IEJ
Iranian Endodontic Journal

A Critical Review of the Role of Geristore® in Contemporary Endodontics

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Article Type: **Review Article**

Received: 10 Mar 2025
Accepted: 19 Jun 2025
Published: 01 Jul 2025
Doi: *10.22037/iej.v20i1.48268*

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Introduction: Geristore® (GS) is an advanced dual-cure resin-modified glass ionomer with favourable biological and physical properties, including biocompatibility, fluoride release, and excellent sealing ability. Originally developed for restorative purposes, its clinical versatility has nonetheless extended into endodontics. The current critical review primarily aims to evaluate the biological characteristics, endodontic applications, and possible clinical potential of GS as a biomaterial in modern endodontic practice. **Methods**: A comprehensive literature search was conducted across major databases (MEDLINE, PubMed, Scopus, Cochrane, EMBASE, Google Scholar, and grey literature) without restrictions on date and/or language. Relevant peer-reviewed studies on the composition, properties, and endodontic uses of GS were identified, screened, investigated, and critically analysed. **Results**: Geristore® has demonstrated promising outcomes in endodontic procedures, *e.g.*, root-end filling, perforation repair, vital pulp therapy, retrograde vital pulp therapy, intra-orifice barrier placement and the management of external cervical resorption, Additionally, various studies have highlighted its favourable soft tissue compatibility, sealing ability (even in moist environments) as well as its acceptable mechanical properties. However, certain limitations, including reduced flexural strength and higher cytotoxicity compared to calcium silicate-based materials, such as mineral trioxide aggregate, have been reported. **Conclusion**: Geristore® presents as a clinically useful alternative for specific endodontic indications where biocompatibility, sealability, and ease of handling seem critical. However, further high-quality clinical trials and comparative studies are essential to validate its long-term performance and establish its role relative to established endodontic biomaterials.

Keywords: Endodontics; Geristore®; Resin-modified Glass Ionomer; Root Canal Therapy; Vital Pulp Therapy

Introduction

Nowadays, modern dentistry, specifically present-day endodontics, is moving towards minimally invasive approaches to maximise the preservation of dental structure [1]. Therefore, additive treatments, *e.g.*, regenerative endodontics, are considered a priority over subtractive therapies, *e.g.*, dental implants, and thus, treatment concepts and methods focusing on the survival of the tooth as well as the healing of dental tissues and structures have gained specific attention [2, 3].

Deep carious lesions occurring between the tooth structure and surrounding periodontal ligaments can sometimes cause the tooth to be unrepairable, a phenomenon which may finally result in the extraction of the involved tooth. Moreover, in deep caries, the applied restorative material cannot be placed in biological width (BiW) or subcrestal defects due to the soft tissue inflammatory response [4, 5]. Consequently, crown lengthening (CL) is recommended to provide appropriate grounds for the restorative material. However, CL has shown to have several disadvantages; *e.g.*, increased crown/root ratio, furcal exposure, and undesirable effect on the bone level of adjacent teeth [6, 7]. Therefore, restorative materials that can possibly be accepted by periodontium and periodontal ligaments would be ideal and thus have been further investigated. Evidence has shown that the

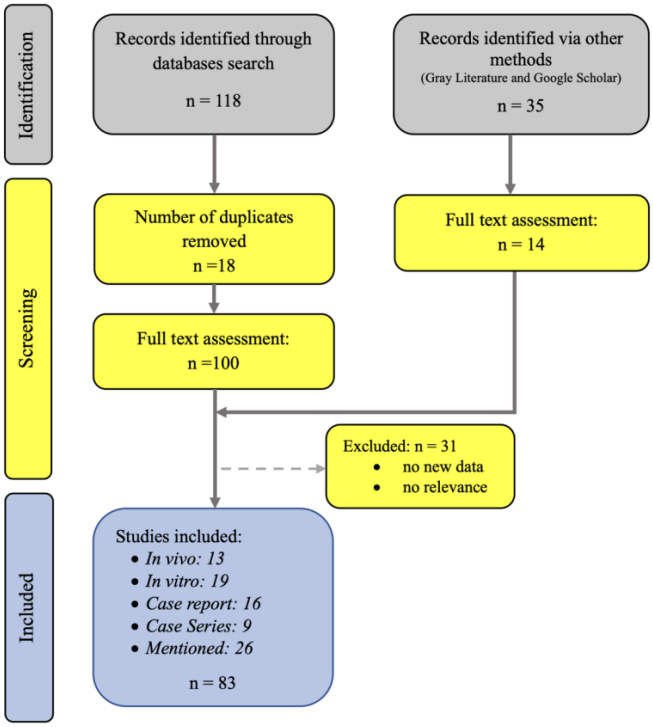

Figure 1. Summary of the methodology used in the current critical review

gingiva and periodontium can tolerate restorative materials to a degree; subsequently, deep margin elevation (DME) has been introduced to limit the indications of CL procedures and compensate for the problems associated with CL. Long-term follow-ups and corresponding systematic reviews have shown that teeth treated with DME demonstrate a higher survival rate compared to teeth managed by CL [8-10], despite exhibiting the same limitations in biological width.

