Wear behaviour of different bioactive restorative materials

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Abstract

Aim Dental wear is one of the most common causes of dental tissue deterioration and loss, especially in the posterior sectors restoration where the masticatory loads are higher. The tribology of dental materials is of great importance in the choice of restorative materials, especially in paediatric dentistry. Activa BioActive-Restorative (Pulpdent Corporation, Watertown, USA) is a recent bioactive ionic resin created with the aim of combining the mechanical and physical properties of composite materials with the chemical and biological advantages of glass ionomer cements. The aim of the present study was to test the wear resistance of Activa Bioactive Restorative in vitro by comparing it with two other bioactive materials, a compomer (Dyract eXtra, Dentsply Sirona, USA) and a giomer (Beautifil II LS, Shofu Dental Corporation, Japan).

Materials and methods Wear tests carried out on three bioactive materials were performed using the CSM Tribometer. Wear was evaluated using 3D topographies from which the wear volumes were contextually obtained. Finally, a gravimetric investigation was performed to evaluate the loss of mass suffered by the three bioactive materials following the wear test.

Results Activa Bioactive Restorative shows a lower wear volume and depth than other bioactive materials, in accordance with its lower coefficient of friction. Activa Bioactive Restorative reports a minor increase in the friction coefficient after 80 meters of sliding. The wear rate, evaluated by gravimetric investigation, showed an effective loss of mass in Dyract Extra compared to Beautifil II LS and Activa Bioactive Restorative.

Conclusions Activa Bioactive Restorative can be considered satisfactory in terms of wear resistance compared to the other materials. It could also be suggested for use in paediatric patients for its ease and speed of application, biocompatibility, safety and durability of the restoration.

KEYWORDS Biocompatible materials, paediatric dentistry, dental restoration wear.

Introduction

Conventional restorative materials require less invasive preparations thanks to their adhesive properties, ensuring good functional performance and excellent aesthetic result, in line with the concept of minimally invasive dentistry [Dhar et al., 2015]. Restorative materials can be classified according to the type of polymerisation or the quantity and type of filler: acrylic resins, on bis-GMA-based composite resins, microfilled or hybrid resins and microhybrid, nanofilled and finally bioactive resins. Filler influences the shrinkage stress and makes the material more resistant to abrasion, but at the same time has the disadvantage of being more viscous and consequently more difficult to apply [Bromo F. et al., 2011; Draughn and Harrison,1978]. In the conservative restoration of a deciduous tooth, the most suitable material should guarantee high biocompatibility as well as the physical and chemical properties capable of guaranteeing an optimal marginal seal to reduce the risk of the onset of secondary caries, and good resistance to masticatory forces, especially in the posterior sectors. In this regard, resin-based composites (RBCs) for dental restorative materials have become the most used dental material due to their aesthetics properties, reasonable cost, versatility, and clinical performance [Ferracane et al.. 2024]. However, these materials are not without defects such as polymerisation contraction and the consequent stress that can derive from it, causing mechanical failures of the restoration, the formation of micro-gaps at the interface level and post-operative sensitivity, secondary caries and pulpal irritation [Jensen and Chan, 1985]. So, bioactive materials have been developed over time (glass ionomer cements - GIC, resin-modified glass ionomer cements - RMGIC - and compomers). However, despite having excellent bioactive capabilities, they do not guarantee the same physical and mechanical properties as resin composites, especially particularly with regard to hardness and wear resistance [Jefferies et al., 2014]. For this reason, research has focused on developing materials that combine the remineralising properties of early biomaterials with the mechanical properties of composite resins, leading to the creation of new material classes such as giomers and bioactive resins, including Activa Bioactive Restorative (Pulpdent Corp., Watertown, MA, USA). Activa BioActive Restorative integrates the strength and aesthetics of composite resins with the beneficial characteristics of glass ionomers [Pulpdent ACTIVA BioActive white Paper Manual, 2022]. In fact, Activa BioActive Restorative is composed of a bioactive ionic resin matrix, an elastic component and bioactive glass ionomer fillers with physical and chemical properties similar to those of natural teeth. In addition, it releases and recharges with calcium, phosphate and fluoride ions and does not contain Bisphenol A, bis-GMA and BPA derivatives, ensuring not only the aesthetics and marginal integrity of the restoration but also its biocompatibility in the oral cavity [Theodore et al., 2020; Sahoo et al., 2019]. Biocompatibility is a crucial aspect in the choice of innovative materials for dental restoration, especially in paediatric dentistry. Since restorations must remain in the oral cavity for long periods and interact with the organism, it is essential that the materials used exhibit low toxicity. Therefore, the combination of low toxicity with favourable mechanical and biological properties makes these materials particularly suitable for the treatment of younger patients. Another crucial factor in ensuring the long-term performance of dental restorations is the wear resistance of the materials used [Ferracane, 2006]. In this regard, there are some studies on the wear of dental materials but the works regarding the degree of wear of compomers, giomers and latest generation bioactive composites are limited. In fact, the aim of this study was to compare the tribological performance of this bioactive resin (Activa Bioactive-Restorative) with two other bioactive materials useful in paediatric dentistry, a compomer and a giomer, for an optimal choice of materials in the clinical practice of paediatric dentistry.

