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Shifting the C-Factor Paradigm: Moving Beyond Static Geometric Confinement in Posterior Bulk-Fill Resin Composites with Semi-Split Delayed Gap Closure Approach

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Abstract

Background: Polymerization shrinkage stress is one of the principal determinants of marginal integrity in direct posterior composite restorations. The configuration factor (or C-factor) is the ratio of bonded to unbonded surface area. It is conventionally treated as a fixed geometric property of the prepared cavity; it is calculated once and then applied as a static predictor of shrinkage stress for the entire setting reaction.

Objective: To compare this conventional static C-factor model against a dynamic, time-dependent effective C-factor introduced by the Semi-Split Delayed Gap Closure (SS-DGC) technique, and to consider the clinical implications of treating the C-factor as a variable rather than a constant.

Discussion: In conventional bulk or incremental placement, the C-factor of a Class I cavity sits near 5.67 from the first instant of light exposure, so nearly all polymerization shrinkage stress accumulates against a geometry that is already maximally constrained. The SS-DGC interrupts that trajectory. This technique starts by creating a face-diagonal relief gap into the occlusal surface immediately after placement, which drops the effective C-factor to approximately 2.1 for an initial, low-intensity cure. Over the next five minutes, modeled with a Kohlrausch-Williams-Watts (KWW) stretched-exponential relaxation function, viscoelastic flow dissipates a meaningful share of that early stress before the gap is mechanically closed with the same batch and shade composite and a high-intensity secondary cure restores the original, fully constrained geometry. Because shrinkage stress builds as the product of both effective C- factor over time and the instantaneous rate of conversion over time rather than as a function of C-factor alone, shifting the timing of constraint relative to the conversion curve lowers cumulative interfacial stress even though the final bonded geometry never changes.

Clinical Significance: Treating the C-factor as a dynamic, sequence-dependent variable gives clinicians a mechanistic reason to manipulate cure architecture; not just cavity geometry or material selection, when managing shrinkage stress in high C-factor posterior cavities.

Conclusion: The static C-factor model, while foundational, only describes the geometric ceiling of constraint. It says nothing about the stress actually generated, which depends on when that constraint is imposed relative to conversion. The dynamic, effective C- factor over time framework behind the SS-DGC technique reframes shrinkage-stress management as a timing problem rather than a purely geometric one, complementary to the material-based and geometry-based strategies already in use.

Keywords: Static; Dynamic; C-factor; Class I; Bulk-Fill Composite; Semi-Split Delayed Gap Closure; Conventional; Time-Dependent Polymerization; Geometric; Confinement; Shrinkage Stress; Viscoelastic Relaxation; Posterior Composite Geometry

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Introduction

Direct resin composite remains the restorative material of choice for posterior teeth, but polymerization shrinkage still limits how long these restorations last [1,2]. As the resin matrix converts from monomer to polymer, it contracts by approximately 2% to 6% in volume while bonded within a rigid cavity, and this generates shrinkage stress at the tooth-restoration interface [3]. Once that stress exceeds the bond strength of the adhesive interface, the results are marginal gap formation, microleakage, postoperative sensitivity, cuspal deflection, and secondary caries [4-6].

How much stress actually reaches the interface depends heavily on cavity geometry, not just on the amount of shrinkage. This was described as the configuration factor (or C-factor) which is the ratio of bonded to unbonded (free) surface area in a restoration. (1) Cavities with a high proportion of bonded wall relative to free surface as in Class I occlusal box, limit how much the composite can flow to relieve stress as it sets. That is why this configuration is generally regarded as the most biomechanically demanding in restorative dentistry, where a typical Class I preparation has a C-factor near 5.67 [1,7].

For the last four decades, the C-factor has served as a cornerstone in operative dentistry, shaping incremental layering protocols, cavity design, and material selection [1,8,9].

