Original research paper

Microscope observations of ART excavated cavities and restorations

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Summary

This *in vitro* light and scanning electron microscope study examined 39 extracted tooth specimens, hand excavated and restored according to atraumatic restorative treatment (ART), using 'press finger', by 'skilled' and 'novice' operators. Surface features of five excavated cavities, 12 restoration surfaces and the tooth restoration relationships of 22 bisected restored tooth crowns were examined to better understand the clinical effect of the technique. Hand-excavated cavity surfaces were rough with a complex surface arrangement of grooves, crevices, ridges, furrows and overhangs. Enamel and dentine were covered with debris except where surface fractures exposed enamel prisms and occluded dentinal tubules. Ten of the 22 bisected restored specimens had large voids (1-3 mm in length) within the glass-ionomer cement (GIC) restoration or at the tooth-restoration interface. Smaller bubbles (<50 μm) and irregular shaped inclusions were common in all restorations. Adaptation of the GIC to the cavity margin was extremely variable and easily distinguished from the effects of dehydration shrinkage. It is thought that cavity surface irregularities could cause placement problems making it difficult to adapt the GIC to cavity peripheries. While 'press finger' enabled excellent penetration of GIC into fissures, the technique left restoration surfaces rough. At low magnification, surfaces were irregular; at magnifications higher than X500 scratches, pits, porosities, chipping and voids were evident. However, the 'press finger' technique was able to merge the GIC to a fine edge on the occlusal surface so that the restoration margin was not obvious. No apparent difference was found between the restorations placed by the 'skilled' and 'novice' operators. Tooth-restoration relationships in the ART approach are entirely different to those of traditional restorative techniques. The ART approach requires skill, diligence and comprehension to be undertaken correctly.

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Introduction

Atraumatic restorative treatment (ART) has been used as a caries management technique in disadvantaged communities around Johannesburg since 1996.[1] Advantages of ART are that it can be used where clinic-based oral health care is absent and is suitable to treat those apprehensive of conventional restorative dental treatment. Accordingly it has a place in private practice and an increasing number of practitioners are eager to offer ART as a treatment option. The consequent demand for training in ART by dentists and dental therapists in the public and private sectors has prompted the Division of Public Oral Health at the University of the Witwatersrand to run courses on the approach. The course introduces the method rationale, the techniques of hand excavation of caries, filling of the excavated cavity with glass-ionomer cement (GIC) and the 'press finger' technique which spreads excess restorative material into occlusal pits and fissures, thereby sealing the tooth surface. After the lectures and demonstrations the participants are required to restore ten teeth *in vitro* using ART. The course instructor undertakes a clinical assessment of each step of the procedure.

The epidemiology and survival rate of ART in clinical field trials is well described[2] but few laboratory studies have been undertaken to examine aspects of ART which could impact on its clinical success. No description exists of ART cavity structure or of tooth/GIC relationships resulting from this procedure.

This study was done to detail the surface of the hand-excavated tooth cavity and restored tooth using scanning electron microscopy (SEM) and light microscopy (LM) to better understand the clinical effect of the ART approach, assist in teaching the approach and improve clinical outcomes.

Materials and methods

Ethical clearance to collect human teeth for this study was obtained from the Committee for Research on Human Subjects (Medical) of the University of the Witwatersrand, Johannesburg. Extracted teeth with carious lesions suitable for ART were selected from a pool of teeth removed during routine treatment procedures. The teeth were mounted with plaster in round plastic moulds and kept in a humidifier until use. After a lecture and demonstration time lasting 4 hours, course participants were each required to restore ten teeth with Ketac Molar (3M/ESPE, Germany) using ART and 'press finger'. During courses run in the year 2000, 31 restored teeth were selected for further study. The choice of specimens was based on the fact that the teeth were suitably seated in the plaster moulds for easy removal with minimal damage. After removal from the plaster the teeth were allowed to air dry for 24 hours. For examination of the 'press finger' restoration surface, the roots of 12 of the 31 teeth were removed using a hacksaw and the

