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From Conventional Single-Event Polymerization to Biomechanically Separated Polymerization: A Conceptual Framework for the Semi-Split Delayed Gap Closure Technique in Direct Bulk-Fill Resin Composite Restorations

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ABSTRACT

Background: Conventional composite placement comes down to three steps: the material is placed, it is cured once, and it ends up in a state of maximum constraint. Every strategy currently used to manage shrinkage stress, whether incremental layering, low-shrinkage monomers, flowable liners, or soft-start and pulse-delay curing, works by changing something inside that single middle step. None of them add a new one.

Objective: To describe the six-stage process behind the Semi-Split Delayed Gap Composite (SS-DGC) technique, set it against the three-stage conventional sequence, and consider what a six-stage architecture actually changes mechanically that a three-stage one cannot.

Technique Rationale: SS-DGC introduces four stages between placement and final cure that the conventional sequence simply has no room for. These are: cutting a gap that lowers the effective C-factor from roughly 5.67 to roughly 2.1 before any light exposure occurs; an initial low-intensity cure carried out under that reduced constraint; a five-minute relaxation period that follows a Kohlrausch-Williams-Watts (KWW) stretched-exponential decay ($\tau \approx 5$ min, $\beta = 0.40–0.60$); and closing the gap, which sets up a new, smaller constraint ahead of the final high-intensity cure.

Discussion: The six-stage sequence includes two changes in geometry, one genuine relaxation period, and two reactions that run on independent timelines. None of which the three-stage conventional sequence has at all. Conventional technique reaches maximum constraint and maximum conversion at the same moment. The SS-DGC reaches full cure with most of the restoration already relaxed, leaving only a small final gap-fill increment newly constrained.

Conclusion: Adding stages to a curing sequence is not the same as slowing down the stages that already exist. Whether this six-stage architecture's lower terminal stress state translates into a measurable clinical benefit is a separate question from the mechanistic case made here, and will need dedicated experimental and clinical study.

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Introduction

Despite its apparent simplicity, conventional composite placement culminates in an unavoidable biomechanical outcome where restoration becomes mechanically constrained as polymerization proceeds. Every strategy proposed for managing shrinkage stress, including incremental layering, low-shrinkage monomers, flowable liners, soft-start and pulse-delay curing, works by altering what happens during that middle step [1-6]. None of them add a step. They slow the reaction, or run it at a gentler ramp, but the underlying sequence remains the same: place, cure once, reach maximum constraint.

The Semi-Split Delayed Gap Closure (SS-DGC) technique restructures that sequence [7,8]. Instead of placement, polymerization, maximum constraint, the SS-DGC runs through placement, gap creation, initial cure, stress relaxation, gap closure, and final cure. Two of these six stages involve light, two involve a deliberate change to the restoration's geometry, and one involves no clinical action beyond waiting.

This paper examines both restorative sequences step by step and then, in Section 5, evaluates the biomechanical advantages conferred by the additional procedural framework. These advantages do not arise because the fundamental polymerization

reactions are inherently less aggressive, but because the SS-DGC technique introduces additional, strategically timed clinical steps that are absent from the conventional approach, thereby modifying how polymerization shrinkage stress develops, dissipates, and is ultimately transmitted to the tooth–restoration interface.

Two Process Architectures

The process architecture of conventional single-event curing versus the SS-DGC six-stage sequence is shown in Figure 1. Conventional technique has a single event separating an unset restoration from a fully constrained one. SS-DGC has four additional stages sitting between those same two endpoints, and each does distinct mechanical work [20]. Gap creation changes the restoration's geometry before any reaction begins. Initial cure runs a reaction under that altered geometry. Stress relaxation allows that reaction's stress to dissipate without adding any new constraint. Gap closure re-establishes a bonded interface across what had been a free surface, setting up a second, different constraint geometry for the final cure [9,10].

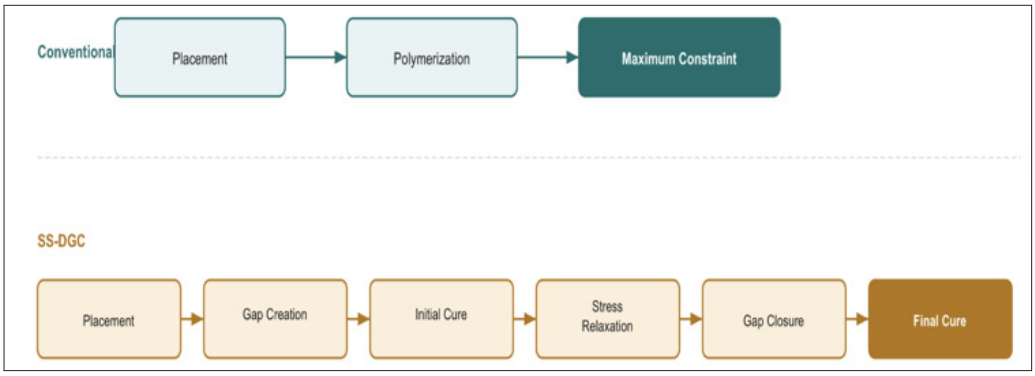


Figure 1: Process architecture: conventional single-event curing (three stages, one reaction) imposing maximum constraint immediately. The SS-DGC six-stage sequence (two reactions separated by a deliberate change in geometry and a relaxation interval), where constraint is delayed via a two-event, gap-mediated cure architecture.

