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ORIGINAL SCIENTIFIC ARTICLE

Dental materials for primary dentition: are they suitable for occlusal restorations? A two-body wear study

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Abstract

Aim This was to evaluate the wear resistance of different materials, compomers, resin-modified glass ionomer cements (RMGICs), glass ionomer cements (GICs), used for posterior restorations in primary teeth and to compare the results with the reference material, amalgam.

Study design Eight specimens of each material were subjected to two-body wear test, using a chewing simulator. The wear region of each material was examined under a profilometer, measuring the vertical loss (μm) and the volume loss (mm^3) of the materials.

Results The results showed significant differences of vertical loss and volume loss of the test materials ($p < 0.001$). Amalgam had the highest wear resistance. Twinky Star (compomer) had the lowest vertical loss and volume loss. There was no significant difference of vertical loss among compomers, Dyract Extra, Dyract Flow and Dyract Posterior. Riva Self Cure (GIC) had no statistically significant difference compared with the compomers (except Twinky Star). No statistically significant difference was found also between Equia (GIC) and Ketac Moral (GIC) with Dyract Extra (Compomer). RMGICs were found to have the lowest wear resistance.

Statistics For the statistical analysis, the PASW 20.0 (SPSS Statistics, IBM, Chicago) package was used. Means and standard deviations were measured with descriptive statistics and analyzed using one-way ANOVA.

Conclusion Compomers and some GICs, that have moderate wear resistance, may be sufficient for occlusal restorations in primary dentitions.

Keywords Wear resistance · Chewing simulator · Compomers · RMGIC · GIC

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Introduction

The restorative materials available for primary teeth range from the traditional amalgam to the newest compomers. Depending on the clinical situations, all these materials can be used for primary teeth restorations (AAPD 2012). The clinical use of amalgam in recent years has been abandoned in some countries, because of parents' demands for tooth-coloured restorations and the introduction of new materials with very promising properties. Nowadays glass ionomer cements (GICs), resin-modified glass ionomer cements (RMGICs), resin composites (RCs) and compomers are recommended for the restorations of the primary teeth.

Glass ionomer cements (GlCs) were introduced in the early 1970s. Several properties of these materials, such as good biocompatibility, chemical adhesion to the mineralized tissue, thermal expansion similar to the dentine, fluoride uptake and release and better tolerance to moisture, make them suitable to be used as primary dentition restorations and are popular among dentists. On the other hand, their poor mechanical properties, such as low fracture strength, "toughness" and wear, make them unsuitable to be used as restorative materials in stress-bearing areas (van Noort 2007). Many manufacturers try to improve the mechanical properties of GICs by reducing porosity of materials, incorporating metallic particles into the matrix and producing a resin coating to protect the material surface from water dehydration or contamination. In the 1980s a new material designated as resin-modified glass ionomer cement was developed. This material aimed to improve the mechanical properties of GICs by incorporating light-cured resin components to the matrix (Lohbauer 2010). RMGICs are considered to be good restorative materials for paediatric dental patients because of the rapid cure (in comparison with the GICs) and the high fluoride release (Lohbauer 2010). The main disadvantage of these materials is the increased water absorption because of the hydrophilic polymer matrix, which can affect their mechanical properties, such as wear resistance (Beriat and Nalbant 2009).

Polyacid-modified resin composites (compomers) were introduced one decade after the RMGICs. These materials combine the aesthetic results from RCs and the adhesion properties and the fluoride release of GICs. Because of their increased wear resistance, compomers can be used in a wider range of applications compared with RMGICs and GICs and have similar clinical indications with RCs. They are considered to be good restorative materials, especially for primary teeth, because of the fluoride release and the higher wear resistance compared to RMGICs and GICs. For this reason, there are compomers available specifically for children. For example, the Twinky Star™ from Voco is available in colours with glitter incorporated that make them more attractive to children (Nicholson 2007).

