Adhesion, biomaterials, and CAD/CAM

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We're living in a challenging and intense world, with an unclear future on the horizon. In a context that challenges our beliefs, we must strive to be professionals and experts – to keep the faith. In dentistry, the plethora of materials and techniques available to us can be challenging for our 'dental faith'. As a practitioner trying to find their way amidst an avalanche of new dental products, new technologies, and contradictory scientific publications, it is more important than ever to examine our beliefs, our values, and the foundations that will allow us to make the best choices.

Four synergistic components play their part in making these decisions: science, experience, good sense, and the patient.

Science

In theory, the scientific method is a fundamental basis according to which a hypothesis is tested using varied levels of evidence (expert opinions, in vitro tests, clinical case presentations, series of cases, cohort and random clinical studies, systematic reviews and meta analyses). Unfortunately, the scientific approach has its failings.

Clinical study conditions don't always represent clinical reality. For medical ethical reasons it isn't possible to standardise all clinical conditions. Results are 'polluted' by a multitude of confusing variables, such as the operator, the nature of the clinical table, the patient habits, and so on.

Consequently, it's not unusual to have a null hypothesis (absence of differences between the method or material tested and the control method), especially with clinical studies which present a majority of factors provoking confusion, by default.

With this in mind, studies combined with digital simulation and in vitro tests represent considerably more advantageous research tools thanks to the possibilities of extreme standardisation (Korioth and Versluis, 1997; Magne et al, 1999).

Experience

It has been shown that one of the significant variables of clinical practice is represented by the practitioner himself and by his skill to master a specific approach. For example, in medicine, a study on carotid stenting clearly showed that patients treated by experienced operators presented lower risks of complications (Calvet et al, 2014).

Similar data exist concerning the performances of dental bonding as much in vitro as in vivo (Unlu et al, 2012; Kemoli et al, 2009).

Clinicians who participate in numerous training courses and who develop bonding skills will consequently be more likely to produce more reliable results (Bouillaguet et al, 2002).

Good sense

It is clear that numerous daily clinical acts lack high level scientific substantiation. The scientific community itself recognises the existence of a 'speaking pig', according to Bandolier's parable. This is a parable that explains that good sense must be employed even in scientific methods.

According to this parable, a researcher trained a pig to speak. You might think this is crazy, but if the aforementioned pig spoke to you to wish you a good evening, we

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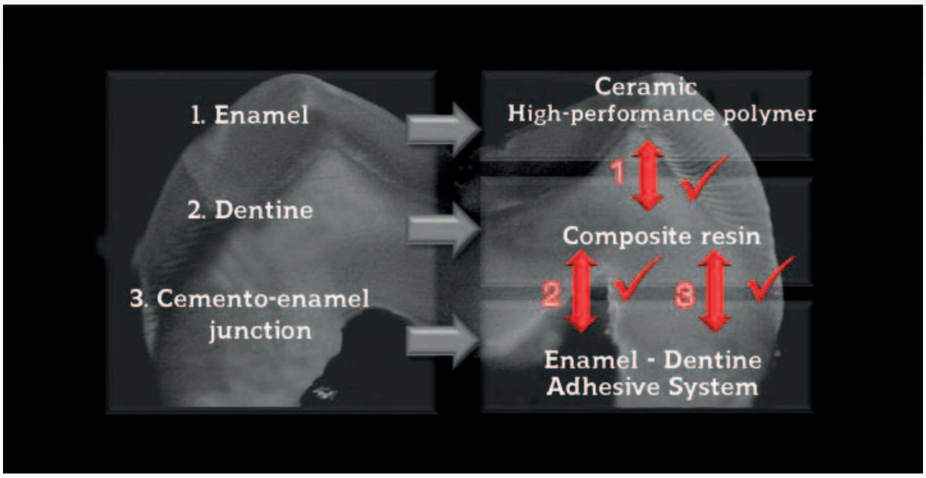

Figure 1: Three skill levels of adhesion are necessary to apply the biomimetic principle.

