Evaluation of Marginal and internal adaptation of adhesive class II restorations, in vitro fatigue tests
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Chapter 8:

Rationale for the application of direct & indirect adhesive restorations in the treatment of posterior teeth
Managing stress development

While composite resin properties, such as physico-chemical characteristics, wear resistance, radiopacity, handling and aesthetics, can be regarded, as clinically satisfactory, composite polymerization shrinkage remains the material's ultimate drawback. Although it was significantly reduced in modern composite formulations (Bowen et al, 1983; Davidson et al, 1984; de Gee et al, 1993; Labella et al, 1999; Stravidakis et al, 2000), it is still too high to allow direct techniques to be simply applied in large class I and II restorations (i.e.: using a bulk filling technique with either chemical or light cured composite). Immediate and delayed composite polymerization shrinkage stresses and masticatory forces actually have potential to damage the internal and marginal adaptation. Apart from the restorative technique influence, these forces and their consequences are affected by several factors such as:

- cavity volume
- cavity configuration (Feiltzer et al, 1987; Yoshikawa et al, 1999)
- extension of the cavity toward CEJ
- enamel thickness and quality (presence or absence of wear facets, cracks and fissures, etc...)
- dentin quality (location and depth; diameter, density and orientation of tubules; degree of tissue sclerosis; possible contamination (i.e.: by eugenol based dental cements); decay, etc...)
- bond strength of the adhesive
- material composition and structure

Therefore, after having analyzed the conditions specific of the tooth to be restored, the clinician's major challenge remains to balance stresses with adhesion and favor stress reduction or relief by all possible means. Stresses can actually be controlled or relieved by different means, not all of which are under the control of the operator.

1) controlled stress reduction (Fig.8.1):
   - application of a thick "elastic" bonding resin (first stress breaker layer) (Kemp-Scholte and Davidson, 1990a & b) (Fig.8.1A)
   - use of the selective bonding technique (Lutz et al, 1986a and b; Krejci and Stavridakis, 2000) (Fig.8.1B)
   - application of a "low elasticity module " base-lining (second stress breaker layer) (Bindi, 1998) (Fig.8.1C)
2) stress relief by other phenomenon (only partially or not under the control of the operator):
   - deformation of the composite at the free surfaces, so called "flow" (Davidson and De Gee, 1984) (Fig.8.1E)
   - elastic deformation of the adhesive and restorative materials (Fig.8.1F)
   - elastic deformation of the tooth (Fig.8.1F)
   - water sorption

Theories and controversies about stress development and polymerization vectors in posterior restorations

Understanding how stress develops during composite polymerization is of main importance as this information would bring definite solutions and concepts for controlling its negative effects. However, the monitoring of stress kinetics and distribution within composite increments during the build-up of a restoration is a challenging task and has thus far been approached only by indirect observations (evaluation of the final restoration marginal seal or adaptation) or computer simulation (finite element analysis: Versluis et al, 1997 and 1998; Labelia et al, 1999; Ausiello et al, 2001 and 2002; Barink et al, 2003). Although there is no universally accepted proof or model available, some basic rules seem to apply to direct light-curing of composite restorations. Actually, the stress magnitude and direction probably is governed by the following main factors:

- **light**: activation mode – intensity – direction – spectrum
- **increment**: thickness – configuration (ratio free to bonded surface)
- **composite**: reactivity (relative to initiator-catalyst amount) – opacity – chroma
- **filler**: composition – size – shape – amount
- **cavity shape**
- **adhesion efficacy**

Light activation

Many protocols of light-activation were proposed, such as continuous curing (with different light intensities), ramp-curing, soft-start (sequential curing) curing and pulse-delay curing. The recognized problem of continuous curing (the classical approach) is the fast development of stresses and contraction due to the early and short duration of the gel phase, until which "flow" is made possible without rising stress. The idea was then to slow down the polymerization reaction by either reducing the initial light intensity (soft-start curing or low-
intensity curing) (Uno and Asmussen, 1991; Feilzer et al, 1993 and 1995; Goracci et al, 1996; Sakaguchi and Berge, 1998), initiating the curing reaction by a short illumination and delaying the final cure (pulse-delay curing) (Koran and Kurschner, 1998, Suh, 1999; Sahafi et al, 2001a and b) or by increasing the inhibitor concentration (Braga and Ferracane, 2002). While studies on low-intensity and soft-start curing were unable to confirm the expected reduction in polymerization stresses, pulse-delay curing proved much more effective to attain this objective, perhaps by actually slowing down polymerization kinetics or by alteration of the resin structure (reduced cross-linkage) (Asmussen and Peutzfeld, 2001; Sahafi et al, 2001a and b). In addition, it was shown that extended curing times have little influence on the resin degree of conversion but significantly increase contraction stresses (Braga and Ferracane, 2002). Therefore, the use of high irradiance curing units (>1000 mW/cm$^2$) appears only necessary for indirect curing (luting of indirect restorations) while it could even be detrimental to restoration quality when applying direct techniques. This suggests a practical curing time of 20 to 40s with a medium light irradiance (400 to 800 mW/cm$^2$) for direct incremental techniques.