One important property for a restorative material that can be used for posterior restorations is to be wear resistant. This resistance is a mechanical property that restricts the progressive loss of the material when two surfaces are moving in contact. Attrition or two-body abrasion of the material or tooth surface occurs when the surfaces are in direct contact, without the presence of a further abrasive. Three-body abrasion is caused by the presence of third body (also abrasive), which acts between two antagonistic surfaces (Mair et al. 1996). One of the most important reasons for abrasion wear is the presence of food, acting as a third body between the two surfaces during the mastication cycle. In vivo measurements showed that wear is most likely to be observed at the occlusal contact areas (Mair et al. 1996). Wear resistance of dental materials is difficult to evaluate, although there have been many in vitro and in vivo studies. Because the in vivo studies are time-consuming and difficult to carry out, with a sufficient number of dental patients (Turssi et al. 2003), researchers try to simulate oral environment using laboratory procedures. Several oral simulator devices, with different methods of actuation, have been produced (Heintze 2006).

Low wear resistance is a disadvantage for all of the above types of materials. The aim of the present study was to evaluate the wear resistance of 11 different materials that are used in the primary dentition with a two-body wear simulator device, using amalgam as a reference material. The null hypothesis was that there was no significant difference between the materials.

Materials and methods

Four compomers (com), five GICs, two RMGICs and amalgam were used in the present study (Table 1). Amalgam was used as a reference material as it has a high wear resistance and long-standing clinical success (Heintze 2006). All the above materials are recommended for restorations in primary teeth.

Eight flat specimens for each direct restorative material were fabricated using aluminium holders ($d = 10$ mm, depth = 3 mm, SD Mechatronik, Feldkirchen, Germany). The materials were directly placed in the holders in a layering technique according to manufacturer's instructions. For compomers and RMGICs, each layer was cured using a conventional QTH polymerization device (Elipar TriLight, 3M ESPE, 750 mW/cm^2). The top layer was covered with a clear strip to remove excess material. Then the flat specimens were polished with SiC papers up to 1,000 grit, until they were homogenously finished. After finishing, a resin coat layer was applied on the surface of all GICs (except of ChemFil, because it is not recommended) and light-cured according to manufacturer's instructions. Steatite, a multicomponent semiporous crystalline ceramic material, composed mainly of silica and magnesium oxide and a very small percentage of titanium dioxide, ferric, calcium, potassium, and sodium oxide were used as antagonists. The shape of the steatite was spherical with a diameter of 6 mm to mimic the human molar cusps (Krejci et al. 1993) and have similar wear rates on composite material enamel antagonists (Wassell et al. 1994). The steatite balls were luted in the aluminium holders with a core build-up composite (LuxaCore, DMG, Germany). The specimens were placed in distilled water at 37 °C for 24 h before use.

After 24 h, the specimen and antagonists were mounted in the mastication simulator (SD Mechatronik, Feldkirchen, Germany) (Fig. 1). Five-kilogram weights (corresponding to 50 N) were used in each chamber and the sliding movement was set to 0.7 mm. The frequency of the antagonist movement was 1.7 Hz and each mastication cycle was repeated 120,000 times. During the in vitro mastication process water at 37 °C was used to simulate oral environment and to remove worn particles from the materials' surface. Wear was evaluated using a

Table 1 The type and the composition of the test materials for the restoration of primary teeth

