



**UvA-DARE (Digital Academic Repository)**

**The ART of GIC proximal restorations in primary teeth**

Bonifacio, C.C.

[Link to publication](#)

*Citation for published version (APA):*

Bonifácio, C. C. (2012). The ART of GIC proximal restorations in primary teeth

**General rights**

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

**Disclaimer/Complaints regulations**

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <http://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

# Chapter 1

## Introduction



## Introduction

The introduction of adhesive dental materials changed the principles of cavity preparation. At the same time, a better understanding of the caries process promoted the substitution of the mechanical design by the biological principles of cavity preparation. The concept of Minimal Intervention (MI) dentistry advocates not only saving sound tooth material before applying an adhesive technique and/ or restorative material but it also includes the remineralisation of non-cavitated lesions, inducing repair instead of replacement of inadequate restorations and a careful education of the patient (1).

One of the most investigated MI approaches in the last twenty years is the Atraumatic Restorative Treatment (ART), which was developed in response to the unavailability of restorative care for populations with limited resources (2). This approach of treating cavitated carious lesions uses only hand instruments to remove the soft carious tissue and the cavity is restored with a high-viscosity glass-ionomer cement (GIC). The same material is placed in excess to seal remaining fissures using the “press-finger” technique. Simultaneously, a preventive program is implemented alongside the restorative treatment. Learning the importance of removing dental plaque and having healthy eating habits, the patient can shift from high to low caries risk, consequently reducing the indications for extractions.

## Atraumatic Restorative Treatment

Developed in the 1980s to manage dental caries in underserved communities, the main goal of ART was to provide an affordable alternative for preventing decayed teeth from being extracted where the required resources for modern dental treatment such as electricity, piped water and finances were scarce (3). The efforts of implementing mobile units with mobile drilling and suction equipment, portable dental chairs and generators would be too expensive to implement and maintain, and were discarded as having been deemed not economically sustainable (4, 5).

When working in the Dental School in Dar es Salaam, Tanzania, Dr. Jo Frencken audited the dental clinics in the country side and observed that most of the dental equipment was not functioning but that hand instruments were available. The cavities were large enough to be treated with excavators and there was no need for drilling machines. A pilot study in 28 cavities, cleaned with hand instruments and restored with polycarboxylate cement showed promising results and the method was well accepted by the patients. These results were presented in a scientific meeting of the Tanzanian Dental Association in 1986 and the ART approach was officially born (3).

Some years later, a randomized clinical trial comparing ART using GIC as the filling material with the conventional treatment using amalgam was conducted in permanent and primary teeth (6), and the favourable results of the ART approach caught the attention of many people working in under-served communities. In 1994, ART was adopted by the World Health Organization (WHO) and in 2002 by the World Dental Federation (FDI). The introduction of ART also challenged some concepts such as the need for complete

removal of affected dentin and step-wise excavation (7), and supported concepts such as the exclusive use of hand instruments (8).

Hand instrumenting is a more effective and efficient method than rotating equipment to remove caries in cavitated lesions in primary teeth and is less likely to lead to over-preparation of the dentin (9-11). Removing only the infected tissue, local anesthesia is seldom required and dental anxiety in children is reduced (12-14). In this way, ART is not only less traumatic to the patient (15) but also to the tooth structures (9, 10).

### **ART procedure**

*Caries removal:* Firstly, it is important to remove food debris, which can easily be combined with brushing instructions. If the cavity opening is not large enough for the use of excavators, the enamel must be cut with dental hatchet or enamel access cutters. The infected tissue is removed with sharp excavators. At the enamel/dentin junction, the excavation is done until hard tissue is exposed to allow a good seal of the remaining lesion.

*Cavity restoration:* The restorative material for ART is a high-viscosity GIC and in most of cases. The lack of electricity implies the use of the hand-mixed version. Cavity conditioning with polyacrylic acid is performed using the liquid of the GIC diluted in water for 10-20 seconds. The cavity is then rinsed and dried using cotton pellets. Moisture isolation is achieved using cotton rolls. Proximal cavities are filled after placement of matrix bands and wedges.

*Press finger technique:* The cavity and adjacent pits and fissures are slightly overfilled and the material is pushed into the cavity with a gloved index finger covered with a layer of petroleum jelly. The finger is removed sideways to simultaneously seal the remaining fissures, the excess of the material is removed and the occlusion is checked after the initial setting (3 min). After final adjustments, another layer of petroleum jelly is applied. The patient is asked not to eat for at least one hour.

### **Applications of ART**

Although developed for outreach rural areas in developing countries, ART is also mentioned as a treatment option in modern equipped dental practices (16, 17). Additionally, this technique can be used in special-needs patients, elderly living in nursing homes and patients with high anxiety levels (13, 18).

Occlusal cavities are, without doubt, the best indication for ART restorations using high-viscosity GIC. The results of meta-analyses show significantly higher survival rates in occlusal cavities for ART restorations made with GIC than for conventionally prepared amalgam restorations (19-22). The survival rates of occlusal-ART restorations in primary and permanent molars after three years are generally 85% or higher while for the proximal-ART restorations this percentage drops to 49% (22, 23).

ART may also be applied in anterior teeth but the appearance of GIC is not as good as that of a resin-based material and it is not the first option for permanent teeth of patients with aesthetical requirements (17). The low wear-resistance of GIC leads to a roughening of the surface and discoloration develops in time. In cervical lesions, though,

GICs are preferred above composites as far as aesthetics is not a priority, as they present better retention (24). ART has been used to treat cervical lesions in elderly patients living in nursing homes (25, 26), and Lo *et al.* (25, 26) reported no difference in success rate after one year between the conventional approach using drill and resin-modified GIC (91.7%) and the ART approach with high-viscosity GIC (87%).

The performance of GIC in multiple-surface or proximal preparations is considered not good enough as a long-lasting restoration in permanent teeth, neither with the conventional nor the ART technique (27, 28). For the primary dentition, amalgam proximal restorations did not seem to survive longer than GIC with ART (29, 30). An “imperfect” ART restoration, however, might be effective in the control of progression of carious lesions and avoid extractions of primary teeth until they naturally exfoliate (31, 32).