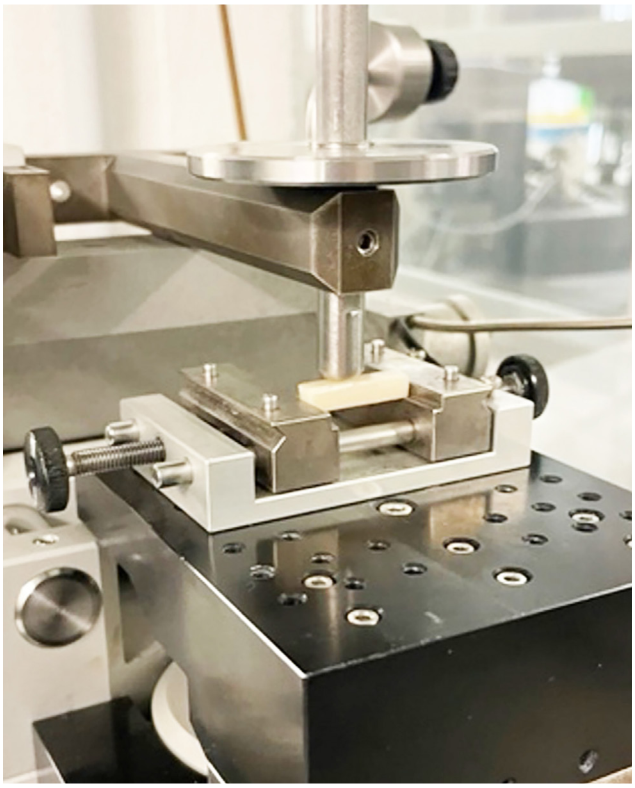


FIG 1 Wear test by CSM Tribometer.

Materials and methods

Three bioactive materials were selected for the present in vitro study (Table 1). To evaluate and compare the degree of wear of these materials, twelve samples were prepared:

- Four samples with Activa Bioactive-Restorative
- Four samples with Beautifil II LS
- Four champions with Dyract Extra

Subsequently, the prepared samples were subjected to wear tests using a CSM Instruments Tribometer (Needham, Massachusetts) at the Department of Industrial Engineering of the University of Rome "Tor Vergata" (Fig.1). The available testing machines influenced the selection of sample size and the maximum load to which the samples could be subjected.

Sample preparation

Twelve aluminum specimen holders (30 mm long and 10 mm high) were sandblasted and pre-treated with Optibond Solo Plus (Ivoclar Vivadent). The three bioactive materials to be tested were placed using the following methods:

- Activa Bioactive Restorative using the Activa-Spenser, a 5 ml static automix syringe (Pulpdent)
- Beautifil II LS and Dyract Extra using a spatula to optimally distribute the material inside the sample holder.

To ensure the surface to be tested was smooth and homogeneous, a Mylar matrix and a glass plate were placed on top of the sample holder. Subsequently, each material, appropriately compacted, was light-cured from both above and below using a light source with an intensity of 400 mW/cm2 for 40 s.

