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Occlusal onlays as a modern treatment concept for the reconstruction of severely worn occlusal surfaces

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According to the Fifth German Oral Health Study, the caries experience in the German population is declining sharply. The number of teeth still present at an advanced age has also increased significantly in recent decades. This shows a clear trend towards long-term tooth preservation – possibly with fixed dental prostheses – which is further supported by the possibility to place implants to increase the number of abutments. The pronounced decline in caries experience has given Germany a leading international position in terms of dental health. But there is increasing evidence of risks associated with dental hard-tissue damage because of erosion/biocorrosion, attrition, and abrasion. The defect morphology of these wear-related lesions is different from that of caries lesions; occlusal surfaces are more often affected in the posterior region. Against this background, restorative treatment concepts have become significantly more differentiated in recent decades. Predominantly subtractive concepts to provide mechanical retention for the restoration using traditional cements are now replaced by less invasive, primarily defect-oriented procedures wherever feasible. In the case of pronounced dental hard-tissue loss, additive approaches also allow restorations that restore function. In addition, there are modifications of traditional procedures, such as defining the treatment goal in the lead-up to the treatment itself with the aid of a diagnostic wax-up. The wax-up provides orientation for the subsequent tooth preparation and allows a particularly economical approach to the removal of healthy dental hard tissue. Furthermore, the introduction of new preparation designs has contributed significantly to the preservation of dental hard tissue on the teeth to be restored. This article describes the principles of minimally invasive treatment using occlusal onlays for the reconstruction of severely worn occlusal surfaces.
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The Fifth German Oral Health Study (DMS V) found a reduction of more than 30% in the incidence of caries in younger adults (35 to 44 years) as well as a reduction of 50% in the incidence of root caries since 1997. In addition, the number of remaining teeth in advanced age has increased significantly: younger seniors aged 65 to 74 years had on average at least five more of their own teeth in 2014 than in 1997 (DMS III, 10.4 teeth; DMS V, 16.9 teeth).[1] With this extremely positive development Germany currently occupies a leading international position.

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There is a clear trend towards tooth preservation over longer periods – partly supported by fixed dental prostheses (FDPs) and by the option to place implants to increase the number of restorative abutments. The pronounced decline in caries experience has repeatedly been described as a positive development. Nevertheless, there is increasing evidence of risks associated with dental hard-tissue damage due to erosion/biocorrosion, attrition, and abrasion.[2,3] These effects are further potentiated by the fact that the teeth remain in function for longer.[4]

TREATMENT INDICATIONS IN TOOTH WEAR

Against this background, restorative treatment concepts have become significantly more differentiated in recent decades.[5] On the one hand, traditional approaches using metal-framework crowns and FDPs are still considered the gold standard due to their documented favorable clinical long-term prognosis.[6] On the other hand, however, the considerable loss of dental hard tissue associated with crown or FDP preparations is increasingly viewed critically. Attempts are made to avoid these invasive measures as far as possible or at least to postpone them until later in life.[7]

Indirect restorative therapy to replace lost dental hard tissue will usually be considered in pathologic tooth wear or in cases with additional functional or esthetic impairment.[8] If the indication is based on pathologic tooth wear alone, the treatment must be preceded by a pertinent diagnosis of tooth wear to check whether an *indirect* procedure is inevitable or whether a less invasive *direct* procedure might be offered instead.[9] However, it is not advisable to delay the restorative intervention until a maximum of hard-tissue destruction has occurred, since residual enamel can be used to provide a secure and permanent adhesive bond for a new restoration. What is needed, therefore, is a valid tool for detecting and quantifying tooth wear.

The multi-stage Tooth Wear Evaluation System (TWES) seems currently to be the best tool for this purpose. The system first provides a qualitative tooth-wear screening result. If tooth wear is present ("positive" result, TWES grade 2 or higher), the system's finer grained tooth-wear status provides a more detailed quantitative assessment and classification of tooth wear.[8,10] On this basis, tooth wear can be monitored regarding progression, and a well-informed decision can be made regarding any necessary restorative therapy. Such therapy is indicated in patients with TWES grade 3 (corresponding to a loss of more than one-third of the clinical crown), or grade 4 (loss of more than half of the clinical crown) or the the tooth wear causes pain and/or leads to functional disorders (temporomandibular or craniomandibular disorders).

