials and reported favorable clinical outcomes. Although slight deterioration in marginal integrity, marginal discoloration, and anatomical form was observed with Beautifil II, no significant changes were detected in Beautifil Flow Plus restorations (Ozer et al., 2021).

Similarly, Tian et al. compared a giomer-based restorative system (Beautifil II with FL-Bond II) with a nanofilled resin composite system (Filtek Z350 with Scotchbond Multi-Purpose). The eight-year follow-up showed comparable clinical performance between the two systems. Overall, these and similar clinical studies suggest that giomers may reduce the risk of secondary caries through fluoride release and the biological effects attributed to S-PRG fillers (Tian et al., 2024). Nevertheless, it has been emphasized that larger-scale studies with longer follow-up periods are needed to substantiate these biological benefits at the clinical level.

In another clinical study, El Ghamrawy et al. evaluated the performance of Beautifil II LS (Low-Shrinkage), a giomer restorative material containing Bis-MPEPP, a low-shrinkage monomer that distinguishes it from conventional giomer systems. This modified resin matrix has been reported to reduce polymerization shrinkage stress, thereby improving marginal adaptation and color stability. After 12 months of clinical follow-up, no secondary caries, marginal discoloration, or loss of retention were observed in Beautifil II LS restorations. The authors concluded that the modified monomer structure may enhance the clinical stability of giomer materials; however, long-term clinical data remain limited (El Ghamrawy, Kamal, & Hamza, 2025).

Overall, clinical studies of giomer-based restorative materials have reported high retention rates, low rates of secondary caries, and satisfactory esthetic stability. Beautifil II and Beautifil Flow systems have demonstrated favorable clinical performance over follow-up periods of three to eight years, whereas the newer Beautifil II LS has maintained these outcomes through reduced polymerization shrinkage and improved marginal adaptation afforded by its modified monomer system. Nevertheless, further long-term clinical studies with larger sample sizes are needed to establish the long-term clinical performance of giomer materials.

Ion-Releasing Resin Composites

ACTIVA, classified as an ion-releasing resin composite, contains an ionic resin matrix and fluoroaluminosilicate glass fillers and is formulated without bisphenol A (BPA) or Bis-GMA. This proprietary matrix enables sustained release of calcium, phosphate, and fluoride ions and allows their recharge through saliva-mediated processes (Banon et al., 2024).

Market as a bioactive material that responds to changes in the oral environment through ion exchange, ACTIVA is intended to combine the mechanical and esthetic properties of resin composites with the desirable characteristics of glass ionomer cements, including moisture tolerance, chemical adhesion to tooth structure, ion release, and rechargeability. ACTIVA BioACTIVE Restorative has been reported to reduce microleakage by promoting apatite formation within marginal gaps, strengthening dentin, and releasing more fluoride than conventional glass ionomer cements (Birant & Gümüştaş, 2024). The material exhibits both micromechanical and ionic/chemical bonding potential to enamel and dentin. Its resin matrix contains a modified polybutadiene-modified diurethane dimethacrylate. ACTIVA fulfills the minimum flexural strength requirement of 80 MPa established by ISO 4049 for occlusal restorative materials. However, its mechanical properties have been reported to decrease over time as ion release progresses (Van Dijken, Pallesen, & Benetti, 2019).

During mixing, ACTIVA BioACTIVE undergoes a dual-setting mechanism. An acid–base reaction is initiated when polyacrylic acid and dimethacrylate phosphate monomers interact with silanized fluoroaluminosilicate (FAS) glass particles, triggering ion release similar to that observed in conventional glass ionomer-based materials. Simultaneously, resin polymerization is initiated by chemical initiators and completed by light curing. The silanized FAS fillers can interact chemically and mechanically with the resin matrix. The ions released during the acid–base reaction are either exchanged with the surrounding environment or participate in forming ionic cross-links between polyacrylic acid chains. Furthermore, trivalent ions, such as aluminum, can bind to both polyacrylic acid and dimethacrylate phosphate, integrating the resin network with the ionic network and thereby enhancing the material's structural integrity and durability (Pinto et al., 2023).