### **Shortcomings of proximal-ART restorations in primary molars**

There are many factors that may influence the success of proximal-ART restorations in primary molars. Factors such as operator, material, extend of caries removal, isolation method, post-restoration meal, size of the lesion/preparation and cooperation of the patient are related to failures in proximal-ART restorations.

#### *Operator effect*

Even though the application of ART seems to be easy for any dentist, an operator training course is indicated (29). In a recently published meta-analysis, the authors excluded the studies performed by operators who were not dentists, as they supposed the little experience of the non-dentists could influence the results (22). However, the literature shows that ART restorations made by dental students (33) or by dental health workers can have higher survival rates than those performed by dentists (33, 34). Individual characteristics of the operators may be always of influence. Frencken *et al.* (35) found an operator effect in a study comparing the ART approach using GIC with conventional amalgam restorations in spite of the fact that all the dentists had ample experience in applying the ART approach and had followed a training course on ART prior to the study.

Proximal cavities require more caution from the operator than occlusal ones in several aspects, starting with preparation and caries removal, which are both more difficult in cervical areas of proximal cavities. During restoration, contamination with saliva and blood must be avoided. Even when a rubber dam is used, the control of the saliva flow is difficult as the cervical margin lies under the contact point. The restoration technique is also more sensitive as there is an increased risk of lack of adaptation in the cervical area of the cavity and the finger-press technique is hampered by the presence of the matrix band. Another factor is the use of hand-mixed GIC, which may impose an extra variable in addition to the operator (36). When using such an operator-sensitive technique, a comprehensive training course is recommended (34). Knowledge in cariology is essential but most important is to practice the technique under supervision of an experienced operator in order to execute it properly (29).

#### *Caries removal*

Inadequate caries removal may result in insufficient sound dental structure to adhere. The adhesion of GIC to caries-affected dentin is lower than that to sound dentin (37). The insufficient caries removal may also lead to inadequate cavity sealing (38) and fracture of the restorations due to the lack of a strong dentin support. However, partial caries removal is preferable to complete caries removal in deep lesions to avoid pulp exposure (39), which often leads to immediate extraction for the primary dentition when treated under field conditions.

However, partial caries removal is preferable to complete caries removal in deep lesions to avoid pulp exposure, which often imply immediate extraction (39).

#### *Isolation method*

The isolation from blood and/or saliva contamination is a fundamental step for a good adaptation and sealing of the restoration. In a study in the rainforest in Suriname, van Gemert-Schriks *et al.* (40) showed that in more than 30% of the restorations made by experienced dentists there was blood or saliva contamination. However, no difference in success rate was found between the groups with and without contamination. Carvalho *et al.* (41) did not find any improvement on the survival rate using either a rubber dam or cotton rolls as isolation methods for proximal-ART restoration in primary teeth. Kemoli *et al.* (42), however, observed that the use of a rubber dam resulted in a statistically significant higher survival rate, but it is questionable whether this difference is clinically relevant. With a survival rate of 30% after two years in a sample of 804 patients, the significant difference found for the rubber dam group might be not clinically relevant to justify the use of a rubber dam in ART restorations.

#### *Size of the cavity*

The size and position of the cavity will influence the access of excavators to the cavity as well as the direct or indirect view of the operator. Kemoli *et al.* (43) observed that the one-year survival rate of proximal-ART restorations was significantly better for the cavities with mean dimensions between 2 and 3 mm, when compared to smaller or larger sizes. In the smaller cavities it might be more difficult to accomplish an adequate caries removal and material adaptation. On the other hand, the larger ones may have suffered a pulpal injury effect or failed because of bulk fracture of the cement (43).

#### *Post - restoration meal*

After placing the restoration, all patients are instructed not to eat for at least one hour but in practice some of them eat already a few minutes after the restoration is placed, hereby loading the incompletely set cement. Kemoli *et al.* (44) documented the type and consistency of the next meal taken by the children who received proximal-ART restorations. The type and consistency of food were classified as hard, soft or mixture. The children who had a "hard" consistency meal after the placement of the restoration showed a significantly higher failure rate at baseline and also two years later.

#### *Cooperation of the patient*

During the treatment, the cooperation of the patient is important and may influence the success of the final restoration, regardless of the technique. Studies show that the acceptance of the ART in child- and adult-populations is high, and is attributed to the absence of anesthesia and drilling, which increases comfort for the patient (15, 45). Although ART may be more acceptable than conventional treatment, the low survival rates for ART restorations in proximal cavities may lead to higher frequency of dental treatment and to eventual pain experience, in case caries progression occurs in the tooth with a failed restoration.

#### *Material*

The main failures of proximal-ART restorations are their partial and total loss, which are frequently attributed to the GIC (40, 46-48). The mechanical properties and, in particular, the poor fracture resistance of the GIC have led to the conclusion that a stronger and more durable material would be beneficial to the success rate of the proximal-ART restorations (46, 47, 49). However, there is no evidence that materials such as glass carbomer cement, resin composite and amalgam used in field conditions will perform better than GIC in proximal-ART restorations (30, 46, 47, 49, 50).

The high-viscosity of the material and the use of hand instruments instead of burs challenge the insertion of the GIC in the deepest site of the cavity. Two studies showed that more than two-thirds of the restorations had a cervical gap on bite-wing radiographs (51, 52). Another study (38) showed that most of the restorations with a cervical gap at baseline ended up having secondary caries adjacent to them.

All these limitations of the proximal-ART restorations cannot individually explain the high failure rate of these restorations. A combination of these variables is most likely a better explanation and for each operator a different combination can be found. ART is not the ideal method for proximal cavities; however, no other alternative and accessible restorative treatment has yet shown better results in field studies. The need for restoring these cavities is, most of the times, essential to allow removal of dental plaque and, in this way, control the caries increment. In this thesis the focus is on the material of choice for ART, the glass-ionomer cements, its properties and possible modifications.