Wear test protocol

The wear resistance of each specimen was evaluated in a dry linear reciprocating creep test using a standard tribometer manufactured by CSM Instruments (Needham, Massachusetts). The test was performed with a 6 mm diameter 100Cr6 sphere at a sliding speed of 8 cm/s and an applied load of 8 N for a total

Composite	Manufacturer	Type	Resin Matrix	Filler
Activa Bioactive Restorative. (Lot:211215)	Pulpedent, Watertown,MA (USA)	Ionic composite resin	Blend of diurethane and methacrylates with modified polyacrylic acid (44.6%). Contain no bisphenol A, no bis-GMA, no BPA derivatives.	Reactive glass filler (21.8wt%); inorganic filler(56wt%), sodium fluoride (0.75%) patented rubberised resin (embrace),water
Dyract eXtra (Lot:2208000583)	Dentsply Sirona (USA)	Compomer	Bis-GMA, UDMA, carboxylic acid modified dimethacrylate (TCB), TMPTMA, TEGDMA, BHT,	Strontium aliminosodium fluorophosphor silicate glass (50 vol %)
Beautifil II LS (Lot:032037)	Shofu Dental Corporation (Japan)	Giomer	Bis-GMA TEGDMA UDMA Bis-MPEPP	83% weight S-PRG filler based on Fluoroboroalumino-silicate glass mean particle size 0.4 um Polymerisation initiator, pigment and others

TABLE 1 Bioactive restorative materials used in the study.

Distance	Mean Dyract	StDv Dyract	Mean Beautifil II	StDv Beautifil II	Mean Activa	StDV Activa
0	0.21895	0.106801	0.19063333	0.07534058	0.19658	0.21937281
5	0.39849939	0.10990401	0.40346867	0.10974817	0.39839255	0.28659166
10	0.52440444	0.10360587	0.51644437	0.13415895	0.51499466	0.16892285
15	0.60993376	0.08473798	0.56967301	0.13460012	0.58587642	0.07783004
20	0.66601336	0.07131687	0.59215195	0.12446627	0.61410406	0.04232218
25	0.70145122	0.07530125	0.60335599	0.11291061	0.61412252	0.04613066
30	0.72316193	0.08886482	0.61483005	0.10381672	0.60455185	0.06344171
35	0.73639125	0.10090563	0.6317818	0.09787169	0.59998844	0.0736777
40	0.74494072	0.10743286	0.65467429	0.09463614	0.60727622	0.067168
45	0.75139228	0.10867574	0.68081864	0.09302266	0.6256575	0.04498521
50	0.75733281	0.10636609	0.70596667	0.09101418	0.64945743	0.01515496
55	0.7635788	0.10249312	0.72590352	0.08623429	0.6718622	0.01268647
60	0.77040088	0.09898925	0.73804037	0.07746847	0.68833886	0.03212847
65	0.77774846	0.0974505	0.74300703	0.06632763	0.69824369	0.04226061
70	0.7854743	0.09758191	0.74624461	0.05839616	0.70316542	0.04532963
75	0.79355913	0.09492863	0.75959818	0.06333492	0.70054994	0.03772339
80	0.80233624	0.08275091	0.80290939	0.09717282	0.67115281	0.0077739

TABLE 2 Friction coefficient for different bioactive dental materials (Mean – Standard Deviation).

distance traveled of 80 m. The coefficient of friction - distance curves were obtained from the test. Furthermore, the samples were characterised by measuring the volume, depth and width of the wear track. Each trace of wear was measured three times to avoid individual differences and then averaged. The evaluation of the traces was carried out using a "contact gauge surface profiler" (Talysurf CLI 2000, Taylor-Hobson, Leicester, UK). The 3D maps were acquired from areas measuring 7 × 2 mm², with a profile spacing and resolution of 2, at a scanning speed of 2 mm/s. At the end of the tribological test, the morphological characteristics of the wear traces were examined using a stereoscope (SMZ745T, Nikon, Düsseldorf, Germany). The scans returned isometric and contour images quickly providing qualitative information on the worn area. Furthermore, the surface, volume and depth of the wear marks could be obtained from the 3D maps. Finally, a gravimetric analysis was performed to evaluate the mass loss using a precision balance (0.01 mg resolution) before and after each wear test.

Results

The variation of the mean friction coefficient of the samples as a function of the sliding distance is shown in Figure 2. All samples

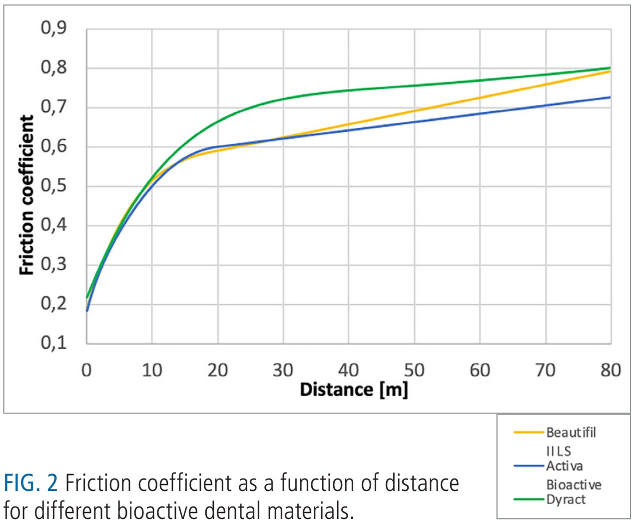


FIG. 2 Friction coefficient as a function of distance for different bioactive dental materials.