Material	Type	Composition	Shade/batch number
Riva self cure (SDI Limited Victoria, Australia)	GIC	Polyacrylic acid, tartaric acid, fluoro-alumino-silicate glass	A2/B1103213EG
ChemFil *Rock* (Dentsply)	GIC	Polyacrylic acid, iron oxide pigments, titanium, dioxide pigments, tartaric acid, calcium-aluminium-zinc-fluoro-phosphor-silicate glass, water	A2/1005004003
Fuji IX GP (GC)	GIC	Polyacrylic acid, polybasic carboxylic acid, distilled water, alumino-fluoro-silicate glass	A2/1101121
Equia (GC)	GIC	Polyacrylic acid, distilled water, alumino-silicate glass	A2/1111181
Ketac MolarQuick Aplicap (3M, ESPE)	GIC	Polycarboxylic acid, tartaric acid, calcium-lanthanum-aluminium-fluoro-silicate glass, pigments	A2/435558
Twinky Star (VOCO)	Com	Bisphenol-A-glycidyl-methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEG-DMA), butylated hydroxytoluene (BHT) (average filler size: 0.7, filler volume 60.8 %)	Blue/1247255
Dyract posterior (Dentsply)	Com	UDMA, carboxylic acid modified dimethacrylate (TCB Resin), alkanoyl-poly-methacrylate, strontium-fluoro-silicate glass, strontium fluoride, photo initiators, BHT	White opaque/ 1211000507
Dyract flow (Dentsply)	Com	Strontium-alumino-fluoro-silicate glass, highly dispersed silicon dioxide, ammonium salt of dipentaerythritol penta acrylate monosphate (PENTA), N,N-dimethyl aminoethyl methacrylate, carboxylic acid modified methacrylate macromonomers, diethylene glycol dimethacrylate (DGDMA), camphorquinone, ethyl-4-dimethylaminobenzoate, 2-hydroxymethoxybenzophenone, BHT and other stabilisers, iron pigments, titanium dioxide (average filler size: 0.8, filler volume 43 %)	A2/1208000963
Dyract extra (Dentsply)	Com	UDMA, TCB resin, TEG-DMA, trimethacrylate resin, camphorquinone, ethyl-4-dimethylaminobenzoate, BHT, UV stabiliser, strontium-alumino-sodium-fluoro-phosphor-silicate glass, highly dispersed silicon dioxide, strontium fluoride, iron oxide and titanium dioxide pigments (average filler size: 0.8, filler volume 47 %)	A2/1210000141
Ionolux (VOCO)	RMGI	*Powder*: polyacrylic acid, fluoro-silicate glass, amine *Liquid:* HEMA, polyacrylic acid, glycerindimethacrylate, UDMA, BHT	A3/1248222
Fuji II LC (GC)	RMGI	Polyacrylic acid, HEMA, aluminium-fluoro-silicate glass, tartaric acid, water, UDMA, silicone dioxide (average filler size: 1.80)	A3/1210168
Amalgam dispersalloy (Dentsply)		Silver, tin, copper, zinc admixture of lathe-cut rods, silver-copper spheres	121031

high-resolution non-contact profilometer equipped with white light sensors (CyberSCAN CT 100, Cyber Technologies GmbH, Ingolstadt, Germany) that ensure a *z*-resolution of up to 0.2 µm. The mean vertical loss (µm) and mean volume loss (mm^3) of the original samples were measured using the software CHRocodile S 600 (Cyber Technologies). The non-attrition regions of the examined materials were taken as reference plans (Fig. 2a, b).

After wear measurements, the attrition surfaces were examined under a digital light microscope (Stemi SV6, Zeiss, Germany) and photographs of representative samples were taken. The selected samples were used as representative for scanning electron microscopy (SEM) analysis to determine the surface morphologies and the wear patterns. The specimens were mounted on aluminium stubs, sputter-coated with gold and examined under a SEM (Leitz ISI 50, Akashi, Tokyo, Japan) at ×250 magnification.

For the statistical analysis the PASW 20.0 (SPSS Statistics, IBM, Chicago) package was used. Means and standard deviations were measured with descriptive statistics and analysed using one-way ANOVA. Pearson's correlation was used to evaluate the relationship between the vertical and the volume loss.

Results

One-way ANOVA showed significant differences among the test materials (Fig. 3a, b). Table 2 shows the mean vertical loss and mean volume loss of the materials. Amalgam had the lowest vertical and volume loss among all the examined materials. Twinky Star had the highest wear resistance among compomers, GICs and RMGICs. Fuji II LC was found to have the lowest wear resistance. The correlation between vertical loss and volume loss was high ($r = 0.963$, $p < 0.001$).