The affected patients benefit not only in terms of having their affected teeth preserved. It has also been demonstrated that patients with severe functional and esthetic problems experience a significantly improved quality of life following a restorative intervention.[11] This improvement was related to orofacial appearance, oral well-being, overall performance, and masticatory function, as well as reduced pain.[12]

Direct vs indirect restorations

When determining the type of restorative treatment to be performed, *additive* approaches should be preferred to predominantly *subtractive* approaches. For smaller defects and younger patients, if possible, *direct* composite restorations should be provided, as these are less expensive and allow minimally invasive procedures. According to a study by Schmidlin et al,[13] the results obtained with direct restorations are initially good. However, clinical follow-ups by the same study team showed that in more complex cases, direct posterior composite restorations discernibly deteriorate after 5.5 years and more in terms of surface texture, anatomical shape, and marginal fit.[14] The survival rate of composite as a restorative material in complex direct rehabilitations depends on the position of the teeth, being most unfavorable in the case of molars.[15]

In contrast, *indirect* restorations – such as those made of glass-ceramics – facilitate a safer and more stable implementation of a physiologic occlusion. In more extensive restorative approaches they provide better control over the optimal form and esthetics as time progresses, but they are associated with higher cost.[16] In recent decades, the invasiveness of indirect restorations has been significantly reduced. This is demonstrated by measurements of the amount of hard tissue removed as a function of different preparation geometries. For full crowns in the anterior and posterior regions, up to 70% of the hard tissue of the clinical crown must be removed,[17] whereas the tissue loss is only half as large for partial crowns and for occlusal onlays.[18] These findings increasingly influence the treatment decision in favor of indirect restorations.[19]

For *endodontically treated teeth,* the amount of remaining dental hard tissue had a significant positive influence on fracture strength in various in-vitro studies, irrespective of the tooth type.[20,21] It is therefore more important to realize that with endodontically treated molars, a treatment decision in favor of a partial crown instead of a full crown can preserve an additional up to 45% of the dental hard tissue.[19]

Regarding endodontic follow-up treatment, *devitalization* is an important criterion. It was found that in clinical studies on all-ceramic partial crowns and veneers covering observation periods of up to 12.6 years, either no devitalization occurred,[22] or the devitalization rate was much lower than in studies of metal-ceramic full crowns.[23] Low-level invasiveness of the preparation and restoration seems to have a beneficial effect on maintaining the vitality of restored biologic abutments. Against this background, a paradigm shift has taken place in fixed prosthetics in recent years in the direction of less invasive treatment concepts.[24-27]

The present article details the treatment concept of glass-ceramic occlusal onlays, which greatly reduce the amount of dental hard tissue that must be removed, and attempts to evaluate this type of restoration.

PRETREATMENT

VDO acceptance check

Occlusal onlays are a treatment modality that has been increasingly used in the context of complex rehabilitation ever since suitable restorative materials became available, especially when associated with an increase in the vertical dimension of occlusion (VDO). Since the neuromuscular and phonetic acceptance of a restored VDO cannot be reliably anticipated, it is advisable to try it out first. There are several options available to achieve this, including try-ins and fine-tuning of diagnostic wax-ups. However, determining the neuromuscular response requires a more protracted review in terms of a functional and, if possible, phonetic, and esthetic "test drive." Various established treatment techniques exist; they are briefly outlined below.