This paper looks at a different model where the C-factor is not fixed but changes over the course of curing. This model is the Semi-Split Delayed Gap Closure (SS-DGC) technique which was developed by the present authors for restoring large/deep occlusal cavities with bulk-fill resin composites. It was first described in 2020 [10], and subsequent work characterized the biomechanical role of the temporary diagonal gap and the benefits of delaying its closure [11], introduced the delayed-closure modification itself [12], and set out its staged three-step clinical protocol [13]. That line of work led to the formal SS-DGC technique, which times gap closure to coincide with the composite's dark-curing viscoelastic relaxation window [14], an explicit conceptual framework built around a time-dependent effective C-factor grounded in staged curing and mechanical stress decoupling [15], and a further hypothesis for exploiting the viscoelastic stress-relaxation window of bulk-fill composites more broadly [16]. In the SS-DGC, a temporary, mechanically created relief gap is cut into the occlusal surface of a Class I composite restoration right after placement, then it is closed partway through the curing sequence. The SS-DGC technique steps are presented in Figure 1.

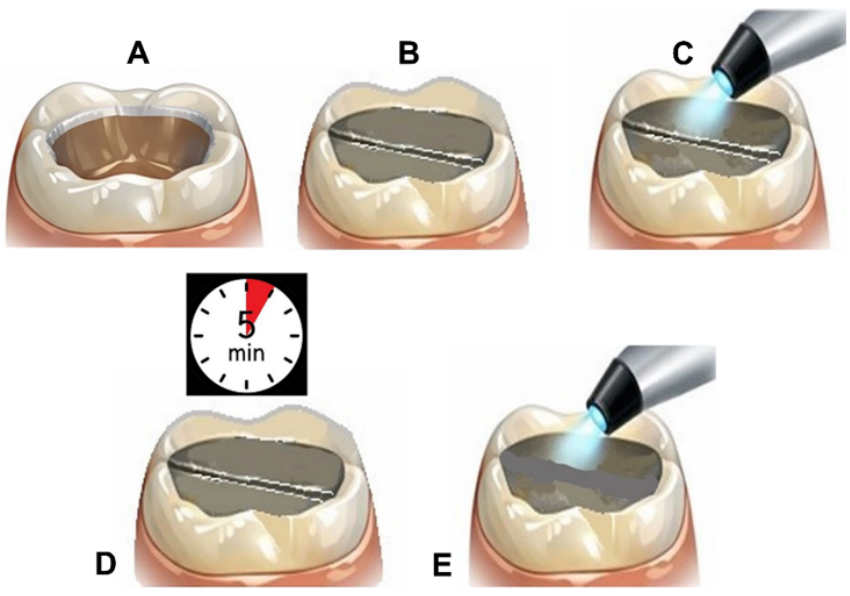


Figure 1: Steps of the Semi-Split Delayed Gap Closure Technique. (A) A deep Class I cavity is prepared with adhesive applied. (B) A single composite increment is placed in the cavity, and a face-diagonal gap is created across the occlusal surface prior to curing. (C) Initial low-intensity curing is performed. (D) The diagonal gap is kept open for 5 minutes. (E) Secondary high-intensity curing is performed after closing the diagonal gap with the same batch and shade composite used originally.

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Because the ratio of bonded to free surface area is not the same before and after that closure, the restoration's effective C-factor is a function of time rather than a single fixed number. In the following sections, the static C-factor model governing conventional placement is compared with the dynamic effective C-factor model governing SS-DGC, considering what it means, mechanistically and clinically, to treat the C-factor as something that can be deliberately sequenced rather than only designed around.

Rationale

The Static C-Factor Model of Conventional Placement

In conventional placement, resin composite is placed in a prepared Class I cavity as one bulk, and from that point on the ratio of bonded to free surface area does not change. Class I cavity has 5 bonded surfaces: buccal, lingual, mesial, distal, and pulpal, and one unbonded surface: the occlusal. For the cavity dimensions used in this paper: 4 mm (L), 3 mm (W), 4 mm (D), the static C-factor works out to about 5.67 [1,7]. Because that ratio is set at the outset, shrinkage from the first moment of light exposure to final set develops against the same, maximally constrained geometry.

The Dynamic, Effective C-Factor Over Time Model of SS-DGC

The SS-DGC began as a modification of the semi-split bulk-filling placement sequence [10], and it departs from convention by placing the entire composite mass as a single uncured increment and then mechanically cutting a face-diagonal gap across the occlusal surface. This gap measures 1.5 mm wide, 2 mm deep, running corner-to-corner along a 5 mm diagonal (derived from the cavity's 3-4-5 proportions). The biomechanical role of this gap as a deliberate stress-relieving feature has been characterized in detail elsewhere [11].