Table 1. The De Munck et al meta-analysis revealed the adhesive performances (dental bonding resistance in micro-tension) of the 10 most tested adhesives in research, as well as the loss of adhesion after one year (in % in brackets

Meta-analysis of adhesive performance (dentine bond strength in microtension)			
1. Optibond FL	49.7 MPa	44.8 MPa	(-10%)
2. Clearfil SE Bond	45.4	38.6	(-15%)
3. Scotchbond 1	42.2	30.9	(-27%)
4. Xeno III	38.6	28.6	(-26%)
5. Scotchbond MP	38.4	30.3	(-21%)
6. Clearfil S3	37.8	26.1	(-31%)
7. One-Step	36.3	23.2	(-36%)
8. Prime & Bond NT	35.9	23.5	(-36%)
9. Prompt L-Pop	31.4	20.4	(-35%)
10. One-up Bond F	27.9	18.0	(-35%)

hope that you would be surprised without necessarily thinking about the 100 pigs selected randomly so as to verify the phenomena. What's most important is the fact that the pig speaks.

Along the same lines, we can ask the question, is a randomised study necessary to prove that the use of a parachute will prevent death in the event of an air crash (Verkamp, 2010)?

These examples show that good sense must be applied in each situation. Equally, it's not unusual that contradictory scientific data is produced, thus requiring a decision based on experience and good sense.

The patient

Finally, it is entirely possible that science, experience, and good sense all indicate the same therapeutic solution. Nevertheless, the patient can be unable to choose this solution due to, for example, questions of finance or availability.

A part of the treatment, or a 'low cost' alternative, that doesn't necessarily correspond to the ideal solution proposed by the treatment team must therefore be explored.

The biomimetic approach and Bio-Emulation

The retention and type of resistance of dental preparations has, for a long time, been a key reference for the placement of traditional restorations, as much for prosthetics (bridges and crowns) as for 'conservation' (fillings). These approaches (which are unfortunately still to be found in the armamentarium of certain of our colleagues) didn't give the optimal maintenance of healthy tissue and pulp vitality and could result in a reduced life cycle for the dental organ concerned (Simonsen, 1991).

Fortunately, over the last 20 years, a fundamental element that has characterised natural tooth restoration has been unanimously approved of by new generations: it concerns the deep respect for healthy dental tissues and the recognition of the fact that an intact natural tooth is not the result of human willingness, but is the result of a divinely conceived, engineered, work of art.

Therefore, it is the clinician's responsibility to maintain the biological, functional, mechanical, and aesthetic balance of the dental tissues in relation to the restorations required (Magne and Douglas, 1999). The socio-economic stakes can be critical. The success of developing restoration materials and techniques in these domains has an immediate and long-term impact on dental surgery, as much in poor as in rich countries around the world.

With this in mind, the study of the natural tooth at all levels remains the driving force behind the approach known as 'biomimetic' or 'Bio-Emulation' (Magne, 2006; Bazos and Magne, 2014; Bazos and Magne, 2011).

Natural teeth are composed of a 'brain' (the pulp), itself protected by a hybrid mechanical structure, both resistant and resilient. Indeed, the dentine forms an elastic structure, capable of absorbing the repeated shocks of chewing thanks to elastic and viscoelastic deformation.

Equally, the periodontal ligament and alveolar bone support this compensatory deformation. The enamel operates in total synergy with the dentine, furnishing it a morphological and functional stability in spite of the abrasive, attrition and chemical erosion 'attacks'.

The cornerstone: 'trinitarian' adhesion

The combining of the enamel with the dentine via the dentino-enamel junction (DEJ) forms the cornerstone of the long-term operation of the natural tooth (Lin and Douglas, 1994). The same goes for dentino-enamel adhesion in the biomimetic approach, which has enabled the total abandon of the principles of retention and forms of resistance (including dental and root posts) and the application of the principal of the absolute preservation of healthy tissues, even in the most desperate of situations concerning anterior and posterior teeth (Walls, 1995a; Walls, 1995b; Magne and Magne, 2005a; Magne et al, 2016).

Nonetheless, a profound knowledge of adhesion principles is necessary to correctly apply biomimetic principles so as to reproduce structural continuity between the enamel and the dentine (DEJ).

Three adhesive interphases must be considered (Figure 1): the composite resins constitute the hub of this 'trinitary' adhesion because they enable the combining of the restoration material and the tooth. It is generally agreed that resinous adhesion to restoration material can be easily mastered, be it resin (direct or indirect in the form of high performance polymer) or ceramic.

A methodical approach by micromechanical retention (etching by fluorhydric acid for ceramic, microabrasion for polymer), meticulous cleaning (by ultrasonic wash) and chemical coupling (silane application and heat-drying) is generally recommended (Roulet et al, 1995; Jardel et al, 1999; Magne and Cascione, 2006; Magne and Knezevic, 2009).