### **Glass-ionomer cements**

GICs were developed in the 1970s by combining the benefits of two existing materials: polycarboxylate cement and silicate cement (53). The main advantages of the GICs are the chemical bonding to the enamel and dentin allowing a proper seal of the cavity and the sustained release of fluoride. Other advantages of the conventional GICs are their biocompatibility with dental structures, an insignificant shrinkage during the setting reaction, a linear coefficient of thermal expansion similar to tooth structures and a low thermal conductivity. Disadvantages of the GICs include a long setting reaction, a low wear resistance and a relatively low compressive and tensile strength, in particular during the first 24 hours. These characteristics exclude the GICs as the first choice of restorative material for multi-surface restorations, such as the proximal ones (54).



GICs are available in hand-mixed and encapsulated systems. As with any material presented in a powder and liquid form, the powder/liquid ratio determines the properties of the GIC. By encapsulating the material, the operator variability is reduced as the powder/liquid proportion is pre-determined by the manufacturer and the mixing is mechanically driven (36). The GIC is subsequently injected in the cavity allowing a better adaptation. The composition of the powder is generally based on fluoroaluminosilicate glass, sodium and silica. The liquid is composed of weak organic acids with a high molecular weight, usually an aqueous solution of polyacrylic acid, maleic acid and itaconic acid (55). These acids may also be incorporated into the powder in a freeze-dried form. The chemical setting reaction starts in the presence of water, when after dissociation of the acids, the hydrogen ions attack the glass particles releasing calcium, strontium, aluminium, sodium and fluoride. This acid-base reaction results in a poly-acid salts matrix. The poly-acids are responsible for the adherence to dental structures under wet conditions (56).

Adhesion is a result of an ion exchange between the GIC and some dental structures, which is mainly represented by the reaction of the carboxyl group from the acid with the calcium ions from the tooth (chelation). After two- to four-minutes, the initial setting is finished and the material loses its glossy appearance. This is an indication that most of the carboxyl groups have reacted with the powder particles. In this initial stage, the material is very sensitive to water sorption and the uptake of water will result in weakening of the surface. The second stage lasts 24 to 48 hours and is a slower continuation of the acid-base reaction, involving the release of calcium and aluminium cations within the matrix. During this stage the material is very susceptible to dehydration. The water evaporation in this stage would lower the mechanical properties of the material. To reduce this water sensitivity it is imperative to protect the GIC surface during its setting reaction.

In the search for improved mechanical properties of the GIC, the conventional GIC has been modified. The so-called metal-modified GIC contains amalgam alloy, silver, stainless steel or even gold particles fused to (Cermets, such as Ketac Silver, 3M Espe) or mixed with (Miracle Mix, GC Europe) the glass particles (57, 58). Although supposed to perform better than conventional GIC, the literature does not always support these "additions" (59). Another significant modification was the addition of metacrylate groups, giving rise to the resin-modified GIC (60). This modification allowed a better working- and setting-time as these materials are based on a dual-cure setting reaction (61). The resin-modified GIC is frequently used as a liner in combination with a resin composite or amalgam restoration. However, the addition of a hydrophilic monomer (HEMA) has a negative effect on biocompatibility.

Glass ionomers have a relatively low cost compared to resin composites, and they are technically less sensitive. These characteristics make them an accessible material to the world population. Associating the low cost with the adhesive auto-setting reaction and the potential effect of inducing remineralisation, the GIC became the material of choice for use in the ART (59). Moreover, conventional GICs contain fewer components that can cause allergic reactions when compared to resin composites or resin-modified GIC (62).

### **High-viscosity glass-ionomer cements**

The restorations made with ART are intended to be long lasting and the restorative material of choice should be able to withstand masticatory forces (63). Specially developed for the ART technique, the high-viscosity GICs are the ideal material for clinical conditions when optimal saliva isolation cannot be achieved (64-66). To increase the concentration of glass in the matrix, the size of the glass particles was reduced, allowing some degree of packability and improving mechanical properties (59). On the other hand, the higher powder/liquid ratio raised the viscosity of the GIC, reducing wettability. This less-fluid consistency may have a negative effect in the adaptation, bonding and the retention of the restoration.

### **Mechanical properties**

Better mechanical properties of the high-viscosity GIC improved the ART restoration survival rate (20) but its fracture strength and early-wear rates remained unsatisfactory compared to amalgam and resin composite materials (27). The setting reaction is shortened because of the higher powder concentration but it is still a long-term reaction, which makes it a sensitive material in particular during the first 24 hours, a period in which the material is prone to dissolution (65). This might result in lower strength of the surface and as a consequence, in low early wear resistance and flexural strength. To avoid the consequences of water sensitivity during the setting reaction, it is recommended to protect the GIC's surface. Petroleum jelly is the most used coat but copal cavity varnish, light-cured bonding resins, cocoa butter or even nail varnish can also be used (67-70).

The brittleness of the material and the fact that it is prone to dehydration and erosion must be considered when performing mechanical tests. The bond strength tests for GICs, for example, cannot always express the interface bond strength as they frequently report cohesive failures within the material, limiting the results to the material strength (71-74).

### **Adhesion to dental structures**

The adhesion of GIC to hard dental tissues appears to be mainly of a chemical nature (3). In addition to this chemical bonding, a mechanical interlocking of the cement in dentinal tubules is reported (73, 75). The chemical adhesion is formed through ionic and polar attractions between hydroxyapatite and polycarboxylate radicals in a way that the latter displace the phosphate and calcium ions from the former, maintaining the electrical neutrality (76) and promoting the chemical bond. This interaction layer is also considered to be beneficial in reducing the hydrolytic degradation of the bonding interface and consequently, enhancing the restoration longevity (77).

The bond strength may be influenced by two factors: the morphology of the adherent and the surface treatment. The presence of contaminant agents can interfere in the surface energy and therefore, reduce the wettability (78). In this way, the dentin pre-treatment with polyacrylic acid is indicated to increase the bond efficiency of the GIC. The acid produces a superficial cleaning and a partial demineralisation, which creates micro-

porosities and enhances the possibility of chemical and micromechanical interaction with the hydroxyapatite (73, 76).

