Bulk-fill resin-based composite restorative materials: a review

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In brief

Provides an overview of available bulk-fill composite materials.

Details techniques to optimise bulk-fill composite restoration success and placement.

Reviews the bulk-fill composite material properties including their relative merits and shortfalls.

Resin-based composite (RBC) materials are increasingly being used for the restoration of posterior teeth. The increasing demand for aesthetic, tooth-coloured restorations coupled with the patient's concerns regarding the use of mercury containing restorations, has driven a surge in the use of RBC materials. With the Minamata Convention in 2013 calling for the phase-out of dental amalgam and dental schools increasingly teaching techniques for RBC restorations in posterior teeth, it is likely that the dental profession's reliance upon RBC for the restoration of posterior teeth will only increase. In order to simplify and speed-up the placement of large posterior RBCs, manufacturers have produced a range of materials which can be placed in single or deeper increments, known as bulk-fill RBCs. Over a relatively short period of time many bulk-fill RBCs have been marketed quoting increment depths between 4-10 mm. The placement of these larger increments of RBC may reduce the time needed when placing posterior restorations and thereby reduce technique sensitivity. This article aims to review the properties and handling characteristics of the bulk-fill RBC materials currently available, while advising the optimal techniques of placement.

Introduction

Resin-based composite (RBC) materials are increasingly being used for the restoration of posterior teeth.[1] The increasing demand for aesthetic, tooth-coloured and mercury-free restorations has driven a surge in the use of RBC dental materials. With the Minamata Convention in 2013 calling for the phase-out of dental amalgam, and dental schools increasingly teaching RBC techniques, it is likely that the dental profession's reliance upon RBC for the restoration of posterior teeth will increase.[2] In total, 128 countries (including the UK) have signed up to the Minamata Convention to phase down the use of mercury containing dental amalgam.[3]

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Refereed Paper. Accepted 16 January 2017
DOI: 10.1038/sj.bdj.2017.214
©British Dental Journal 2017; 222: 337-344

RBC restorative materials have a number of advantages over dental amalgam including improved aesthetics. RBCs allow for a conservative cavity preparation and are adhesively bonded to the tooth with a compatible bonding system. Studies are increasingly supporting the longevity of RBC as a material for restoring both Class I and II cavities.[4,5] The placement of posterior RBC restorations, however, is not without its limitations. Proper isolation of the tooth is required and an incremental layering technique is currently recommended.[6] The layering of RBC improves light penetration allowing for complete polymerisation of the material and is thought to reduce overall polymerisation shrinkage stresses on the tooth. However, this technique can be time-consuming and can lead to the introduction of restoration voids. If not carried out effectively, areas of uncured or partially cured composite resin may remain at the base or between layers at the bottom of each increment. This can lead to reduction in strength, prevent adequate sealing of the restoration or cause post-operative sensitivity and early failure of the restoration. The time taken for placement and the increased incidence of post-operative sensitivity compared to amalgam, are major potential barriers to the phasing out of amalgam.

Glass ionomer materials (GIC) also provide an alternative tooth coloured restoration to amalgam. Conventional glass ionomers provide benefits of possible fluoride release, minimal shrinkage and a resistant dentine bond.[7] In more recent years, efforts to improve the qualities of glass ionomer materials have included zinc reinforcement and resin modified glass ionomers (RMGIC).[7] In-vitro studies have found GICs to have significantly inferior tensile and compressive strengths compared to RBCs (Table 1).[8] In addition, modern RBCs have superior bond strengths to dentine compared with RMGICs and GICs (Table 2).[9] They also have inferior aesthetics to conventional RBC materials and have shown dissolution in acidic environments (ie , plaque presence).[7] In clinical studies failure rates have been reported as high as 40% at six years.[10] A recent review of the current literature demonstrated some studies advocating the use of RMGICs in posterior load bearing scenarios, while it was concluded that there is limited and variable good quality research when compared with conventional RBC materials.[7]

In order to simplify and speed-up the placement of large posterior RBCs, manufacturers have produced a range of RBC materials which can be placed in single or deeper increments, known as bulk-fill RBCs. Over a relatively short period of time many bulk-fill composite resins have been marketed quoting increment depths between 4–10 mm. The placement of these larger increments of RBC may reduce the time needed when placing posterior RBCs and thereby reduce technique sensitivity. This article aims to review the properties and handling characteristics of the bulk-fill RBCs currently available, while advising the optimal techniques of placement.

Classification of bulk-fill RBCs

Bulk-fill RBC restorative materials can be categorised into high-viscosity or low-viscosity, light or dual cured. Table 3 discusses some of these available materials, their maximum incremental depth and whether or not they require a conventional RBC capping layer. Clinical applications and treatment examples are discussed later. Figure 1 illustrates how each sub-class of bulk-fill RBC restorative materials should ideally be applied when compared with conventional layering in an ordered sequence; the authors accept these technical diagrams are not exhaustive of all techniques and many combinations may be appropriate. All of the bulk-fill restorative materials can be capped with conventional RBC to improve their aesthetics or physical characteristics of the restoration; for some of the materials this is advised as essential in providing the restoration.