The following sections examine each pathway individually before integrating them into a comparative analysis.

The Conventional Pathway: One Continuous Event

Placement: The composite is placed into the prepared occlusal cavity as a single bulk increment while still in the uncured state. At this stage, the cavity's static C-factor is effectively established, regardless of whether it is explicitly considered during the restorative procedure. The ratio of bonded surfaces (the four axial walls and one pulpal floor) to the unbonded free occlusal surface is determined entirely by the cavity geometry and remains unchanged throughout polymerization. Consequently, the conventional C-factor is fixed before polymerization begins and does not evolve as the curing reaction proceeds [1,8].

Polymerization: Light is delivered and the reaction proceeds from initiation through gelation to whatever terminal conversion it reaches, without interruption. The C-factor fixed at placement governs the entire reaction. Whatever pre-gel viscoelastic relaxation the resin retains is confined to a window measured in seconds, and once the network vitrifies, no further redistribution of stress happens on any clinically relevant timescale [2,7,11]. Soft-start and pulse-delay variants change the shape of this one step, stretching the pre-gel phase or blunting the peak stress rate, but they do not add a step. It remains one continuous reaction from first light to final conversion [11-14].

Maximum Constraint: The sequence ends here, and the name does double duty: it marks both the highest bonded-wall constraint and the highest degree of conversion, reached at the same moment. That combination is exactly the condition under which the composite material's capacity to relax further is at its lowest. Whatever shrinkage stress accumulated during polymerization is now largely locked into the network, because there is no later stage in which the geometry changes or the stress gets a chance to dissipate. The restoration is finished, and so is its stress history.

The SS-DGC Pathway: Six Discrete Stages

Figure 2 shows the workflow of the Semi-Split Delayed Gap Closure technique. The six sequential stages comprise bulk placement, temporary face-diagonal gap creation, initial low-intensity photoactivation, 5-minute dark relaxation, gap closure, and final high-intensity photoactivation These stages are presented below in detail.

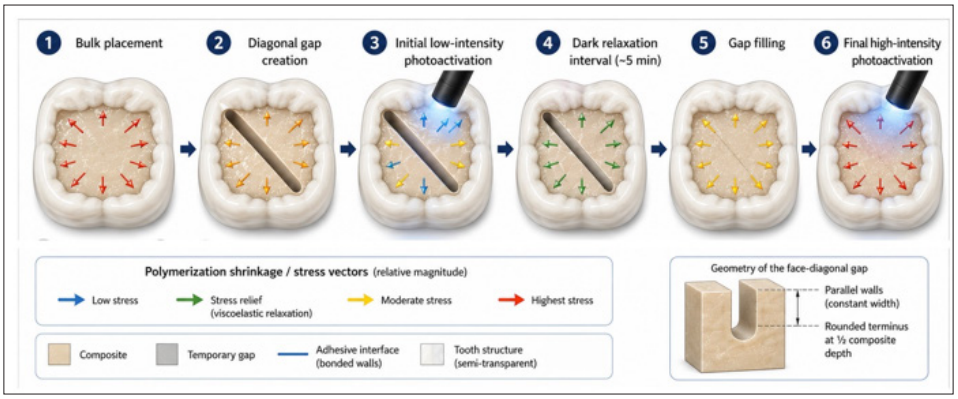


Figure 2: Workflow of the Semi-Split Delayed Gap Closure technique. The six sequential stages are shown. Polymerization shrinkage vectors are depicted as color-coded arrows indicating the relative magnitude of stress within the composite at each stage: blue = low stress, green = stress relief during viscoelastic relaxation, yellow = moderate stress, red = highest stress. The temporary face-diagonal gap is confined within the composite mass, with parallel walls and a rounded terminus at one-half of the composite depth.

Placement: As in conventional technique, the full composite mass is placed in bulk into the prepared occlusal cavity and left uncured. The difference is that nothing about the restoration's final geometry has been fixed yet. In the conventional sequence, placement already determines the C-factor the eventual cure will run under. In the SS-DGC, placement is only a staging step. The geometry that matters comes next.

Gap Creation: A face-diagonal gap, cut corner-to-corner across the occlusal face, 1.5 mm wide and 2 mm deep, is created through the still-unset mass before any light reaches it. This is the step that drops the effective C-factor from roughly 5.67 (in the conventional Class I), down to roughly 2.1.1,8,15 Because the mass is still fully plastic at this point, the cut is clean and the geometry change is complete before any reaction has begun anywhere in the restoration. The reduced-constraint condition applies to the entire reaction that follows, not just to whatever happens afterward.

