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Clinical applications of glass ionomers in endodontics: a review

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Glass ionomer cements (GICs) are biocompatible and have capacities to release fluoride and to bond to dentine, and thus are appropriate for use in endodontics. This paper reviews the composition and properties of different GICs, including their biocompatibility and antibacterial activity, their applications as intraorifice barriers and root canal sealers, and their use in the repair of root perforations, root-end fillings and temporary coronal restorations.

Key words: *Glass ionomers, coronal seal, root-end filling, perforation repair, root canal sealer*

Glass ionomer cements (GICs) were first developed as the product of an acid–base reaction between a basic fluoro-alumino-silicate glass powder and polycarboxylic acid in the presence of water[1,2]. Many modifications and improvements to the original formulation have since been made. Today, conventional GICs are hybrid materials with both organic and inorganic constituents. These materials are composed of calcium fluoro-alumino-silicate glass powder and aqueous solutions of homo- and copolymers of acrylic acid-containing tartaric acid[3]. Because GICs are not true ionomers in the chemical sense, they are more accurately described as glass polyalkenoate cements. However, this term has not been used as widely as the GIC designation[4].

COMPOSITION OF GICS

Glass ionomer cements may be supplied as powder and liquid or as powder that is mixed with water. In powder/liquid materials, the powder consists of a sodium alumino-silicate glass of similar composition to that used in silicate materials. The ratio of alumina to silica in the glass is greater than that used in silicates. Glass ionomer cements contain significant levels of fluoride, which, although not directly involved in the setting reaction, may have an effect on the caries susceptibility of the surrounding tooth substance. The liquid component of the original GICs was a 50% aqueous solution of polyacrylic acid. However, nowadays it may consist of an aqueous solution of acrylic acid or of a maleic acid/acrylic acid copolymer[5].

ANTIMICROBIAL EFFECTS

Heling and Chandler[6] assessed four root canal sealers [Pulp Canal Sealer EWT (Kerr, Romulus, MI, USA), Sealapex (Sybron Endo, Orange County, CA, USA), AH-26 (Dentsply DeTrey, Konstanz, Germany), Ketac-Endo (ESPE GmbH & Co., Seefeld Oberbay, Germany)] for their antibacterial effects within dentinal tubules. Findings showed that all sealers exhibited antibacterial activity at 24 hours, except Ketac-Endo. The activity of Pulp Canal Sealer EWT was similar at 24 hours and 7 days. Sealapex had greater antibacterial effect at 7 days than it did at 24 hours. The strongest effects were demonstrated by AH-26. Shalhav *et al.*[7] evaluated the antibacterial activities of Ketac-Endo and Roth's cement (Roth International Ltd., Chicago, IL, USA) using an agar diffusion test (ADT) and a direct contact test (DCT). The results showed that in the ADT, freshly mixed Ketac-Endo exhibited a two-fold greater inhibition zone than Roth's cement, whereas in the DCT, both freshly mixed Ketac-Endo and Roth's cement completely inhibited bacterial growth. The 24-hour and 7-day samples of Ketac-

Endo showed no antibacterial activity, whereas Roth's cement continued to exhibit a strong effect at those time-points. Lai *et al.*[8] evaluated the antibacterial effects of three resinous root-end filling materials [Fuji II LC (GC Corporation, Tokyo, Japan), a resin-modified GIC; Dyract (Dentsply Ltd, Konstanz, Germany), a compomer; Spectrum (Dentsply Ltd, Konstanz, Germany), a composite resin] on the growth of four obligate anaerobic bacteria (*Fusobacterium nucleatum*, *Porphyromonas gingivalis*, *Porphyromonas endodontalis*, *Prevotella intermedia*) using the inhibitory ADT. Findings indicated no statistically significant overall differences in the response of the black-pigmented *Bacteroides* species. Spectrum had more antibacterial effect against *F. nucleatum* than Dyract. Fuji II LC was ineffective against *F. nucleatum*. However, positive control plates showed bacterial growth in all cases.