Clinical examples

The following cases illustrate cavities restored with some of the available bulk-fill RBC materials. Some of these examples of large restorations in endodontically treated teeth require an indirect cuspal coverage restoration and the RBC forms a core restoration. The fracture resistance of endodontically treated teeth restored with either bulk-fill RBC or conventional composite has been found to be similar.[11]

Bulk-fill RBC

Bulk-fill RBCs are designed to be placed in deeper increments (3 mm+) than conventional RBCs (2 mm maximum). The clinical example shown in Figure 2 shows how bulk-fill RBC materials can be used more efficiently to restore large cavities with RBC such as that following completion of root canal treatment.

Bulk-fill base RBC

The low viscosity, light-cured flowable materials have been termed bulk-fill bases as they always require a conventional layer of RBC to cap the restoration due to reduced wear resistance and hardness properties.[12] The clinical example in Figure 3 shows how a bulk-fill base RBC can be used along with a conventional RBC to efficiently restore large cavities.

Sonic-activated bulk-fill RBC

Kerr have produced Sonic Fill 2, a high viscosity bulk-fill resin RBC which becomes low viscosity with the use of sonic vibration (allowing the material to flow into the cavity). The manufacturers claim that material contains a highly filled composite resin, combined with modifiers that are activated by sonic energy produced by a specially designated handpiece to reduce the viscosity of the material during placement.[13] It can therefore be applied into the cavity as a flowable RBC before returning to a more viscous state that can be carved

Table 1 Compressive and tensile bond strengths of GIC, dental amalgam and a Nanohybrid composite[8]

	Compressive strength (MPa)	Tensile strength (MPa)
GIC (Voco - Argion Molar)	107	9
Dental Amalgam (Duralloy)	184	40
Nanohybrid RBC (Voco – Grandio)	294	53

Table 2 Shear bond strengths of GIC, RMGIC and RBCs to dentine[9]

	Mean sheer bond strength (MPa)
GIC (GC – Fuji IX)	3.81
RMGIC (GC – Fuji II LC)	9.71
Nanohybrid RBC (3M ESPE - Filtek Z250 + Adper Single Bond)	18.16

Table 3 Classification of bulk-fill RBC restorative materials

	Bulk-fill RBC	Bulk-fill base RBC	Sonic-activated bulk-fill RBC	Dual cure bulk-fill RBC
Commercially available materials	3M ESPE - Filtek Bulk-Fill Posterior Restorative (Fig. 2) Ivoclar Vivadent- Tetric EvoCeram Bulk-Fill Voco - x-tra fil	Dentsply - SDR (Fig. 3) 3M ESPE - Filtek Bulk-Fill Flowable Heraeus Kulzer - Venus Bulk-Fill Ivoclar Vivadent - Tetric EvoFlow Bulk-Fill Voco - x-tra base	Kerr - SonicFill 2 (Fig. 4)	Coltene - Fill Up (Fig. 5) Parkell – HyperFil
Viscosity	High	Low	2-phase	Medium
Method of cure	Light	Light	Light	Dual
Maximum depth per increment	4 mm	4 mm*	5 mm	Any depth
Need for conventional RBC capping layer	No	Yes	No	No

*3M ESPE - Filtek Bulk-Fill Flowable (class 1 cavity = 4 mm) (class 2 cavity = 5 mm)

or moulded. The clinical example shown in Figure 4 shows how a high viscosity bulk-fill restorative material can be used to efficiently restore large access cavities with RBC following completion of root canal treatment. The flowable properties resulting from sonic vibrations may lead to close adaption of the material to the cavity walls, however, care must be taken to prevent the creation of ledges and overhangs such as that seen on the mesiopalatal cusp in Figure 4l. This can easily be smoothed and polished after occlusal adjustment.

Dual cure bulk-fill RBC

Two dual cure bulk-fill RBCs have also come onto the market. These aim to combine both chemical and light-cure technology to enable the surface of restorations to be light-cured for polishing, while the full depth of the