Fig. 1 Photograph illustrating the oral simulator used in this study

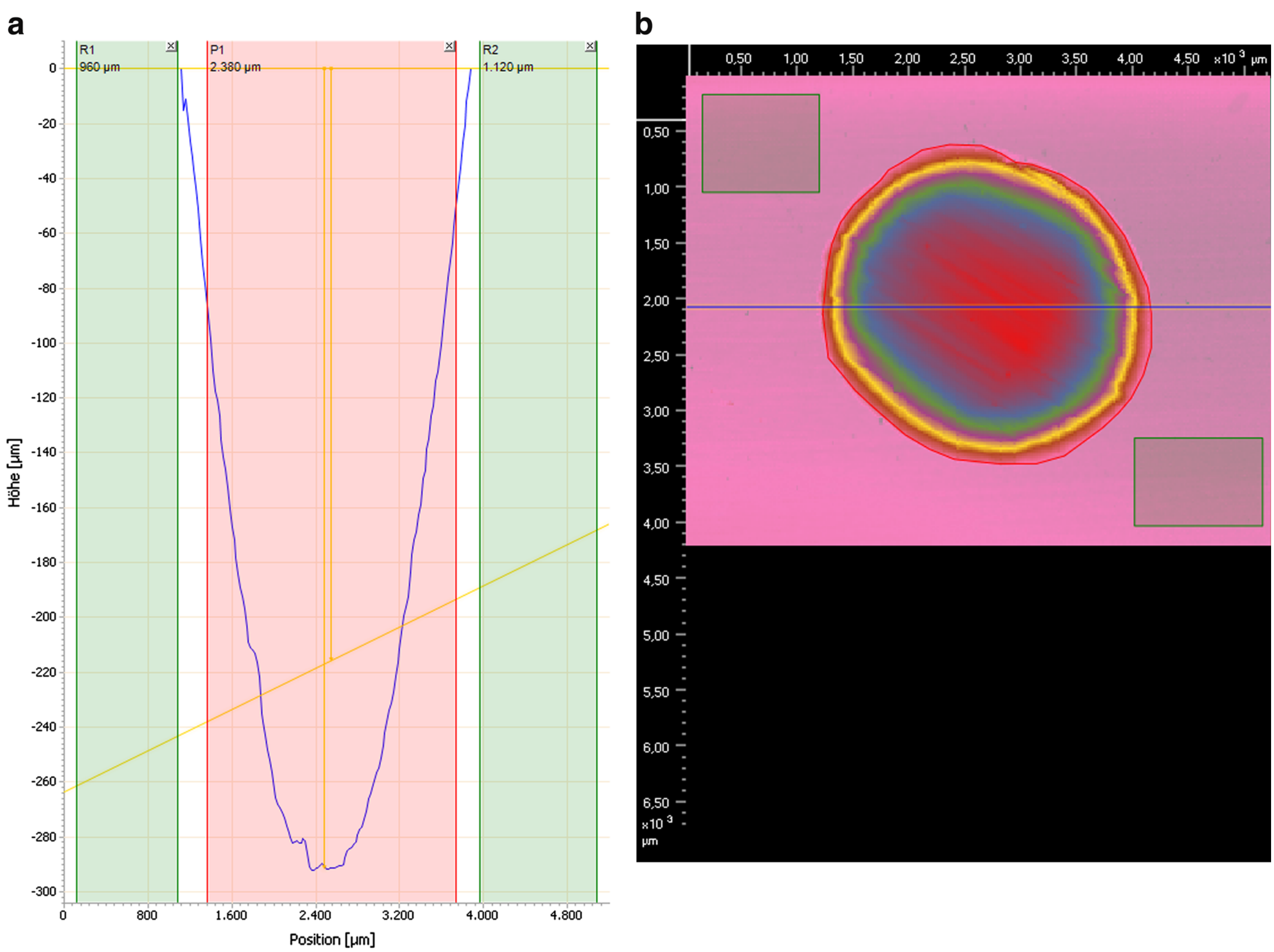

Fig. 2 Measuring **a** the vertical loss of ChemFil and, **b** the volume loss of Dyract extra using a profilometer