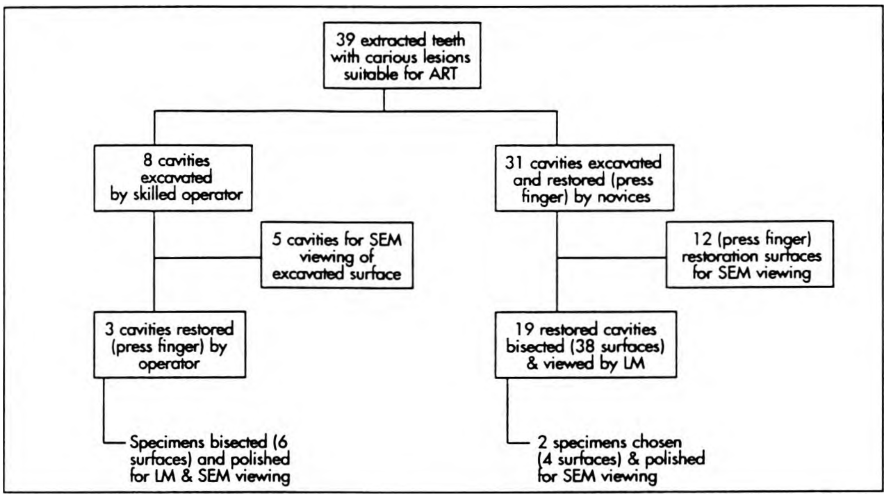

Fig. 1. Flow diagram of specimen numbers and treatments.

crowns mounted on aluminium stubs using double-sided adhesive tape and DAG (Acheson Colloids, UK) with the occlusal surface uppermost. The specimens were then sputter coated (Polaron, UK) with 15 nm of gold palladium for examination of the 'press finger' restoration surface. The remaining 19 restored tooth specimens were processed to allow investigation of the sectioned restoration. The teeth were embedded in a clear resin (a 5:1 mix of Araldite M and HY956 resin (Plastomax, Persequor, South Africa) and allowed to cure at 60°C for 12 hours. Thereafter the teeth were sectioned midway through the restored cavity parallel to the long axis of the tooth using a slow speed, water-cooled, rotary disc saw (Isomet Buehler, USA). The sectioned surface of each specimen was then viewed dry at magnifications of X8 to X40 in incident and transmitted light using a dissecting microscope (Wild M420 Makroskop, Heerbrugg, Switzerland). Two tooth specimens (four halves) were randomly selected for further SEM study, re-embedded in the same resin and polished to facilitate SEM examination. Each sectioned tooth surface was polished (IMP Tech 20 DVT, IMP, South Africa) using a succession of wet silicon carbide papers of grit size 180-2500. Final polishing took place using a diamond paste from 3.0-1.0 μ and DP lubricant (Struers A/S Denmark). In between diamond polishing the surface was cleaned ultrasonically (B-220 Brandson, SmithKline, USA) using alcohol. The polished samples were mounted on aluminium specimen stubs using double-sided adhesive tape and DAG. Thereafter the specimens were sputter coated with gold palladium and viewed in a JEOL 840 scanning electron microscope (JEOL, Japan).

The carious lesions in the remaining eight teeth were hand excavated by a dentist skilled in ART. Five specimens were mounted and sputter coated to permit examination of the excavated cavity surface using SEM. The other three cavities were restored by the 'skilled' dentist according to ART using 'press finger'. These three restored specimens were embedded, sectioned through the restoration, re-embedded and the sectioned surface polished for SEM viewing as described for the 'novice' specimens above, to enable examination of internal restoration features. These sectioned specimens were studied, in addition to the two cavities restored by the 'novice' practitioners, to establish if there were differences between restorations prepared by 'novice' and 'skilled' operators. A flow chart of specimen breakdown and preparation is given in Figure 1.

All features of interest in the excavated cavity and restoration were photographed. In addition aspects of the restored specimens which could impact both positively or negatively on the longevity of the treatment were noted.

Results

Excavated cavity

The shape and size of the ART cavity is determined by the extent of the carious lesion. From the specimens examined it was not possible to define a typical cavity configuration; however all cavities examined in this study encompassed both enamel and dentine (Fig. 2). Crests of unsupported enamel were evident (Fig. 2). The cavity margins did not form a right angle to the tooth surfaces but were generally chipped and indented and followed an irregular course (Fig. 3). Fractured enamel surfaces were evident but generally enamel surfaces were smeared and debris covered, obscuring the enamel prism structure. Cavity shape varied tremendously between specimens and it was not possible to determine the point at which the cavity wall became the cavity floor. At low magnification the excavated cavity surface had a complex surface arrangement: pocketing was evident, as well as grooving, crevicing, ridging and furrowing on both enamel and dentine (Fig. 2). All dentine surfaces were covered or smeared with debris but in some areas the underlying dentine structure was visible showing occluded dentinal

Fig. 2. This cavity surface shows pocketing, grooving, crevicing, ridging and furrowing on both enamel and dentine surfaces. Unsupported enamel is evident (←). Note the chunks of surface debris (circled) and dehydration crack indicating the dentino-enamel junction (dej).