However, the influence of curing protocol on restoration quality remains to be evaluated in a relevant clinical configuration and compared to other means for reducing polymerization stresses. Further research is then needed to determine whether the use, for instance of pulse-delay curing, can lead to a simplification of existing restorative techniques.

**Light intensity & direction**

Within a thin increment (≤1mm) of a low chroma and translucent composite material, we do assume that the light produced by a powerful curing device (above 600 mW/cm$^2$ curing light irradiance) kept close to the material surface will be attenuated but will remain at an intensity susceptible to generate an almost uniform distribution of polymerization stresses (Fig.8.2A) (Rueggeberg and Jordan, 1993; Rueggeberg et al, 1994a; Asmussen and Peutzfeld, 1999). Until research invalidates this assumption, our clinical concept will be developed accordingly.

**Increment thickness**

We have to expect a different (non-uniform) distribution of polymerization stresses when curing large and thick increments (more than 2 mm of restorative material, especially with opaque and dark shades) or when light intensity is significantly reduced, for instance when the bulb is deficient or in case of light absorption by a restorative material or tooth substance (indirect curing) (Rueggeberg et al, 1994a, b and c; Myers et al, 1994; Asmussen and Peutzfeld, 1999; Kinomoto et al, 1999; Rueggeberg et al, 1999) (Fig.8.2B and 8.2C). The observed polymerization patterns in thick composite layers seem to confirmed former assumptions (Hansen, 1982; Lutz et al, 1986a); actually, polymerization shrinkage is roughly directed toward the light source and away from the cavity base but is influenced by the increment thickness and
surface of adhesion at the cavity walls (cavity configuration) (Asmussen and Peutzfeld, 1999). Maximal stress might occur at the internal angles in a box-shape cavity (Kinomoto et al., 1999).

**Increment configuration**

The ratio between the free and bonded surface determines the amount of stress relief by flow at the free surface (Feilzer et al., 1987; Asmussen and Peutzfeld, 1999; Kinomoto et al., 1999). The rationale for applying multilayer techniques is to reduce the overall polymerization stress by increasing the number of increments and giving them an ideal geometry augment the total free surface (Fig. 8.1D). Clinical experience and the largest number of studies support this theory. As a matter of fact, the application of a "bulk" technique should be indicated only for preventive restorations (minimal volume).

**Composite structure and composition**

The ratio resin-filler is another governing factor in determining polymerization shrinkage magnitude and material physical performances. Therefore, choosing a material with a high filler content is a prerequisite for producing restorations of good quality in posterior teeth. In addition, an expired material will not only potentially change the curing kinetics but also can favor premature restoration degradation because of incomplete material polymerization. Composite structure seems less influential than aforementioned parameters (Rueggeberg et al., 1993; Rueggeberg et al., 1994c).

**Conditions to achieve optimal results & clinical concept**

Three conditions need to be considered – the minimally invasive restoration – the medium size restoration – and the large restoration (Dietschi and Spreatifico, 1997). For the two “extreme” situations, a clear approach is mandated; a bulk technique for the minimal preparation (Simonsen, 1985) and a semi-direct or indirect inlay-onlay for a large volume and cusp replacement (Krejci et al., 1993; Dietschi and Herzfeld, 1998). The medium size restorations require a more discerning approach, as the best treatment option implies an optimal combination between the clinical effort and final restoration quality. Although layering techniques and base-liners have the potential to reduce effectively the damaging consequences of aforementioned stresses, the spontaneous post-polymerization shrinkage, which take place during the following 5 to 10 days after light activation (Leung et al., 1983; Davidson et al., 1984; Kydal and Ruyter, 1994), still represent a major obstacle to the use of direct techniques in very large cavities with unfavourable configuration (such as 2 surface class II or class I restorations).

Thereafter, the following guidelines are to be taken into consideration:
1) Occlusal cavity, less than 1/3 of the bucco-lingual tooth width: horizontal layering technique (Lutz and Kull, 1980)

2) Occlusal cavity, more than 1/3 of the bucco-lingual tooth width: oblique layering technique (Weaver et al, 1988)

3) Proximal cavity within the contact point area: horizontal layering technique (Lutz and Kull, 1980)

4) Proximal cavity outside the contact point area: 3-sited light-curing method (Lutz et al, 1986a and b)

Polymerization stresses can further be absorbed by a lining or base made of a more "elastic" material, such as a thick bonding resin layer (Davidson, 1994; Choi et al, 2000; Ausiello et al, 2001 and 2002), a flowable composite (Olsburgh, 2000), a glass ionomer or compomer (Lutz et al, 1986a; Davidson et al, 1994; Friedl et al, 1997; Hannig et al, 1997; Bindi, 1998; Olsburgh, 2000). A recent paper however questioned the use of low elasticity adhesives which reduce the interfacial fracture toughness ($K_{IC}$); this type of material would therefore not be ideal to create a high interfacial fracture resistance in bonded restorations (Tam and Pilliar, 2000). This perhaps speaks in favour of using adhesives with intermediate elasticity and which create a thicker layer (Ausiello et al, 2002). Despite the fact that Compomers did show a good potential as liner underneath adhesive restorations, our own experience questions now this indication. Actually, it is likely that the water sorption which take place in products such as Dyract (Detrey-Dentsply, Constance, Germany) produces a slight volumetric expansion, which in turn, creates micro or macro cracks in the surrounding tooth structure (especially in a class I configuration or when the compomer is applied in deep cavity depressions) (Fig 8.3).