Conventional pretreatment with positioning splints

The conventional pretreatment is based on the wearing of an occlusal splint that serves to produce both the planned condylar position and the intended vertical dimension. This method is well established and proven but has the following limitations:

- Speech is impaired especially in the case of Michigan-type maxillary splints, which prevents them from being worn during the day. Owing to the intermittent use, this type of splint is associated with functional disadvantages. In addition, their appearance and shape cause significant esthetic and phonetic restrictions.[28] As an alternative, various authors have described mandibular splints that are open in the front.[29] These splints are almost invisible, and speech is impaired to a smaller extent. However, these splints need continuous monitoring to detect possible changes in incisal tooth position.
- Under certain circumstances, the attempted increase in vertical dimension to restore physiologic conditions is smaller than the required thickness of conventional positioning splints made from polymethyl methacrylate (PMMA). In that case, the occlusal splint cannot fully achieve the planned vertical dimension.
- Furthermore, the treatment with a positioning splint in one jaw requires an occlusion in the opposite jaw that permits stable three-dimensional indexing of the occlusal splint.

- In addition to the above-mentioned absolute restrictions, one drawback of classic positioning splints is that they are placed in only one jaw. Thus, in the case of maxillomandibular restorative treatment, they represent the entire change in VDO in a single splint and therefore do not reproduce the occlusal plane as later provided by the restoration.[30]

The economic advantage of classic occlusal splints made from PMMA and worn in one jaw is the comparatively lower cost, compared to other alternatives described below. With regard to reaching the treatment objectives the *general advantage of classic occlusal PMMA-splints* is the option to perform occlusal adjustments during initial therapy, including changes to the condylar position, depending on the functional situation. Such classic relaxation and positioning splints thus continue to be the method of choice for the initial treatment for pain relief and functional rehabilitation.[31]

Innovative alternative: simulation splints made from CAD/CAM-milled polymers

In cases where one of the above conditions is not met, removable CAD/CAM (computer-aided design/computer-assisted manufacture) simulation splints can be a novel alternative. Designed based on a diagnostic wax-up and milled and finished to full contour from tooth-colored polycarbonate, these splints approximate the definitive restoration in terms of function and esthetics. This form of single jaw or maxillomandibular full-contour simulation splint meets with substantially greater patient acceptance.[32]

Owing to the characteristics of the material, these splints can be very thin, down to a thickness of only 0.3 mm. The splints are removable, so the therapy is reversible, and they can be worn 23 hours a day (23-hour splint). Nevertheless, the limit of this method is also defined by the extent to which the VDO can be increased. Despite the reduced minimal thickness, experience has shown that as part of a two-splint (maxillomandibular) concept the material preferably can be used for changes to the VDO with an increase in the incisal pin distance of more than 4 mm.

Repositioning onlays

Another pretreatment alternative is fixed tooth-colored, individually adhesively cemented repositioning onlays made of PMMA.[33,34] These are manufactured in the classic manner, based on a diagnostic wax-up, [34] or using a CAD/CAM process chain. In terms of function and esthetics, they correspond almost perfectly to the future restorations.[35,36] As repositioning onlays are adhesively cemented single-tooth restorations and fixed to the worn teeth without preparation, the treatment is complicated and the cost is relatively high. On the other hand, because the shape is identical to the intended restorative situation and owing to fixed cementing, patients can even eat with the repositioning onlays in place, which makes the evaluation period as realistic as possible regarding both esthetics and function (long-term treatment).

For these reasons, especially in functionally sensitive patients, repositioning onlays are the only treatment alternative that provides lifelike proprioception. However, the PMMA restorations are difficult to modify intraorally. Also, the reversibility of this treatment is limited, so that the baseline situation is more difficult to restore, should this be needed.[37] Moreover, the cost is significantly higher than for removable splints. The adhesive attachment requires a relatively large amount of chair time, and several follow-up appointments – at which the occlusion is readjusted to match to the individual patient's neuromuscular adaptation – result in additional cost.[38]

Once the mandibular position has been reached over several months, the process of functional rehabilitation is transferred towards definitive restorations. With the repositioning onlays in place, this conversion to "definitive" restorations typically occurs in a stepwise manner; for each step a number of teeth are prepared for subsequent restoration with occlusal onlays or partial crowns (or crowns, if necessary), while the remaining repositioning onlays stabilize the mandibular position as equilibrated previously. This step-by-step approach can greatly simplify complex rehabilitations, bypass risks, and distribute the high cost across multiple treatment stages.[32]