Fig. 3. Chipped and indented cavity margin with fractured (f) and smeared (s) enamel surfaces.

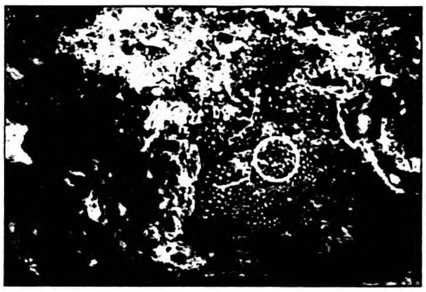

Fig. 4. Some dentine structure is visible showing occluded dentinal tubules (circled) but most of the dentine surface is covered or smeared with debris.

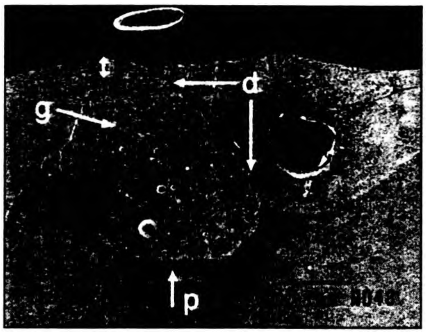

Fig. 5. Poor GIC-cavity adaptation (← p) is evident at the bottom of the cavity but good against one wall (← g). Where dehydration shrinkage has taken place the GIC margin closely follows the contours of the cavity margin (section between arrows d). The thickness of the GIC over the left cusp is around 300 µm (↕). The shallow excavated pit on the right was blocked at its base with an air bubble during restoration leaving a void 1 mm in diameter and preventing GIC adaptation along almost 50% of the cavity interface. Note the numerous bubbles within the GIC.

tubules (Fig. 4). The dentino-enamel junction (dej) was evident as a result of specimen dehydration which caused cracking at that interface. Surface debris hampered the location of the dej in areas with no artefactual cracks. Large pieces of detritus were also present in the cavity despite washing and conditioning with polyacrylic acid as the technique requires.

Sectioned restoration

Twenty-two restored specimens (19 prepared by 'novices', three by the 'skilled' ART practitioner) were sectioned giving 44 surfaces which were examined with the LM. Of those, five specimens (10 sectioned surfaces) were further polished for SEM examination.

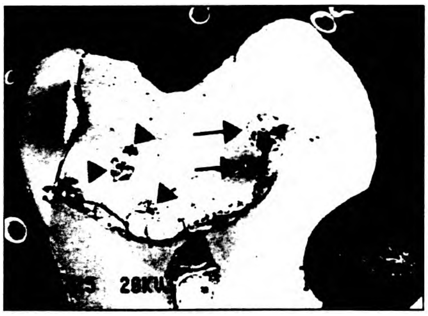

Fig. 6. Voids are apparent within the GIC (arrow heads) and at the GIC-tooth interface (arrows) in this specimen. Such interfacial voids account for 16% of the tooth-GIC interface.

Fig. 7. Strands of cotton wool (c) caught in the bottom of the cavity. Note the unsupported enamel (←) and thick layer of GIC over the cusps.

The most striking feature of the restored cavities were the numerous voids, both large and small, within the GIC and at the tooth-restoration margin. Ten of the 22 restored specimens had large voids both within the restorative material and at the cavity-GIC margin (Figs 5 and 6). Such voids were spherical or irregular with smooth inner margins which indicated that they had formed because of air entrapment (Fig. 5). Interfacial voids prevented adaptation along considerable lengths of the tooth-GIC interface (Figs 5 – 7). All sectioned specimens had bubbles within the GIC which were <50 µm in diameter. Concentrations of bubbles ranged between 100 and 200 within a surface area of 500 μm^2. Irregular-shaped voids and inclusions within the GIC were frequently seen. One of the inclusions was identified as strands of cotton wool (Fig. 7); in another specimen a blue thread was seen. The origin of irregular inclusions in other specimens was more obscure (Fig. 8).