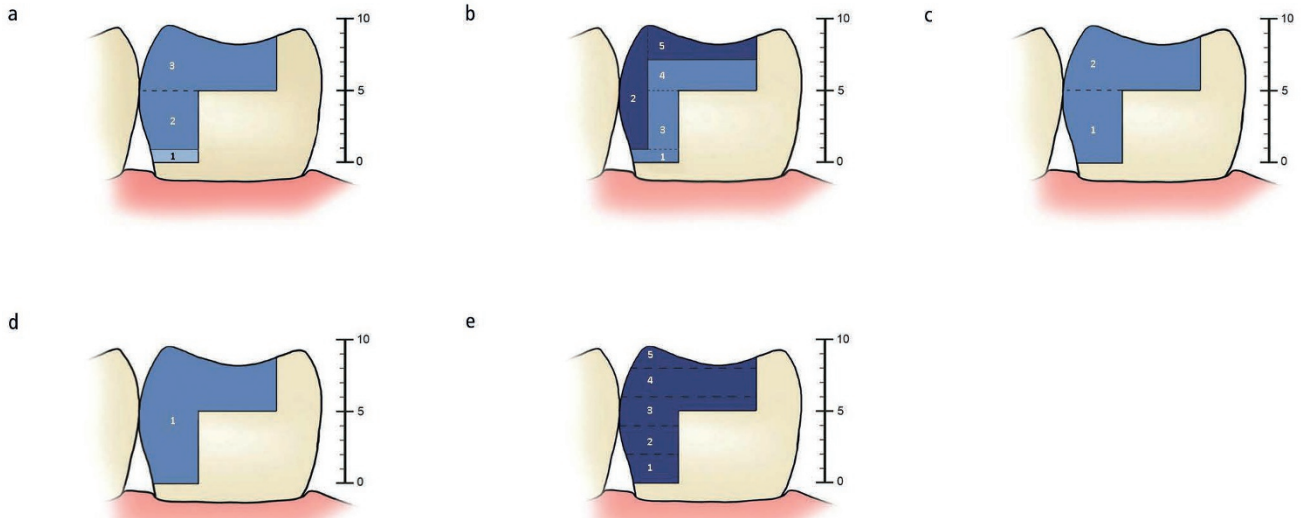

Fig. 1 a) Application of a bulk-fill RBC in 4 mm layers with an optional conventional flowable RBC liner that is, 3M ESPE - Filtek Bulk-Fill Posterior Restorative; Ivoclar Vivadent- Tetric EvoCeram Bulk-Fill; Voco - xtra fil. b) Application of a bulk-fill base RBC in 4 mm layers with a marginal ridge and occlusal capping layer of conventional RBC. Note that a 1 mm seal is shown at the base of the cavity with the bulk-fill base RBC that is, Dentsply - SDR; 3M ESPE - Filtek Bulk-Fill Flowable; Heraeus Kulzer - Venus Bulk-Fill; Ivoclar Vivadent - Tetric EvoFlow Bulk-Fill; Voco - xtra base. c) Application of a sonic activated bulk-fill RBC in 5 mm layers that is, Kerr - SonicFill 2. d) Application of a dual cure bulk-fill RBC in a single increment layer that is, Coltene - Fill Up; Parkell – HyperFil. As these RBCs typically have inferior aesthetics a capping layer of conventional RBC can be incorporated to improve these attributes. e) Application of conventional RBC in 2 mm increments that is, Kerr - Herculite XRV

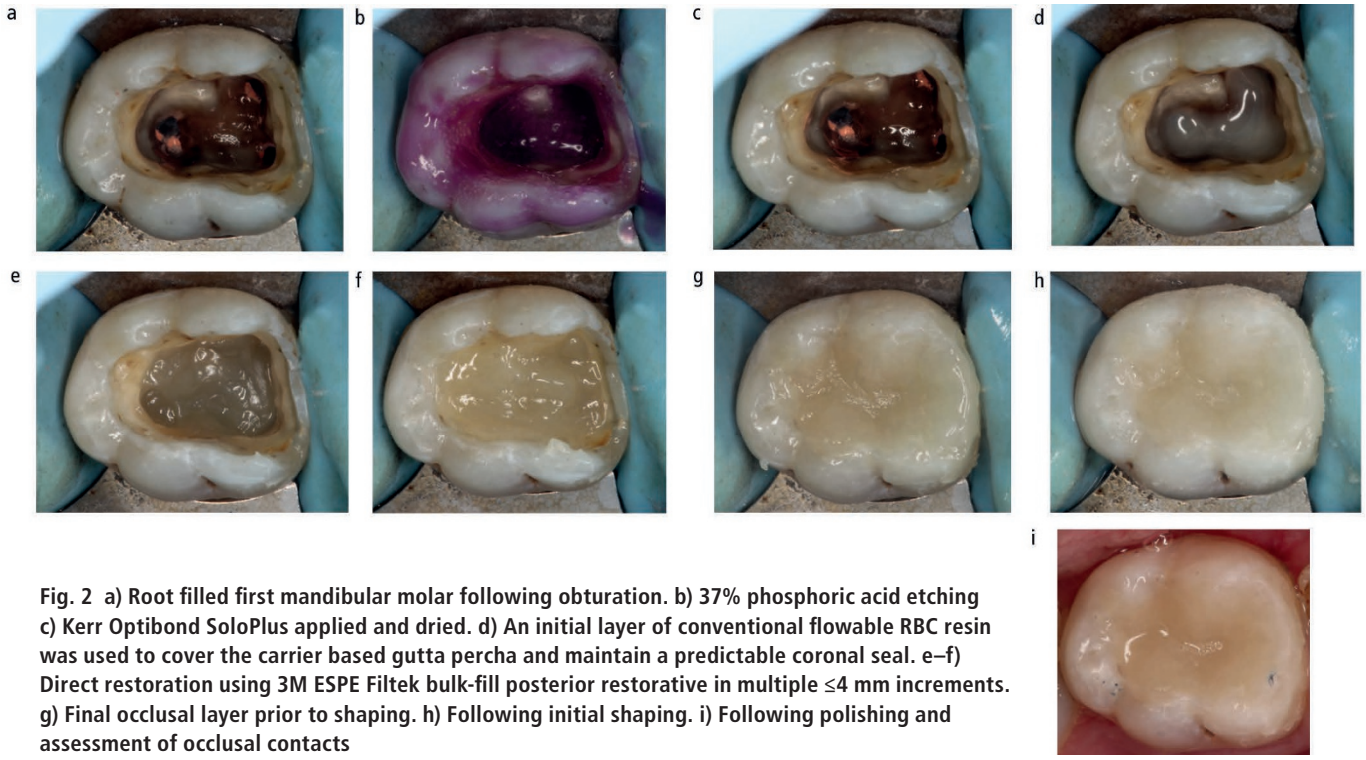

Fig. 2 a) Root filled first mandibular molar following obturation. b) 37% phosphoric acid etching c) Kerr Optibond SoloPlus applied and dried. d) An initial layer of conventional flowable RBC resin was used to cover the carrier based gutta percha and maintain a predictable coronal seal. e–f) Direct restoration using 3M ESPE Filtek bulk-fill posterior restorative in multiple ≤4 mm increments. g) Final occlusal layer prior to shaping. h) Following initial shaping. i) Following polishing and assessment of occlusal contacts