ALL-CERAMIC OCCLUSAL ONLAYS

Features and benefits

Adhesively cemented all-ceramic partial restorations are a safe treatment modality in the posterior region.[23,39,40] With the *decreasing* incidence of caries, accompanied by an *increasing* incidence of biocorrosive defects – also in generalized form – changed defect morphologies of the dental hard tissue are gaining in importance.[1,4,5] Thus, the requirement profile for minimally invasive, defect-oriented, adhesively cemented single-tooth restorations has changed. Today, restorative treatment in the posterior region focuses more on occlusal defects, seeking to restore adequate function, esthetics, and biomechanics, and to help prevent further pathologic wear.

In view of the sometimes extreme changes in the occlusal contours due to tooth wear, adhesively cemented occlusal onlays made of high-strength glass-ceramics are a more desirable type of restoration than the classic full crowns, which are twice as invasive (Fig 1). The occlusal onlays' supragingival preparation margins offer many advantages:

- superior vision during preparation
- more predictable conventional and digital impressions
- reduced loss of dental hard tissue and thus reduced risk of devitalization
- increased availability of enamel for bonding
- less or no traumatic interference with the marginal gingiva
- well-controlled adhesive cementation, possibly under rubber dam.

Instruments used for preparation

Today's tooth-colored restorative materials and digital production methods – as well as the increasingly more important occlusal aspects of the defect morphology – have given rise to a new set of specifications for preparation shapes (Figs 2 and 3). Therefore, the preparation instruments used must help ensure the following:

- defect-oriented minimally invasive preparations rather than stereotypical crown shapes

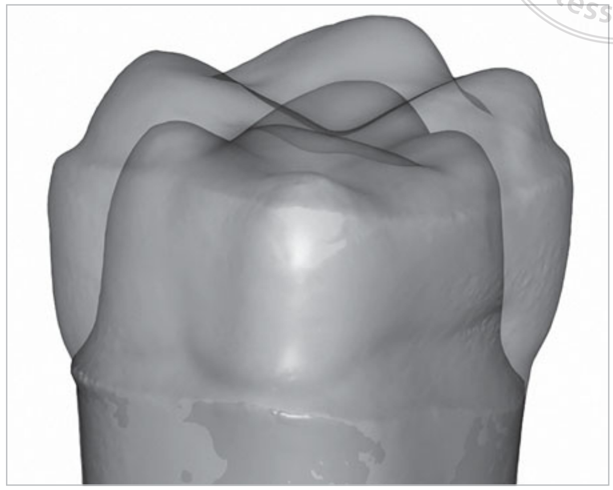

Fig 1 Approximately 70% of the volume of the clinical crown of a posterior tooth is removed for a full-crown preparation (internal contour), whereas only about 30% is lost for an occlusal onlay, unless more tissue has already been lost (see Fig 3b).

- no sharp corners or acute angles and sufficient thickness of ceramic materials
- sufficiently wide cutting radii when providing CAD/CAM restorations.

So far, however, no preparation instruments have been available that meet these requirements regarding the preparation of ceramic occlusal onlays. Hence, the authors of the present paper inspired the development of appropriate cutting geometries for occlusal onlays on premolars and molars that support the dentist's efforts to implement an ideal preparation design (4665 or 4665 ST occlusal onlay set; Komet Dental).[41]

Preparation

To ensure economical removal of the dental hard tissue, it is helpful to start with the application of an additive mock-up to the defective tooth structure. As a prerequisite this requires a functional anatomical wax-up that simulates the planned contour of the tooth (or teeth) to be prepared. The wax-up's color should provide a pronounced contrast (such as gray wax on a white, beige, or golden brown plaster cast) to make the baseline margins clearly recognizable.

As a basis for the later thermoforming the waxed-up model needs to be duplicated first. Subsequently, from

Fig 2 Try-in of lithium disilicate ceramic monolithic occlusal onlays with an occlusal thickness of 1 mm in the maxillary posterior region. Across large areas of the preparation surface, enamel could be retained for secure and permanent adhesive bonding. (Laboratory procedures: Otto Prandtner, MDT, Munich.)