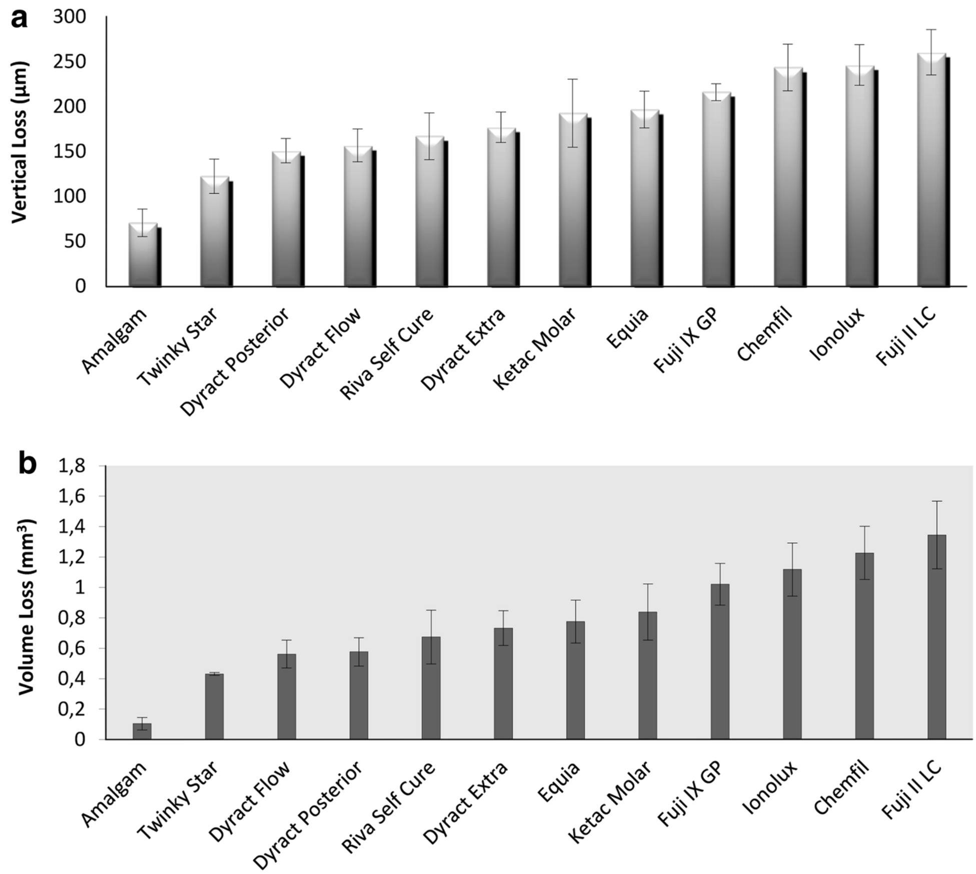

Fig. 3 **a** Graphical presentation of mean vertical loss (μm) and standard deviations of the measured materials, **b** Graphical presentation of mean volume loss (mm^3) and standard deviations of the test restorative materials

Figure 4 shows the attrition region of each material. The wear patterns between compomers and GICs or RMGICs are obviously different. Among compomers, Twinky Star (Fig. 4d) presented a smoother surface with minimal scratches and grooves. Dyract posterior (Fig. 4b) and Dyract extra (Fig. 4a) had a similar appearance; Dyract flow (Fig. 4c) appeared scratched and rougher than the surfaces of the other compomers. GICs (Fig. 4e–i) and RMGICs (Fig. 4j–k) presented similar irregularities on the attrition region which also had voids and cracks. Riva self cure (Fig. 4f) had the smoothest attrition region without intrinsic defects.

Table 2 Mean vertical loss (μm) and volume loss (mm^3) of the measured materials

Material	Type	Mean (sd) vertical loss (μm)	Mean (SD) volume loss (mm^3)
Amalgam		70.55(15.27)a	0.1046(0.041)A
Dyract extra	Compomer	176.92(16.88)c,d,e	0.7325(0.114)C,D
Dyract posterior	Compomer	150.84(13.54)c	0.5760(0.093) B,C
Dyract flow	Compomer	156.75(18.28)c	0.5619(0.091)B,C
Twinky star	Compomer	122.27(19.24)b	0.431(0.01)B
Ketac molar	GIC	192.65(37.83)d,e,f	0.838(0.185)D
Riva self cure	GIC	166.91(26.08)c,d	0.6737(0.177)C,D
Equia	GIC	196.59(20.47)e,f	0.7758(0.141)D
ChemFil	GIC	243.59(26.05)g	1.227(0.175)F,G
Fuji IX	GIC	216.06(9.42)f	1.021(0.138)E
Ionolux	RMGI	246.27(22.55)g	1.118(0.175)E,F
Fuji II LC	RMGI	260.34(25.28)g	1.344(0.223)G