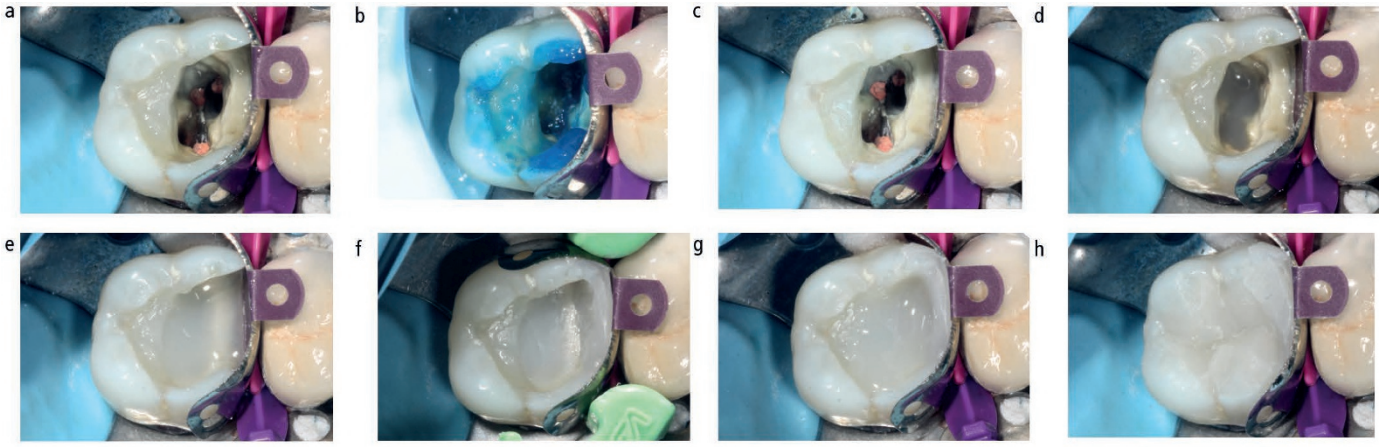

Fig. 3 a) Maxillary first molar following obturation. b) 37% phosphoric acid etching. c) Following 10 seconds drying. d and e) Initial increments of a bulk-fill base material, Dentsply SDR in multiple ≤4 mm increments. The low viscosity nature of SDR means that it can be used predictably to cover the gutta percha and pulp floor to maintain a coronal seal. f) Followed by application of a conventional micro-hybrid RBC to form the marginal ridge contact point where a sectional matrix and ring was used to help form a smooth and well contoured proximal contact. g) Final increment of Dentsply SDR bulk-fill base RBC h) Followed by application of final conventional RBC layer over the occlusal surface. i and j) The tooth was polished and adjusted to conform to the existing occlusal contacts

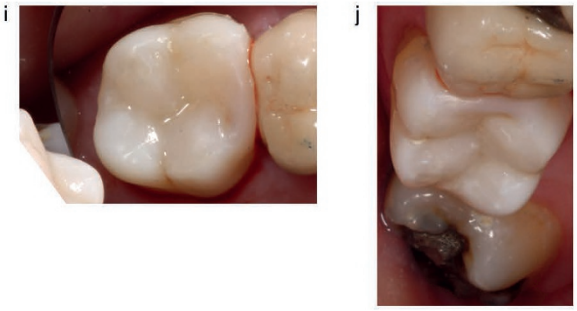

Table 4 Manufacturers recommended curing depths and light-curing timing for purely light-cured bulk-fill materials

Light-cured RBC	Maximum depth of cure	Manufacturer's length of cure – seconds (S)	
		Minimum intensity 550 mW/cm^2	1000 mW/cm^2 intensity or greater
3M ESPE– FiltekT Bulk-Fill Posterior Restorative	4 mm[19] (Class I, III, IV, V) 5 mm[19] (Class II)	Class I,III,IV, V (4 mm):[19] i. 40s Class II (up to 5mm):[19] i. 20s Occlusal ii. 20s Buccal + Lingual	Class I,III,IV, V (4 mm):[19] i. 20s Class II (up to 5 mm):[19] i. 10s Occlusal ii. 10s Buccal + Lingual
3M ESPE– Filtek Bulk-Fill Flowable	4 mm[20]	Universal shade:[20] i. 20s Shades A1, A2, A3:[20] i. 40s	Universal shade:[20] i. 10s Shades A1, A2, A3:[20] ii. 20s
Dentsply – SDR	4 mm[21]	i. 20s[21]	No additional recommendations
Heraeus Kulzer - Venus Bulk-Fill	4 mm[21]	i. 20s[21]	No additional recommendations
Ivoclar Vivadent- Tetric EvoCeram Bulk-Fill	4 mm[17]	i. 20s[17]	i. 10s[17]
Ivoclar Vivadent- Tetric EvoFlow Bulk-Fill	4 mm[18]	i. 20s[18]	i. 10s[18]
Kerr – SonicFill 2a	5 mm[13]	i. 20s[13] *Minimum intensity: 650 mW/cm^2	10s[13]
Voco – x-tra base	4 mm[23]	Universal shade:[23] i. 10sec A2 Shade:[23] i. 40s	Universal shade:[23] i. 10s A2 shade:[23] i. 20s
Voco – x-tra fil	4 mm[24]	i. 20s[24]	i. 10s[24]