Initial Cure: A low-intensity cure is delivered with the gap left open. Shrinkage generated during this reaction is drawn toward the unconstrained gap rather than toward the bonded axial and pulpal walls. The reduced intensity slows the reaction, stretching the pre-gel window and giving residual viscous flow more time to work [11,14]. This is the first of the sequence's two reactions, and it runs entirely under the geometry established in the step before it.

Stress Relaxation: A roughly five-minute interval follows in which nothing further is asked of the network: no new light, no new constraint. Nothing in the conventional sequence corresponds to this step, not a compressed version of it, just an absence of it. Over this interval, the primary increment relaxes along something close to a Kohlrausch-Williams-Watts (KWW) stretched-exponential decay, with a characteristic relaxation time (τ) around five minutes and a stretching parameter (β) in the 0.40–0.60 range [11,16,17]. letting a substantial share of the first reaction's stress dissipate before anything new is imposed.

Gap Closure: The gap is filled with the same batch and shade composite originally used, not a flowable liner to avoid introducing an additional variable, which re-establishes a bonded interface across what had, for the previous two stages, been a free surface. This is the second change in constraint geometry the restoration undergoes, and it happens only once the first reaction has already relaxed. The gap is kept clear of the adhesive interface throughout, so this step stays confined to the body of the composite restoration.10

Final Cure: A high-intensity cure completes conversion of the gap-fill composite increment. Because that increment is small in volume and the surrounding material is already vitrified and relaxed, this reaction runs against a substrate that is no longer actively contracting. The constraint experienced here, in both magnitude and character, differs from what the initial cure experienced, and differs again from the single constraint the conventional sequence's one reaction runs under from start to finish [9,12].

Comparative Biomechanical Analysis

The two technique sequences differ in three ways, and each difference maps onto a specific stage rather than onto the pace of a single reaction.

The constraint geometry changes twice in SS-DGC, once at gap creation and again at gap closure, and not at all in the conventional sequence, where the C-factor fixed at placement governs the entire reaction to come. The initial cure and final cure are therefore solving two different boundary-value problems, not two halves of the same one.

The relaxation stage exists in one sequence (SS-DGC) and not the other (conventional). Soft-start protocols slow the rate at which stress accumulates within the conventional sequence's single reaction, but at no point does that reaction actually stop long enough for the material to relax; there is no step for it to happen in. SS-DGC's stress-relaxation stage is a five-minute interval, long enough relative to the material's own relaxation time constant to let a substantial share of the initial cure's stress dissipate before gap closure and final cure begin [11,16].

The two reactions in SS-DGC also run on independent kinetics. The initial cure follows a slower, low-intensity path toward a first network, while the final cure completes conversion quickly against a substrate that has already vitrified and relaxed. The conventional sequence has only one reaction-rate history for the entire mass, so there is never a point where a second, independently initiated reaction lands on an already-settled network [9,12].

The clearest way to see the net effect is to compare the two terminal states. The conventional technique reaches maximum constraint at the same moment it reaches maximum conversion, so the restoration is most constrained exactly when it is least able to relax. The SS-DGC reaches its final cure with most of the restoration already relaxed from the initial cure, and only the small

gap-fill increment carrying newly generated, largely undissipated stress. Both restorations end up fully polymerized. They do not carry the same stress history to get there [6,14].

Clinical and Material Implications

Each of the six SS-DGC stages corresponds to a discrete clinical action, against the conventional technique's two stages: place, then cure. That is a real procedural cost, more chair time than a single bulk fill, a gap that has to be cut with some precision, and a requirement that the gap stay clear of the adhesive interface throughout.

It also reframes the incremental-versus-bulk-fill debate, which has generally been argued in terms of how many increments it takes to keep the C-factor down at each step [6,14]. The SS-DGC turns that into a question of how many biomechanically distinct stages, not just increments, fit into the sequence between placement and final cure [18] The soft-start and pulse-delay literature has similarly treated "delay" as something that happens inside one reaction [9,12,17]. whereas the SS-DGC's stress-relaxation stage is a stage in its own right, sitting between two separate reactions rather than inside one of them [16,17].

Whether the lower terminal stress state this six-stage architecture implies actually shows up as better marginal integrity or reduced postoperative sensitivity is a separate question from the mechanistic case made here, and it will need its own experimental and clinical testing.

Conclusion

Conventional composite placement, whether carefully incremented or intensity-modulated, remains a three-step sequence: placement, one reaction, maximum constraint. The Semi-Split Delayed Gap Closure technique replaces that with six steps; placement, gap creation, initial cure, stress relaxation, gap closure, and final cure, in which two steps change the restoration's geometry, one step does nothing but allow relaxation. Of these steps, two independently timed reactions take the place of the conventional sequence's single one. The distinction is architectural rather than simply kinetic: the SS-DGC does not just slow down the reaction the conventional technique already runs, it inserts steps that reaction never had room for. Whether that architecture's lower terminal stress state holds up as a measurable clinical advantage remains a question for controlled study, but the six-step and three-step sequences are not the same process running at different speeds.

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