The same superscripted letters in the mean vertical loss (lower-case letters) and in the mean volume loss (upper-case letters) indicate statistically homogenous subsets ($p > 0.05$)

Discussion

Within the limitations of the current study, the null hypothesis that there was no significant difference on wear resistance between the materials was rejected. These results are in accordance with previous studies, which showed that compomers are more wear resistant than GICs and that in turn GICs abrade less than RMGICs (Zantner et al. 2004; Correr et al. 2006). RCs have the highest wear resistance among all the materials (Pelka et al. 1996; Peutzfeldt et al.

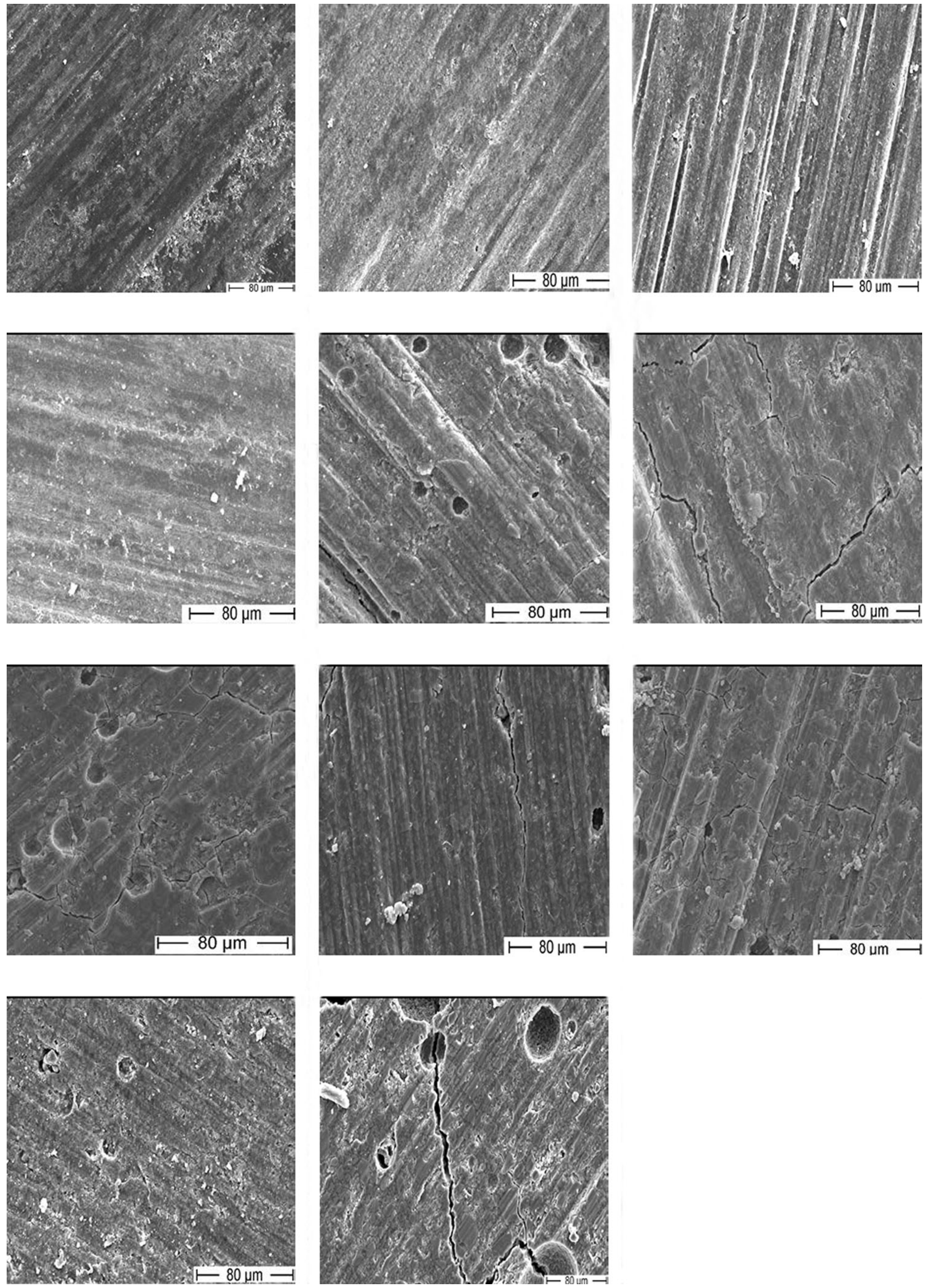

Fig. 4 SEM microphotographs of representative specimens at ×250 tested after 120,000 cycles (*scale bar* 80 μm). From *left to right:* **a** Dyract extra, **b** Dyract posterior, **c** Dyract flow, **d** Twinky star, **e** Ketac Molar, **f** Riva self cure, **g** Equia, **h** ChemFil, **i** Fuji IX, **j** Ionolux, **k** Fuji II LC

1997; Zantner et al. 2004; Correr et al. 2006). These results confirmed previous study in which wear resistance of nine RCs was compared. Only Twinky Star (compomer) showed no statistically significant difference with Filtek Supreme XTE, a nanofilled resin composite with a mean vertical loss of approximately 117 μm. These results are comparable as the same researcher made the procedure following the same method (unpublished data).

The lower wear resistance of compomers compared to RCs could be due to different structures and different polymerization processes. It is well known that compomers undergo both polymerization of monomers and acid–base reaction. The acid–base reaction starts only after the onset of water take-up from the oral environment (Nicholson 2007). The ongoing acid–base reaction results in a carboxylate-rich surface that can lead to a decreased interfacial integrity between the matrix and the filler. The decreased interfacial integrity could lead to wear. The wear of compomers could also increase due to the plasticizing effect of water. Additionally, compomers have a different matrix composition, higher size of filler particles and decreased filler volume compared to RCs (Latta et al. 2001; Correr et al. 2006; van Noort 2007).