Geristore®(GS) is a restorative, dual-cured, resin-modified glass ionomer (RMGI) that has been shown to possess many of the necessary properties. Geristore® has long been used for restorative purposes; nevertheless, since the introduction of resin-based dental composite restorative materials, its use has declined. Geristore® was first applied for cavity restoration in 1991 [11] and due to the outcomes, its use continued to rise for different objectives [12, 13]. Nonetheless, owing to its superior compatibility with soft tissue, GS has been recently deliberated for modern-day applications; *e.g.*, vital pulp therapy (VPT) [14], perforation management [15] and retrograde root filling [16]. It appears that human gingival fibroblasts (HGF) as well as human periodontal ligament fibroblasts (PDLF) can attach, proliferate, and spread on the surface of GS, comparable to the cell attachment on mineral trioxide aggregate (MTA) [17-21]. In addition, several studies have investigated the soft tissue reactions, *e.g.*, angiogenic activity, cytokine expression, and histological changes, towards GS and found relative similarities with bio-active materials [14, 22-24]. Furthermore, GS has been shown to have good sealability even when exposed to contamination with blood and saliva [25].

The present critical review aims to elaborate on the biological properties, previous and potential clinical applications, and possible prospects of GS as a resin-modified glass ionomer restorative material. In addition, the current study introduces GS as a promising filling material where BiW can be manipulated.

Methodology

To conduct a comprehensive and reproducible critical review of Geristore® in modern endodontics, a structured and disciplined search strategy was implemented. The main concept and study question (*i.e.*, Geristore®), keywords/phrases, and subject areas relevant to the research were initially identified, and a combination of "Medical Subject Headings" (MeSH) and free-text terms was used. The key terms included *"Geristore"*, OR *"resin-modified glass ionomer"*, OR *"RMGI" AND "endodontics"*, OR *"root-end filling"*, OR *"perforation repair"*, OR *"vital pulp therapy"*, OR *"retrograde VPT"*, OR *"biocompatibility" AND "clinical outcomes"*, OR *"cytotoxicity"*, OR *"bioactivity"*, OR *"comparative study"*.

Then, a broad search was performed, including the following electronic databases: PubMed, Scopus, Web of Science, MEDLINE, Cochrane Library, EMBASE, and Google Scholar, along with grey literature sources. There were no restrictions on publication language and/or year.

Inclusion Criteria:

- Peer-reviewed articles evaluating GS in endodontic applications.
- *In vitro*, *in vivo*, case reports/series, and clinical trials.
- English and non-English studies with accessible abstracts.

Exclusion Criteria:

- Studies focusing solely on restorative/orthodontic uses with no endodontic context.
- Reviews or studies with insufficient methodological detail.

The mentioned rigorous methodology was accurately conducted to ensure a transparent and comprehensive review of the existing literature (Figure 1).

Background and Development

Geristore® is a self-adhesive dual-cure resin-modified glass ionomer [also referred to as "*compomer*" in the literature [26]]

recommended to be used with Tenure® Multi-Purpose Bonding System to achieve maximum enamel-dentine bonding. In addition, GS may be addressed for possible bonding to metal, composite, and porcelain restorations, after being abraded with diamond and/or sandblasted [27]. The resin component of GS, *i.e.*, Bisphenol A-glycidyl methacrylate (Bis-GMA), is covered by N-(2-hydroxy-3-((2-methyl-1-oxo-2propenyl) oxy) propyl)-n-tolyl Glycine (NTG-GMA) as the binder between hydrophobic and hydrophilic substrates, Ethoxylated Bisphenol-A-dimethacrylate (EBMA) as the monomer, and 2-hydroxyethyl methacrylate (HEMA) to improve bonding strength [27-29]. Furthermore, GS is considered a fluoride-releasing material with triple curing reactions caused by a light initiator, a chemical initiator, and a polymerization accelerator, as well as an acid-base reaction [30, 31].