Fig 3a Caries defect morphology: very different from defects caused by biocorrosion or attrition.

Fig 3b Loss of dental hard tissue characterized by biocorrosion and attrition with pronounced changes in the occlusal morphology of the posterior teeth and reduced vertical dimension of occlusion. The patient complained of a severely impaired maxillary anterior esthetics and increased thermal and chemical irritability.

the duplicate model an outer thermoforming foil (such as Duran transparent, thickness 0.5 mm; Scheu-Dental) is derived. This in turn is filled with light curable temporary crown and FDP composite resin (such as Luxatemp Automix Solar, DMG), then placed on the respective tooth arch and light cured through the foil. It is recommended to isolate the natural teeth with liquid petroleum jelly beforehand to ensure uncomplicated later removal, for example with a scaler (such as a Goldman #6/7, handle #6, part code SHG6/77; Hu-Friedy). Hence the unprepared tooth is recontoured with the mock-up, simulating the planned later therapeutic contour of the tooth.

After applying the additive mock-up to the defective tooth structure, the preparation is initiated by cutting depth markings into the mock-up and/or the tooth structure, in the depth required as the minimal occlusal thickness for the planned restorative material (eg, 1 mm in case of monolithic lithium disilicate ceramics). For comfortable placement of the depth markings and the subsequent occlusal preparation a combination preparation diamonds with laser markings 1 mm from the instrument tip (855D.314.016; Komet Dental) can be used (Fig 4). If the preparation was based on a mock-up or the tooth surfaces are still in contact with the antagonists, this procedure will create enough vertical space for the occlusal onlays.

Highlighting the depth marks in dental hard tissue or a core restoration with a graphite or felt-tip pen provides visual control of the subsequent tissue reduction.[42] This ensures that no more hard tissue is removed than necessary to achieve a sufficient restoration thickness of 1 mm. After removing the mock-up, efficient contouring and leveling of the occlusal surface is made possible by tilting the same combination instrument shown in Fig 4. This also removes all burrs and sharp edges from the occlusal surfaces, which is particularly important if teeth have been damaged by attrition and erosion/biocorrosion, as their shapes may have become dissimilar to the natural tooth morphology.

For the final shaping of the occlusal surface, the OccluShaper (8370, Komet Dental) introduces new grit geometries that provide anatomically shaped convex cusp support for the future occlusal onlay while leaving enough space in the central fissure for the dental technician to implement an immediate side shift (ISS). The cutting geometry of this instrument allows the dentist to shape the occlusal surface in one step. However, the different sizes of premolars and molars require the use of different instrument sizes (OccluShaper for premolars, 370.314.030; OccluShaper for molars, 370.314.035; Komet Dental). Both these sizes are also available as finishers (coded in red) (Fig 5).[41]

Fig 4 After applying and curing a low-viscosity composite with the help of the thermoforming foil (derived from the wax-up) on the damaged posterior teeth (mock-up), a diamond preparation tool with 1-mm laser markings (855D.314.016, Komet Dental) was used for depth marking and initial preparation. This procedure allows economical removal of dental hard tissue and creates sufficient clearance for the restorative material.

Figs 5a and 5b Creation of an occlusal plateau for a lithium disilicate ceramic occlusal onlay. The specific geometry of the abrasive body (OccluShaper as finisher, 8370.340.035; Komet Dental) creates anatomically shaped convex cusp support for the future occlusal onlay while leaving enough space in the central fissure for the dental technician to implement an immediate side shift (ISS) during dynamic occlusion.

After leveling and shaping the occlusal surface, the oral and vestibular surfaces are prepared, contoured, and finished with a rounded chamfer approximately 0.5 mm in depth. It is recommended to use a special cutter with a guide pin at the tip for this purpose (8849P.314.016, Komet Dental). The guide pin, which is *not* diamond-coated, limits the penetration depth for the chamfer to a maximum of 0.5 mm during preparation (Fig 6). If possible, the preparation margin should be placed *above* the tooth equator, as the amount of hard tissue that must be removed increases considerably if the preparation is extended into the area *below* the equator. The preparation areas are already defined by the diagnostic wax-up.