Cutting the diagonal gap brings the effective C-factor down to about 2.1 for as long as the gap stays open. A low-intensity primary photoactivation is delivered with the gap still open, starting conversion under this reduced constraint. This is consistent with earlier work showing that curing-light parameters govern bulk-curing quality and how evenly conversion reaches wall to wall [17]. The gap remains open for a five-minute interval, during which stress relaxation is modeled with a Kohlrausch-Williams-Watts (KWW) stretched-exponential function, using a characteristic relaxation time (τ) of about five minutes and a stretching exponent (β) between 0.40 and 0.60, in keeping with the non-Debye, distributed relaxation behavior already reported for viscoelastic flow in setting composite [18,19]. After this modeled relaxation window, which is informed by the original protocol for delayed diagonal-gap closure [12] and its subsequent three-step refinement [13], the gap is mechanically closed with additional composite of the same batch and shade of composite, restoring the original bonded geometry. After which a high-intensity secondary cure finishes polymerization under the restored, high-C-factor condition.

The key point separating the two models is that shrinkage stress does not build up as a function of C-factor on its own, it accumulates as the product of both the instantaneous effective C-factor and the instantaneous rate of conversion, integrated across the whole curing sequence [1,3]. In conventional placement, the C-factor is just a constant equal to the static C-factor, so this product peaks exactly when the rate of conversion (along with the rate of shrinkage) is highest, during the early, fast phase of polymerization. The SS-DGC deliberately pushes that highest-conversion-rate portion of the reaction into the low-effective C-factor, gap-open interval, and saves the high-C-factor, gap-closed condition for the secondary cure, by which point most of the conversion (and most of the shrinkage) has already occurred. When the tiny temporary diagonal gap is finally filled and cured, the volume of shrinking material is so minuscule that it generates negligible residual stress on the already stabilized, stress-relieved initial foundation. This is essentially the principle formalized as a dynamic, time-dependent effective C-factor in the SS-DGC conceptual framework [12,14,16-18].

The final dynamic C-factor, and the final static C-factor, end up identical between the two techniques. What differs is only the order in which constraint is imposed relative to the conversion reaction.

Appendix A at the end of this paper provides computation of the static and dynamic C-factors.

Discussion

The static C-factor model still has real explanatory value. It correctly predicts that cavities with a higher ratio of bonded to free surface generate more interfacial stress for a given composite and curing protocol, and that relationship is well supported experimentally [1,8,9]. Its shortcoming is not that the ratio itself is wrong, but that the ratio alone is an incomplete predictor of the stress a restoration actually experiences, as it says nothing about when that ratio applies relative to the conversion reaction. Two restorations can share an identical final C-factor of 5.67 and still generate very different cumulative interfacial stress, depending on whether one reaches that constrained geometry before significant conversion has occurred, or only after most conversion (and most shrinkage) has already taken place under a more

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forgiving, lower-constraint condition.

This is consistent with, and builds on, several established findings in the shrinkage-stress literature. Incremental filling works in part because each increment briefly sees a lower C-factor than the finished restoration will have. Also, soft-start or pulse-delay photoactivation protocols work in part by slowing the rate of conversion through the gel-point transition, when the composite is least able to flow and relieve stress [9,19,20]. Both strategies manipulate one term of the effective C-factor over time product; either geometry for incremental layering, or reaction rate for modulated photoactivation without touching the other. The SS-DGC can be read as manipulating both terms together, in a coordinated sequence. That rationale runs through the original delayed-closure protocol [12] and its three-step refinement [13], and is developed further as an explicit hypothesis for exploiting the composite's viscoelastic stress-relaxation window [16]. It is conceptually related to fiber-reinforced "wallpapering" approaches and other strategies that aim, in their own ways, to interrupt a continuous shrinkage-stress vector across a large restoration [21,22].