Properties

Various studies have examined the physical, chemical, and biological properties of GS as a restorative and endodontic filling material, revealing that GS exhibits fluoride-releasing characteristics with the ability to release and recharge ions [32, 33]. In a study, it has been demonstrated that flexural properties, *i.e.*, strength, toughness, and Weibull modulus, could play a considerable role in achieving success in a restorative material. Furthermore, it has been shown that GS, as an ion-leaching material, can show better flexural properties than those of high-viscosity glass ionomer cement and resin-modified glass ionomer cement. However, GS exhibits weaker flexural properties compared with microhybride resin-based dental composites [34]. Moreover, GS has been used in different applications due to its fluoride-releasing capability, proper radiopacity, low coefficient of thermal expansion, and low setting shrinkage [12]. Besides, GS can create a strong chemical bond to the calcium component of dentine; consequently, the material would be able to properly bond to the adjacent dentinal structure [35]. Additionally, the acceptable biological properties of GS have caused its use in different conditions; *e.g.*, when it is placed adjacent to HGF and PDLF, GS has disclosed its biocompatibility [17]. Also, PDLF and HGF have shown superior attachment to GS in a quantitative study. In the exploration for the attachment mechanism, attempts to block the attachment site using antibodies against collagen type I and Arginylglycylaspartic acid peptide have not hindered cellular attachment to GS, suggesting an alternate extracellular matrix-based attachment mechanism [19]. Furthermore, the cellular attachment and spread of HGF on GS have been reported to be comparable to those on MTA as a bioactive material, suggesting further use of GS in several applications [17, 18].

Geristore® and Restorative Dentistry

In direct restorative treatments, GS has seen decreased usage due to advancements in bonding systems and dental composite properties [36]. Nonetheless, certain situations remain in which the application of RMGIs, such as GS, is deemed advantageous [27, 37]; including scenarios where bonding to tooth structure is challenging, *e.g.*, in cases with older teeth or sclerosed dentine [11]. Moreover, GS is useful when the lesion/restoration is close to the soft tissue [12, 38] or pulp territory [39, 40]. In addition, GS appears to be beneficial in cases of a vital split tooth [41], or high caries activity where aesthetics is a concern; *e.g.*, post-radiation xerostomia [42]. However, In Indirect restorations, where treatments are typically constructed extra-orally and placed intra-orally, the use of GS seems implausible, since it may lead to more failure due to comparatively weaker bonding strength than the new generation of materials [43, 44].

Geristore® and Orthodontic appliances

Although orthodontic adhesives are available for bonding procedures, RMGIs are often favoured for patients with a high risk of caries, owing to their fluoride-releasing capability and antibacterial activity [45, 46]. Additionally, GS has been shown to possess the capacity to bond with several other materials, *e.g.*, amalgam [47]; offering beneficial attributes. However, using GS for the stated applications may not reflect the latest advancements in the field [48].

Geristore® and Periodontology

Periodontal furcation involvement is a significant indicator of periodontal disease progression, and its treatment strategies have traditionally revolved around non-surgical and surgical therapies, including scaling and root planing, open flap debridement, and, currently, regenerative procedures [49]. Various treatment approaches have been conventionally used; however, restoring the involved furcation with RMGIs, *e.g.*, GS, owing to its tissue compatibility, was used to be considered before the introduction of dental implants [50]. Furthermore, different studies have reported the use of GS in surgical and non-surgical treatments with subsequent follow-ups, evaluating soft tissue healing [37, 51].

Additionally, root coverage periodontal procedures are implemented following gingival recession for both aesthetic and functional improvements [52]. The stated recession is often accompanied by non-carious cervical lesions (NCCL), which are the defects caused by factors other than caries; *e.g.*, abrasion, abfraction, and other physical/chemical invasions. The literature suggests that RMGIs, when used for the restoration of NCCL, generally demonstrate better longevity and clinical performance compared to dental composites [53]. However, the results for both materials have been satisfactory, with outcomes

showing great stability; presumably due to the improved gingival contour facilitating better oral hygiene [54]. While GS has not been directly used for the above-mentioned procedure, it has been suggested that, given the superior compatibility of GS with soft tissues as well as the positive response from gingival fibroblasts, GS could potentially prove effective.

Geristore® and Endodontics

Owing to the complex association between the root canal system and surrounding periodontium, specific (bio)materials with desirable properties, *e.g.*, sealability, biocompatibility, and structural durability, are necessary to achieve success in endodontic treatments, including root-end filling, perforation management, and VPT [55, 56].