reach a steady state around 20 meters of creep. Although Dyract Extra settles on higher friction coefficient values (M 0.66, DS 0.07) while Beautifil II LS and Activa Bioactive Restorative show similar values around 0.6 (respectively M 0.59, DS 0.12; M 0.61, DS 0.042), Beautifil II LS exhibits a significantly more pronounced increase in the wear coefficient as a function of distance compared to the other materials used for comparison, reaching the values obtained with Dyract Extra at the end of the test (M 0.8, SD 0.09). Activa Bioactive Restorative reports a minor increase in the friction coefficient after 80 meters of sliding (M 0.67 - DS 0.01), as shown in Figure 2. and in Tab 2. Analysing the 3D maps (Fig. 3) of the tracks, all grooves are present parallel to the sliding direction, probably attributable to abrasive tearing or "gougin abrasion", characterised by less evident grooves and the formation of small craters because of the tears to which the material was subjected. Furthermore, the deformation does not appear to be homogeneous within the track as there are areas at different depths, although this phenomenon is less pronounced for Beautifil II LS. In any case, Dyract Extra is the material with the most pronounced wear trace as well as a slight pile up on the sides of the trace, due to plastically deformed material. The volumes of wear confirm the trend of the curves, with Dyract Extra being the track with the greatest volume and depth. Furthermore, the larger surface found for Beautifil II LS results in a larger contact surface with the ball and therefore higher friction coefficients. Regarding the gravimetric analysis performed to acquire the wear rate, it was possible to find a weight variation in the Dyract Extra in which an actual loss of mass was detected (Table 3) unlike the Beautifil II LS and Activa Bioactive Restorative in which the rate of wear is significantly lower since the weight change corresponds to approximately 0.001 mg. Therefore, if for Dyract Extra the wear results in a loss of material due to abrasive wear, for Beautifil II LS and Activa Bioactive Restorative the wear only leads to a slight plastic deformation as they have a significantly lower lost mass.

TABLE 3 Mass loss of the wear track on samples.

Discussion

Restorative dentistry is constantly evolving, seeking materials that can offer not only satisfactory mechanical and physical properties, but also aesthetics and longevity of the restoration with lower risks of microgaps at the adhesive interface and secondary caries. Bioactive restorative materials not only aim to restore the form and function of the tooth but also to interact with the surrounding tissues to promote remineralisation and improve long-term outcomes [Jefferies, 2014]. In paediatric dentistry, there is ongoing research into bioactive and biocompatible materials to enable increasingly effective, yet rapid and minimally invasive treatments. Materials such as high-viscosity glass ionomer cements and bioactive resins are being explored to improve comfort for both the paediatric patient and their family [Beretta et al., 2023]. A bioactive ionic resin, Activa Bioactive Restorative (Pulpdent Corporation, Watertown, MA, USA) has been introduced to the market. Clinical and in vitro studies have been conducted to evaluate the properties of this material, [Theodore et al., 2020; Sahoo et al., 2019; Pangabdian et al., 2021; Garoushi et al., 2018; Awad et al., 2020; Yap et al., 2021; Bhadra et al., 2019; Andrei et al., 2017; Francois et al., 2020; Omidi et al., 2018; Roulet et al., 2020; Lardani et al., 2022] including wear tests [Sahoo et al., 2019; Garcia-Godoy and Morrow, 2015]. The tribology of dental materials is of great importance in the choice of restorative materials to be used in paediatric dentistry. If uncontrolled, dental wear can lead to masticatory dysfunctions with consequent reduction in quality of life and can be a cause of restoration failure in paediatric patients, who often present bruxism and/or bad habits [Ferracane, 2006]. The results of the present study show that Activa Bioactive Restorative has a relatively higher wear resistance than the other bioactive materials examined, showing a lower volume and depth of wear marks (Fig. 4) and a lower friction coefficient (Fig. 2, Table 2). Through 3D topographies, it was possible to find scars parallel to the flow direction in the wear tracks of the three materials (Fig. 3), which have a reduced depth in the case of Activa Bioactive Restorative due to the lower friction coefficient. In summary, Dyract Extra tends to suffer more pronounced wear while maintaining a higher coefficient of friction during use, this data clinically translates into a greater risk of compromise of the restoration over time. Beautifil II LS and Activa Bioactive Restorative instead show less wear and a more contained plastic deformation that could indicate a greater resistance and stability of the restoration over time. Activa Bioactive Restorative undergoes a slight plastic deformation that suggests a good adaptability of the material making it more resistant in the long term. However, Activa Bioactive Restorative with its lower wear and slight plastic deformation proves to be a promising choice for deciduous teeth, subject to greater abrasion. Furthermore, the reduced mass loss highlighted by Activa Bioactive Restorative indicates a possible elastic deformation of the material to be attributed to the composition of the material and the resilient matrix containing elastomeric components capable of absorbing energy [Pangabdian et al., 2021], essential in deciduous teeth subject to greater abrasion. Furthermore, Activa Bioactive Restorative, unlike other materials, has the advantage of being free from bisphenol A (BPA) or bis-GMA derivatives, compounds studied by several authors for their potential negative effects on the endocrine system [Hatta et al. 2023]. This aspect enhances the biocompatibility of the material, adding an extra level of safety. It aligns with the current trend of favouring dental materials that are not only bioactive but also safer, especially in paediatric patients. Therefore, despite the limitations of this in vitro study, which cannot perfectly replicate real in vivo conditions due to the absence of tests involving higher loads or conducted in a humid environment, it can be concluded that Activa Bioactive Restorative with its lower wear and contained plastic deformation proves to be a promising choice for the restoration of deciduous teeth without compromising the physiological wear typical of paediatric patients.

