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Long-term cost-effectiveness of glass hybrid versus composite in permanent molars

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ABSTRACT

Objectives: We assessed the long-term cost-effectiveness of glass hybrid (GH) versus composite (CO) for restoring permanent molars using a health economic modelling approach.
Methods: A multi-national (Croatia, Serbia, Italy, Turkey) split-mouth randomized trial comparing GH and CO in occlusal-proximal two-surfaced cavities in permanent molars (n=180/360 patients/molars) provided data on restoration failure and allocation probabilities (i.e. failure requiring re-restoration, repair or endodontic therapy). Using Markov modelling, we followed molars over the lifetime of an initially 12-years-old individual. Our health outcome was the time a tooth was retained. A mixed-payers' perspective within German healthcare was used to determine costs (in Euro 2018) using fee item catalogues. Monte-Carlo-microsimulations, univariate and probabilistic sensitivity analyses were conducted. Incremental cost-effectiveness ratios (ICER)s and cost-effectiveness-acceptability were quantified.
Results: In the base-case scenario, CO was more effective (tooth retention for a mean (SD) 54.4 (1.7) years) but also more costly (694 (54) Euro) than GH (53.9 (1.7) years; 614 (56 Euro). The ICER was 158 Euro/year, i.e. payers needed to be willing to invest 158 Euro per additional year of tooth retention when using CO. In a sensitivity analysis, this finding was confirmed or GH found more effective and less costly.
Conclusion: CO was more costly and limitedly more effective than GH, and while there is uncertainty around our findings, GH is likely a cost-effectiveness option for restoring permanent molars.
Clinical significance: When considering the long-term (life-time) cost-effectiveness, GH showed cost savings but CO was limitedly more effective. Overall, cost-effectiveness differences seems limited or in favour of GH.

1. Introduction

Based on environmental concerns and the resulting Minamata agreement, the usage of dental amalgam is increasingly phased-down or phased-out globally [1]. Alternative materials like resin composites (CO) or glass ionomers are increasingly in the focus [2], while clinical data comparing them against each other (or against amalgam itself) are sparse. The resulting uncertainty limits policy-makers', but also dental practitioners' and patients' ability to make informed decisions when choosing between both materials [2].

While CO have well-demonstrated physical properties and high esthetics, their placement is technically sensitive and resource intense. Glass ionomers can be placed in bulk and under lower technical efforts, but only recently have been introduced as material suitable to restore posterior, load-bearing cavities, mainly as specific material properties (i.e., wear resistance and flexural strength) have improved considerably. In recent years a new class of materials based on glasses have been introduced, termed glass hybrids (GH), which show better wear resistance [3] and fracture toughness than previous generations [4], but remain less flexible than CO [5].

Both materials have been compared against each other in a recent split-mouth randomized controlled multi-national trial [6], where extended restorations were placed in permanent molars of adults. We recently used the 3-years data from this trial to determine the short-term

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cost-effectiveness of GH and CO in the four countries of the trial (Croatia, Serbia, Italy, Turkey). We found GH to come at lower costs in three of the four countries (only in Italy, costs were similar), and at similar or only limitedly lower survival compared with CO.

Evaluating the long-term sequelae of initial treatments and failures has been found relevant, though. As shown in previous analyses, initial cost differences may be altered by the long-term need for different re-treatments. Besides survival, the type of failure may further be determining the costs (e.g., a failure leading to restoration repair is less costly than a failure leading to endodontic therapy) and health outcomes (e.g. endodontic therapy sets the tooth on a very different course compared with repair of the restoration) [7–9].

In the present study, we compared the long-term cost-effectiveness of CO and GH using health economic modelling. Modelling allowed us to translate the 3-years clinical data into a long-term horizon and to gauge the long-term need for treatments and resulting costs when using different materials. We hypothesized that the favourable short-term cost-effectiveness of GH found in the previous evaluation was confirmed in a long-term horizon.