There are two distinct aspects to resinous tooth adhesion. First of all, bonding to the enamel by acidic etching and secondly dampening through a low viscosity resin, both are generally acknowledged as being stable and extremely reliable. Nevertheless, it must be noted that the enamel, once etched, remains fragile and specific precautions (gentle pressure) are essential so as not to damage the hydroxyapatite prisms during the dentine conditioning, or even during the application of the adhesive on the enamel itself.

It is also important to note the importance of the bevels for a transversal section of the prisms and for an optimal adhesion, especially in the interdental zone (Carvalho et al, 2000; Hugo et al, 1992).

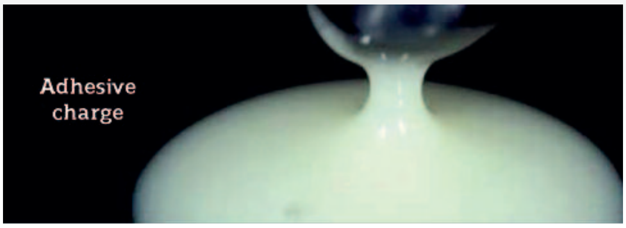

Figure 2: A structural adhesion to the dentine requires a filled adhesive such as Optibond FL, which contains 48% of filling (weight).

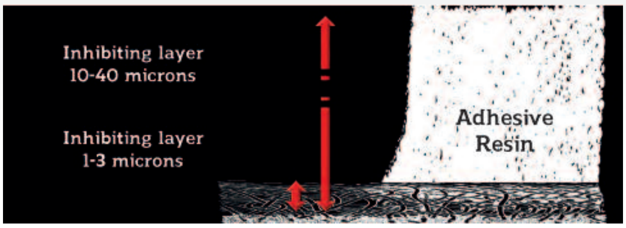

Figure 3: Problematics of the inhibiting layer in dentine adhesion. This layer can attain a thickness of 40 microns, which poses a problem of polymerisation of adhesive systems that are too thin. The hybrid layer itself only presents a thickness of between 1 and 3 microns

Dentine adhesion is a much more controversial subject. This is because more than a hundred adhesive systems are used around the world, many of which lack established and 'proven to be efficient' clinical surveillance. Adhesive systems are the perfect example of the plethora of commercial methods and products used and of a dental market influenced by competition between brands rather than by clinical performance. Consequently, certain adhesives are developed and promoted uniquely to target a competitor brand.

A healthy and structured dental adhesion

In 2012, a meta-analysis conducted on the parameters involved in dental adhesion highlighted the unjustified plethora of commercialised adhesive systems (Table 1). The study revealed a list of the 10 most tested adhesive systems. Optibond FL (Kerr) and Clearfil SE Bond (Kuraray) are the top two systems.

First commercialised in 1992 (first version – dual polymerisation), then replaced by the current version in 1994, Optibond FL (Figure 2) remains the uncontested market leader, with an adherence close to 50 MPa and the weakest level of degradation.

Purely for comparison purposes, a study on dentino-enamel adhesion revealed a constraint between 47.7 and 51.5 MPa (Urabeet al, 2000). It must be concluded that adhesive systems have the potential to reproduce the DEJ, on condition that simplified systems are avoided, particularly the 'all-in-one' systems (De Munck et al, 2012).

Another essential element is the adhesive application. Dentine hybridisation implies the demineralisation of the surface layer of the dentine. Nevertheless, the hybrid layer remains extremely thin, between 1 and 3 microns, depending on the system. An adequate polymerisation of the adhesive layer is primordial to protect the hybrid layer (Van Landuyt et al, 2009).

For this reason, it is essential to recognise the inhibiting effect of oxygen on the polymerisation of the resins, which can easily reach a depth of 40 microns (Shawkat et al, 2009) and impact on the adhesive quality on the dentine (Figure 3) (Endo et al, 2005).

Hence, a perfect polymerisation of the interphase adhesive requires a layer of approximately 60 to 80 microns of adhesive resin. Thus, a micro-filled adhesive system such as Optibond FL offers a clear advantage thanks to the resin viscosity, which contains approximately 48% of fillings (includes fillings noticeably radiopaque).