The polyacrylic acid used in the pre treatment is a weak acid with high molecular weight. The high molecular weight gives a high viscous consistency to this acid, which hinders its penetration into the dentinal tubules, and is not harmful to the pulp structures. This is one of the characteristics that classifies the GIC as a biocompatible material. The chemical adhesion itself also improves the biocompatibility of this material. During the setting reaction of the GIC, when polycarboxylate radicals meet calcium ions from the tooth structures, there is a salt deposition at the dentin-GIC interface. This deposition may help promoting a good sealing and preventing bacterial invasion at the interface between tooth and restoration (79).

### **Fluoride release**

The long term and continuous fluoride release is considered to be one of the greatest assets of the GIC. The highest release occurs in the first hours after placement and is due to the slow setting reaction of the material, when a large amount of ionically active elements is released (80). Because of the possibility of recharging fluoride from the environment, the fluoride release may continue thereafter. Although studies show that the fluoride release from GIC is low and clinically insignificant (81-83), others found a preventive effect including hypermineralisation of the adjacent dentin (84, 85) and remineralisation of incipient enamel lesions (86).

### **Indications and limitations of GIC**

The GICs have a wide variety of applications. They can be used as fissure sealant, cavity liner, bonding agent, endodontic sealer, restorative material, and luting cement for prosthetics and orthodontics.

In field situations, GICs are certainly the material of choice for fissure sealing. The retention rate of fissure sealants made in a dental practice setting is showed to be higher for resin-based materials (87, 88) but under field conditions, GIC performs better or similarly to resin-based materials (89, 90). The best indication for GIC sealants is during tooth eruption, when the tooth cannot be satisfactory isolated by the use of a rubber dam. The advantage of GIC sealants is that the material may remain in the bottom of the fissure for a long time, even when the sealant is partially broken or appears to be completely lost (91, 92). Studies investigating the caries preventive effect of resin-based and GIC sealants are inconclusive as to whether one is better than the other (20, 88, 89, 93-95).

As restorative material, GICs are particularly used in paediatric dentistry. Occlusal restorations in the primary dentition made with high-viscosity GICs show lower failure rates than the ones made with amalgam (19-22). Also in proximal restorations, the high-viscosity GICs show a good survival up to three years when made under optimal clinical conditions, in permanent (27, 28) and primary teeth (63, 96). In the primary dentition, Marks *et al.* (96) reported 92% survival after 12 months using a hand-mixed material, while Rutar *et al.* (63) observed 93% survival after two years using an encapsulated one; both studies were conducted in proximal cavities under optimal clinical conditions. On the other hand, the

survival rates of proximal restorations made with GIC in a field setting vary from 76.1% after two years to 12.2% after three years (40, 49).

In the permanent dentition, Zanata *et al.* reported good survival over a ten-year period for occlusal ART restorations performed under clinical conditions, but the success for proximal cavities decreased significantly from two- (87%) to ten-year (31%) periods (28). Another indication for GIC as a restorative material is in cervical lesions. The fluoride release and adhesive qualities of the GIC make them the most effective and durable in bonding to cervical lesions, fulfilling all the requirements of the guidelines for dentin and enamel adhesive materials established by the American Dental Association (24).

The GICs used as a liner and luting agent are generally the resin-modified ones. The liners are used in combination with an amalgam or resin composite restoration with the aim of protecting the pulp against acids used for etching prior to the application of a resin-bonding agent, or against the thermal conduction of amalgam restorations. Because of its biocompatibility, conventional GIC can be used in deep carious lesions as a protection layer for the pulp tissues. A GIC liner can also be applied in the so-called "open sandwich" technique (97). The "open sandwich" technique is recommended in circumstances where the cervical area of the cavity is difficult to isolate from the exudation of gingival crevicular fluid or blood. In these cases, the use of an adhesive and fluoride releasing material in the cervical area, such as the GIC, is indicated to prevent secondary caries formation (98). However, on the long term, a liner of GIC may have a negative effect on the fracture resistance of the composite restoration (99).

The development and diffusion of the ART approach has stimulated dentistry manufacturers to expand the number of GICs indicated for ART. Although several brands are available, most of the long-term follow-up studies use the most well known materials; the ones presenting better mechanical properties in laboratory experiments and also the most expensive ones (44, 48, 100, 101). It is of interest to study new and less established GIC brands in laboratory and clinical studies and verify if they may be applicable to proximal cavities made in isolated and rural areas of developing countries. In these areas where often no other option of restorative dental treatment is available, the costs of the materials and the high-carries activity of the population must be considered when choosing both restorative approach and material.

### **Aim and outline of the thesis**

The laboratory and clinical studies in this thesis evaluated the influence of GICs indicated for ART on the longevity of Class II or proximal-ART restorations. We explored different brands, a new nano-filled resin coating and a new insertion technique to improve material adaptation, aiming to increase the longevity of this type of restorations.

Many brands of high-viscosity GIC have been developed and marketed for the use with ART, but only few of them have been tested in clinical trials (8, 46, 47, 49, 50). In order to choose the materials to be tested in a clinical trial, the physical-mechanical properties of GICs indicated for ART were investigated (**chapter 2**). A laboratory study evaluated the wear resistance, knoop hardness, flexural and compressive strength of six GICs indicated for ART. From this study, three GICs were selected for a clinical trial based on their composition, price and mechanical properties. The effect of GIC brand on the survival rate

of proximal-ART restorations in primary molars is described in **chapter 3**. This study was conducted in Itatiba (in the southeast of Brazil) and considered not only the survival of the restorations but also the survival of the tooth.

During the evaluation period of this clinical study, we observed a high failure rate of the restorations and an alternative method to improve the survival rate of proximal-ART restorations was desired. Searching for a better marginal adaptation of ART restorations, we performed a laboratory study using a flowable GIC as a liner (two-layer insertion technique). **Chapter 4** describes the material adaptation and the microleakage of this new insertion technique.