A key advantage of GS in clinical practice is its user-friendly handling, attributed to the resin-modified composition of the (bio)material. Unlike some other bioactive materials (*e.g.*, MTA), which require careful mixing and extended setting time, GS can be light-cured and readied within seconds, significantly reducing the chairside time. Additionally, the unique delivery system of GS allows for precise application, and thus, it can be injected directly into the target site (*e.g.*, perforations, root-end preparations) using its mixing tip(s), eliminating the need for additional instruments. The above-mentioned feature is specifically beneficial in minimally invasive procedures or difficult-to-access areas, where ease of placement is critical.

Root-end filling

Root-end filling, also known as retrograde filling or root-end surgery, is usually considered when conventional or orthograde root canal therapy yields post-treatment complications. The possible unwanted outcomes could be attributed to a variety of factors, including extra-radicular infections or anatomical/iatrogenic problems, which impede proper cleaning, shaping, and obturation processes [57]. When properly executed using modern techniques, endodontic microsurgery can display high success rates ranging from 91.4% to 94.4% for true endodontic lesions [58].

While GS has various clinical applications, its use as a root-end filling (bio)material is predominantly noteworthy and has been well-documented in the dental literature [59, 60]. This is mainly due to its antibacterial property, low cytotoxicity, acceptable sealability, and relative capability to strengthen the restored tooth [61, 62].

The antibacterial activity of GS is elaborated as an important property in achieving successful treatment and root-end filling [63]. Intracanal microorganisms are one of the most significant causes that could result in endodontic failure when pathologically activated; therefore, a (bio)material with inherent antibacterial properties could help eliminate or reduce bacterial concentration, implantation, and proliferation at the site, preventing infection and/or reinfection. In addition, GS has shown antibacterial activity against Enterococcus faecalis (mostly found in compromised root canal therapies), Pseudomonas aeruginosa, and Staphylococcus aureus [64].

A tight seal, or sufficient sealability, is essential in root-end filling materials to inhibit the intrusion of fluids into the root canal space [65]. Different studies have compared the sealability of GS with that of MTA and a number of other traditional biomaterials, *e.g.*, super-ethoxy benzoic acid (EBA) and Intermediate Restorative Material (IRM). In environments contaminated with blood and saliva, GS has exhibited superior sealing properties compared to MTA, while their sealability was comparable when they were used in dry conditions [25]. In another study, it has been demonstrated that GS provided a more effective seal than MTA, Super-EBA, and IRM, regardless of the storage medium used for the extracted teeth [66, 67]. Although it had been previously reported that a decrease in pH could increase the solubility and leakage of resin-ionomers, further research indicated that the sealability of GS used in conjunction with calcium phosphate cement improved as pH decreased, showing similar performance to MTA [68]. A study has indicated greater microleakage of GS compared with MTA and Biodentine™, which might be attributed to its marginal adaptation relying on a chemical bond that, in turn, could be affected by cavity contamination [33].

Multiple studies have compared the cytotoxicity of GS with other (bio)materials used in root-end fillings, and exhibited minimal cytotoxicity [20] as well as substantial cellular attachment of GS [17]. When evaluating the cytokine response to GS compared with that of Emdogain™ and MTA, it was observed that although Emdogain™ and MTA initially augmented the expression of inflammatory cytokines in the short term, late anti-inflammatory action was displayed with significant effect on the majority of selected cytokines. Nonetheless, GS did not notably affect cytokine expression; thus behaving as a relatively neutral (bio)material [69]. However, a recent study has reported higher cytotoxicity and genotoxicity of GS on PDL fibroblasts compared with MTA and EndoSequence [70].

The contradictory findings on cytotoxicity may arise from several factors:

- *Variations in study design and methodology:* Differences in cell lines (*e.g.*, primary human fibroblasts *vs.* immortalised cell lines), culture conditions or exposure times can affect the results. The bioactivity of MTA may be more pronounced in long-term studies due to its slow-setting hydration reaction, whereas the resin components of GS could exhibit initial cytotoxicity that diminishes over time [71, 72].

- *Material composition and surface properties:* The cytotoxicity of GS reported in some studies might stem from batch-to-batch variability in component ratios or residual unpolymerised monomers. Moreover, surface topography seems to play a critical role; *i.e.*, the smoother surface of GS (compared to MTA's microporosity) may alter fibroblast attachment and inflammatory response(s) [73].
- *Clinical vs. in vitro conditions:* Experimental studies often fail to completely replicate the dynamic oral environment, where the performance of GS may significantly differ from *in vitro* controlled experiments.