As such, this adhesive acts as a composite fluid (liner) and enables a structural adhesion with the restoration. Indeed, a thick layer of adhesive resin is recommended to improve restoration adaptation (Pecie et al, 2013). It is important to understand this structural aspect in the adhesive dentine. An extremely fine adhesive, the all-in-one type, carries the risk of being badly polymerised (Van Landuyt et al, 2009) with all the complications that can ensue (compression with damage to the hybrid layer during the placement of the restoration, solubility increased etc).

Immediate dentine sealing (IDS) of dental preparations

Structural dentine adhesion requires a substantial and uniformly dense adhesive layer of roughly 80 microns. Therefore, it is essential that this layer be included during the restoration impression (semidirect or indirect), be it an analogue or a digital impression. This explains why we need

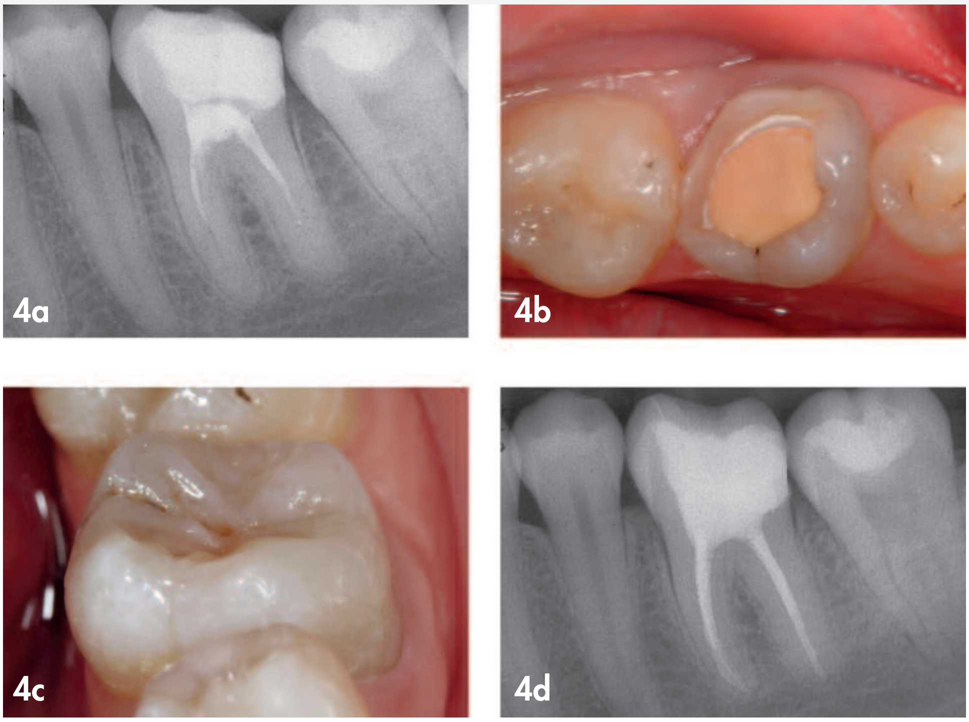

Figure 4: Restoration without posts or crown of a severely decayed first molar. Radiological situation (a) and clinical (b) following the elevation of the distal margin by direct adhesive restoration. Clinical (c) and radiological (d) situation after laying an indirect composite resin onlay (sealing of the onlay done in the Geneva Student University Clinic with Philippe Beuret).

to apply the adhesive system to the dentine immediately following the dental preparation (Magne, 2005).

In addition to demonstrating an adhesive quality that is superior to that of the traditional technique, the IDS assures a multitude of protective functions during and subsequent to the provisional phase and avoids the use of anaesthetic for the final restoration test, as well as facilitating the occlusal adjustments after the adhesive sealing.

A methodical application of the IDS has been described (Magne, 2014), and more than 20 advantages of the technique have been listed by the author, who possesses more than 20 years' experience.

An adhesive filler such as Optibond FL represents a clear benefit for the IDS technique through its capacity to generate a consistent resin layer, whereas a non-filled resin has an insufficient depth in the convex zones of the dental preparation (Stavridakis et al, 2005).

Neither posts nor crowns: an achievable goal?