Because of the promising laboratory findings, the two-layer technique was clinically applied in the cavities that resulted from a complete loss of the restoration from the previous trial (described in **chapter 2**). As inserting the GIC in two layers with two different consistencies is a laborious procedure, we investigated the operator effect on the survival rate of proximal-ART restorations using this two-layer technique in primary molars (**chapter 5**).

We speculated that the good results of the flowable layer as liner could be also originated from an improved bond strength of the flowable GIC to tooth structures. This could result from its better adaptation and a higher concentration of polyacrylic acid available. **Chapter 6** describes the results of a microtensile bond strength test of this flowable glass-ionomer cement layer bonding to sound and caries-affected dentin of primary teeth.

To confirm the validity of our results in the previous bond strength test, we evaluated different micro-mechanical bond strength tests for the assessment of the adhesion of GIC to the dentin. We submitted different GIC-based materials to microtensile and microshear bond strength tests in order to assess their ranking as well as their failure pattern (**chapter 7**).

Concluding from the previous study that microshear bond strength tests seemed to better represent the clinical behaviour of brittle materials such as the GIC, we investigated the microshear bond strength of flowable GIC to sound and caries-affected dentin (**chapter 8**).

To evaluate the mechanical properties and stress distribution of the two-layered GIC, a three-point-bending test was performed and a Finite Element Analysis was used to interpret the results. This study is described in **chapter 9**.

To draw a preliminary conclusion as to whether the two-layer technique compared favourably to the conventional insertion technique of GIC in proximal-ART restorations, it was necessary to compare it with a conventional one-layer technique. The 18-month results of a randomised controlled clinical trial are described in **chapter 10**.

As most of the drawbacks of the GICs are related to their low mechanical properties in the first hours and the highest failure rates of ART restorations are reported in the first six months, improving the early mechanical properties of the material may help in improving restoration survival. We used a nano-filled resin (G-Coat Plus) to protect the surface of a GIC (**chapter 11**). It is assumed that such a layer protects the GIC during its slow- and long-setting period. This chapter investigates the flexural strength and the early wear resistance of a high-viscosity GIC coated and uncoated with a nano-filler-containing fluid resin.

## References

1. Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry--a review. FDI Commission Project 1-97. *Int Dent J.* 2000 Feb;50(1):1-12.
2. Frencken JE, Pilot T, Songpaisan Y, Phantumvanit P. Atraumatic restorative treatment (ART): rationale, technique, and development. *J Public Health Dent.* 1996;56(3 Spec No):135-40.
3. Frencken JE, van Amerongen WE. The atraumatic restorative treatment approach. In: Fejerskov O, Kidd E, editor. *Dental caries: the disease and its clinical management.* Oxford: Blackwell Munksgaard; 2008. p. 427-42.
4. Smales RJ, Yip HK. The atraumatic restorative treatment (ART) approach for primary teeth: review of literature. *Pediatr Dent.* 2000 Jul-Aug;22(4):294-8.
5. Frencken JE. Evolution of the the ART approach: highlights and achievements. *J Appl Oral Sci.* 2009;17 Suppl:78-83.
6. Frencken JE, Songpaisan Y, Phantumvanit P, Pilot T. An atraumatic restorative treatment (ART) technique: evaluation after one year. *Int Dent J.* 1994 Oct;44(5):460-4.
7. Massara ML, Alves JB, Brandao PR. Atraumatic restorative treatment: clinical, ultrastructural and chemical analysis. *Caries Res.* 2002 Nov-Dec;36(6):430-6.
8. Molina GF, Cabral RJ, Frencken JE. The ART approach: clinical aspects reviewed. *J Appl Oral Sci.* 2009;17 Suppl:89-98.
9. Celiberti P, Francescut P, Lussi A. Performance of four dentine excavation methods in deciduous teeth. *Caries Res.* 2006;40(2):117-23.
10. Lenters M, van Amerongen WE, Mandari GJ. Iatrogenic damage to the adjacent surfaces of primary molars, in three different ways of cavity preparation. *Eur Arch Paediatr Dent.* 2006 Mar;7(1):6-10.
11. Rahimtoola S, van Amerongen E. Comparison of two tooth-saving preparation techniques for one-surface cavities. *ASDC J Dent Child.* 2002 Jan-Apr;69(1):16-26, 11.
12. van Bochove JA, van Amerongen WE. The influence of restorative treatment approaches and the use of local analgesia, on the children's discomfort. *Eur Arch Paediatr Dent.* 2006 Mar;7(1):11-6.
13. Rahimtoola S, van Amerongen E, Maher R, Groen H. Pain related to different ways of minimal intervention in the treatment of small caries lesions. *ASDC J Dent Child.* 2000 Mar-Apr;67(2):123-7, 83.
14. de Menezes Abreu DM, Leal SC, Mulder J, Frencken JE. Dental anxiety in 6-7-year-old children treated in accordance with conventional restorative treatment, ART and ultra-conservative treatment protocols. *Acta Odontol Scand.* 2011 Nov;69(6):410-6.
15. Schriks MC, van Amerongen WE. Atraumatic perspectives of ART: psychological and physiological aspects of treatment with and without rotary instruments. *Community Dent Oral Epidemiol.* 2003 Feb;31(1):15-20.
16. Seale NS, Casamassimo PS. Access to dental care for children in the United States: a survey of general practitioners. *J Am Dent Assoc.* 2003 Dec;134(12):1630-40.