Adaptation of the GIC to the cavity margin was extremely variable, both between specimens and within a single specimen. The GIC remained bonded

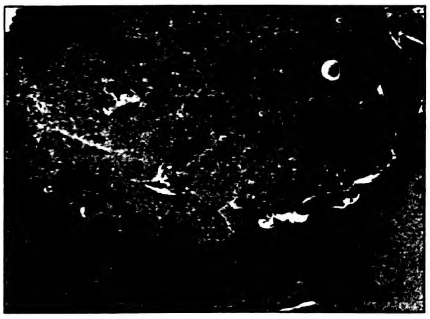

Fig. 8. Higher magnification of Fig. 6. Irregular inclusions within the GIC (← i). Poor GIC-cavity adaptation is visible on the right surface whereas on the left some of the GIC remains bonded to the cavity wall (←). Note the numerous small bubbles within the GIC.

Fig. 9. Note the thin layer of GIC over the cusps (←). Penetration of GIC into fissures seems inadequate at this magnification.

to the cavity surface despite specimen preparation (Fig. 8 – 10) whereas in other specimens adaptation was poor (Fig. 5) or hampered by voids (Fig. 6). It was necessary to define good and poor GIC adaptation to the cavity wall and distinguish it from the effects of specimen dehydration which caused the GIC to shrink, pulling away from the cavity wall in all specimens. Good adaptation was easily recognised in that the GIC margin ran parallel to and replicated exactly the contours of the irregular cavity margin. If adaptation was poor the GIC margin followed a different course to the cavity margin (Fig. 5). There were no obvious differences between the features of novice and skilled prepared ART cavities.

Generally the GIC was seen covering cusps on the occlusal surface indicating that excess restorative material was not well removed from that surface following 'press finger' sealing. The thickness of the GIC could vary from 500 µm (Fig. 7) to a thin layer of 10 µm (Fig. 9). Penetration of GIC into fis-

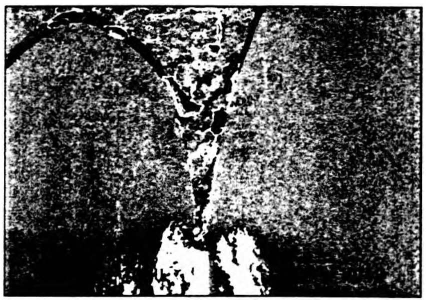

Fig. 10. High power view of Fig. 9. GIC has penetrated to a point where the fissure is 70 μm wide, three quarters down its sectioned length. The material remains bonded to the cavity surface in the base of the fissure despite dehydration shrinkage which has caused a crack within the material at the point where the fissure is 150 μm wide.

sures could be excellent (Figs 9 and 10) although an excavated pit was blocked with an air bubble (Fig. 5) in one specimen.

Restoration surface features

All ART restoration surfaces were rough. Gross roughness took the form of grooves and pits presumably caused by carving. Banked margins, peaks of GIC and rippled surfaces (Fig. 11) were also seen. At magnifications higher than X500 scratches, pits, porosities, chipping and voids were evident (Fig. 12). Restoration margins were not always readily apparent as the 'press finger' technique was able to merge the GIC to a fine edge on the occlusal surface. In other specimens the GIC formed a ridge at the restoration periphery.

Discussion

Hand excavation of carious tooth tissue follows the course of the caries attack, the path of this attack can be extremely tortuous. This results in a cavity surface of partially demineralised tooth structure which is highly irregular, chipped, smeared with debris and scattered with loose detritus. It is not clear how closely this 'smeared layer' is comparable to the 'smear layer' found on bur-cut cavity surfaces where heat denaturation of tooth material is effected.[3] A similar appearance for hand-excavated dentine has previously been described.[4] Such a cavity surface is at variance with the ideal features of cavity preparation which undergraduate students of dentistry are traditionally taught and are deemed essential for favourable clinical outcomes with conventional restorative materials and techniques.