An important prerequisite for long-term success is a preparation with margins located primarily in enamel. In individual cases and if a strict indication exists, the preparation margin might be locally elevated in the presence of a composite core build-up in areas of deep caries lesions ("deep margin elevation" or "proximal box elevation" [PBE]).[43-45] It is advisable to make all transitions soft and rounded to avoid load peaks within the restoration.[46]

After adjusting the height and the oral and vestibular surfaces, the interproximal cross-sections of the teeth are already reduced. This allows minimally invasive preparation, limited, wherever possible, to enamel. A practical alternative for this application is novel diamond-coated sonic tips, with one variant each for the mesial (SFM6, Komet Dental) and distal (SFD6, Komet Dental) proximal spaces (Fig 7a). These new sonic files are so thin that they are perfectly suited for all-enamel proximal preparation enamel while being large enough to allow preparing the proximal aspect of the preparation surface in one step with secure guidance. The cervical edge of the sonic tips is shaped to produce a marginal geometry as required for ceramics. Diamond coating on only one side prevents trauma to adjacent teeth without the necessity to employ a matrix (Fig 7b).

Finally, a fine-grained diamond (8856.314.014, Komet Dental) can be used to connect the transition areas and to remove remaining ledges.

Fig 6 Creation of a circular marginal rounded chamfer for a lithium disilicate ceramic occlusal onlay. The guide pin at the tip of the cutting instrument, which is not diamond-coated (8849P.314.016; Komet Dental), limits the marginal penetration depth to 0.5 mm, preserving the enamel and preventing over-preparation.

Fig 7a Special sonic tip SFD6 for the creation of a proximal (in this case, distal) preparation margin, with diamond coating on only one side to prevent trauma to adjacent teeth. The cervical edge of these sonic tips is shaped to produce the exact marginal geometry needed for high-strength dental ceramics. (Photo reproduced with permission of Komet Dental.)

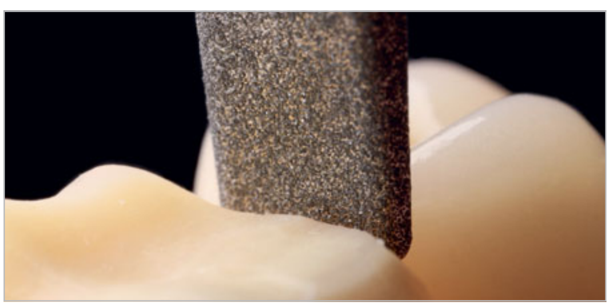

Fig 7b Creation of a proximal preparation margin with an oscillating instrument that is available in a mesial and a distal orientation. Diamond coating is present on only one side of the instrument, which prevents trauma to the adjacent tooth during preparation.

Provisionalization and impression

Provisional restorations can be created chairside using the multiple-use diagnostic thermoforming foil and a bis-GMA (bisphenol glycidyl methacrylate)-based provisional restorative material (such as Luxatemp Automix Solar, DMG). It is advisable to isolate the surrounding hard and soft tissues with liquid petroleum jelly. Low-retention provisional occlusal onlays are best left splinted if possible and inserted using a non-filled or low-filled adhesive (such as Heliobond, Ivoclar Vivadent, or Optibond FL Adhesive, Kerr) previously applied with a brush to the finished unetched preparation surfaces and to the inner surfaces of the provisionals.

After removing any excess with foam-rubber pellets (Pele Tim; Voco) and Superfloss (Oral B), the adhesive layer was cured with a polymerization lamp through the provisional restoration for 30 seconds. In cases with extremely low retention, so-called “spot etching” (phosphoric acid etching of a small circular enamel area within the preparation surface, about 2 mm in diameter, for only 10 seconds) is recommended before delivering the provisional. The resulting partial microstructures quite reliably prevent retention loss after the adhesive is cured.