Overall, GS could be considered an acceptable root-end filling material, compared to other (bio)materials used for the same objective in different studies. The benefits of GS, as cited in various articles, include biocompatibility with cells and tissues, distinctive handling and setting properties compared to MTA [74]. However, the disadvantages are not specifically related to GS, but rather pertain to resin-based materials; *e.g.*, shrinkage and specific conditions needed for the bonding process [75-77]. Additionally, an *in vitro* study has suggested that the flexural strength of teeth treated with GS seems inferior to those treated with Biodentine™ and Endosequence® Bioceramic Root Repair Material [78]. In the context of periapical healing, an experimental animal study has revealed that GS has shown the least favourable histological result, while there was no radiographic difference between GS, IRM, and MTA [79].

In addition to the above, GS has been employed as a root-end filling material during intentional replantation procedures, which is largely attributed to the self-adhering property and light-cure setting capability of GS; optimising the time required to fill the root end outside the socket, leading to satisfactory outcomes [80].

Perforation management

Perforation management is considered a crucial aspect of endodontic practice, in which accidental breaches during dental procedures or pathologic processes are observed, and may lead to an undesirable communication between the root canal system and external root surface(s)[81]. A wide range of (bio)materials, with different properties, *e.g.*, biocompatibility, radiopacity, sealability, and structural durability, are currently used for the management of perforations [82, 83]. The (bio)materials used should be able to show compatibility with various fluids and diverse cell types sensitive to their environment [84]. Several studies have investigated the roles of different (bio)materials, *e.g.*, MTA, Biodentine™, and GS, in managing perforations [35, 85, 86]. A specific study, aimed at examining the properties beneficial for perforation management, has investigated different aspects of GS; *i.e.*, osteoblast attachment, 3-[4,5-dimethylthiazol-2-yl]-2,5 2,5-diphenyl tetrazolium bromide (MTT) assay, and alkaline phosphatase activity. The research has revealed that the cellular attachment to GS has been on par with MTA, whereas the MTT assay has demonstrated that the cellular proliferation with GS may surpass MTA in the initial hours. However, MTA has shown higher alkaline phosphatase activity, making it the preferred choice for lesions adjacent to the apical region, while GS, with its smooth surface, good cell attachment/proliferation, could be recommended for use in the cervical region or its proximity [73].

Perforations exposed to oral fluids necessitate treatment with a material that offers quick setting and structural durability [87]. Given its lengthy setting time and potential washout in oral fluids, MTA cannot be considered a viable option; however, GS, with its unique combination of biocompatibility, durability, and aesthetic characteristics similar to those of resin-based dental composites, is discussed as an appropriate material [88, 89]. Consequently, GS has been deliberated as an acceptable (bio)material for perforation management owing to its desirable properties [90]. Therefore, its suitability for optimal root perforation management has been extensively explored, with a focus on different attributes; *e.g.*, biocompatibility, sealability, and so forth [91, 92]. Numerous case reports in the literature have also presented the successful outcomes of perforations treated with GS [93-97]. A recent case study, addressing unsuccessful management of root perforation with MTA, has reported its successful treatment using a free gingival graft with de-epithelialization with GS, showing the possible suitability of GS as a potential (bio)material to consider for managing crestal and subcrestal perforations [35].

Vital pulp therapy

Vital pulp therapy (VPT) has recently gained attention within the science of endodontics. The success rate of VPT has been improved by the introduction of bioactive materials; specifically, calcium silicate-based biomaterials, *e.g.*, MTA and CEM cement [98]. Vital pulp therapy modalities include stepwise excavation, indirect pulp capping, direct pulp capping, miniature/shallow (partial) pulpotomy, and full pulpotomy [99, 100]. An important purpose of VPT is the conservation of compromised pulpal vitality to maintain the response of the dental pulp immune system and preserve tooth structure [101-103]. Given its soft tissue compatibility, GS has been considered for use in VPT [104]. An *in vivo* study has investigated the angiogenic activity of GS compared with VPT, commonly used (bio)materials, *e.g.*, white MTA and calcium hydroxide. The obtained results have suggested that GS could outperform white MTA in terms of stimulating blood vessel formation, crucial for efficient tissue healing [14].

Retrograde vital pulp therapy (rVPT)

Vital root resection, combined with regenerative rVPT, represents a biologically oriented approach aimed at the preservation of the vitality and re-functionalisation of teeth that might otherwise require extraction. The innovative rVPT is specifically beneficial for teeth with severe periodontal involvement and root fractures [105]. In rVPT, through selective removal of the compromised root and maintaining the remaining tooth structure, vital root resection can offer a conservative alternative to traditional methods [105, 106]. In addition, rVPT is complemented by utilizing bioactive scaffolds and bioceramic materials to promote healing and regeneration at the root-end, preserving the tooth's natural defense mechanisms, sensory functions, and structural integrity [107].