BIOCOMPATIBILITY

Blackman *et al.*[9] implanted pellets of a silver-GIC and a zinc oxide-eugenol cement into the soft tissues and bones of 30 rats. Following experimental periods of 14 days, 30 days and 80 days, the animals were killed and tissue sections were prepared. The responses to each of the materials initially and at 30 days consisted of mild inflammation. No severe inflammatory responses were noted in any of the groups. By 80 days, although mild inflammation persisted, the materials appeared to be well tolerated. Bone apposition occurred in the silver-GIC group, whereas the zinc oxide-eugenol group produced fibrosis. Kolokouris *et al.*[10] evaluated the biocompatibility of Ketac-Endo and Tubli-Seal (Sybron Endo, Orange County, CA, USA) in rat connective tissue. Forty-four white female Wistar–Furth rats were used. Each sealer was placed in a Teflon tube and implanted subcutaneously. The implants were removed after 5, 15, 60 and 120 days, fixed and histologically prepared for microscopic evaluation. Mild inflammatory reaction was observed with Ketac-Endo at day 5. The connective tissue was infiltrated with plasma cells. Lymphocytes and macrophages were observed. The intensity of the reaction diminished by day 15 and continued to reduce progressively to days 60 and 120. Severe inflammation with differing degrees of necrosis was observed with Tubli-Seal on days 5 and 15, and the material remained irritating even after longterm implantation periods (60 and 120 days). Schwarze *et al.*[11] evaluated the longterm cytocompatibility of several endodontic sealers [N2, Apexit (Ivoclar Vivadent Inc., Schaan, Liechtenstein), RoekoSeal (Coltene Whaledent, Langenau, Germany), AH-Plus (Dentsply DeTrey), Ketac-Endo, Endomethasone (Septodont, Saint Maur-des-Fosses, France)] using immortalised 3T3 fibroblasts and primary human periodontal ligament fibroblasts, and found that N2 extracts caused pronounced cytotoxic effects in both cell cultures. In addition, statistically significant cytotoxic alterations were induced by 10-week eluates of Endomethasone. None of the other materials investigated significantly altered cell metabolism. Yoshimine *et al.*[12] found that the GIC sealer KT-308 (GC Corporation, Tokyo, Japan) was cytocompatible and had good potential as a root canal sealer. Koulaouzidou *et al.*[13] evaluated the antiproliferative activities of three dental materials [4-methylthioamphetamine (MTA), zinc oxide-eugenol cement, GIC] against a panel of established fibroblastic cell lines (L929, BHK21/C13, RPC-C2A). Results demonstrated that the materials with the least to greatest antiproliferative effects were, respectively, MTA, GIC and zinc oxide-eugenol cement in all cell lines tested.