2. Methods

2.1. Study design and sample size

This is a health economic modelling study. Using a Markov model and building on a 3-years report of a randomized controlled trial comparing GH and CO, we were able to reflect on the long-term path of molars restored with GH (EQUIA Forte, GC, Tokyo, Japan) or a nano-hybrid CO (TetricEvoCeram, IvoclarVivadent, Schaan, Liechtenstein). The trial had been registered (ClinicalTrials.gov NCT02717520) and ethically approved in each of the four study centers. Further details on the trial methodology, including sample size estimation, can be found elsewhere [6]. Briefly, CO and GH were randomly placed in pairs of molars in adult patients attending the dental university hospitals of the School of Dental Medicine, University of Zagreb (Croatia), the School of Dental Medicine, University of Belgrade (Serbia), the IRCCS Galeazzi Orthopaedic Institute, University of Milan (Italy), and the Ege University School of Dentistry, Izmir (Turkey). Participants needed to be older than 18 years, show no signs of drug abuse or bruxism or being pregnant, and required two occlusal-proximal two-surfaced restorations in molars of the same jaw. Molars needed to respond positive to ethyl chloride, have an antagonist and adjacent teeth, a stable occlusal relationship, no full dentures or crowns and bridges in occlusal contact, no pulp exposure during carious tissue removal, no allergy to any products used in the study. There was no limitation with regard to the cavity extent except for cusps not being included, while, for example, subgingingival extension was rare.

A total of 360 restorations (two per patient; 1 GH and 1 CO, randomly assigned to molars using a random numbers generator) were placed. Reporting follows the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [10].

2.2. Target population, setting, perspective and horizon

We modelled a population of permanent molars receiving either CO or GH in initially 12-years old individuals using TreeAge Pro 2019 R1.1 (TreeAge Software, Williamstown, MA, USA). The teeth were followed over the patients' remaining average lifetime, which was assumed to be 66 years based on the life expectancy of males in Germany [11]. The simulation period would be minimally longer for females.

This study adopted a mixed public-private-payer perspective in the context of German healthcare. In Germany, the medical insurance is two-tiered, with most individuals (>87%) being publicly insured (statutory insurance) and a minority being privately insured. Within the statutory insurance, nearly all dental procedures are covered; only few need to be partially or fully paid out-of-pocket or by private (additional) insurances.

2.3. Comparators

Our comparators were CO and GH. In the 4-center trial informing our initial modelling steps (i.e. those on initial failures of the CO and GH restorations), the different restorations had been placed as follows. After anesthesia (if needed), cotton rolls and high-speed suction had been used for moisture control in GH and rubber-dam in CO. Cavities had been prepared using diamond burs (Komet, Lemgo, Germany) under water cooling and carious tissue removal had been performed until hard dentin remained in the periphery and leathery dentin in pulpo-proximal cavity areas. Sectional matrices (Palodent Plus, Dentsply, York, PA, USA) had been used and CO and GH placed according to manufacturers' instructions, including cavity conditioning prior to the restoration in GH and the placement of a resin-based coat afterwards. Curing had been conducted using a LED curing lamp (D-Light, GC; 1200 mW/cm2, slow mode) for 20 s per increment in CO. Patients were followed-up annually for 3 years. Evaluation was performed by experienced, blinded, calibrated examiners using the FDI-2 criteria [6]. It was specifically recorded what kind of re-treatments (re-restoration, repair, endodontic therapy) were required in case of restoration failure.

2.4. Currency, price date and discount rate

Costs were calculated in Euro 2018 based on the German statutory and private dental fee catalogues, Bewertungsmaßstab (BEMA) and Gebührenordnung für Zahnärzte (GOZ). Details on unit prices and quantities are shown per course of treatment in the appendix. All costs were estimated per tooth. Costs were discounted at 3% per annum [12]. Discounting accounts for time preference. Discount rates were varied to explore the impact of higher or lower discounting. Given our study's perspective, opportunity costs were not accounted for.

2.5. Model, input variables, health outcome

A model-based cost-effectiveness study was performed, using an established and validated Markov simulation model consisting of initial and follow-up health states [13]. The possibility of teeth transitioning between health states was based on transition probabilities. The possible pathways through the model were as follows (Fig. 1). Placed GH and CO restorations could fail according to the trial's data and be replaced, repaired, or endodontically treated. Note that in the base-case we conservatively assumed that these so-called allocation probabilities are identical in both groups (the overall numbers of events in the trial was limited and pooling both groups to come to allocation probabilities increased the robustness of our analyses). In a sensitivity analysis, we employed allocation probabilities specifically for CO and GH instead (for example, CO had experienced relatively more endodontic complications than GH).