17. Burke FJ, McHugh S, Shaw L, Hosey MT, Macpherson L, Delargy S, et al. UK dentists' attitudes and behaviour towards Atraumatic Restorative Treatment for primary teeth. *Br Dent J*. 2005 Sep 24;199(6):365-9.
18. Carvalho TS, Ribeiro TR, Bonecker M, Pinheiro EC, Colares V. The atraumatic restorative treatment approach: an "atraumatic" alternative. *Med Oral Patol Oral Cir Bucal*. 2009 Dec;14(12):e668-73.
19. Frencken JE, Van 't Hof MA, Van Amerongen WE, Holmgren CJ. Effectiveness of single-surface ART restorations in the permanent dentition: a meta-analysis. *J Dent Res*. 2004 Feb;83(2):120-3.
20. van 't Hof MA, Frencken JE, van Palenstein Helderma WH, Holmgren CJ. The atraumatic restorative treatment (ART) approach for managing dental caries: a meta-analysis. *Int Dent J*. 2006 Dec;56(6):345-51.
21. Mickenautsch S, Yengopal V, Banerjee A. Atraumatic restorative treatment versus amalgam restoration longevity: a systematic review. *Clin Oral Investig*. 2010 Jun;14(3):233-40.
22. de Amorim RG, Leal SC, Frencken JE. Survival of atraumatic restorative treatment (ART) sealants and restorations: a meta-analysis. *Clin Oral Investig*. 2012 Apr;16(2):429-41.
23. de Amorim RG, Figueiredo MJ, Leal SC, Mulder J, Frencken JE. Caries experience in a child population in a deprived area of Brazil, using ICDAS II. *Clin Oral Investig*. 2012 Apr;16(2):513-20.
24. Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. *Dent Mater*. 2005 Sep;21(9):864-81.
25. Pilot T. Introduction--ART from a global perspective. *Community Dent Oral Epidemiol*. 1999 Dec;27(6):421-2.
26. Lo EC, Luo Y, Tan HP, Dyson JE, Corbet EF. ART and conventional root restorations in elders after 12 months. *J Dent Res*. 2006 Oct;85(10):929-32.
27. Scholtanus JD, Huysmans MC. Clinical failure of class-II restorations of a highly viscous glass-ionomer material over a 6-year period: a retrospective study. *J Dent*. 2007 Feb;35(2):156-62.
28. Zanata RL, Fagundes TC, Freitas MC, Lauris JR, Navarro MF. Ten-year survival of ART restorations in permanent posterior teeth. *Clin Oral Investig*. 2011 Apr;15(2):265-71.
29. Taifour D, Frencken JE, Beiruti N, van 't Hof MA, Truin GJ. Effectiveness of glass-ionomer (ART) and amalgam restorations in the deciduous dentition: results after 3 years. *Caries Res*. 2002 Nov-Dec;36(6):437-44.
30. Honkala E, Behbehani J, Ibricevic H, Kerosuo E, Al-Jame G. The atraumatic restorative treatment (ART) approach to restoring primary teeth in a standard dental clinic. *Int J Paediatr Dent*. 2003 May;13(3):172-9.
31. Mallow PK, Durward CS, Klaipo M. Restoration of permanent teeth in young rural children in Cambodia using the atraumatic restorative treatment (ART) technique and Fuji II glass ionomer cement. *Int J Paediatr Dent*. 1998 Mar;8(1):35-40.

32. Bonifacio CC, Hesse D, Raggio DP, Bönecker M, van Loveren C, van Amerongen WE. The effect of GIC-brand on the survival rate of proximal-ART restorations. *Int J of Paediatr Dent*. 2012;(in press)
33. van den Dungen GM, Huddleston Slater AE, van Amerongen WE. [ART or conventional restorations? A final evaluation of proximal restorations in deciduous molars]. *Ned Tijdschr Tandheelkd*. 2004 Sep;111(9):345-9.
34. Kemoli AM, van Amerongen WE, Opinya G. Influence of the experience of operator and assistant on the survival rate of proximal ART restorations: two-year results. *Eur Arch Paediatr Dent*. 2009 Dec;10(4):227-32.
35. Frencken JE, van't Hof MA, Taifour D, Al-Zaher I. Effectiveness of ART and traditional amalgam approach in restoring single-surface cavities in posterior teeth of permanent dentitions in school children after 6.3 years. *Community Dent Oral Epidemiol*. 2007 Jun;35(3):207-14.
36. Dowling AH, Fleming GJ. Are encapsulated anterior glass-ionomer restoratives better than their hand-mixed equivalents? *J Dent*. 2009 Feb;37(2):133-40.
37. Palma-Dibb RG, de Castro CG, Ramos RP, Chimello DT, Chinelatti MA. Bond strength of glass-ionomer cements to caries-affected dentin. *J Adhes Dent*. 2003 Spring;5(1):57-62.
38. Kemoli AM, Amerongen WE. Effects of oral hygiene, residual caries and cervical Marginal-gaps on the survival of proximal atraumatic restorative treatment approach restorations. *Contemp Clin Dent*. 2011 Oct;2(4):318-23.
39. Ricketts DN, Kidd EA, Innes N, Clarkson J. Complete or ultraconservative removal of decayed tissue in unfilled teeth. *Cochrane Database Syst Rev*. 2006(3):CD003808.
40. van Gemert-Schriks MC, van Amerongen WE, ten Cate JM, Aartman IH. Three-year survival of single- and two-surface ART restorations in a high-caries child population. *Clin Oral Investig*. 2007 Dec;11(4):337-43.
41. Carvalho TS, Sampaio FC, Diniz A, Bonecker M, Van Amerongen WE. Two years survival rate of Class II ART restorations in primary molars using two ways to avoid saliva contamination. *Int J Paediatr Dent*. 2010 Nov;20(6):419-25.
42. Kemoli AM, van Amerongen WE, Opinya GN. Short communication: Influence of different isolation methods on the survival of proximal ART restorations in primary molars after two years. *Eur Arch Paediatr Dent*. 2010 Jun;11(3):136-9.
43. Kemoli AM, van Amerongen WE. Influence of the cavity-size on the survival rate of proximal ART restorations in primary molars. *Int J Paediatr Dent*. 2009 Nov;19(6):423-30.
44. Kemoli AM, Opinya GN, van Amerongen WE, Mwalili SM. Two-year survival rates of proximal atraumatic restorative treatment restorations in relation to glass ionomer cements and Postrestoration meals consumed. *Pediatr Dent*. 2011 May-Jun;33(3):246-51.
45. de Menezes Abreu DM, Leal SC, Mulder J, Frencken JE. Pain experience after conventional, atraumatic, and ultraconservative restorative treatments in 6- to 7-year-old children. *Eur J Oral Sci*. 2011 Apr;119(2):163-8.