CLINICAL APPLICATIONS

Root canal sealer

Oguntebi and Shen[14] assessed the effects of the film thickness of different sealers [Roth's Type I Cement (Roth International Ltd, Chicago, IL, USA), Sealapex (Sybron Endo, Orange County, CA, USA), Lee Endofil (Petropolis, RJ, Brazil), AH-26, Ketac-Cem (3M ESPE, Seefeld, Germany)] on the apical seal of thermoplasticised root canal obturations. They found no significant differences among the five sealers. Smith and Steiman[15] found that Ketac-Endo showed significantly more leakage than zinc oxide-eugenol-based sealers. Brown *et al.*[16] found that the apical seal exhibited by Ketac-Endo was not significantly different from that provided by Roth's 801 sealer. In a study designed to assess the effect of Ketac-Endo on the success and failure of endodontic therapy, Friedman *et al.*[17] found that treatment results were compatible with those reported in previous studies and supported the clinical use of Ketac-Endo as an acceptable endodontic sealer. In an *in vitro* dye leakage study, Rohde *et al.*[18] compared the apical microleakage of Ketac-Endo with those of Roth 801E and AH-26 sealers and found that Ketac-Endo root canal sealer showed greater dye penetration than the Roth 801E and AH-26 products. Malone and Donnelly[19] evaluated coronal microleakage in obturated root canals using two different sealers [Super-EBA (Harry Bosworth Co., Skokie, IL, USA), Ketac-Endo] without coronal restorations and found that neither sealer allowed bacterial penetration through the apical foramen during the 60-day test period. Lee *et al.*[20] investigated the sealing ability of GI as a root canal sealer with and without lateral condensation of gutta-percha cones. Ten gutta-percha cones were embedded in Grossman's sealer (Fill Canal, Dermo Laboratories, RJ, Brazil) and 10 in GI sealer. The sealers were mechanically separated from the gutta-percha. The cone surfaces were examined using scanning electron microscopy, which revealed a characteristic etch pattern on the GI group and a hybrid layer on the cone surfaces of the Grossman's sealer group. Additionally, 40 maxillary incisors were divided into four treatment groups consisting of, respectively: GI sealer with lateral condensation (group 1); GI sealer with only one master cone (group 2); Grossman's sealer with condensation (group 3), and Grossman's sealer with only one master cone (group 4). Mean leakage values in groups 1–4 were 0.81 ± 0.75 mm, 4.30 ± 1.82 mm, 0.67 ± 0.80 mm and 1.10 ± 1.68 mm, respectively. Statistical analysis showed that the group 2 treatment resulted in greater leakage than the other three treatments. Dalat and Onal[21] compared the apical leakage of Ketac-Endo and AH-26 using two different filling techniques and a controlled vacuum procedure, and found that there were no significant differences between the products in any of the samples. Timpawat and Srinaparatanakul[22] evaluated the apical sealing abilities of Ketac-Endo and zinc oxide-eugenol sealers with and without a smear layer using a dye penetration technique. Findings showed that the apical seal exhibited by Ketac-Endo did not differ significantly from that provided by zinc oxide-eugenol cement, regardless of the presence or absence of a smear layer. Ozata *et al.*[23] evaluated the apical sealing abilities of Apexit, Ketac-Endo and Diaket (3M/ESPE, Minneapolis, MN, USA) root canal sealers using a methylene blue dye penetration technique. Findings showed no significant difference between Apexit and Diaket. However, there was significantly more leakage with Ketac-Endo. McDougall *et al.*[24] found that KT-308 (a GI-based sealer) effectively prevented penetration by *Enterococcus faecalis*. In an *in vivo* study, Friedman *et al.*[25] found the coronal sealing ability of KT-308 to be significantly better than that of Roth 801. Timpawat *et al.*[26] compared the bacterial penetration of root canals obturated with three root canal sealers (AH-Plus, Apexit, Ketac-Endo) using *E. faecalis* as a microbial tracer to determine the length of time required for bacteria to penetrate the obturated root canal to the root apex. Findings showed no statistical difference between Ketac-Endo and AH-Plus, but Apexit allowed significantly higher leakage at 30 days. At 60 days there was no statistical difference between Ketac-Endo and Apexit, but Apexit allowed greater leakage than AH-Plus. Miletić *et al.*[27] assessed the apical sealing abilities of five root canal sealers (AH-26, AH-Plus, Apexit, Diaket, Ketac-Endo) in 60 single-rooted teeth after 1 year of storage. Findings showed that Apexit allowed significantly more leakage than AH-Plus and Ketac-Endo, whereas AH-26 and Diaket did not differ significantly from any of Apexit, AH-Plus or Ketac-Endo in terms of leakage afforded. Another issue concerning the GIC-based sealers is their adhesion (bond strength) to gutta-percha and dentine. Using a fluid filtration technique, Pommel *et al.*[28] assessed apical leakage with four endodontic sealers and found that teeth filled with Sealapex displayed a higher rate of apical leakage than those filled with AH-26, Pulp Canal Sealer EWT or Ketac-Endo. Furthermore, no statistically significant difference in leakage emerged among AH-26, Pulp Canal Sealer and Ketac-Endo. Neither did these authors find any correlation between the sealing efficiency of the sealers and their adhesive properties[28]. Economides *et al.*[29] evaluated the microleakage of two root-end filling materials with and without the use of bonding agents using a fluid transport model. Teeth were prepared with a step-back technique prior to the performance of an apicectomy. The teeth were then divided into four groups. Teeth in group A were filled with Fuji II LC GIC, those in group B with Fuji II LC and a new bonding agent, Fuji Bond, those in group C with Admira composite resin (VoCo GmbH, Cuxhaven, Germany), and those in group D with Admira and Admira Bond, a new bonding agent. At 24 hours, 1 month and 2 months after filling, leakage was determined under a low pressure of 0.1 atm. Results demonstrated that at all experimental times, GI groups showed significantly less microleakage than resin groups. Furthermore, at 24 hours significantly less leakage was observed in root sections filled with Admira Bond than in those filled with Admira. In another *in vitro* study, Cobankara *et al.*[30] evaluated the antibacterial activities of five different root canal sealers [RoekoSeal, Ketac-Endo, AH-Plus, Sealapex, Sultan (Sultan Chemists Inc., Englewood, NJ, USA)] against *E. faecalis* as a test organism using both the ADT and DCT. According to their findings, Ketac-Endo, Sultan and AH-Plus all produced similar results in the DCT. These sealers were more potent inhibitors of bacterial growth than Sealapex and RoekoSeal. In the ADT, RoekoSeal showed no antibacterial activity. Furthermore, there was no significant difference among AH-Plus, Sealapex and Sultan, and Ketac-Endo demonstrated lower antimicrobial activity than these sealers. In addition, time had no effect on the antibacterial activities of the tested sealers. Gogos *et al.*[31] compared the shear bond strength of four root canal sealers, including Fibrefill (Pentron, Wallingford, CT, USA), a methacrylate resin sealer, Endion (VoCo, Cuxhaven, Germany), a GI sealer, Topseal (Dentsply, Konstanz, Switzerland), an epoxy resin sealer, and CRCS (Coltene Whaledent Hygenic, Mahwah, NJ, USA), a calcium hydroxide sealer, to human root canal dentine. Findings showed that Fibrefill produced the highest shear bond strength, and Endion and CRCS had significantly lower shear bond strength than Fibrefill and Topseal.