For re-restored restorations and also for teeth receiving endodontic therapy, a crown was assumed to be placed, which could fail and be replaced once. In case endodontic therapy failed, non-surgical and eventually surgical re-treatment were employed. If no further restorative or endodontic treatment option remained, extraction of the molar and its replacement using implant-supported single crowns (ISC, with both the implant and the crown coming with risks) was assumed (in a sensitivity analysis, we assessed how not replacing the molar impacted on cost-effectiveness).

Risks of failure and resulting transition and allocation probabilities were built on data used in previous studies (which in turn had used large cohort studies or systematic reviews) and the therein included calculations, as described in Table 1. Using this model allowed to determine the long-term time a tooth was retained, which was our health outcome.

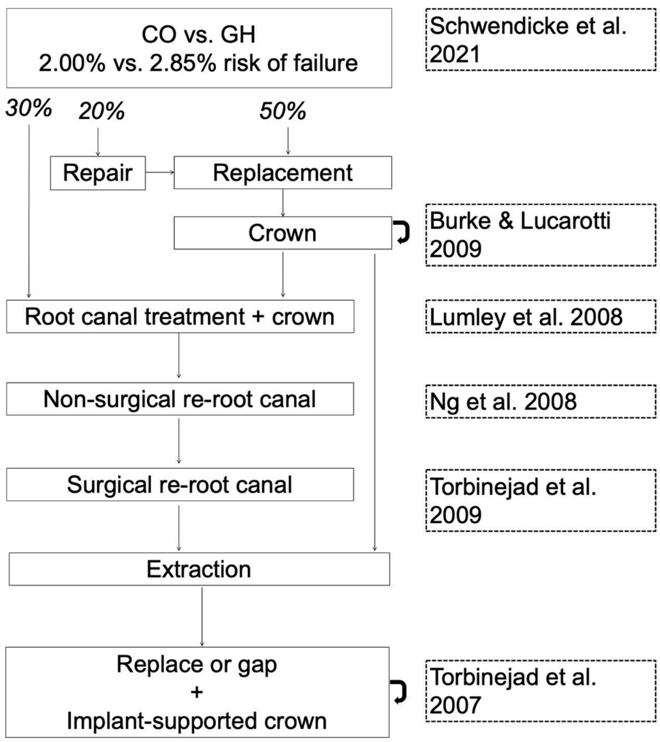

Fig. 1. Input data and model. The state diagram shows the different health states (solid boxes). Transition or allocation probabilities determined the chance of passing between them, indicated by arrows. The data sources used to inform the various transitions and allocations are shown in dotted boxes at the left and right.

2.6. Analytical methods

To analyse the model, we performed Monte-Carlo microsimulations, with 1000 independent teeth being followed over the lifetime in annual cycles. Incremental-cost-effectiveness ratios (ICER) were used to express cost differences per gained or lost effectiveness when comparing the two strategies. To introduce parameter uncertainty, we randomly sampled transition probabilities from a triangular or uniform distributions between calculated 95% CI or the range of parameters [14]. Univariate sensitivity analyses were additionally performed. Using estimates for costs (c, in Euro) and effectiveness (e, in years), we further explored the net benefit of each strategy combination,

$$\text{net benefit} = \lambda \times \Delta e - \Delta c,$$

with λ denoting the ceiling threshold of willingness to pay, i.e. the additional costs a decision maker is willing to bear for gaining an additional unit of effectiveness [15]. If $\lambda > \Delta c/\Delta e$, an alternative intervention is considered more cost-effective than the comparator despite possibly being more costly [14]. We used the net-benefit approach to calculate the probability of a detection strategy being acceptable regarding its cost-effectiveness for payers with different willingness-to-pay ceiling thresholds.

3. Results

3.1. Study parameters

The input parameters for our study are shown in Table 1. We varied the allocation probabilities in a sensitivity analysis, accounting for different allocation probabilities in different groups.

Table 1
Input parameters.