An improved formulation, ACTIVA Pronto, contains similar bioactive components but is supplied as a single-component, light-cured material. Because polyacrylic acid is absent, no acid–base reaction occurs. Nevertheless, calcium-phosphate complexes enable the material to retain some ion-releasing capability. Its moisture-friendly resin matrix facilitates ion release and recharge, creating a favorable microenvironment for apatite formation. In addition, ACTIVA Pronto has been reported to exhibit superior polishability and long-term gloss retention compared with the original formulation, resulting in improved esthetic stability (Pracheth et al., 2024).

The chemical composition and structural characteristics of these materials directly influence their clinical performance and long-term behavior. Accordingly, the clinical effectiveness of ACTIVA has been evaluated in several studies. In a clinical study, Yehia et al. compared ACTIVA with a resin-modified glass ionomer cement (RMGIC) and reported a 100% survival rate for both materials after 12 months. In addition, ACTIVA exhibited superior esthetic performance compared with RMGIC (Yehia, Ibrahim, Abou-Auf, & Elzogbhi, 2022). However, in a randomized clinical trial, Van Dijken et al. found that the annual failure rate of ACTIVA applied without an adhesive system (24.1%) was substantially higher than that of a conventional resin composite (2.5%), suggesting that an adhesive may be necessary for optimal clinical performance (Van Dijken et al., 2019). Similarly, an in vitro study by Tohidkhah et al. demonstrated increased microleakage and reduced microtensile bond strength when ACTIVA BioACTIVE Restorative was used without an adhesive system, raising concerns about its self-adhesive properties (Tohidkhah, Kermanshah, Ahmadi, Jalalian, & Ranjbar Omrani, 2022).

Furthermore, in a two-year randomized controlled clinical trial, Banon et al. compared ACTIVA BioACTIVE with Dyract eXtra (a compomer) and found no significant differences in clinical and radiographic success rates. ACTIVA demonstrated superior color matching but worse marginal discoloration. In addition, its shorter application time was considered a practical advantage, particularly in pediatric dentistry (Banon et al., 2024).

Overall, although ACTIVA appears to exhibit biological activity and favorable clinical performance under certain conditions, its long-term success largely depends on the application protocol and clinical context.

Self-Adhesive Restorative Materials

Among self-adhesive restorative materials, Surefil One is among the most widely recognized systems. It is based on a proprietary technology, MOPOS, developed by the manufacturer. MOPOS consists of a high-molecular-weight polyacrylic acid functionalized with polymerizable groups. This technology was designed to combine the self-adhesive characteristics of conventional glass ionomer polyacids with the cross-linking capability of structural monomers found in resin composites (Albelasy, Hamama, Chew, Montasser, & Mahmoud, 2024).

The self-adhesive mechanism of Surefil One is based on polymerizable polyacid technology. Polyacid chains containing carboxylic acid functional groups are covalently incorporated into the same three-dimensional cross-linked network as the (meth)acrylate matrix monomers via free-radical copolymerization, thereby preserving the acidic groups within the polymer matrix. These functional groups interact with calcium-rich regions of enamel and dentin hydroxyapatite through ionic and hydrogen bonding, facilitating initial adhesion to the tooth surface. Simultaneously, integration into the composite-like polymer network provides mechanical strength. As a result, self-adhesion can be achieved in a single clinical step without separate etching and adhesive procedures (Klee, Renn, & Elsner, 2020).

Surefil One reportedly contains camphorquinone and persulfate initiators, enabling both light- and chemically activated polymerization. In addition, the material contains a certain amount of water, which is essential to its setting mechanism (Albelasy et al., 2024).