Distinctive features that characterise the wear of GICs are void nucleation, crack propagation and detachment of glass particles (Lohbauer 2010). Many factors are thought to influence wear resistance of the GICs, such as integrity between the matrix and the glass particles, glass particles' size and shape, unreacted polymer matrix and the remaining fillers after GICs setting and porosity of the materials (Xie et al. 2000). SEM images of the GICs (Fig. 4e–i) showed similar wear patterns with voids and cracks on their surfaces due to drying or due to the SEM preparation process. The number of voids is an indication of porosity of the materials. Riva self cure (Fig. 4f) had fewer voids and smoother attrition surface than the other GICs indicating its higher wear resistance compared to the other GICs. Equia (Fig. 4g) and Ketac Molar (Fig. 4e) had also smoother surfaces and narrower voids than ChemFil (Fig. 4h) and Fuji IX (Fig. 4i), verifying the materials' wear rank.

Protective agents are an additional method to enhance the properties of GICs. They prevent water contamination or dehydration (Lohbauer 2010) that can negatively influence the physical and mechanical properties of GICs during the initial stage of setting. On the one hand, water contamination can remove important calcium and aluminum ions from the material surface, which are responsible for the good properties of the GICs. On the other hand, dehydration can cause cracking of the material surface and loss of mechanical strength. There are different types of protective agents available in the market, such as petroleum jelly, cocoa butter, waterproof varnishes and light-polymerized resin coatings. The light-polymerized resin coatings are suggested to be the most suitable due to their stability over time. Resin coating prevents wear and microfractures of GICs and improves the appearance of the restorations by producing smoother surfaces and by preventing discorolation (van Noort 2007; Lohbauer et al. 2011; Basso 2011). Although protective agents for GICs are highly recommended, some drawbacks, such as reduced fluoride release, are also observed. The study of Lohbauer et al. (2011) showed that resin coating did not improve the three-body wear resistance of the tested material, Equia (GIC). However, these authors emphasised that the coating agent might protect GIC from wear at least until the coating layer is abraded. In this study, light-polymerized resin coatings were used in all GICs, except Chemfil, which showed the lowest wear resistance amongst all GICs.