It is in particular useful to apply base-liners, when using a so-called "one-bottle adhesive. Although most of modern adhesive systems provide bond strength values in a similar range (May et al, 1997; Wakefield et al, 1998; Wilder et al, 1998; Tanumiharja et al, 2000), they do not necessarily provide the same quality of restoration adaptation. Actually, unlike the thick-filled adhesives, the "one-bottle" adhesives rely on the formation of a very thin adhesive layer (a few microns only), which has no potential of "stress absorption" and a low interfacial fracture toughness.

When applying the selective bonding concept, with aim of determining the location of the separation when polymerization forces exceed a certain value, some specific adhesives are to be recommended (i.e.: Syntac Classics, Vivadent, Schaan-Liechtenstein; A.R.T. Bond, Cotlenwhaledent, Alstätten, Switzerland) (Fig 1B). In larger cavities, a conventional glass ionomer base can be applied (Table 8.1), which play the same role and help reducing the amount of composite material to be cured in situ. However, one have to exert care when restoring fragile upper premolars, especially in case of a class II cavity design, with a group
guidance (specific occlusion pattern) and/or parafunctional forces, which present a risk of cusp fracture due to a limited adhesion surface.

Table 8.1 offers a guideline for selecting the adhesive system and concept, base-liner and restorative technique, according to the clinical situation.

**Clinical relevance**

In order to obtain the maximal quality and durability of direct posterior composite restoration, the clinician has to be aware of the following rules:

- limit the cavity size and extension, where a direct technique is applied
- evaluate all conditions which govern stress development and adhesion efficiency
- subsequently, use appropriate means (selection of the adhesive system and concept, application of a base-liner and use of a multilayer technique) to optimally reduce the negative consequences of polymerization stresses
Table 8.1: Suggested restorative techniques according to cavity design, cavity size and adhesive concept (the clinician choose between TB or SB).

<table>
<thead>
<tr>
<th>Cavity design</th>
<th>Cavity volume</th>
<th>Total Bonding</th>
<th>Selective Bonding</th>
<th>Technique</th>
<th>Layering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Minimal</td>
<td>DBA* (+) Thick DBA (+) Base-lining</td>
<td>GI Base (+) DBA + resin (+)</td>
<td>Direct (Semidirect)</td>
<td>Vertical/oblique</td>
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<tr>
<td></td>
<td>Medium</td>
<td>(+) (+) (+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>(+) (+) (+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td>Minimal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adhesive</td>
<td>Medium</td>
<td>(+) (+) (+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>(+) (+) (+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class II MO/OD</td>
<td>Minimal</td>
<td>(+) (+) (+)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Medium</td>
<td>(+) (+) (+)</td>
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<td></td>
<td>Large</td>
<td>(+) (+) (+)</td>
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<tr>
<td>Class II MOD</td>
<td>Minimal</td>
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<td></td>
<td>Medium</td>
<td>(+) (+) (+)</td>
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<td></td>
<td>Large</td>
<td>(+) (+) (+)</td>
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<tr>
<td>Cusp coverage</td>
<td>(+) (+) (+)</td>
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</tbody>
</table>

* DBA, but without stress-breaker layer formation

TB = Total Bonding
SB = Selective Bonding

RATIONALE FOR THE TREATMENT OF POSTERIOR TEETH
Figure 8.1: Means and phenomenon which allow stress compensation or reduction. A: thick bonding resin layer; B: Selective bonding concept; C: low elasticity module base-liner; D: Multilayer technique; E: flow at the free surfaces; F: elastic deformation of tooth substrate and restorative material.
Figure 8.2: Expected polymerization vectors in thin (A&B) or thick layers (C), according to the light tip distance, the light intensity and increment thickness - chroma and opacity. A stands for – the light tip kept close to material surface– high light intensity– low composite chroma and opacity. B stands for – the light tip kept further to material surface – low light intensity – high composite chroma and opacity . C stands for a thick increment (other parameters do not play any role).

Figure 8.3: Composite restoration after 2 years of clinical service. A fracture of the disto-buccal cusp is clearly visible. Such finding is unlikely to be only in relation with masticatory forces; actually this was frequently observed when the compomer Dyract was applied as a base; water-sorption and subsequent swelling is the likely explanation of this early failure.
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