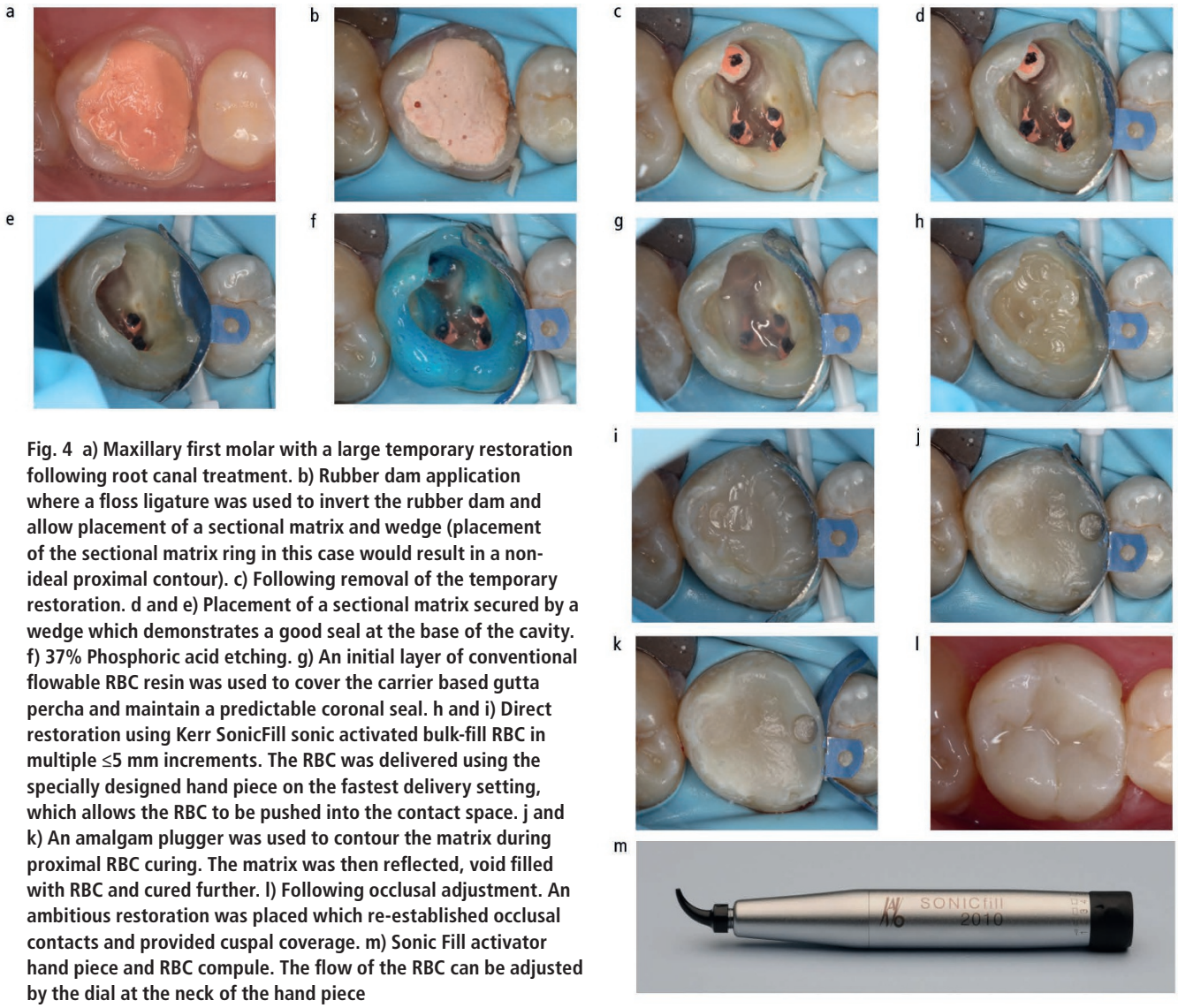

Fig. 4 a) Maxillary first molar with a large temporary restoration following root canal treatment. b) Rubber dam application where a floss ligature was used to invert the rubber dam and allow placement of a sectional matrix and wedge (placement of the sectional matrix ring in this case would result in a non-ideal proximal contour). c) Following removal of the temporary restoration. d and e) Placement of a sectional matrix secured by a wedge which demonstrates a good seal at the base of the cavity. f) 37% Phosphoric acid etching. g) An initial layer of conventional flowable RBC resin was used to cover the carrier based gutta percha and maintain a predictable coronal seal. h and i) Direct restoration using Kerr SonicFill sonic activated bulk-fill RBC in multiple ≤5 mm increments. The RBC was delivered using the specially designed hand piece on the fastest delivery setting, which allows the RBC to be pushed into the contact space. j and k) An amalgam plugger was used to contour the matrix during proximal RBC curing. The matrix was then reflected, void filled with RBC and cured further. l) Following occlusal adjustment. An ambitious restoration was placed which re-established occlusal contacts and provided cuspal coverage. m) Sonic Fill activator hand piece and RBC compule. The flow of the RBC can be adjusted by the dial at the neck of the hand piece

restoration will be chemically-cured over time. The surface of Fill-up (Coltene) can be light-cured, polished and finished. Fill-up can be used with Parabond (Coltene) or One Coat 7 Universal with One Coat Activator (Coltene). Meanwhile the full depth of the restoration will be chemically cured within three minutes and can be suitable for bulk-filling cavities of any depth (10 mm+) in a single increment.[14] The clinical example below shows how a dual cure bulk-fill restorative material can be used to efficiently restore large cavities with RBC in a single increment (Figs 5 and 6).