Frencken and Holmgren[5] maintain that partially demineralised, minimally infected inner carious dentine can safely be left behind when using the newer GICs, provided that bonding of restorative material to the tooth surfaces is adequate. The current study has shown that voids preventing interfacial sealing are not uncommon at ART tooth restoration interfaces. Firstly, this could be due in part to cavity surface irregularities which can cause placement problems making it difficult to adapt the GIC to cavity peripheries as a result of an enamel overhang or surface ridge. Secondly, the stiffness of GIC could prevent it from flowing into depressions thereby causing air entrapment. A thorough initial packing of GIC using a plugger, particularly in crevices, appears crucial to prevent voids forming at the irregular cavity interface. Given the presence of cariogenic bacteria remaining in the carious dentine cavity surface, any unsealed interface could result in a focal resurgence of caries activity leading to restoration failure. This should be viewed in the light of consistent reports indicating that GIC may not be as cario-suppressive as previously thought.[6,7]

The threads of cotton wool found within one specimen probably originated from the pellet used for cavity cleansing and drying. This could have snagged on a rough edge of the cavity surface and acted as a plug preventing the GIC from reaching that portion of the cavity. While such inclusions could be caused by carelessness on the part of the operator, others are probably due to the nature of cavity preparation and restorative procedure for ART. Irregular-shaped inclusions incorporated within the restorative material appeared similar to cavity detritus and in one case a dentine chip was identified. At the cavity surface, inclusions could be due to vaseline globules introduced into the restoration surface during the 'press finger' technique. The clinical consequences of the smaller particles of matter introduced within the GIC cannot be assessed whereas the large voids resulting from the cotton threads or trapped air must impact on

Fig. 11. Low power view of the ART restored occlusal tooth surface showing the rough 'press finger' surface. Note that the GIC margin is difficult to follow with ditching (top arrow) and raised ledges (bottom arrow). The cracks in the GIC are dehydration artefacts.

Fig. 12. High magnification micrograph showing the irregular nature of the GIC surface and a large crevice in the centre of the field 300 μm long and 200 μm wide.

stress distribution within the restoration.

The numerous smaller voids found within the GIC were probably due to the incorporation of air bubbles during hand mixing, a phenomenon that has been documented.[8] The presence of such voids in restorative materials have been linked to reduced wear, increased plaque accumulation, reduced strength and poor sealing.[9] Every effort should be made to decrease the size and number of voids formed within ART restorations to improve the clinical outcome.

A conventional restorative approach requires the adaptation of the material to the cavity margin to obtain an integrated and smooth marginal interface. The rough cavity margin which results from hand excavation mitigates against such integration endorsing the use of the 'press finger' technique as a vital step in sealing the ART cavity interface. This is obtained by extending the GIC beyond the cavity margin. An increased benefit is derived by covering and filling adjacent pits and fissures with the restorative material – the restoration-sealant philosophy of the approach. The GIC was well extended into the fissures showing that 'press finger' is eminently suitable to achieve this aim.

Unfortunately the 'press finger' technique in combination with carving of excess material creates a very rough restoration surface. Plaque could accumulate on these surfaces, thereby creating adverse clinical conditions which could prevent the ART restoration from achieving its potential clinical lifespan. Variable roughness will enhance the retention of oral flora.[10] While fluoride within the GIC is known to suppress the metabolic activity of resident microflora its effect on plaque accumulation rate is uncertain.[11] However considering that ART restorations are placed in a potentially caries-prone environment, more attention needs to be focused on the role of rough ART surfaces on the oral health of the patient.

Carving of excess GIC following 'press finger' is considered as the final step in the ART approach. The sectioned specimens showed that in some cases a thick tier of GIC remained over the cusps. This would never be the case in the clinical situation as the bite would always be tested before the patient left the chair. We feel that in this instance the course participants were remiss in not removing the excess satisfactorily.

It could be argued that the many deficiencies seen within the specimens could be due to poor skill and gross technique deficiency as most specimens were prepared by novices. However all course attendees were either private or public dentists or dental therapists who had formal dental training and extensive clinical experience. No difference was found between the restorations placed by the skilled operator and those prepared by the novices. It seems unlikely therefore that the operators who prepared the specimens used in this study were incompetent. The ART approach requires skill, diligence and comprehension to be undertaken correctly and it is a fallacy to regard it as a third-rate option for Third World populations.

It appears from these microscope observations of ART cavities and restorations that tooth-restoration relationships in this approach are entirely different to those of traditional restorative techniques. The unique features of the approach are so at variance with traditional dogma[1,2] that the skills required to obtain a 'good' ART restoration are considerable. The aim of this paper was to describe the ART cavities and restorations to enable those eager to use the approach to gain a better understanding of the uniqueness of the cavity and the consequences of the restorative procedure. Such insights can only culminate in improved ART procedures with enhanced clinical consequences.

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