In rVPT, GS plays a crucial role in reinforcing the seal over the calcium silicate-based biomaterial applied. The properties of GS, including strong bonding, biocompatibility, and resistance to oral conditions, ensure the stability and durability of the repair [108, 109]. Additionally, the application of GS protects the treated site from external factors, enhancing the success of the therapy [14].

Promising outcomes of rVPT have been demonstrated in several case reports, exhibiting hard tissue healing and stable alveolar bone levels [105]. This biologically oriented method may offer a less invasive and cost-effective alternative to conventional treatments, paving the path for improved patient outcomes and long-term tooth preservation

Intra-orifice barrier

In endodontics, intra-orifice barriers function as a critical part of restoring endodontically treated teeth [110]. Placed within the coronal part of the root canal system, the mentioned barriers form an additional protective layer against microleakage, creating a seal to shield the root filling from potential contamination by oral fluids and bacteria. Besides, they significantly contribute to the long-term success of endodontic treatments, particularly when the final restoration might be delayed [111]. Various materials are considered for use as intra-orifice barriers, including resin-based dental composites, glass ionomer cements, bioactive materials (*e.g.*, MTA and Biodentine™), and RMGIs, including GS. Given its previously mentioned characteristics, GS can serve as a viable intra-orifice barrier. However, other materials, *e.g.*, Fuji-Plus and MTA, may demonstrate superior performance as barriers [112].

External cervical resorption

External cervical resorption (ECR) is the outcome of odontoclastic activity, which causes a dynamic phenomenon, resulting in the loss of tooth/root structure. Different factors have been proposed as potential triggers for ECR; *e.g.*, trauma, orthodontic movement, and internal bleaching [113]. Diagnosis of ECR can be complicated due to its subtle symptoms, yet careful clinical examination as well as advanced radiographic techniques may further assist in revealing and evaluating ECR, its extent, and possible pink spots in cases of invasive cervical resorption [114, 115].

The treatment of ECR usually involves *(i)* eliminating the granulation tissue that has intruded into the resorptive lesion, and *(ii)* restoring the affected area with a biocompatible material, *e.g.*, GS [116]; however, surgical procedures may be necessary depending on the severity of resorption [117]. Various case studies have reported the effective employment of GS for the restoration of the defect resulting from cervical resorption [118-120].

Since invasive cervical resorption predominantly occurs in anterior teeth, where aesthetics is crucial [121], employing subtractive treatments, *e.g.*, CL to expose and treat the defect, may lead to an unsatisfactory appearance [122]. Geristore®, with its acceptable aesthetics, ability to bond to overlying restorative dental composite, colour matching and polishing qualities, can be deemed a favoured choice for treatments, specifically in the aesthetic zone, with long-term stability of soft tissue [123]. Besides, GS has been successfully used in non-aesthetic zones, with defects in deep areas near the crestal bone and subgingival regions [124-126]. In addition, GS has been reported to effectively manage post-internal bleaching in cervical resorption [122]. Furthermore, GS has been used in an uncommon bilateral case of ECR after a soft tissue graft, achieving outstanding follow-up results. It was shown that, although the defect was located apically to the cementoenamel junction, probing during the follow-up recorded depths ≤4 millimeters [127].

Propagated crown fracture removal

Propagated crown fractures (PCF) are a significant dental issue that could happen after endodontic treatment, leading to persistent pain during biting or chewing, deterioration of the localized periodontium, and eventual tooth loss. Often, PCF extends apically, making the needed treatment challenging. Prognosis for PCF has traditionally been poor, with extraction being a common solution. However, Michelson has introduced a novel treatment for the mentioned fractures, aiming at the preservation and refunctionalisation of the dental structure. In the proposed approach, the involved site is initially sealed with MTA to promote periodontal healing, and then, GS is applied over MTA to enhance the repair [128]. Seemingly, not only does the incorporation of GS protect the underlying MTA, but it also aids in sealing and stabilising the repair site due to the strong bonding properties and