In recent years, several multicenter clinical studies have evaluated the clinical performance of Surefil One. In a one-year clinical study, Ellithy et al. compared Surefil One, a self-adhesive dual-cure restorative material, with Filtek One used with Scotchbond adhesive. Both restorative systems achieved a 100% survival rate. Surefil One showed functional and biological performance comparable to the resin composite; however, its esthetic performance was considered inferior (Ellithy, Abdelrahman, & Afifi, 2024). Similarly, Rathke et al. reported that 96% of restorations across different cavity types were clinically acceptable after 1 year, although color matching was suboptimal due to the material's single-shade formulation (Rathke, Pfefferkorn, McGuire, Heard, & Seemann, 2022).

In a two-year follow-up study by Albelasy et al., Surefil One was compared with Cention N and Tetric PowerFill. 100% survival rates were observed for both Surefil One and Tetric PowerFill, whereas Cention N showed a survival rate of 96.3%. No secondary caries were detected in any group. However, Cention N exhibited greater deterioration in marginal adaptation after two years than the composite-based materials (Albelasy et al., 2024).

Overall, the available evidence indicates that Surefil One provides clinically acceptable short-term performance and survival rates comparable to those of contemporary resin composites. Nevertheless, long-term clinical data remain limited, and further studies are needed to determine whether the biological and self-adhesive properties claimed for this material translate into clinically relevant long-term benefits.

Alkaline Ion-Releasing Restorative Materials

Cention N was developed to prevent demineralization by neutralizing acids through ion release. According to the manufacturer, the material contains three inorganic glass fillers: conventional inert barium aluminosilicate glass, an ionomer glass based on calcium barium alumino-fluorosilicate, and a basic calcium fluorosilicate glass referred to as an “alkasite” filler. Alkasites are considered a subgroup of resin-based composites and have been reported to possess anticariogenic properties through the release of calcium and hydroxyl ions (Birant & Gümüştaş, 2024).

Because of the presence of alkaline glass fillers, Cention N can raise the environmental pH by releasing hydroxyl ions. This buffering effect may help protect against secondary caries, and ion release has been shown to increase under acidic conditions. Compositional analyses have also confirmed its relatively high calcium content, which is considered consistent with its proposed remineralization potential. Although Cention N can be used without an adhesive system, the manufacturer recommends using an additional adhesive in non-retentive cavities. Furthermore, the material has been reported to exhibit ion-recharge capability, enabling repeated release of fluoride and calcium ions over time and thereby contributing to its proposed bioactive behavior (Bektaş et al., 2024).

Although Cention N is a hybrid material, it shares characteristics with both glass ionomer cements and resin-based composites and is classified as an alkasite restorative. It can polymerize via self-curing or light-curing mechanisms. Light-cured Cention N has been reported to achieve a higher degree of conversion and greater stability than the self-cured formulation (Justen, Scheck, Münchow, & Jardim, 2024; Marovic et al., 2022). Because it can be placed in 4–5 mm increments, the material may also be considered a bulk-fill restorative. However, owing to its limited shade options, its clinical indications are generally restricted to Class I, II, and V restorations.

Clinical studies evaluating Cention N have shown promising outcomes in both primary and permanent dentitions. Soneta et al. compared restorations using glass ionomer cement and Cention N in children during the mixed dentition stage and reported that Cention N had superior retention and antibacterial activity, particularly against Lactobacillus species (Soneta et al., 2022).

In another clinical study, Oz et al. compared the 12-month clinical performance of Cention N and G-ænial Posterior in Class II restorations in adult patients. Both materials showed comparable clinical success, with no significant differences in marginal integrity or color stability (Oz, Meral, & Gurgan, 2023).

Similarly, in a randomized clinical trial by Mhole et al., Cention N and Tetric N-Ceram were evaluated over 9 months. Survival rates of 97.1% and 100% were reported for Cention N and Tetric N-Ceram, respectively. Both materials exhibited clinically acceptable performance (Mhole et al., 2025). However, the available evidence indicates that further long-term studies are required to establish the durability and long-term clinical effectiveness of Cention N.