Fuji II LC and Ionolux were the two RMGICs examined in this study. Fuji II LC had the lowest wear resistance from all materials tested, which is in accordance with other studies (Correr et al. 2006; Zhao et al. 2009; Abesi et al. 2011). The decreased wear resistance of RMGICs compared to compomers is probably the result of different matrix composition, lower filler load, larger filler particles size and poorer interaction between the matrix and the filler (Correr et al. 2006). For example, the average filler particle size of Fuji IILC is 1.8 and of Dyract is 0.8. It is well known that decreased filler size and increased filler volume can positively influence the wear resistance of dental materials (Lim et al. 2002; Zantner et al. 2004). The different structure of GICs and RMGICs is the reason for the different wear rate. The basic difference between the structure of GICs and RMGICs is that the matrix of RMGICs contains the polymer chains of HEMA monomer that is not found in GICs (de Gee et al. 1996). The hydrophilic nature of HEMA results in water absorption. The water absorption can negatively influence the filler-matrix coupling or can cause hydrolytic degradation of fillers, resulting in a high wear rate (Beriat and Nalbant 2009). Studies showed that the amount of the residual HEMA monomer could influence the water absorption, as more water absorption was observed in more HEMA releasing materials (Beriat and Nalbant 2009). This means that the lower conversion of these monomers in RMGICs during polymerization can lead to lower wear resistance (Zhao et al. 2009).

In the present study, the SD Mechatronik (Willytec) oral simulator device was used which reproduces two-body wear (attrition). Studies have shown that the normal forces produced during mastication range from 20 to 120 N. A force of 50 N used in this study seems to be acceptable, because it simulates normal mastication forces (Gibbs et al. 1981). The number of cycles used in the wear simulators reported in the literature varies between 50,000 and 1,200,000, and occlusal contacts per day with medium chewing forces estimated to range between 300 and 700 cycles (Lohbauer 2010). In the current study 120,000 mastication cycles were produced corresponding approximately from 6 months to 1 year in vivo (Mair et al. 1996; Heintze 2006). Steatite, a multicomponent semiporous crystalline ceramic material, was used as antagonist.

For the measurements of vertical loss and volume loss, a high resolution and high speed 3D scanning system was used. The system composed of white light sensors that ensure a *z*-resolution of up to 0.2 μm and a *x*-, *y*- motion system on a platform. By defining the lowest and the highest confocal points, the light sensor scans the *xy*-plane-points in between to produce a scanned 3D image and a topographic image after combining and digitally processing the multidimensional data contained in the series of planes. As expected, the correlation between vertical and volume loss was high. Heintze (2006) claimed that researchers could measure only one variable to evaluate wear because of the close relationship. Volume loss is a measurement that combines the vertical loss and the area of wear (Delong 2006). Therefore, it is suggested that volume loss is a better parameter to measure wear, because it also relates to the shape of the antagonists (Heintze 2006).

In the present study compomers, RMGICs and GICs, which are used in the everyday paediatric clinical dental practice, because of their good mechanical and physical properties, showed moderate to severe wear. Sometimes the wear was so high that the anatomic form of the primary tooth can be lost. To overcome this problem, some researchers propose the GIC-RC open sandwich technique, or modified RMGIC-RC open sandwich technique, where GIC/RMGIC replaces dentin and fills the cervical part of the cavity box. In this way the restorations can have the desirable properties of the materials, such as reduced microleakage, fluoride release, better adhesion to the tooth and limited wear. The main disadvantage of this technique is the operative time required (Atieh 2008). The completion of restorations with only one material that has the above advantages may reduce the clinical cahir-side time needed, which is a very important factor when it comes to childrens' treatment. Taking into consideration that mild wear of enamel during mastication process naturally occurs in the primary dentition without causing any additional problems (Warren et al., 2002) and that primary teeth exfoliate, compomers or some GICs with a moderate wear resistance may be sufficient as one-material restoration for the occlusal restorations of the primary teeth.

Conclusion

Within the limitations of the present study, it can be concluded that compomers, GICs and RMGICs present moderate to severe wear. Compomers and some GICs with moderate wear resistance can be sufficient for occlusal restorations in primary teeth.

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