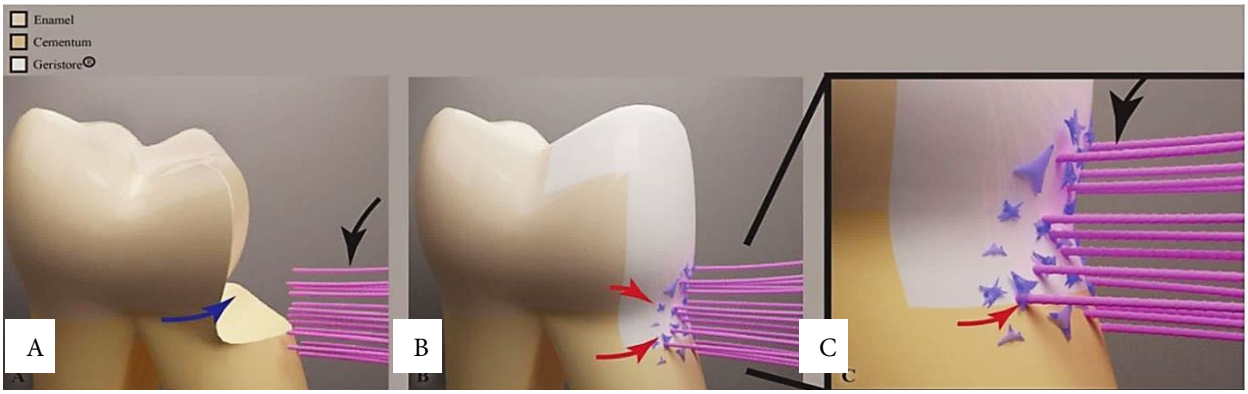

Figure 2. Schematic model; demonstrating an overview of using Geristore® as a treatment modality in deep lesions; *A*) An extensive defect (blue arrow); extending into the cementum as well as biological width and subcrestal area. Gingival collagen fibers (black arrow) are a necessity for the re-establishment of periodontal attachment; *B*) Human gingival fibroblasts (red arrow) have attached to the restorative material, *i.e.* Geristore®; forming the complex needed to form soft tissue re-instatement; *C*) Enlarged view of the possible outcome following the placement of Geristore® as the restorative material into biological width or subcrestal lesions

fluoride release of GS [129]. The corresponding study claims to offer a conservative and effective solution for the management of PCF, significantly improving the prognosis for affected teeth [130].

Deep margin elevation for biological width and subcrestal lesions (in cases of possible Endo-Perio Complications)

Deep margin elevation (DME) is a technique initially introduced as a strategy to re-position deep margins for enhanced isolation/accessibility for direct or indirect restorations, and to reduce the need for crown lengthening surgical procedure [131, 132]. Despite the reports of DME having a higher success rate compared to crown lengthening in systematic reviews [9], the literature suggests that DME should respect BiW [133] and be cautiously used when there is *(i)* field isolation capability, *(ii)* proper sealability in the cervical margin with a matrix, and *(iii)* lack of invasion towards the connective part of BiW [134]. In other words, the restorative materials used may enter the epithelial component of BiW and should stay at a minimum distance of 1 mm from the crestal area [135]. Although the violation of BiW is not acceptable, the evidence suggests the possible placement of some materials in the BiW region. An animal study has reported the formation of connective tissue on resin-modified glass ionomer cement in deep cavities invading BiW [136]. There are criteria necessary for the material used/placed in direct contact with soft tissue; *e.g.*, satisfactory cell-attachment ability, acceptable biocompatibility, and proper cytokine reaction [137]. However, the necessity for clinical trials to apply this material/technique widely is vital.

Based on explicit scoping in the literature, GS could have promising outcomes given the evidence supporting the attachment of HGF on GS, as well as the satisfactory clinical outcomes of using GS in various applications. Additionally, it can be hypothesised that periodontal fibroblasts could potentially attach and form gingival fibers to GS even when the material is applied to BiW and subcrustal lesions. The mentioned placement could reduce the need for tooth extraction or crown lengthening (Figure 2).

Geristore® in medical applications

While the use of GS has been reported in medical experiments, *e.g.*, as a pathway for transferring specific substances to the skull, securing/fixing cannulas in animal models [138, 139], the applications may hold indirect relevance to endodontic practice. The mentioned uses could exhibit the high tissue compatibility and mechanical stability of GS, even under physiological conditions [140, 141]. Therefore, the corresponding findings could reinforce the potential utility of GS in minimally invasive procedures, *e.g.*, endodontic, where precise (bio)material placement and soft tissue response are critical [142-144]. However, unless further translational evidence becomes available connecting the medical applications to clinical endodontics (*e.g.*, regenerative scaffold anchoring or biologically integrated restorations), the stated area remains peripheral to the main focus.