Root-end filling

Pissiotis *et al.*[32] assessed the apical microleakage of retrograde fillings with amalgam and with silver-GICs using a modified dye penetration method. Forty instrumented human teeth were divided into four groups. Each group was characterised by a different retrograde filling material or technique as follows: silver-GI (group 1); silver-GI with previous acid wash of the cavity (group 2); silver-GI in a previously acid-washed cavity, protected with varnish (group 3), and zinc-free amalgam (group 4). Results showed the least microleakage occurred in group 1 teeth. Inoue *et al.*[33] compared microleakage after retrofillings of amalgam, amalgam with cavity varnish, GIC containing silver and intermediate restorative material (IRM) using a fluid filtration method for 24 weeks. Thirty-six extracted human incisors and canines were instrumented, obturated with gutta-percha without sealer, subjected to apicoectomy and retrofilled with the study materials. Findings demonstrated that all four retrofilling materials allowed some apical and coronal leakage at all time-points. The amalgam group showed statistically significant apical leakage at 1.5 hours. The use of cavity varnish significantly reduced apical leakage in the amalgam group at 1.5 hours. The silver-GIC and IRM groups showed significantly less coronal leakage compared with the amalgam group at 1.5 hours. Friedman *et al.*[34] compared the leakage of amalgam and varnish, GIC and a composite resin as retrofilling materials using a dye leakage method and correlated leakage data with healing. Results showed no statistically significant differences among the three groups. Consequently, dye leakage did not correlate with previously assessed healing. In an electrochemical study to assess the sealing abilities of different root-end filling materials, Al-Hadainy *et al.*[35] indicated that GI sealed significantly better than the other materials, followed by amalgam, heat-sealed gutta-percha and zinc polycarboxylate cement, respectively. Gerhards and Wagner[36] evaluated the sealing abilities of amalgam, Harvard-Cement (Harvard Dental International, Berlin, Germany), Diaket, gold leaf and Ketac-Endo as retrofilling materials. Results demonstrated that retrofills with Ketac-Endo showed significantly less leakage than those with amalgam, there was no significant difference between the amalgam and Diaket groups, and the sealing abilities of Harvard-Cement and gold foil were lower than that of amalgam. Wu *et al.*[37] evaluated the sealing efficacies of amalgam, MTA, Super-EBA, and two GICs [Fuji II and Hi Dense (Click Dental Supplies Ltd, NJ, USA)] at 3-, 6- and 12-month intervals. At all time-points, both GICs (Fuji II and Hi Dense) and MTA showed less leakage than the conventional amalgam and Super-EBA, of which the amalgam leaked more. Siqueira *et al.*[38] evaluated the sealing abilities of Sealer 26 (Dentsply Industria e Comercio Ltda., Petropolis, RJ, Brazil), a resinous root canal sealer prepared in a thick consistency, IRM, and a GIC (Fuji IX; GC Corporation, Tokyo, Japan) in preventing bacterial leakage. Leakage was observed in all teeth in the Fuji IX group and in 95% of the teeth retrofilled with IRM. Of the teeth retrofilled with Sealer 26, 65% showed leakage. No difference was detected between Fuji IX and IRM. However, Sealer 26 was significantly more effective in preventing bacterial leakage compared with the other materials tested. In a systematic review, Theodosopoulou and Niederman[39] indicated that the most effective retrofilling materials, when measured by dye penetration, were composites > GIC > amalgam > orthograde gutta-percha > Super-EBA.