Mechanical properties

Depth of cure

It is widely accepted that conventional RBC restorations should be placed and cured in 2 mm increments to allow adequate conversion of the unpolymerised RBC resin.[15] The real depth of cure achieved for a given material can vary with the shade and translucency; darker shades with greater opacity actually have a shallower depth of cure compared to lighter more translucent resins.

The majority of bulk-fill materials on the market are purely light-cured, although some are dual-cure. Manufacturers have attempted to increase the depth of cure by a variety of methods including:

- Reducing the filler content[16]
- Increasing filler particle size[16]
- The use of additional photo-initiators.[17,18]

Reducing the filler content and increasing the filler size within RBC reduces the amount of scatter at the resin-filler interface and increases the amount of absorbed light that can activate the photo-initiator. Tetric EvoCeram Bulk-fill increases the depth of cure by using several different photo-initiators.[17,18] The manufacturers claim that it is the addition of a highly reactive photo-initiator, named Ivocerin that allows it to be polymerised in larger increments, when compared to standard photo-initiators such as, camphorquinone or lucririn.[17,18]

Despite these changes, however, the majority of these light-cured bulk-fill materials are still limited to being used in increments of 4–5 mm. Table 4 shows the variations in the manufacturers curing recommendations.

It is important to note that some of the manufacturers light-curing claims are based on high intensity LED light-curing units (Table 4). Some companies recommend a minimum light-curing light intensity which may be higher than many existing units (Table 4). Another factor to consider is the

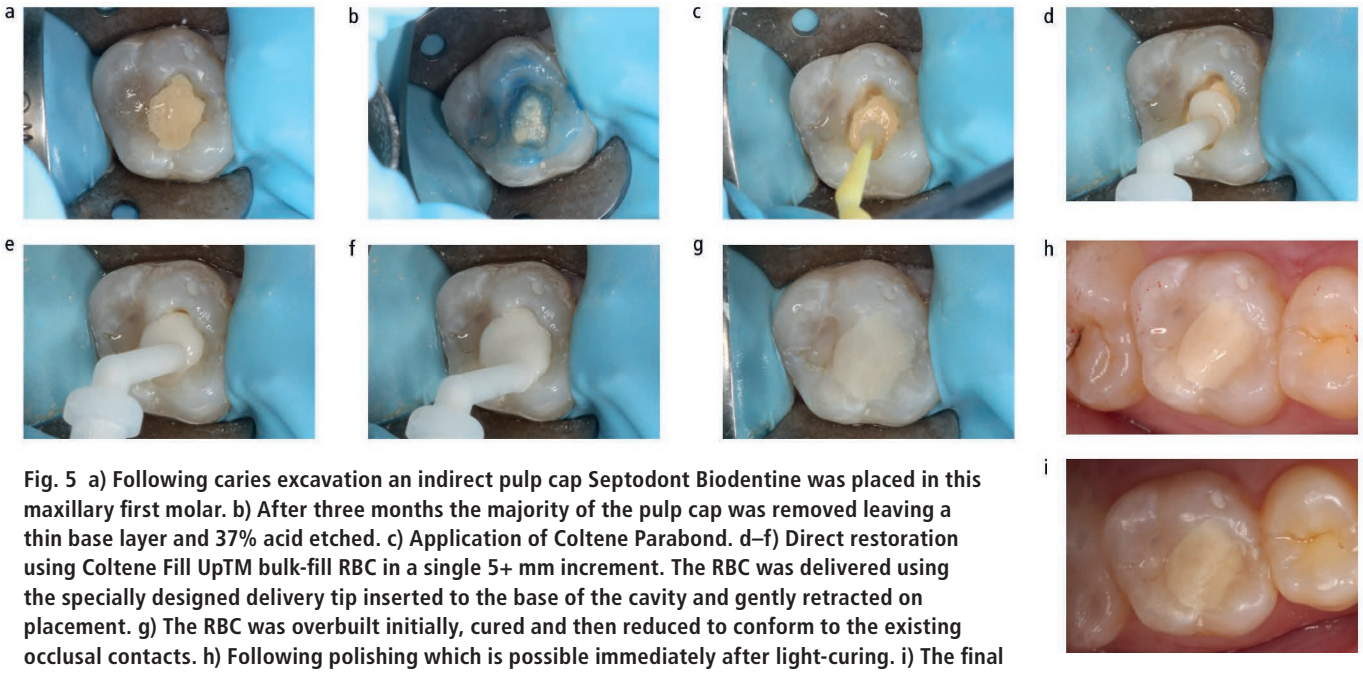

Fig. 5 a) Following caries excavation an indirect pulp cap Septodont Biodentine was placed in this maxillary first molar. b) After three months the majority of the pulp cap was removed leaving a thin base layer and 37% acid etched. c) Application of Coltene Parabond. d–f) Direct restoration using Coltene Fill UpTM bulk-fill RBC in a single 5+ mm increment. The RBC was delivered using the specially designed delivery tip inserted to the base of the cavity and gently retracted on placement. g) The RBC was overbuilt initially, cured and then reduced to conform to the existing occlusal contacts. h) Following polishing which is possible immediately after light-curing. i) The final photograph shows the material at one week post-op illustrating a potential post-operative colour change seen with this material