The KWW relaxation function behind the five-minute interval reflects something already recognized about stress-relaxation kinetics in setting composite. That is to say flow-mediated stress dissipation does not follow simple exponential decay, but a distribution of relaxation times consistent with a heterogeneous, evolving polymer network [3,18]. That is analogous to (though mechanistically distinct from) the flow-dependent stress relief described in early dentin-bond competition studies, where enough viscous flow during the pre-gel phase preserved adhesive integrity against contraction stress [4]. In the SS-DGC, the deliberately created diagonal gap gives that flow an additional geometric outlet beyond what the intact cavity geometry alone would allow. The current authors have described this as extending the pre-vitrification relaxation window through deliberate timing with dark-curing viscoelastic behavior [14], and have elaborated it further as a conceptual hypothesis applicable to bulk-fill composites more broadly [16].

The major finding of this study is that the SS-DGC technique achieved a 62.96% reduction in the C-factor, lowering the geometric constraint metric from a static C-factor of 5.67 to a manageable dynamic effective value of 2.10.

To understand why this macro-geometric alteration drastically improves clinical outcomes, it must be evaluated alongside the time-dependent polymer physics occurring during the 5-minute dark-cure window. Polymerization stress accumulation is not merely a product of volumetric change, it is dictated by a strict race between the material's stiffening rate and its capacity for viscoelastic stress relaxation.

By partially segmenting the bulk composite increment, the 62.96% reduction in bonded-to-unbonded surface area profoundly shifts the boundary conditions of the cavity. In a conventional single bulk-fill (C -factor = 5.67), the polymer network is constrained in almost all directions, locking internal molecules in place and preventing fluid flow. Conversely, in the SS-DGC, the partially segmented geometry (C-factor = 2.1) introduces a wide, free diagonal split. This open boundary allows the material to shrink laterally and deform outward toward its respective bonded walls without dragging the opposing tooth structures with it, preventing micro-separation at the adhesive interface.

This massive geometric relief directly amplifies the material's natural stress-dissipation mechanisms during the subsequent 5-minute dark-cure window. This interplay can be mathematically illuminated by the KWW stretched exponential model: $\sigma(t) = \sigma 0 \cdot \exp [- (t/\tau) \beta]$ [18,19].

During this 5-minute (t = 300 s) post-irradiation window, the removal of continuous light exposure causes the instantaneous polymerization rate ($d\alpha/dt$) to decelerate sharply. The reaction shifts from aggressive photo-induction to a slow, controlled dark-curing phase. Because the geometric constraint was previously slashed by 62.96%, the molecular chains maintain enough spatial mobility to exploit the material's characteristic relaxation time (τ) [23].

In the early stages of dark curing, the characteristic relaxation time (τ) remains low relative to the elapsed time (t), which means that the polymer network can dissipate accumulated forces rapidly. As time passes within the 5-minute window, the network inevitably grows more complex, cross-linked, and crowded. This micro-structural heterogeneity causes the fractional exponent (β) to drop well below 1, indicating a highly varied distribution of internal relaxation modes [23].

Crucially, because the clinician waits a full 5 minutes before filling the remaining diagonal gap, the total elapsed time (t) comfortably outpaces the material's internal relaxation clock (τ). Even as the material hardens and (β) diminishes; eventually locking the composite into a rigid vitrified state, the internal molecular chains have already had sufficient time to slip past one another and permanently discharge their residual strain tensors [24].

Consequently, when the minuscule remaining diagonal gap is finally filled and photo-activated, the bulk of the restoration has already reached physical and viscoelastic equilibrium. The volume of the final closing composite increment is so small that its subsequent shrinkage

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stress is completely negligible. By combining a 62.96% reduction in initial geometric constraint with the deliberate preservation of viscoelastic relaxation parameters (τ, β), the SS-DGC technique successfully mitigates interfacial tension, presenting a highly predictable approach to restoring deep posterior cavities [23,24].

Several clarifications regarding the mechanical limits of the SS-DGC technique must be established. The dynamic, effective C-factor model does not argue that the protocol decreases total volumetric shrinkage, nor does it change the final C-factor of the completed restoration as those remain properties of the material and the finished cavity geometry, respectively, unchanged from conventional placement [11,15].