Comparative Studies and Evaluation of Clinical Meta-Analyses

As discussed previously, the use of bioactive restorative materials in dentistry has attracted growing interest for their proposed ability to reduce secondary caries, promote remineralization, and extend restoration longevity (de Carvalho et al., 2025; Fernandes et al., 2023; Garoushi, Vallittu, & Lassila, 2018; Melo et al., 2023). However, despite promising findings from laboratory studies, including enhanced remineralization, antimicrobial activity, and improved integrity of the adhesive interface, substantial gaps remain regarding their long-term clinical effectiveness and their actual impact on oral health (de Carvalho et al., 2025).

Recent comparative studies have shown substantial differences among bioactive restorative materials in mechanical properties, ion-release characteristics, and surface behavior. Garoushi et al. reported that ACTIVA BioACTIVE Restorative had the highest fracture toughness (1.1 MPa·m^1/2) but the lowest wear resistance among fluoride-releasing restorative materials, and that its fluoride release remained lower than that of conventional glass ionomer cements (Garoushi et al., 2018). Marović et al. demonstrated that Cention N exhibited superior mechanical properties compared with glass ionomer cements, although water sorption and solubility were adversely affected over time (Marovic et al., 2022). Similarly, Šalinović et al. reported that ion-releasing materials such as Cention Forte, EQUIA Forte HT, and Biodentine increased the microhardness of demineralized dentin. Among these materials, EQUIA Forte HT exhibited the greatest remineralization effect, whereas alkasite systems demonstrated lower ion release. These findings suggest that glass-hybrid materials may be superior in ion release and mineral deposition, whereas resin-based bioactive materials offer mechanical advantages but exhibit more limited bioactive effects (Šalinović et al., 2023). Furthermore, Birant et al. observed a reduction in microhardness following thermal aging in all materials tested; however, an increase in fluoride release was detected in the Cention N group, suggesting greater resistance of the alkasite structure to thermal stress and ion depletion. Collectively, the available evidence indicates that the physical and chemical properties of bioactive materials are strongly influenced by their glass composition, resin matrix, and ion-release mechanisms. Glass-hybrid materials and conventional glass ionomer systems appear to provide superior ion release, whereas resin-based materials such as ACTIVA and Cention N exhibit more favorable mechanical performance (Birant & Gümüştaş, 2024).

In recent years, systematic reviews and meta-analyses have evaluated the clinical performance and longevity of bioactive restorative materials compared with conventional restorative systems (de Carvalho et al., 2025; Fernandes et al., 2023). In a meta-analysis, Carvalho et al. found that bioactive restorative materials used in posterior restorations, including ACTIVA™ BioACTIVE, giomers, and Cention N, did not show a statistically significant advantage over conventional resin composites for secondary caries prevention or retention ($p > 0.05$) (de Carvalho et al., 2025). Likewise, Fernandes et al. reported that conventional resin composites had the highest probability of clinical success for retention (SUCRA = 82.6%), followed by bioactive resin composites (SUCRA = 67.3%). In Class V restorations, resin-modified glass ionomer cements showed the highest probability of success (SUCRA = 89.9). Overall, bioactive resin composites performed comparably to conventional resin composites, whereas fluoride-releasing glass ionomer and resin-modified glass ionomer cements appeared to offer advantages for patients at high risk of caries (Fernandes et al., 2023). Pinto et al. evaluated the effectiveness of fluoride-, calcium-, and phosphate-releasing restorative materials in controlling secondary caries and found that fluoride-releasing glass ionomer cements and fluoride-containing amalgams reduced caries risk in permanent teeth, whereas resin composites were associated with a significantly higher risk. In primary dentition, resin-modified glass ionomer cements showed the most favorable outcomes, while conventional glass ionomer cements exhibited a higher risk of caries because of their inferior mechanical properties (RR = 1.79) (Pinto et al., 2023).