drop in intensity when the distance from the light tip is increased. One study found that increasing the distance from the light-cure tip to the RBC restoration surface, decreased light intensity by 10% for every 1 mm.[25] While it has been found that when curing through 2 mm of RBC the intensity can be reduced to 6% of its initial intensity.[26] It is for this reason that the authors advise caution when attempting to cure increments of 4 mm or more. An assessment of the direct access, distance of the light tip from the base of the cavity and the intensity of the light-curing unit should be considered when deciding suitable curing times for each individual case. In addition, the effectiveness of light-cure units within general practice has often been found to be inadequate with up to 50% of units not reaching minimum irradiation levels (300 mW/cm^2).[27] Therefore, it is recommended that light-curing units are regularly maintained and assessed for their power output.[28]

There is mixed evidence regarding the manufacturers light-cure times. Some studies have suggested that recommended light-cure times for bulk-fill materials cannot be advocated, with longer curing times being required.[29] One *in vitro* study identified that some of the available bulk-fill base RBCs had significantly lower depths of cure than those claimed by the manufacturer.[30] However, most recent studies support the manufacturer's claims, that with optimal curing conditions the RBC can achieve an adequate hardness at the increased depths.[31–33] If the increment depth is too large uncured resin may remain at the base, which may result in post-operative sensitivity, marginal leakage, caries and mechanical failure of the restoration. The advent of dual-cured RBC materials is an exciting innovation, as it negates concerns over depth of cure, whilst retaining the desirable properties of RBC restorations.

Polymerisation shrinkage

Incremental placement of purely light-cured RBC is recommended to reduce the effect of polymerisation shrinkage that occurs on curing.[20] When the unpolymerised RBC resin touches more than one wall of the cavity preparation it increases the c-factor.[34] This shrinkage stress can lead to failure of the restoration at the weakest interface which is between the tooth and restorative material.[34] This in turn can result in a number of potential problems including secondary caries, marginal staining, tooth fracture, and post-operative sensitivity. The manufacturers of bulk-fill materials claim lower polymerisation stresses than conventional RBCs when placed in greater increment thickness.

Overall, the bulk-fill materials have been shown to have similar volumetric shrinkage to conventional RBC controls, which may suggest there is no overall benefit to using these materials.[30] However, when looking at the shrinkage stress specifically, in vitro studies have shown bulk-fill materials exhibit less shrinkage stress than conventional RBCs.[33] This suggests that while the bulk-fill materials shrink, this is not necessarily to the detriment of the marginal integrity. Manufacturers have altered the shrinkage stress effect in a number of ways including inclusion of shrinkage stress relievers which have a lower elastic modulus.[11] SDR has included a polymerisation modulator which interacts with the camphorquinone photo initiator to result in a slower elasticity modulus development.[21]

Marginal gap formation

When looking at marginal gap formation and adaptation, studies are not conclusive. Some have shown no statistical difference between a number of bulk-fill materials compared to conventional RBC,[35] whereas some literature suggests there is an improvement of the marginal seal with bulk-fill materials compared with conventional layering.[36] A further study has found that the higher viscosity bulk-fill RBCs result in greater marginal gap formation.[37] One method to overcome this problem with high-viscosity materials is heating them prior to placement and/or using a low viscosity RBC material to seal the base of the cavity. Dual cure bulk-fill RBCs have also shown acceptable marginal adaption post curing.[38]

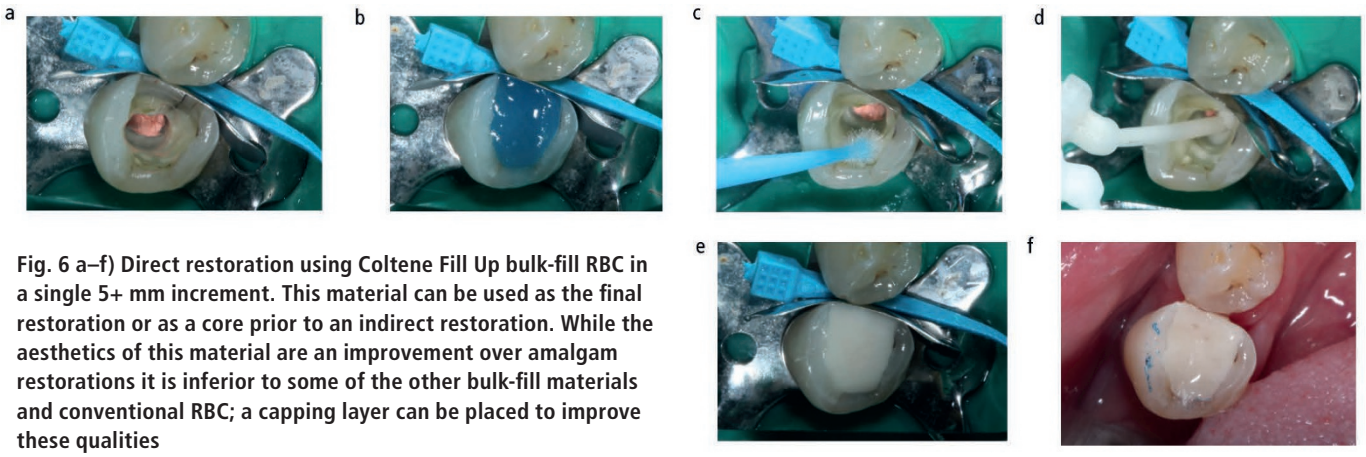

Fig. 6 a–f) Direct restoration using Coltene Fill Up bulk-fill RBC in a single 5+ mm increment. This material can be used as the final restoration or as a core prior to an indirect restoration. While the aesthetics of this material are an improvement over amalgam restorations it is inferior to some of the other bulk-fill materials and conventional RBC; a capping layer can be placed to improve these qualities