In this context, it is particularly interesting to explore the possibility of completely abandoning the use of posts and crowns, even in the case of extreme situations. Clinical data appears very favourable (Walls, 1995c; Magne et al, 2000; Magne and Magne, 2005b). This approach has been used by the author for over 20 years with major implications including both the medico-biological aspect (specifically, the saving of the healthy tissues and the maintenance of the tooth vitality) and the socio-economic context (namely the reduction of costs when compared to the traditional, more invasive, prosthetic approach).

The bases of the concept 'neither posts nor crowns' have also been documented in an experimental and numerical manner (Magne and Douglas,1999). For teeth having a significant loss of coronary tissue (Figures 4 and 5), a traditional treatment by prosthetic crowns involves the removal of large quantities of intact dental substance (Edelhoff and Sorensen, 2002a; Edelhoff and Sorensen, 2002b), with potentially negative effects on the biomechanical coronary and the periodontal tissues (the necessity for a clinical elongation of the crown for short teeth), as well as considerable financial consequences.

By using the adhesive system, we are able to preserve the tissues as much as possible and limit the costs. Several publications that are currently being prepared by the author

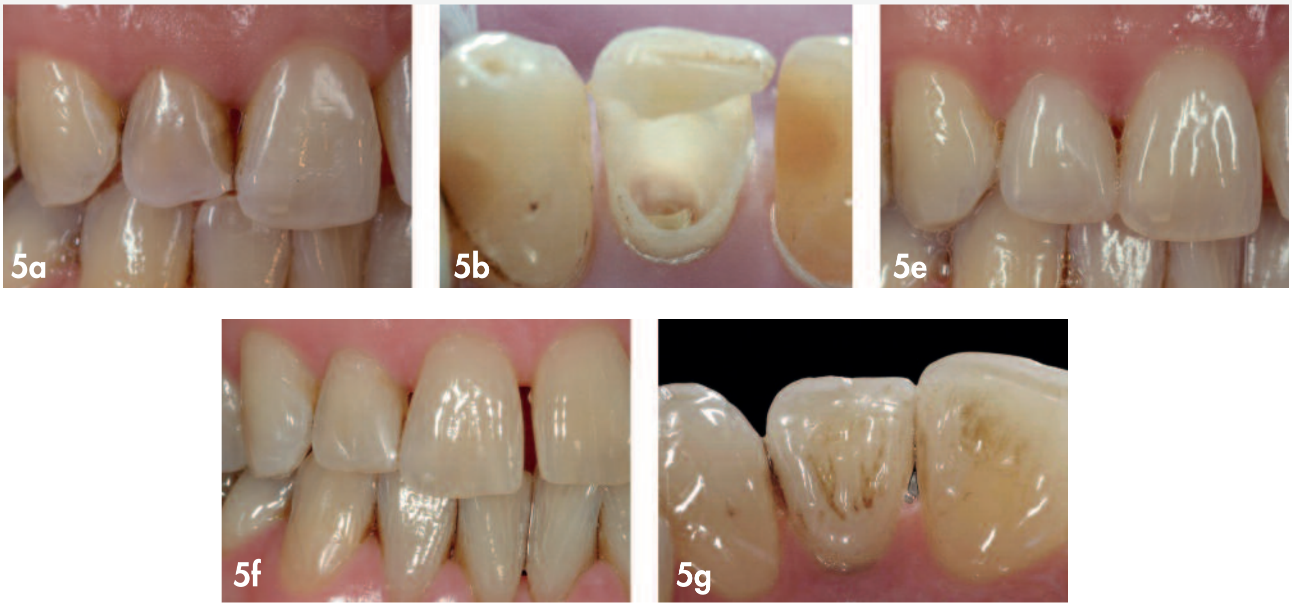

Figure 5: Long-term monitoring of a case of lateral incisive treated with neither post nor crown. Initial situation on 1994 (a, b). Tooth UL4 is devitalised, discoloured and presents considerable decay (b). Clinical situation following internal whitening and direct adhesive restoration (c). Follow-up at 11 years from the buccal view (d) and lingual view (e). The restoration is still functioning today more than 20 years later (2015).

and his research team also prove that the utilisation of root posts is unnecessary, even when the anterior or posterior teeth entirely lack the dental banding effect.

It has also been shown that in the case of complications, adhesive restorations are generally replaced or repaired very economically in sharp contrast to prosthetic crown failure, which often necessitates costly major ductal surgery or extraction (Smales and Berekally, 2007).