Clinical Implications

While the biological properties and *in vitro* findings of GS are relatively well-documented, it is important to highlight that the majority of available literature consists of experimental studies due to the inherent challenges of conducting large-scale clinical trials in dentistry. Clinical data on GS primarily comes from case reports and small-sized case series, where its selection as a (bio)material of choice was often based on its unique properties, *e.g.*, biocompatibility, fluoride release, and strong dentinal bonding.

In clinical comparisons to gold-standard (bio)materials, *e.g.*, MTA, GS has demonstrated benefits and limitations. For instance, while MTA remains the favoured biomaterial for apical perforations and root-end fillings (owing to its superior bioactive properties and alkaline phosphatase activity), GS has shown better performance in cervical/subcrestal perforations, where its rapid setting, suitable adhesion, and biocompatibility are advantageous [87, 90]. Clinical reports suggest that GS provides comparable short-term success rates to MTA in certain applications, though long-term data remains limited [33, 68].

In VPT, GS has exhibited promising angiogenic properties in preclinical studies [14]; however, clinical evidence is scarce compared with MTA or calcium silicate-based materials, seeming to have more extensive validation [99, 104]. Similarly, for external cervical resorption, GS has been successfully used in multiple case reports, demonstrating good aesthetic and functional outcomes [35, 118], though no large-scale comparative studies with MTA or Biodentine™ exist.

Future Prospects

A critical area identified is the need for long-term clinical trials comparing GS with other (bio)materials in various endodontic applications; providing valuable insights into the long-term performance, biocompatibility, durability and clinical outcomes of GS in comparison to bioceramics and calcium silicate-based (bio)materials, helping to better establish its position within endodontic treatments. Additionally, future studies could focus on the (bio)material's role in specific clinical procedures and well-designed clinical trials comparing GS with established gold-standard materials in various applications, including rVPT, and explore its efficacy in complex cases, *e.g.*, perforation repair and regenerative procedures. By addressing these gaps, researchers can contribute to a more comprehensive understanding of GS's potential in the evolving landscape of endodontics. Until then, clinicians should weigh GS's proven benefits against the limitations highlighted in existing case-based evidence.

Conclusions

As the development of resin-based dental composite restorative material progresses, the use of RMGIs, formerly a popular alternative to amalgam in aesthetically important regions, has declined. Nonetheless, RMGIs still hold a crucial role in everyday dental treatment due to their desirable properties, *e.g.*, fluoride release, self-adhesion, and proven chemical bonding to tooth structure.

Geristore®, a well-established RMGI, has found widespread applications in various areas of dentistry and dental treatments, specifically in present-day endodontics, where high cell compatibility as well as a certain degree of physical, chemical and aesthetic appeal are specifically required; bringing a favourable balance of biocompatibility, antibacterial efficacy, and soft tissue adaptability. In addition, GS is clinically valuable in root-end filling and perforation repair, where its superior sealability under contaminated conditions may well exceed traditional materials, *e.g.*, MTA. Furthermore, GS has shown potential in rVPT and the management of external cervical resorption, supporting minimally invasive alternatives to crown lengthening or extraction. Moreover, the compatibility of GS with DME techniques highlights its potential to preserve the BiW while managing subcrestal lesions.

Despite the aforementioned advantages, certain limitations, *e.g.*, inferior flexural strength compared to bioceramics and variable cytotoxicity *in vitro*, necessitate careful case selection and further validation. To support broader clinical adoption, future research should focus on standardising rVPT protocols to optimise material placement, curing techniques and long-term outcomes; conducting comparative long-term trials against calcium silicate-based materials like Biodentine™; innovating material formulations to enhance mechanical strength without compromising biocompatibility; and exploring regenerative applications of GS as a scaffold or adjunct in pulp revitalization and periodontal healing.)

However, GS has shown its limitations in physical and bonding strength compared with alternative materials used in specific treatments, which has potentially led to its decline in use. Nonetheless, more detailed experimental/*in vivo* investigations and well-designed trials to carefully evaluate the clinical performance and outcomes of using GS compared with other materials are necessary to establish a strong body of evidence for future research and application(s).

Data availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgment

None.

Conflict of interest

None.

Funding support

None.

Authors' contributions

Conceptualization: MR, Methodology: MR/AP, Formal analysis and investigation: MR/AP, Writing-original draft preparation: MR, Writing-review and editing: MR/AP, Supervision: AP. All authors read and approved the final manuscript.

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Please cite this paper as: Radafshar M, Parhizkar A. A Critical Review of the Role of Geristore® in Contemporary Endodontics. Iran Endod J. 2025;20(1): e28. *Doi:* 10.22037/iej.v20i1.48268.