Perforation repair

Dazey and Senia[40] compared the sealing abilities of Tytin (Kerr, Romulus, MI, USA) amalgam, Ketac-Silver (ESPE GmbH Co., Seefeld, Germany) and Prisma VLC Dycal (L D Caulk Co., Milford, DE, USA) in the repair of lateral root perforations *in vitro*. Teeth in the Prisma VLC Dycal group exhibited significantly less dye penetration than those in the other two groups and there was no significant difference between the Tytin and Ketac-Silver groups. Moloney *et al.*[41] evaluated the sealing abilities of amalgam plus cavity varnish, EBA cement and silver-GIC in the repair of lateral root perforations and found that the EBA cement group exhibited significantly less leakage than the silver-GIC group. Furthermore, no differences were found between the other groups. Himel and Al-Hadainy[42] evaluated the sealing abilities of GI and composite resin in the repair of furcation perforations over plaster of Paris barriers. Findings indicated that light-cured GI provided a significantly better seal than light-cured composite resin with or without dentine preparation and acid etching. Fuss *et al.*[43] found that the sealing ability of a silver-GIC (Chelon Silver; 3M/ESPE, Minneapolis, MN, USA) in furcation perforations was significantly better than that of amalgam. Daoudi and Saunders[44] evaluated furcal perforation repair using MTA or Vitrebond (3M, St. Paul, MN, USA) (a resin-modified GIC) with and without the use of the operating microscope using India ink and found that perforations repaired with MTA leaked significantly less than those repaired with Vitrebond.

Intraorifice barrier (double seal)