Lastly, the adhesive technique sometimes enables the saving of teeth at great risk, especially when it concerns very submucosal carious lesions. In this case, the use of the elevation of deep margins technique is suggested (Dietschi and Spreafico, 1998; Magne and Spreafico, 2012; Kielbassa and Philipp, 2015).

In the case of indirect restorations (Figure 4), the technique is applied in conjunction with the IDS, thus facilitating the impression (especially the numerical impression), isolation, and placement of the final restoration.

Restorative materials: a secondary choice

Once adhesion is mastered, the choice of the type of restorative material would seem to become of secondary importance. Indeed, the decision to use either ceramics or composite resin must not be based purely on the physical properties and mechanical performances of the materials.

Their position on the dental arch and the type of antagonist teeth are also critical elements. For posterior teeth, numerous in vitro researches into resistance to fatigue have clearly demonstrated the superiority of high performance polymers (HPP) and materials based on lithium disilicate (Schlichting et al, 2011; Magne et al, 2010).

The astonishing performance of composite resin CAD/CAM blocks justifies the use of the initialism HPP in order to differentiate them from hand stratified restorations, which can present intercalary deficiencies and porosities.

A CAD/CAM block can be manufactured in much better conditions using, for example, heat and pressure. The mechanical properties are potentially improved, giving them an astonishing combination of resilience (principal property of the dentine) and resistance to wear (property attributed to the enamel).

Equally, the HPPs have numerous practical advantages

Figure 6: Natural teeth can be used as databanks in the form of stereolithographic files, which allow the three-dimensional impression of prosthetic structures.

compared to ceramic, such as the speed of machining (no additional firing), machining in fine layers (Tsitrou and van Noort, 2008), reduced wear of milling instruments, and a lower risk of fracture during occlusal adjustments before sealing (Magne et al, 2011).

Lastly, the resins have a chameleon effect (they combine very naturally with the dental tissues) (Fasbinder et al, 2005). The price to pay is the progressive loss of the form and texture of the surface, which doesn't occur with ceramic.

Another advantage of ceramic is this marvellous surface finish (if it's obtained in an appropriate manner), which facilitates hygiene and maintenance. Given that the clinical performances of the HPPs and ceramic are very similar, it is important to apply good sense and to thus use ceramic when the existing antagonist is in ceramic, in order to have a better collective resistance to wear.

When the antagonist tooth is intact, composite resins should be considered, as they offer the best resistance to total wear (material and antagonist) (Kunzelmann et al, 2001). As far as anterior teeth are concerned, there is no doubt that porcelain is the ideal material for indirect veneers.

The CAD/CAM revolution

Today, it is clear that CAD/CAM is much more than a simple restoration tool. It is also a diagnostic tool (Kurbad and Kurbad, 2013; Reiz et al, 2014), a prognosis tool (Zaruba et al, 2014), and above all, a fantastic platform for the biomimetic approach.

It is equally a research tool without parallel because the design and restoration quality can be highly standardised (Magne and Knezevic, 2009). Lastly, it is a necessary tool in the development of virtual dental patients or VDP (Delong et al, 2002), which allows a complete image of the clinical data and the ability to access additional data, otherwise inaccessible, on the patient himself.

The rapid prototyping techniques combined with 3D printing techniques enable the generation of pre-stratified restorations, based on the database, which includes not only the dental morphology but equally the thickness of the dentino-enamel layers (Figure 6).

Now that it has been clearly established that the ideal materials are the natural tooth, the enamel and the dentine, it is possible to envisage totally innovative approaches.

A recently published article revealed that it was possible to produce a natural restoration from a wisdom tooth provided by a donor (Schlichting et al, 2014). The trick was to position the natural crown (ideally) in the milling chamber to avoid any occlusal adjustment whilst having a perfect match with the preparation. This was able to be done thanks to CAD/CAM.

This breakthrough opens the door to other total biomimetic solutions, including on implants etc. Ironically, while millions of dollars are being spent on stem cell research to produce a biomimetic tooth in a petri dish, countless wisdom teeth are extracted and eliminated every day – teeth that could be recycled and used to produce 100% biomimetic restorations.

Conclusion

Using the scientific method, but also applying experience and good sense, it is now possible to offer our patients minimally invasive restorative solutions when we base ourselves on the biomimetic approach.

A total mastery of bonding techniques as well as the implementation of new CAD/CAM tools has permitted the progressive elimination of the old concepts based on mechanical retention and the type of resistance of dental preparations.

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