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Hygroscopic expansion of self-adhesive resin cements and the integrity of all-ceramic crowns

Magdalena Kirsten[a], *Ragai Edward Matta*[b], *Renan Belli*[a], *Ulrich Lohbauer*[a], *Manfred Wichmann*[b], *Anselm Petschelt*[a], *José Zorzin*[a,*]

[a] *Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Dental Clinic 1 – Operative Dentistry and Periodontology, Research Laboratory for Dental Biomaterials, Glückstrasse 11, D-91054 Erlangen, Germany*

[b] *Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Dental Clinic 2 – Department of Prosthodontics, Glückstrasse 11, D-91054 Erlangen, Germany*

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ABSTRACT

Objective. Low pH neutralization and subsequent remnant hydrophilicity can lead to hygroscopic expansion of self-adhesive resin cements (SARCs) after water storage. The aim of this in vitro study was to investigate the effects of hygroscopic expansion of SARCs, used as luting and partial core build-up material, on integrity and cement gap thickness increase of all-ceramic CAD/CAM crowns.

Methods. Human third molars (n = 48) were prepared and anatomical all-ceramic CAD/CAM crowns were manufactured (VITABLOCS Mark II, VITA Zahnfabrik). Crowns internal surfaces were HF etched and silanized. The prepared teeth with their respective crowns were divided into 6 groups (n = 8). In groups 1, 3 and 5 the coronal dentin was removed to simulate a partial core build-up. Groups 1 and 2 were luted with iCEM (Heraeus Kulzer), 3 and 4 with RelyX Unicem 2 Automix (3M), 5 and 6 with Variolink Esthetic DC (Ivoclar Vivadent). All specimens were dual cured and stored in distilled water at 37 °C. Crown integrity was controlled at baseline and in regular intervals until 180 days. Cement gap thickness was measured using an optical 3D scanner (ATOS Triple scan, GOM) at baseline and after 180 days. Crown integrity was statistically analysed using Kaplan–Meier survival analysis and cement gap thickness increase using two-way ANOVA ($\alpha = 0.05$).

Results. After 180 days storage, crack formation was observed in all specimens of group 1 (mean survival time of 85.5 days), in one specimen of group 2 and in two specimens of group 4. Two-way ANOVA analysis revealed a statistically significant interaction between material type and build-up on cement gap size increase for iCEM.

Significance. Within the limits of this study, the application of SARCs with low pH neutralization as partial build-up material under CAD/CAM crowns is not recommended for clinical use.

* *Corresponding author.*
E-mail address: Zorzin@dent.uni-erlangen.de (J. Zorzin).

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1. Introduction

Self-adhesive resin cements (SARCs) were developed to simplify conventional procedures of adhesive luting of indirect restorations, by exploiting their ability to directly bond to tooth substrates. The chemical composition of SARCs is based on methacrylate monomers modified by carboxylic or phosphoric acid-groups [1], known for simultaneously demineralizing and infiltrating dentin and enamel [2] without the need for separate etch and bonding steps. This leads to the formation of micromechanical and chemical bonding achieved by interaction with calcium ions of the tooth substrate [1]. At the initial stage of application, a low pH value and high hydrophilicity are necessary for proper etching and infiltration. With time pH neutralization should slowly ensue by consumption of the protonated moieties [3]. A pH neutralization is achieved by acid–base reactions between the acidic-groups of the functionalized monomers and different (buffering) ions; these are provided either by the substrate, by the acid-soluble glass fillers, or by the calcium hydroxide added to the SARC material for this specific purpose [4]. Parallel to the pH-value increase, a SARC is supposed to naturally become more hydrophobic as the reaction rate decreases [1,3]. Previous studies have shown considerable differences in pH neutralization behaviour of SARCs depending on their composition [3,5,6]. These studies indicate that an insufficient pH neutralization directly affects material properties like conversion rate, bond strength, wear resistance, and tensile strength [5–7]. A persisting hydrophilicity is accounted for inducing hygroscopic expansion due to a continuous water sorption process [8–10]. This has been shown experimentally, demonstrating a significant correlation between pH, hydrophilicity and free hygroscopic expansion stress of different SARCs was demonstrated [3].