Overall, the available meta-analytic evidence indicates that bioactive restorative materials do not provide a clear clinical advantage over conventional resin composites in preventing secondary caries or improving retention. Rather, they appear to offer clinically acceptable performance comparable to that of established restorative materials.

9. Conclusion

At present, there is no universal consensus on the definition of bioactive materials. While some researchers emphasize ion release and biomineralization as the key determinants of bioactivity, others include the ability to elicit specific biological responses in this definition. Furthermore, most available clinical studies are limited to short-term follow-up, and robust long-term clinical evidence remains scarce. Advances in nanotechnology, biomimetic approaches, and the integration of multiple mechanisms into a single material may drive important developments in this field.

Bioactive restorative materials have been proposed to offer several advantages over conventional materials, including preventing secondary caries, promoting remineralization, and preserving the pulp–dentin complex. However, current evidence does not conclusively demonstrate superior clinical performance compared with conventional resin composites. Therefore, large-scale randomized clinical trials with extended follow-up periods are required to establish their long-term clinical effectiveness and to determine whether the biological claims associated with these materials translate into meaningful clinical benefits. Future developments may lead to broader clinical applications of bioactive restorative materials; however, their widespread adoption should be guided by evidence-based clinical outcomes rather than by biological claims alone.

References

Abdelkarim, G., Soumaya, B., Naima, E., Mohammed, B., & Abdellah, H. (2014). What is a bioactive compound? A combined definition for a preliminary consensus. International Journal of Food Sciences and Nutrition, 3, 174–179.

Albelasy, E. H., Hamama, H. H., Chew, H. P., Montasser, M., & Mahmoud, S. H. (2024). Clinical performance of two ion-releasing bulk-fill composites in class I and class II restorations: A two-year evaluation. Journal of Esthetic and Restorative Dentistry, 36(5), 723–736.

Banon, R., Vandenbulcke, J., Van Acker, J., Martens, L., De Coster, P., & Rajasekharan, S. (2024). Two-year clinical and radiographic evaluation of ACTIVA BioACTIVE versus compomer (Dyract® eXtra) in the restoration of class II cavities of primary molars: A non-inferior split-mouth randomised clinical trial. BMC Oral Health, 24(1), 437.

Bektaş, G. G., Özbilgi, Ö. D., İyibilir, A. F., Berkman, M., Karabay, F., Tuncer, S., ... Tekçe, N. (2024). The effect of acidic beverages on surface characteristics of the alkasite, bulk-fill, and universal resin composite restorative materials. European Journal of Research in Dentistry, 8(3), 130–137.

Birant, S., & Gümüştaş, B. (2024). The effect of thermal aging on microhardness and SEM/EDS for characterisation of bioactive filling materials. BMC Oral Health, 24(1), 1142.

de Carvalho, L. F., e Silva, M. G., da Silva Barboza, A., Badaró, M. M., Stolf, S. C., Cuevas-Suárez, C. E., ... de Andrade, J. S. R. (2025). Effectiveness of bioactive resin materials in preventing secondary caries and retention loss in direct posterior restorations: A systematic review and meta-analysis. Journal of Dentistry, 152, 105460.

Ellithy, M. S., Abdelrahman, M. H., & Afifi, R. R. (2024). Comparative clinical evaluation between self-adhesive and conventional bulk-fill composites in class II cavities: A 1-year randomized controlled clinical study. Journal of Esthetic and Restorative Dentistry, 36(9), 1311–1325.

El Ghamrawy, M., Kamal, D., & Hamza, H. (2025). Clinical performance and cost-effectiveness of low-shrinkage giomer resin composite versus resin-modified glass ionomer in cervical carious lesions: A 12-month randomized controlled trial. BMC Oral Health, 25(1), 1295.