Health state	Source (reference)	Transition probability per cycle	Transition to	Allocation probability
CO[a]	[18]	0.020	Re-restore Repair RCT	0.30 (0.30) 0.30 (0.10) 0.40 (0.60)
GH[a]	[18]	0.028	Re-restore Repair RCT	0.30 (0.35) 0.30 (0.35) 0.40 (0.30)
Direct capping[b]	[19]	0.111	RCT Extraction	0.95 0.05
Crown on vital tooth[c]	[20]	0.036	RCT Recementation Repair Re- crown Extraction	0.25 0.15 0.10 0.40 0.10
Root canal treatment	[21]	0.021	Non-surgical re-treatment Surgical re-treatment Extraction	0.20 0.30 0.50
Crown on non-vital tooth[c]	[20]	0.029	Recementation Repair Re- crown[c] Extraction	0.20 0.10 0.60 0.10
Non-surgical root-canal treatment	[22]	0.085	Surgical re-treatment Extraction	0.25 0.75
Surgical root-canal treatment	[23]	0.061	Extraction	1.00
Implant and implant-supported crown	[24]	0.010	Recementation/ Refixing Re-crown Re-implant	0.60 0.20 0.20

[a] In the base case, allocation probabilities after failure were assumed to be identical in both groups. In a sensitivity analysis, allocation probabilities were altered group-specifically.
[b] 95% of exposed pulps were treated using direct capping, 5% were assumed to receive immediate root canal treatment.
[c] For non-vital crowned teeth, risk of endodontic complications was calculated separately [25].

3.2. Base-case scenario

In the base-case scenario, CO was more effective (tooth retention for a mean (SD) 54.4 (1.7) years) but also more costly (694 (54) Euro) than GH (53.9 (1.7) years; 614 (56 Euro). The ICER was 158 Euro/year, i.e. payers needed to be willing to pay 158 Euro per additional year of tooth retention when using CO. Fig. 2 shows the cost-effectiveness plane (Fig. 2a), with CO being more effective, but also more costly in the majority of simulations. This was also reflected in the incremental cost-effectiveness plane (Fig. 2b) and for the majority (59%) of cases. The cost-effectiveness acceptability of CO was limited for payers a willingness-to-pay of 0 Euro/year but increased with increasing willingness-to-pay (Fig. 2c).

3.3. Sensitivity analyses

A range of sensitivity analyses were performed (Table 2). If using the trial-derived group-specific allocation probabilities of CO and GH (see Table 1), the cost-effectiveness of CO decreased significantly. In this case, GH was both more effective and less costly, i.e., saved money at longer tooth retention time (the ICER was -69 Euro per year). This was also reflected in the fact that 99% of all cases in this scenario found GH more cost-effective. Assuming that no lost teeth were replaced or varying the discount rates had only limited impact on cost-effectiveness.