46. Eden E, Topaloglu-Ak A, Frencken JE, van't Hof M. Survival of self-etch adhesive Class II composite restorations using ART and conventional cavity preparations in primary molars. *Am J Dent*. 2006 Dec;19(6):359-63.
47. Topaloglu-Ak A, Eden E, Frencken JE, Oncag O. Two years survival rate of class II composite resin restorations prepared by ART with and without a chemomechanical caries removal gel in primary molars. *Clin Oral Investig*. 2009 Sep;13(3):325-32.
48. da Franca C, Colares V, Van Amerongen E. Two-year evaluation of the atraumatic restorative treatment approach in primary molars class I and II restorations. *Int J Paediatr Dent*. 2011 Jul;21(4):249-53.
49. Ersin NK, Candan U, Aykut A, Oncag O, Eronat C, Kose T. A clinical evaluation of resin-based composite and glass ionomer cement restorations placed in primary teeth using the ART approach: results at 24 months. *J Am Dent Assoc*. 2006 Nov;137(11):1529-36.
50. Koenraads H, Van der Kroon G, Frencken JE. Compressive strength of two newly developed glass-ionomer materials for use with the Atraumatic Restorative Treatment (ART) approach in class II cavities. *Dent Mater*. 2009 Apr;25(4):551-6.
51. Mhaville RJ, van Amerongen WE, Mandari GJ. Residual caries and marginal integrity in relation to Class II glass ionomer restorations in primary molars. *Eur Arch Paediatr Dent*. 2006 Jun;7(2):81-4.
52. Roeleveld AC, van Amerongen WE, Mandari GJ. Influence of residual caries and cervical gaps on the survival rate of Class II glass ionomer restorations. *Eur Arch Paediatr Dent*. 2006 Jun;7(2):85-91.
53. Wilson AD, Kent BE. A new translucent cement for dentistry. The glass ionomer cement. *Br Dent J*. 1972 Feb 15;132(4):133-5.
54. Buerkle V, Kuehnisch J, Guelmann M, Hickel R. Restoration materials for primary molars-results from a European survey. *J Dent*. 2005 Apr;33(4):275-81.
55. Mjor IA. Biological side effects to materials used in dentistry. *J R Coll Surg Edinb*. 1999 Jun;44(3):146-9.
56. Akinmade AO, Nicholson JW. Effect of adhesive layer thickness on the bond strength of a zinc polycarboxylate dental cement. *Biomaterials*. 1995 Jan;16(2):149-54.
57. Simmons JJ. The miracle mixture. Glass ionomer and alloy powder. *Tex Dent J*. 1983 Oct;100(10):6-12.
58. Williams JA, Billington RW, Pearson GJ. The comparative strengths of commercial glass-ionomer cements with and without metal additions. *Br Dent J*. 1992 Apr 11;172(7):279-82.
59. Sidhu SK. Glass-ionomer cement restorative materials: a sticky subject? *Aust Dent J*. 2011 Jun;56 Suppl 1:23-30.
60. White SN. Light-cured glass ionomers. *J Calif Dent Assoc*. 1994 Aug;22(8):39-40, 2-3.
61. Mathis RS, Ferracane JL. Properties of a glass-ionomer/resin-composite hybrid material. *Dent Mater*. 1989 Sep;5(5):355-8.

62. Goldberg M. In vitro and in vivo studies on the toxicity of dental resin components: a review. *Clin Oral Investig*. 2008 Mar;12(1):1-8.
63. Rutar J, McAllan L, Tyas MJ. Clinical evaluation of a glass ionomer cement in primary molars. *Pediatr Dent*. 2000 Nov-Dec;22(6):486-8.
64. Berg JH. Glass ionomer cements. *Pediatr Dent*. 2002 Sep-Oct;24(5):430-8.
65. van Duinen RN, Kleverlaan CJ, de Gee AJ, Werner A, Feilzer AJ. Early and long-term wear of 'fast-set' conventional glass-ionomer cements. *Dent Mater*. 2005 Aug;21(8):716-20.
66. Peetz R, Frank S. The physical-mechanical performance of the new Ketac Molar Easymix compared to commercially available glass ionomer restoratives. *J Dent*. 2006 Sep;34(8):582-7.
67. Valera VC, Navarro MF, Taga EM, Pascotto RC. Effect of nail varnishes and petroleum jelly combinations on glass ionomer dye uptake. *Am J Dent*. 1997 Oct;10(5):251-3.
68. Cefaly DF, Seabra BG, Tapety CM, Taga EM, Valera F, Navarro MF. Effectiveness of surface protection of resin modified glass ionomer cements evaluated spectrophotometrically. *Oper Dent*. 2001 Jul-Aug;26(4):401-5.
69. Nicholson JW, Czarnecka B. Kinetic studies of the effect of varnish on water loss by glass-ionomer cements. *Dent Mater*. 2007 Dec;23(12):1549-52.
70. Brito CR, Velasco LG, Bonini GA, Imparato JC, Raggio DP. Glass ionomer cement hardness after different materials for surface protection. *J Biomed Mater Res A*. 2010 Apr;93(1):243-6.
71. Hosoya Y, Garcia-Godoy F. Bonding mechanism of Ketac-Molar Aplicap and Fuji IX GP to enamel and dentin. *Am J Dent*. 1998 Oct;11(5):235-9.
72. Pereira PN, Sano H, Ogata M, Zheng L, Nakajima M, Tagami J, et al. Effect of region and dentin perfusion on bond strengths of resin-modified glass ionomer cements. *J Dent*. 2000 Jul;28(5):347-54.
73. Lin A, McIntyre NS, Davidson RD. Studies on the adhesion of glass-ionomer cements to dentin. *J Dent Res*. 1992 Nov;71(11):1836-41.
74. Banomyong D, Palamara JE, Burrow MF, Messer HH. Effect of dentin conditioning on dentin permeability and micro-shear bond strength. *Eur J Oral Sci*. 2007 Dec;115(6):502-9.
75. Mount GJ. Enamel etching and glass-ionomer sealants. *Quintessence Int*. 2000 Apr;31(4):227.
76. Wilson AD, Prosser HJ, Powis DM. Mechanism of adhesion of polyelectrolyte cements to hydroxyapatite. *J Dent Res*. 1983 May;62(5):590-2.
77. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, et al. A critical review of the durability of adhesion to tooth tissue: methods and results. *J Dent Res*. 2005 Feb;84(2):118-32.
78. Tyas MJ. Milestones in adhesion: glass-ionomer cements. *J Adhes Dent*. 2003 Winter;5(4):259-66.
79. Sidhu SK, Schmalz G. The biocompatibility of glass-ionomer cement materials. A status report for the American Journal of Dentistry. *Am J Dent*. 2001 Dec;14(6):387-96.