Fernandes, J. B., Contreras, S. M., da Silva Spinola, M., Batista, G. R., Bresciani, E., & Caneppele, T. M. F. (2023). Do bioactive materials show greater retention rates in restoring permanent teeth than non-bioactive materials? A systematic review and network meta-analysis of randomized controlled trials. Clinical Oral Investigations, 28(1), 44.

Ferracane, J. L., Sidhu, S. K., Melo, M. A. S., Yeo, I. S. L., Diogenes, A., & Darvell, B. W. (2023). Bioactive dental materials: Developing, promising, confusing. JADA Foundational Science, 2, 100022.

Francois, P., Fouquet, V., Attal, J. P., & Dursun, E. (2020). Commercially available fluoride-releasing restorative materials: A review and a proposal for classification. Materials, 13(10), 2313.

Garoushi, S., Vallittu, P. K., & Lassila, L. (2018). Characterization of fluoride releasing restorative dental materials. Dental Materials Journal, 37(2), 293–300.

Hamdy, T. M. (2018). Bioactivity: A new buzz in dental materials. EC Dental Science, 17(8), 1–6.

Hench, L. L., Splinter, R. J., Allen, W. C., & Greenlee, T. K. (1971). Bonding mechanisms at the interface of ceramic prosthetic materials. Journal of Biomedical Materials Research, 5(6), 117–141.

Hill, R. (2022). Glass ionomer polyalkenoate cements and related materials: Past, present and future. British Dental Journal, 232(9), 653–657.

Imazato, S., Kuramoto, A., Takahashi, Y., Ebisu, S., & Peters, M. C. (2006). In vitro antibacterial effects of the dentin primer of Clearfil Protect Bond. Dental Materials, 22, 527–532.

Imazato, S., Nakatsuka, T., Kitagawa, H., Sasaki, J. I., Yamaguchi, S., Ito, S., ... Nakano, K. (2023). Multiple-ion releasing bioactive surface pre-reacted glass-ionomer (S-PRG) filler: Innovative technology for dental treatment and care. Journal of Functional Biomaterials, 14(4), 236.

Itota, T., Carrick, T. E., Yoshiyama, M., & McCabe, J. F. (2004). Fluoride release and recharge in giomer, compomer and resin composite. Dental Materials, 20(9), 789–795.

Jefferies, S. R. (2014). Bioactive and biomimetic restorative materials: A comprehensive review. Part I. Journal of Esthetic and Restorative Dentistry, 26, 14–26.

Justen, M., Scheck, D., Münchow, E. A., & Jardim, J. J. (2024). Is Cention-N comparable to other direct dental restorative materials? A systematic review with network meta-analysis of in vitro studies. Dental Materials.

Klee, J. E., Renn, C., & Elsner, O. (2020). Development of novel polymer technology for a new class of restorative dental materials. The Journal of Adhesive Dentistry, 22(1).

Kütük, Z. B., Ozturk, C., Soleimani, R., Yalcin, F. Y., & Gurgan, S. (2018). Clinical performance of a glass-hybrid restorative in extended-size class II cavities. International Journal of Dentistry, 2018.

LeGeros, R. Z. (2002). Properties of osteoconductive biomaterials: Calcium phosphates. Clinical Orthopedics and Related Research, 395, 81–98.

Li, X. L., Fan, W., & Fan, B. (2024). Dental pulp regeneration strategies: A review of status quo and recent advances. Bioactive Materials, 38, 258–275.

Marovic, D., Par, M., Posavec, K., Marić, I., Štajdohar, D., Muradbegović, A., ... Tarle, Z. (2022). Long-term assessment of contemporary ion-releasing restorative dental materials. Materials, 15(12), 4042.

Melo, M. A. S., Garcia, I. M., Mokeem, L., Weir, M. D., Xu, H. H. K., Montoya, C., & Orrego, S. (2023). Developing bioactive dental resins for restorative dentistry. Journal of Dental Research, 102(11), 1180–1190.