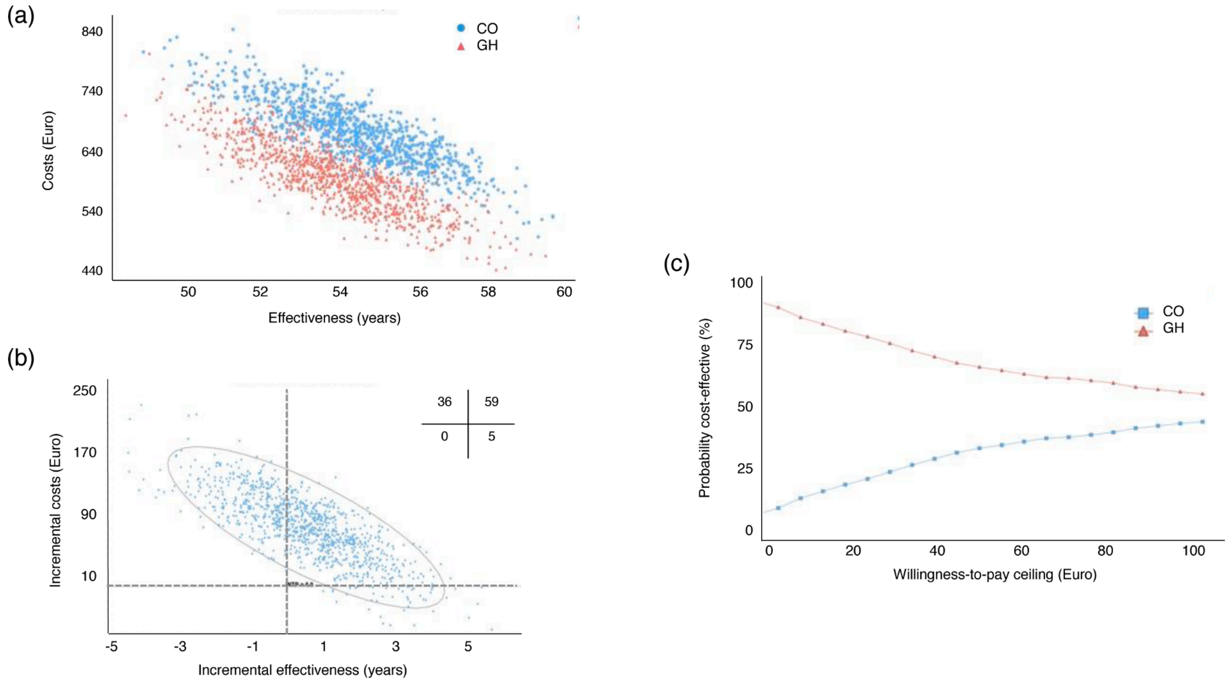

Fig. 2. Cost-effectiveness plane (a), incremental cost-effectiveness (b), and net-benefit analysis (c) of the base-case. (a) The costs and effectiveness of the two comparators are plotted for 1000 sampled individuals in each group. (b) The incremental costs and effectiveness of CO compared with GH are plotted. Quadrants indicate comparative cost-effectiveness (e.g. upper right: higher costs at higher effectiveness; lower right: lower costs and lower effectiveness etc.). Inserted cross-tabulation: Percentage of samples lying in different quadrants. (c) We plotted the probability of comparators being acceptable in terms of their cost-effectiveness depending on the willingness-to-pay threshold of a payer.

Table 2
Cost-effectiveness in the base-case and sensitivity analyses. Mean and standard deviations are shown.

Analysis	CO Cost (Euro)	Effectiveness (years)	GH Cost (Euro)	Effectiveness (years)	Incremental cost-effectiveness ratio ICER (Euro/year)
Base-case	694 (54)	54.4 (1.7)	614 (56)	53.9 (1.7)	158
Group-specific allocation	878 (61)	49.7 (1.6)	598 (52)	54.3 (1.7)	-69
No teeth replaced	513 (31)	54.4 (1.7)	428 (31)	53.9 (1.7)	169
Discounting rate 1%	1211 (94)	54.4 (1.7)	1150 (96)	53.9 (1.7)	119
Discounting rate 5%	480 (38)	54.4 (1.7)	388 (40)	53.9 (1.7)	183

4. Discussion

There is increasing focus in oral health research on developing and/or evaluating amalgam alternative materials, mainly driven by impact of the Minamata agreement and the global phase-down of dental amalgam. Amalgam alternatives will need to fulfill a set of requirements, from applicability over longevity to cost-effectiveness. So far, comprehensive and robust data comparing amalgam alternatives for these aspects are sparse.

In a previous study, we assessed the short-term effectiveness and cost-effectiveness of two amalgam alternatives, CO and GH, under a 3-years horizon within a randomized controlled trial. We here employ these data for health economic modelling, allowing us to extrapolate initial events into long-term aspects like tooth retention or lifetime costs. Such extrapolations are relevant given the long-term sequelae of dental therapies, also considering that not only the failure risk but also the type of failure matters. Moreover, we transferred the findings from the four original trial countries into another healthcare setting, Germany, which allows testing the transferability of results.

We found CO to be more costly and only limitedly more effective in our base-case analysis, resulting in relatively high additional costs for retaining teeth minimally longer. In our sensitivity analysis, where we employed the trial specific allocation probabilities (i.e., considering the specific types of failure and retreatments needed in each group instead of assuming that the types of failures are identical in both groups), we even found CO more costly and less effective. This was mainly as CO required more endodontic interventions after placement, which are expensive and have been shown to determine the fate of the tooth long-term, mainly as endodontic failures over the lifetime then need to be addressed by an ever-escalating chain of interventions like non-surgical or surgical re-treatment and, eventually, extraction. Varying discount rates had limited impact, while assuming that lost teeth were not replaced reduced the costs in both groups, without changing the cost-effectiveness ranking.