Beckham *et al.*[45] conducted a study to assess the sealing abilities of Barrier Dentin Sealant (Holt Dental Supply, Inc., Waukesha, WI, USA), GIC and temporary endodontic restorative material (TERM) against coronal microleakage using a dye penetration technique and found that dye penetration permitted by GIC was statistically significantly greater than the penetration allowed by the other two barrier materials. Wolcott *et al.*[46] evaluated the effectiveness of three pigmented GICs used as intraorifice barriers to prevent coronal microleakage and found that teeth without an intraorifice barrier leaked significantly more than teeth with Vitrebond intraorifice barriers. However, differences in leakage among the experimental GI barriers were not significant. Barthel *et al.*[47] evaluated longterm bacterial leakage along obturated roots restored with temporary and adhesive fillings [including Clearfil (Kuraray, Okayama, Japan), CoreRestore (Kerr, Pearson Dental Supplies, MI, USA), IRM, Ketac-Fil (3M ESPE, MN, USA), and combinations of IRM and wax, and Ketac-Fil and wax]. Findings showed that after 1 year, only three samples in the CoreRestore group and two samples in the Clearfil group resisted leakage. At termination there was no significant difference in the number of leaking samples among the groups. At the beginning of the experiment, IRM performed worst. Between months 5 and 10, Clearfil showed the lowest rate of leakage at a difference that remained statistically significant compared with those of IRM and Ketac-Fil for some months. Tselnik *et al.*[48] assessed the sealing abilities of grey MTA, white MTA and Fuji II LC cement [a resin-modified GI (RMGI)] as intraorifice barriers. Findings revealed no statistically significant difference in leakage between grey and white MTA, or grey MTA and Fuji II LC at 30 days, 60 days and 90 days. Mohammadi and Khademi[49] found that grey mineral trioxide aggregate (GMTA), white mineral trioxide aggregate (WMTA) and Principle (Dentsply Caulk, Milford, DE, USA) (an RMGI) can be recommended as coronal barriers for up to 90 days. Maloney *et al.*[50] evaluated the effect of thermocycling on a coloured GI intracoronal barrier used for the prevention of microleakage in a fluid transport model. Teeth in group 1 received a 1-mm intracoronal barrier of Triage (GC America Inc., Alsip, IL, USA), those in group 2 received a 2-mm Triage barrier, and those in group 3 received no barrier. After incubation to set the sealer, teeth were thermocycled. Teeth in groups 1, 2 and 3 demonstrated movement of 1.68 mm, 0.60 mm and 23.24 mm, respectively. Analysis of variance (ANOVA) and Student–Neumann–Keuls tests showed that seals in group 3 leaked significantly more than those in groups 1 and 2; no difference emerged between groups 1 and 2. Furthermore, a 1-mm or 2-mm intracoronal barrier of Triage significantly reduced coronal microleakage in thermocycled endodontically treated teeth. Mavec *et al.*[51] reported that the use of 3 mm of Vitrebond, an RMGI, as a coronal barrier in post-prepared teeth significantly extended the time to leakage. Wells *et al.*[52] compared Principle with C&B Metabond (Parkell Co., Edgewood, NY, USA) as a coronal barrier. They found that Principle leaked significantly more than C&B Metabond at 1 hour, but that its seal improved at 4 weeks. In an *in vitro* study, Barrieshi-Nusair and Hammad[53] compared the sealing abilities of MTA and GI as intraorifice barriers using a dye leakage model. Results showed that barriers in the MTA group leaked significantly less than those in the GI group. Celik *et al.*[54] evaluated the sealing abilities of four current restorative materials (GIC, polycarboxylate cement, RMGI, flowable composite resin) used as a base over obturated root canals during a 5-month period in a bacterial leakage model. Findings showed that the sealing abilities of all tested materials were better than that in a no-barrier group. Furthermore, the GIC leaked significantly less than the flowable composite. Jack and Goodell[55] compared coronal microleakage between Resilon (Resilon Research LLC, Madison, CT, USA) alone and gutta-percha with a GI intraorifice barrier using a fluid filtration model. Findings demonstrated significantly less leakage in the gutta-percha/GI intraorifice barrier group than in the group using Resilon alone. John *et al.*[56] compared coronal leakage in teeth with 2-mm intraorifice barriers of Fuji Triage GI, grey MTA and white MTA using a fluid flow model and found no significant differences among the three groups. Zakizadeh *et al.*[57] evaluated the efficacies of amalgam, Fuji-Plus (GC Corporation, Tokyo, Japan), Geristore (Dent-Mat Corp., Santa Maria, CA, USA) and MTA as intraorifice barriers in a simulated saliva leakage model using micro-computed tomography (micro-CT). Findings showed that MTA was significantly less porous than Fuji-Plus and Geristore, whereas amalgam was too radiopaque to allow micro-CT measurements. The authors concluded that Fuji-Plus might be an effective intraorifice barrier (up to 70 days *in vitro*), but all four materials showed leakage in some specimens at 90 days[57].

Temporary coronal restoration

Bobotis *et al.*[58] evaluated the sealing properties of various temporary restorative materials [Cavit (3M/ESPE, Minneapolis, MN, USA), Cavit-G, TERM, GIC, zinc phosphate cement, polycarboxylate cement, IRM] quantitatively. The results indicated that Cavit, Cavit-G, TERM and GIC provided leakproof seals during the 8-week testing period, whereas leakage was observed in four of the 10 teeth restored with zinc phosphate cement. The least effective of the materials tested in preventing microleakage were IRM and polycarboxylate cement.

In an *in vitro* study, Barthel *et al.*[59] assessed the abilities of different coronal temporary fillings (Cavit, IRM, GIC, Cavit/GIC, IRM/GIC) to prevent corono-apical penetration of bacteria. According to their findings, the Cavit, IRM and Cavit/GIC groups showed significantly more leakage than the GIC-only and IRM/GIC groups, and all but one IRM/GIC sample leaked before day 12[59].

CONCLUSIONS

Glass ionomer cements are adhesive materials that act as antimicrobial agents with an acceptable degree of biocompatibility. They can be used effectively as root canal sealers, root-end filling materials and intraorifice barriers, and in perforation repair and temporary restoration.

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Conflicts of interest

None declared.

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