Gap-free interfaces have been reported to be lower with increasing depths of preparation as would be expected.[35,39] However, when comparing the same preparation depths with conventional RBC against bulk-fill materials no differences were found.[35,39] This suggests that it is the cavity depth which is a more important factor than the type of RBC material with regards to interface gap formation. Overall, the evidence is reassuring for the marginal adaptation of these new materials.

Physical and aesthetic properties

In the development of conventional RBCs, manufacturers have continually sought to increase the filler content of their products in order to improve the materials' mechanical properties. However, this is not the case in many bulk-fill materials, which tend to have lower filler loading in order to increase the depth of cure.

A recent lab-based study comparing many of the materials within this article including a dual cure material (Fill Up – Coltene), highlighted some concerns over the mechanical properties of strength over conventional RBCs.[12] The authors of this study suggested that also some of the bulk-fill base RBCs have poor long-term stability from softening and highlighted the need for ensuring they are not exposed to the oral environment which may negate their advantages.[12]

Kerr's Sonicfill 2 system has a relatively high filler content (83.5% Wt.), which has been shown to have the higher flexural and compressive strength values, compared to Tetric EvoCeram bulk-fill (79-81% Wt.) and SDR (68% Wt.) which have lower filler contents.[40] The latter requires a capping layer of conventional RBC due to these inferior properties and is therefore a bulk-fill base rather than a material that can be used for an entire restoration.[40] Bulk-fill base RBCs have been found to have comparably low fracture toughness and abrasion resistance to conventional flowable RBCs.[41] Therefore, manufacturers advise that bulk-fill base RBCs are capped with a conventional RBC. This reduces the potential advantage of increased speed of placement compared to materials that do not need a capping layer and may be placed in a single increment depending on the depth of the cavity (Table 3).[16] In addition, the authors recommend that the proximal contact points, as well as occlusal surfaces are restored with a conventional RBC when using bulk-fill base RBCs due to the risk of wear against the adjacent tooth, which may result in an open contact point (Fig. 1B).

Interestingly dual cured bulk-fill RBCs (that is, Fill – up) also have low filler content (65% Wt.),[42] however, the manufacturers have advised this material can be used without a final conventional RBC capping layer. Given the lack of clinical trials the authors give caution to using this material as per manufacture guidelines due to its comparably low filler content which may render it prone to increased wear rates. Within *in vitro* studies the bulk-fill RBCs show a wide range of physical properties and do not perform equally, therefore, the clinician must carefully select materials based on their individual merits.[12,43]

Clinical performance

There is limited good quality in-vitro research regarding bulk-fill RBC materials, while clinical in vivo research is scarce apart from a few trials and case reports. Some clinical evidence is emerging that demonstrates bulk-fill base RBCs are a suitable alternative to amalgam or conventional RBC,[44–46] although more good-quality data is needed. A recent randomised clinical trial utilising a bulk-fill base RBC compared with a conventional layered technique found comparable success over five years.[44] Another study has shown bulk-fill base RBCs to be as successful as stainless steel crowns in the restoration of primary teeth having undergone a pulpotomy.[47]

However, the reality is that currently bulk-fill RBC restorative materials have little clinical research to support their use. Clinicians must weigh up the potential advantages and disadvantages of a material to the particular clinical scenario.

Aesthetics are greatly improved with all RBC materials compared to amalgam, although bulk-fill materials may be limited in terms of shade and translucency of the materials in comparison to conventional hybrid RBCs. For patients in which ultimate aesthetics are a key factor, a capping layer of conventional hybrid RBC is indicated and is compatible with most bulk-fill materials.

Conclusion

Bulk-fill RBC materials provide tooth-coloured restorations that can be more efficient and less technique sensitive to place than conventional RBCs. The mechanical properties, aesthetic result and placement technique varies significantly across the materials available. These materials may be particularly useful when restoring posterior cavities where procedural time is of concern. This may include children and anxious patients where the length of treatment time is ideally kept short, but in the wider context of healthcare provision, if procedures can be made more efficient this will have a positive overall benefit providing the treatment is found to be predictable. Overall there are

early promising in vitro studies supporting the use of bulk-fill RBCs which confirm the manufacturer's claims. However, there is very little clinical (in vivo) research on the long-term outcomes of these materials and so caution is needed as to their efficacy. Such data is needed before the true effectiveness of these materials can be assessed. It is recommended that given the promise of these materials and the phasing out of amalgam, further clinical evidence will soon become available. Until further data is available, it is recommended that clinicians carefully select materials and strictly follow the manufacturer's instructions.

Acknowledgements:
The authors would like to thank the Leeds Dental Institute clinical illustration department for preparing the images and diagrams, and the restorative nursing staff including Carol Walker, Kate Ward, Alex Potter and Lauren Taylor.

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