	Mass pre	Mass post	Mass loss
Activa Bioactive Restorative	0.7488	0.7487	0.0001
Beautifil II LS	0.8541	0.854	0.0001
Dyract eXtra	1.4274	1.4269	0.0005

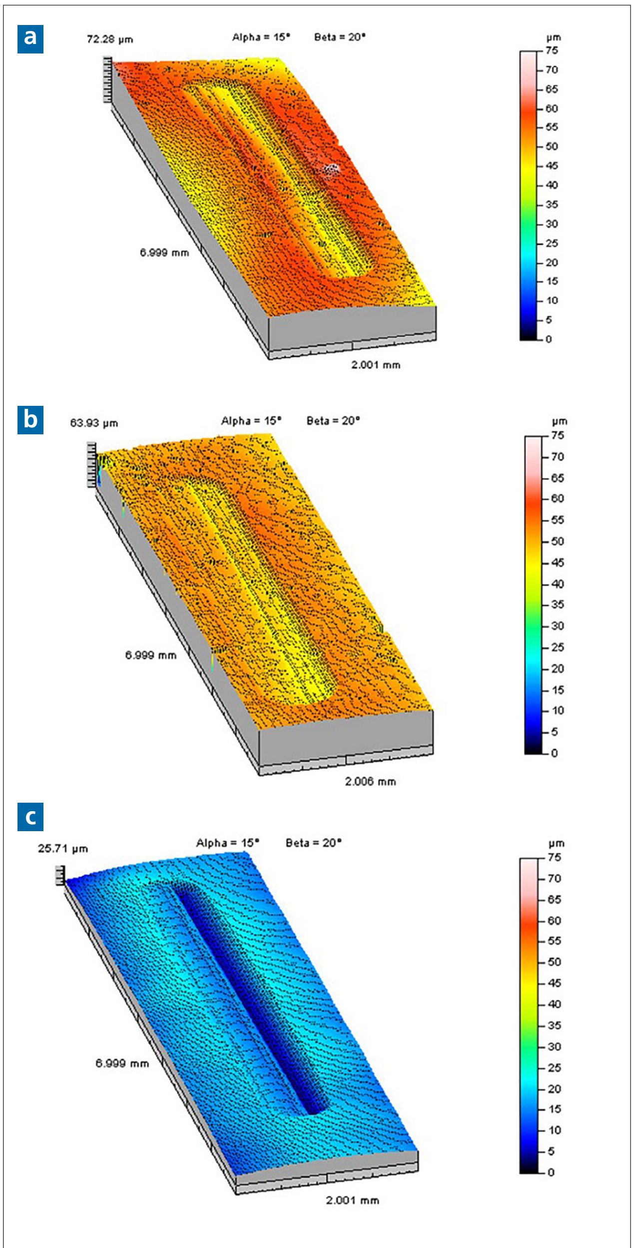
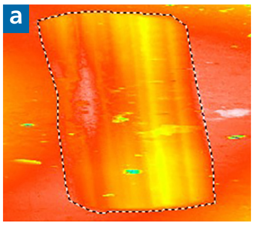


FIG. 3 3D Topography of traces of wear: a) Dyract Extra b) Beautifil II LS c) Activa Bioactive Restorative.