Menezes-Silva, R., Cabral, R. N., Pascotto, R. C., Borges, A. F. S., Martins, C. C., Navarro, M. F. D. L., ... Leal, S. C. (2019). Mechanical and optical properties of conventional restorative glass-ionomer cements: A systematic review. Journal of Applied Oral Science, 27, e2018357.

Miletić, I., Baraba, A., Basso, M., Pulcini, M. G., Marković, D., Perić, T., ... Turkun, L. S. (2020). Clinical performance of a glass-hybrid system compared with a resin composite in the posterior region: Results of a 2-year multicenter study. The Journal of Adhesive Dentistry, 22(3), 235–247.

Miletić, I., Baraba, A., Krmek, S. J., Perić, T., Marković, D., Basso, M., ... Turkun, L. S. (2024). Clinical performance of a glass-hybrid system in comparison with a resin composite in two-surface class II restorations: A 5-year randomized multi-center study. Clinical Oral Investigations, 28(1), 104.

Mhole, M., Tandon, S., Gupta, S., Gosavi, H., Ali, A. R., & Kaul, M. (2025). Evaluation of clinical efficacy of Cention N and Tetric N-Ceram in class I carious lesions in primary mandibular molars. Journal of Oral Biology and Craniofacial Research, 15(6), 1231–1237.

Moreira, E. N. T., Vieira-Junior, W. F., Turssi, C. P., França, F. M. G., & Basting, R. T. (2025). Effect of polishing systems on the roughness, color, and staining of conventional and bulk-fill resin composites with and without S-PRG filler. Clinical Oral Investigations, 29(2), 139.

Moshaverinia, M., Navas, A., Jahedmanesh, N., Shah, K. C., Moshaverinia, A., & Ansari, S. (2019). Comparative evaluation of the physical properties of a reinforced glass ionomer dental restorative material. The Journal of Prosthetic Dentistry, 122(2), 154–159.

Nicholson, J. W. (1998). Chemistry of glass-ionomer cements: A review. Biomaterials, 19(6), 485–494.

Nomura, R., Morita, Y., Matayoshi, S., & Nakano, K. (2018). Inhibitory effect of surface pre-reacted glass-ionomer (S-PRG) eluate against adhesion and colonization by Streptococcus mutans. Scientific Reports, 8(1), 5056.

Ozer, F., Irmak, O., Yakymiv, O., Mohammed, A., Pande, R., Saleh, N., & Blatz, M. (2021). Three-year clinical performance of two giomer restorative materials in restorations. Operative Dentistry, 46(1), E60–E67.

Oz, F. D., Meral, E., & Gurgan, S. (2023). Clinical performance of an alkasite-based bioactive restorative in class II cavities: A randomized clinical trial. Journal of Applied Oral Science, 31, e20230025.

Özcan, M., Garcia, L. D. F. R., & Volpato, C. A. M. (2021). Bioactive materials for direct and indirect restorations: Concepts and applications. Frontiers in Dental Medicine, 2, 647267.

Park, J., & Lakes, R. S. (2007). Biomaterials: An introduction. Springer Science & Business Media.

Pinto, N. S., Jorge, G. R., Vasconcelos, J., Probst, L. F., De-Carli, A. D., & Freire, A. (2023). Clinical efficacy of bioactive restorative materials in controlling secondary caries: A systematic review and network meta-analysis. BMC Oral Health, 23(1), 394.

Pracheth, T. V., Pai, V. S., Vedavathi, B., Girish, P., Sujith, R., Bhaskar, A., & Mazumdar, P. (2024). Comparative evaluation of microleakage in class V cavities restored with newer bioactive restorative materials: Activa Bioactive Restorative and Activa Pronto. International Journal of Clinical Pediatric Dentistry, 17(11), 1272–1277.

Price, R., & Roulet, J. F. (2020). The value of consensus conferences: Peer review by 50 key opinion leaders! Stoma, 7(1), 1–80.