In conclusion, the critical variable shifted by the SS-DGC protocol is the temporal alignment between structural constraint and the resin conversion reaction. The dynamic model argues that this kinetic timing—rather than the endpoint geometry—serves as the primary, clinically relevant determinant of realized interfacial stress. This perspective aligns with the current authors' broader work mapping the biomechanical effects of the diagonal gap and its tactical timing [11], as well as the explicit, staged-curing framework that underpins the SS-DGC protocol [15]. Ultimately, managing the chronological path of stress accumulation offers a predictable pathway to protect the adhesive interface in high-constraint cavity preparations.

Clinical Pearls

- Keep the relief gap confined to the occlusal face only. A channel that reaches or undermines the adhesive interface removes bonded surface area rather than adding free surface area, and will not lower the effective C-factor the way it is meant to.
- Fill the gap with the same batch and shade of composite used for the primary placement. Introducing a flowable liner or a different material at the gap interface just adds an unnecessary interfacial variable to what is already a two-cure sequence.
- Let the full five-minute relaxation interval run before closing the gap. Cutting it short interrupts the KWW relaxation process before a meaningful fraction of stress has had time to dissipate.
- Deliver the primary cure at genuinely low intensity. A primary cure run at full intensity defeats the purpose of the gap-open interval by driving rapid conversion before relaxation can occur.
- Save the high-intensity secondary cure for after the gap is closed. Completing a full cure while the gap is still open will not achieve the intended sequencing; it effectively turns the technique back into conventional placement with an extra step.
- Check that cavity proportions approximate the model 4 mm × 3 mm × 4 mm Class I geometry mentioned in this paper before applying the model 1.5 mm × 2 mm × 5 mm gap dimensions. A substantially different cavity size will change the achievable effective C-factor and may call for recalculation.

Clinical Pitfalls

- Cutting the gap too deep, or too close to the pulpal or axial walls, risking contact with the adhesive interface and undoing the intended reduction in effective C-factor.
- Assuming a lower gap-open C-factor removes the need for a high-intensity secondary cure. Incomplete final conversion compromises mechanical properties regardless of how much stress relaxation was achieved during the gap-open phase.
- Applying the technique to cavity geometries well outside the dimensions mentioned in this paper without adjusting the gap specification, which can produce a smaller or larger free-surface increase than intended and unpredictable effective C-factor values.
- Treating the five-minute relaxation interval as a fixed rule rather than a modeled estimate. Relaxation kinetics can vary with composite formulation, and clinicians should not assume identical behavior across materials without data to support it.
- Neglecting isolation during this multi-stage procedure with extended chair time carries more risk of moisture contamination than a single-stage conventional placement.
- Overgeneralizing the dynamic, effective C-factor over time concept to unrelated techniques or materials without independent validation. The relaxation parameters (τ, β) described here were modeled for this technique's specific geometry and sequence may not transfer directly to other configurations.

Conclusion

The conventional static C-factor model describes the geometric ceiling of constraint in a posterior composite restoration, but it does not, by itself, predict the stress actually generated during setting, because it leaves out the timing of that constraint relative to the conversion reaction. The Semi-Split Delayed Gap Closure technique serves as a dynamic alternative to conventional protocol designs. By temporally decoupling the curing phases, this approach lowers the effective C-factor during the period of peak conversion rate. The structural constraint is only restored after a modeled viscoelastic relaxation window has passed, successfully dissipating early-stage post-irradiation stress. Because the final bonded geometry and total shrinkage

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are the same in both approaches, the variable that actually distinguishes them is sequence (not design) which positions temporal control of constraint as a complementary strategy alongside established geometric and material approaches to shrinkage-stress mitigation.

Clinical Implications

For clinicians managing high C-factor posterior cavities, shrinkage-stress mitigation does not have to rely solely on incremental layering, or low-shrinkage materials. Deliberately sequencing when constraint is imposed relative to the conversion reaction provides an additional, complementary lever.

The published C-factor values should be interpreted merely as an upper bound on structural constraint, rather than a definitive prediction of clinical stress. Two distinct curing protocols can yield identical final restorative geometries yet impose vastly different cumulative stresses on the adhesive interface based on their cure architecture.

While this opens an exciting avenue for stress management, broader protocol-level guidelines await further clinical and laboratory validation of the SS-DGC sequence. Direct stress measurements mapping the full, dynamic trajectory of the effective C-factor over time remain necessary before implementing definitive chairside recommendations.

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