Our findings need some more detailed discussion. First, they are in line with the previous analysis with a short-term analytical horizon; CO and GH show limited differences in short- and long-term effectiveness (e.g., to avoid complications and retain teeth) at different costs (CO being more costly). It is assuring that translating the perspective from that of the four trial countries into the German healthcare setting also did not greatly change this finding, confirming that cost-effectiveness is often-times similar across healthcare settings (despite differences in absolute cost distances etc.) [16]. For decision makers, it would be relevant to have the clinical effectiveness data from the four countries to be confirmed by further studies and in a longer-term horizon (e.g., over 5-10 years, allowing to capture late complications like secondary caries). Based on the results of the present analysis, however, it is conceivable that both GH and CO may be valid amalgam alternatives, and choosing between them should bear in mind their longevity, the efforts for when placing them, the way the different restoration materials fail and the long-term cost-effectiveness.

Second, there is considerable uncertainty around the findings. As mentioned, the initial events after placing the restorations were derived from the trial, which – despite being large, randomized and multicentered, comes with limitations in robustness. Also, the costs of the different materials come with uncertainty. In Germany, there is a fee for basic plastic restorations, currently mainly covering amalgam [17]. This fee was assumed to be charged for GH in the present evaluation. To reflect on the phasedown of amalgam and the associated restrictions around its usage for children, pregnant and lactating women as well as allergic individuals or those with kidney malfunctions, an additional set of fee items was introduced in Germany in 2018. These fees are significantly higher and demand adhesive composite fillings to be placed, but are expected to be limited in their application and scope (i.e. they are currently only used within above described indication spectrum). It remains unclear how different materials may be remunerated within the statutory insurance in the future in case amalgam is fully phased out.

Third, we employed sensitivity analyses to gauge the impact of some important assumptions of our analyses, the most relevant one being the way GH and CO fail. In our base case, we assumed the types of failure to be identical, i.e., 40% of failures were endodontic, 30% were repairs and 30% re-restorations in both groups. In a sensitivity analysis, we varied this along the reported failure types in both groups from the trial, where CO came with higher risks of endodontic complications and GH with more restorative failures. This, as outlined, has a significant impact on the costs for addressing these complications (repairing or replacing a restoration being far cheaper than endodontic therapy), but also the long-term sequelae of these therapies on future treatment needs and tooth retention. It was shown that varying allocation probabilities was determinant for the cost-effectiveness ranking; in most analyses, GH was less costly but also limitedly less effective than CO, while in the sensitivity analyses, it was both less costly and more effective (i.e., dominated CO). Showing this uncertainty around the ranking is relevant, while it should be highlighted that in no scenario CO was more effective and less costly, i.e. dominant over GH.

This study comes with a range of strengths and limitations. First, it is one of few economic analyses on the topic of amalgam alternatives, a field where previous analyses demonstrated high uncertainty [2]. Second, the long-term horizon taken in this study is relevant for payers and patients alike, who are interested into long-term costs and health benefits. As discussed, especially in dentistry – where initial therapies have decades-long impact – such horizon is relevant. Third, and as a limitation, we built the initial sequence of events on a single trial, which comes with significant uncertainty. To overcome this to some degree, a range of sensitivity analyses were performed and for most scenarios, conservative assumptions were used to inform modelling. Fourth, costs were determined from a German healthcare perspective, something we discuss above. They may differ elsewhere, but generally the granular cost determination in German healthcare reflects the true costs occurring to payers and should, within boundaries, be transferable to other, similarly organized healthcare settings (they would significantly differ in systems where all remuneration works on fee bands or capitation, for instance). Last, this is a modelling study, with the model but also the sources informing transition through it coming with assumptions and limitations. The model itself is a simplification of reality and clinically, there will be alternative pathways available. Using a model allows to transparently outline the potential long-term impact of early interventions and hence provides a basis for debate and decisions towards further research or care.

In conclusions and within these limitations, we found CO to be more costly and limitedly more effective than GH to retain permanent molars long-term. The resulting incremental cost-effectiveness ratio was high at 158 Euro per additional year of tooth retention. The finding of CO being more costly was confirmed by a range of sensitivity analyses, while GH may as well be as or more effective than CO for retaining teeth depending on the mode of complication of each material. There is substantial uncertainty around our findings and further clinical validation is required to allow supporting clinical or policy decision-making.

Credit

FS and IM conceived the study, coordinated it. All authors participated in data collection and/or analysis as well as interpretation. FS wrote the paper, all others revised it and agree to be accountable.

Declaration of Competing Interest

We thank GC Europe for providing the materials free of charge. Design, conduct, and reporting of this study was fully independent.

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