Ramadoss, R., Padmanaban, R., & Subramanian, B. (2022). Role of bioglass in enamel remineralization: Existing strategies and future prospects—A narrative review. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 110(1), 45–66.

Rathke, A., Pfefferkorn, F., McGuire, M. K., Heard, R. H., & Seemann, R. (2022). One-year clinical results of restorations using a novel self-adhesive resin-based bulk-fill restorative. Scientific Reports, 12(1), 3934.

Schmalz, G., Hickel, R., Price, R. B., & Platt, J. A. (2023). Bioactivity of dental restorative materials: FDI policy statement. International Dental Journal, 73(1), 21–27.

Sidhu, S. K., & Nicholson, J. W. (2016). A review of glass-ionomer cements for clinical dentistry. Journal of Functional Biomaterials, 7(3), 16.

Soneta, S. P., Hugar, S. M., Hallikerimath, S., Joshi, R. S., Dialani, P. K., & Kohli, N. (2022). An in vivo evaluation of retention and antibacterial efficacy of posterior high-strength glass ionomer cement and glass-hybrid bulk-fill alkasite restorative material as conservative adhesive restoration in children with mixed dentition: A comparative study. International Journal of Clinical Pediatric Dentistry, 15(5), 529–534.

Šalinović, I., Schwendicke, F., Askar, H., Yassine, J., & Miletić, I. (2023). Effects of ion-releasing materials on dentine: Analysis of microhardness, appearance, and chemical composition. Materials, 16(23), 7310.

Tian, F., Mu, H., Shi, Y., Chen, X., Zou, X., Gao, X., & Wang, X. (2024). Clinical evaluation of giomer and self-etch adhesive compared with nanofilled resin composite and etch-and-rinse adhesive: Results at 8 years. Dental Materials, 40(7), 1088–1095.

Tohidkhah, S., Kermanshah, H., Ahmadi, E., Jalalian, B., & Ranjbar Omrani, L. (2022). Marginal microleakage and modified microtensile bond strength of Activa Bioactive, in comparison with conventional restorative materials. Clinical and Experimental Dental Research, 8(1), 329–335.

Vallittu, P. K., Boccaccini, A. R., Hupa, L., & Watts, D. C. (2018). Bioactive dental materials—Do they exist and what does bioactivity mean? Dental Materials, 34(5), 693–694.

Van Dijken, J. W., Pallesen, U., & Benetti, A. (2019). A randomized controlled evaluation of posterior resin restorations of an altered resin-modified glass-ionomer cement with claimed bioactivity. Dental Materials, 35(2), 335–343.

Whitlow, J., Paul, A., & Polini, A. (2016). Bioactive materials: Definitions and application in tissue engineering and regeneration therapy. In Biocompatible glasses: From bone regeneration to cancer treatment (pp. 1–17). Springer International Publishing.

Wu, D., Yao, Y., Cifuentes-Jimenez, C. C., Sano, H., Álvarez-Lloret, P., Yamauti, M., & Tomokiyo, A. (2024). Long-term dentin bonding performance of universal adhesives: The effect of HEMA content and bioactive resin composite. Journal of Functional Biomaterials, 15(12), 379.

Yehia, Y. H., Ibrahim, A. H., Abou-Auf, E., & Elzogbhi, A. F. (2022). Clinical evaluation of bioactive restorative material versus resin-modified glass ionomer in cervical restorations: A randomized controlled clinical trial. Open Access Macedonian Journal of Medical Sciences, 10(D), 33–40.

Yoshihara, K., Nagaoka, N., Maruo, Y., Sano, H., Yoshida, Y., & Van Meerbeek, B. (2017). Bacterial adhesion not inhibited by ion-releasing bioactive glass filler. Dental Materials, 33, 723–734.

Zhang, O. L., Niu, J. Y., Yin, I. X., Yu, O. Y., Mei, M. L., & Chu, C. H. (2023). Bioactive materials for caries management: A literature review. Dentistry Journal, 11(3), 59.