An expanding cement layer is of particular concern when dealing with indirect restorative materials that are mainly linear-elastic, for all the applied load is stored in the material without means of dissipation. For materials showing brittle behaviour and low fracture properties, such as silicate-based dental ceramics, high stresses caused by hygroscopic expansion of the luting cement could potentially lead to crack formation and restoration failure. Sure enough, hygroscopic expansion of resin-based materials has been identified as a main contributor in the cracking of dental ceramic restorations when used whether solely as luting agent or as core build-up [11–13]. It also seems that the restoration design [14] and the fabrication process used to produce the restoration [15] count as two major influencing factors in this phenomenon.

The aim of the present study was to evaluate the effect of hygroscopic expansion of commercially available SARCs on all-ceramic feldspathic ceramic crowns, following an experimental set-up adapted from Sindel et al. [12]. SARCs with different pH neutralization behaviors and hygroscopic expansion stresses were selected based on the study of Roedel et al. [3]. A conventional resin composite luting material served as control.

The research null-hypotheses tested herein were: that SARCs having different susceptibilities to hygroscopic expansion do not affect the integrity of all-ceramic crowns when used (i) solely as luting material or (ii) as or partial core build-up. The third null-hypothesis was that the type of cement has no effect on crown integrity.

2. Materials and methods

2.1. Materials under investigation

Two commercially available SARCs with different pH neutralization behaviour and hygroscopic expansion stress, according to Roedel et al. [3], were investigated in this study: iCEM (iCEM, Heraeus Kulzer, Hanau, Germany) as a material with low pH neutralization (pH_{min} 2.89, $pH_{24\,h}$ 3.23, $pH_{increase}$ 11.76 %) and high hygroscopic expansion stress (29.15 MPa) and RelyX Unicem 2 Automix (RX2, 3M, Seefeld, Germany) as a material with high pH neutralization (pH_{min} 3.77, $pH_{24\,h}$ 4.68, $pH_{increase}$ 24.13%) and low hygroscopic expansion stress (14.50 MPa). The conventional luting resin composite Variolink Esthetic DC (VDC, Ivoclar Vivadent, Schaan, Liechtenstein), combined with the adhesive Syntac (Ivoclar Vivadent) in total-etch mode, served as control since no pH neutralization and hygroscopic expansion stress was expected for this material. Table 1 presents the composition of the materials under investigation as disclosed by the manufacturers.

2.2. Specimen preparation

Forty-eight intact, caries-free, human third molars, extracted for therapeutic reasons under informed consent of the patients, were stored at 4 °C in 0.5% chloramine-T aqueous solution for up to 30 days before use. Each tooth was cleaned, debrided and individually embedded with its roots, up to 5 mm apical of the cemento-enamel junction, in a polyurethane cubic socket (AlphaDie MF, Schütz Dental, Rosbach, Germany). The surface of the socket was sandblasted with 35 μm Al_2O_3 particles (Hasenfratz, Assling, Germany) to provide a suitable surface for optical digitization. All teeth were prepared for anatomical all-ceramic crowns having a circumferential accentuated chamfer finish line of at least 1 mm in depth, with rounded inner angles and a divergence angle of at least 3°. The preparations were performed using a dental high-speed handpiece (INTRAmatic LUX3 25LH, KaVo, Bieberbach, Germany) under profuse water-cooling (50 ml/min) with medium coarse diamond burs (869G 016, green ring 107–181 μm Hager & Meisinger, Neuss, Germany) and finished using fine diamond burs (869F 016, red ring 27–76 μm, Hager & Meisinger).

The prepared teeth were spray coated with titanium oxide (Zirko Scanspray, Zirkonzahn, Gais, Italy), and optically scanned (S600 ARTI, Zirkonzahn). Anatomical all-ceramic crowns were designed using the Zironzahn software Suite (Zirkonzahn). A minimum crown thickness of 1.5 mm circumferentially, 1.5 mm occlusally, and 1.0 mm at margin with a cement gap thickness of 50 μm, were set as the design parameters. The crowns were milled under water-cooling (M5 Milling Unit, Zirkonzahn) from feldspathic ceramic CAD/CAM blocks (VITABLOCS Mark II, L14, A3, Lot. No. +J017EC4I14M0, VITA Zahnfabrik, Bad Säckingen, Germany). Before cementation, the inner surfaces of all crowns were etched with 5%

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