80. Forsten L, Mount GJ, Knight G. Observations in Australia of the use of glass ionomer cement restorative material. *Aust Dent J*. 1994 Dec;39(6):339-43.
81. Wiegand A, Buchalla W, Attin T. Review on fluoride-releasing restorative materials--fluoride release and uptake characteristics, antibacterial activity and influence on caries formation. *Dent Mater*. 2007 Mar;23(3):343-62.
82. Papagiannoulis L, Kakaboura A, Eliades G. In vivo vs in vitro anticariogenic behavior of glass-ionomer and resin composite restorative materials. *Dent Mater*. 2002 Dec;18(8):561-9.
83. Tyas MJ. Cariostatic effect of glass ionomer cement: a five-year clinical study. *Aust Dent J*. 1991 Jun;36(3):236-9.
84. ten Cate JM, van Duinen RN. Hypermineralization of dentinal lesions adjacent to glass-ionomer cement restorations. *J Dent Res*. 1995 Jun;74(6):1266-71.
85. Guglielmi CA, Mohana A, Hesse D, Lenzi TL, Bonini GC, Raggio DP. Influence of ultrasound or halogen light on microleakage and hardness of enamel adjacent to glass ionomer cement. *Int J Paediatr Dent*. 2012 Mar;22(2):110-5.
86. Takeuti ML, Marquezan M, Rodrigues CR, Rodrigues Filho LE, de O Rocha R. Inhibition of demineralization adjacent to tooth-colored restorations in primary teeth after 2 in vitro challenges. *J Dent Child (Chic)*. 2007 Sep-Dec;74(3):209-14.
87. Locker D, Jokovic A, Kay EJ. Prevention. Part 8: The use of pit and fissure sealants in preventing caries in the permanent dentition of children. *Br Dent J*. 2003 Oct 11;195(7):375-8.
88. Ulusu T, Odabas ME, Tuzuner T, Baygin O, Sillelioglu H, Deveci C, et al. The success rates of a glass ionomer cement and a resin-based fissure sealant placed by fifth-year undergraduate dental students. *Eur Arch Paediatr Dent*. 2012 Apr;13(2):94-7.
89. Beirut N, Frencken JE, van 't Hof MA, van Palenstein Helderma WH. Caries-preventive effect of resin-based and glass ionomer sealants over time: a systematic review. *Community Dent Oral Epidemiol*. 2006 Dec;34(6):403-9.
90. Chen X, Du MQ, Fan MW, Mulder J, Huysmans MC, Frencken JE. Caries-preventive effect of sealants produced with altered glass-ionomer materials, after 2 years. *Dent Mater*. 2012 May;28(5):554-60.
91. Torppa-Saarinen E, Seppa L. Short-term retention of glass-ionomer fissure sealants. *Proc Finn Dent Soc*. 1990;86(2):83-8.
92. Seppa L, Forss H. Resistance of occlusal fissures to demineralization after loss of glass ionomer sealants in vitro. *Pediatr Dent*. 1991 Jan-Feb;13(1):39-42.
93. Beirut N, Frencken JE, van't Hof MA, Taifour D, van Palenstein Helderma WH. Caries-preventive effect of a one-time application of composite resin and glass ionomer sealants after 5 years. *Caries Res*. 2006;40(1):52-9.
94. Yengopal V, Mickenautsch S, Bezerra AC, Leal SC. Caries-preventive effect of glass ionomer and resin-based fissure sealants on permanent teeth: a meta analysis. *J Oral Sci*. 2009 Sep;51(3):373-82.

95. Antonson SA, Antonson DE, Brener S, Crutchfield J, Larumbe J, Michaud C, et al. Twenty-four month clinical evaluation of fissure sealants on partially erupted permanent first molars: glass ionomer versus resin-based sealant. *J Am Dent Assoc.* 2012 Feb;143(2):115-22.
96. Marks LA, van Amerongen WE, Borgmeijer PJ, Groen HJ, Martens LC. Ketac Molar Versus Dyract Class II restorations in primary molars: twelve month clinical results. *ASDC J Dent Child.* 2000 Jan-Feb;67(1):37-41, 8-9.
97. McLean JW, Powis DR, Prosser HJ, Wilson AD. The use of glass-ionomer cements in bonding composite resins to dentine. *Br Dent J.* 1985 Jun 8;158(11):410-4.
98. Tyas MJ. Clinical evaluation of glass-ionomer cement restorations. *J Appl Oral Sci.* 2006;14 Suppl:10-3.
99. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. Longevity and reasons for failure of sandwich and total-etch posterior composite resin restorations. *J Adhes Dent.* 2007 Oct;9(5):469-75.
100. Mickenautsch S, Kopsala J, Rudolph MJ, Ogunbodede EO. Clinical evaluation of the ART approach and materials in peri-urban farm schools of the Johannesburg area. *SADJ.* 2000 Jul;55(7):364-8.
101. Yu C, Gao XJ, Deng DM, Yip HK, Smales RJ. Survival of glass ionomer restorations placed in primary molars using atraumatic restorative treatment (ART) and conventional cavity preparations: 2-year results. *Int Dent J.* 2004 Feb;54(1):42-6.