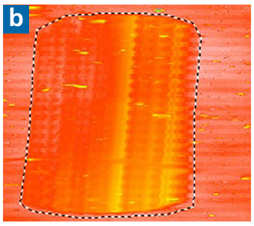
Conclusions

Tribological tests on dental materials help in the choice of restorative materials to be used to minimise wear stress. Based on the results of this study, it can be concluded that:

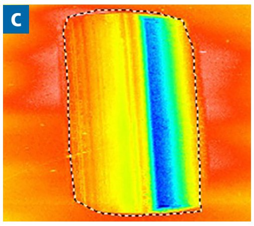
- The analysis of the 3D traces shows that Activa Bioactive



	Hollow	Peak
Surface (mm2):	4.222	0.3849
Volume (mm3):	0.02894	0.0006087
Max depth (µm):	41.55	8.302
Average depth and height(µm):	6.856	1.582



	Hollow	Peak
Surface (mm2):	4.811	0.1529
Volume (mm3):	0.02165	0.0001427
Max depth (µm):	23.73	10.5
Average depth and height(µm):	4.5	0.9328



	Hollow	Peak
Surface (mm2):	3.628	0.1189
Volume (mm3):	0.01889	5.627 e-005
Max depth (µm):	18.34	3.845
Average depth and height(µm):	5.206	0.4733

FIG. 4 3D Topography of the wear volume: a) Dyract Extra b) Beautifil II LS c) Activa Bioactive Restorative.

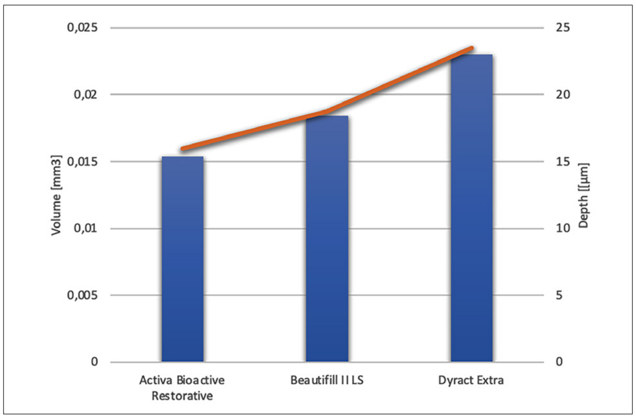


FIG. 5 Average volume and depth of the wear track.

Restorative has an elastic behaviour able to better withstand occlusal stress without suffering a significant loss of substance unlike Dyract Extra.

- As the sliding distance increases, Activa Bioactive Restorative shows a slight increase in the friction coefficient, unlike Beautifil II LS which shows a clear increase in the wear coefficient as a function of the distance until reaching the values obtained with Dyract Extra.
- Activa Bioactive Restorative can be considered satisfactory in terms of wear resistance compared to traditional compomer (Dyract Extra) or giomer (Beautifil II LS).

In conclusion, Activa Bioactive Restorative could represent a valid alternative to traditional materials considering its mechanical properties, the chemical component in the absence of Bisphenol A and the interactive release of fluoride, calcium and phosphate, finding clinical indication especially in direct and indirect restorations, in extended restorations or as cavity lining and in patients at high risk of caries. Furthermore, the use of Activa Bioactive Restorative could also be suggested in fragile and uncooperative paediatric patients in terms of ease and speed of application, biocompatibility, safety and longevity of the restoration. Considering wear resistance, plasticity and the ability to guarantee an excellent marginal seal, Activa Bioactive Restorative could offer long-term benefits in the treatment of patients with bruxism or with mandibular temporal dysfunctions, especially in paediatric dentistry, due to its bioactive capabilities and for its wear resistance in line with the characteristics of deciduous teeth. The continuous search for biomaterials with an optimal combination of wear resistance, aesthetics and biocompatibility is essential to ensure safe and long-lasting dental restorations.

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