Provisionals are also helpful in checking whether enough hard tissue has been removed, as they precisely represent the thickness of the future ceramic occlusal onlays. Therefore, it makes sense to fabricate them before taking the actual impression and to check their thickness (≥ 1 mm) with a probe. In this case, however, the contaminated tooth surfaces should be cleaned, prior to the taking the precision impressions, with rotating nylon cleaning brushes (such as 9531.204.020, Komet Dental) to avoid any interference with the precision impression material (eg, polyether, Impregum/Permadyne; 3M Espe).

Ahead of taking a precision impression of the intrasulcularly prepared teeth, it is advisable to introduce two retraction cords placed on top of each other into the sulcus (Ultrapak, size #000 cord as the first and #0 as the second filament; Ultradent). In the case of equi- and supragingival preparations, the single-strand technique using a size #000 is usually sufficient. Alternatively, retraction pastes can be used (such as ReCord, Kaniedenta). The recommended impression technique is a single-stage putty/wash impression (for example using

Fig 8 Monolithic occlusal onlays made of IPS e.max Press (degree of turbidity [HT]) with an occlusal thickness of 1 mm and a 0.5-mm circular border. (Laboratory procedures: Otto Prandtner, MDT, Munich.)

Fig 9 Try-in of the lithium disilicate ceramic occlusal onlays (IPS e.max Press, degree of turbidity [HT]) with a color-keyed dyed try-in paste (Variolink Esthetic, Try-in, color: warm; Ivoclar Vivadent).

polyether, Impregum/Permadyne, 3M Espe) in a custom tray or a customized tray with retentions, loaded with a polyether adhesive (ex Rimlock, Krupp Dental – now, for example, M+W Select Rim-Lock Smooth; M+W Dental).

Try-in and adhesive cementing

After removing the provisionals, it is recommended to clean the sites with nylon cleaning brushes and a fluoride-free cleaning paste (Zircate Prophy Paste, Dentsply Sirona). In most cases, the adhesive will detach automatically as the provisionals are removed from the finished prepared surfaces. Stubborn bonding residue can also be easily removed with a scaler. On selectively etched enamel surfaces, finishing burs can be used to remove any adhesive remnants and to level the surface locally.

To check the shape and shade of the restorations, they are tried in with colored glycerine gel (such as Variolink Esthetic try-in paste, Ivoclar Vivadent; or Vitique Try-in paste, DMG), which is available in colors that correspond to those of the definitive adhesives (Variolink Esthetic: warm+, warm, neutral, light, light+; Vitique: A1, A2.5, A4, B1, Bleach Light, Transparent, White Pink). The try-in pastes can be used to test minimal last-minute shade adjustments to the occlusal onlays. Their influence is not very pronounced, but it increases with increasing translucency (usually IPS e.max Press HT, Ivoclar Vivadent) and with decreasing thickness of the occlusal onlay (Figs 8 and 9).[47] The marginal fit and the occlusion can be inspected using a self-mixing A-silicone compound (FitChecker, GC, or Fit Test C & B, Voco).

During the try-in, silicate ceramic restorations, and especially occlusal onlays, are highly prone to fracture, which requires an elevated level of patient compliance. To clean the interior surfaces of the ceramic occlusal onlays contaminated by the try-in, nylon brushes should be used and the onlays should be thoroughly rinsed.

The internal surfaces of the lithium disilicate ceramic restorations are then etched with hydrofluoric acid gel (such as IPS Ceramic Etching Gel, Ivoclar Vivadent). The etching time depends on the type of ceramic used; for lithium disilicate ceramics, it is 20 seconds. To remove residual acid, the etched restorations are sprayed with a water/air mixture for 30 seconds, and the acid is neutralized (IPS Ceramic Neutralizing Powder, Ivoclar Vivadent). Submersion in a container filled with ethanol 90% in an ultrasonic bath for several minutes can be helpful in removing persistent excess material.

Following visual inspection of the etching pattern, a primer (such as the effective silane component of

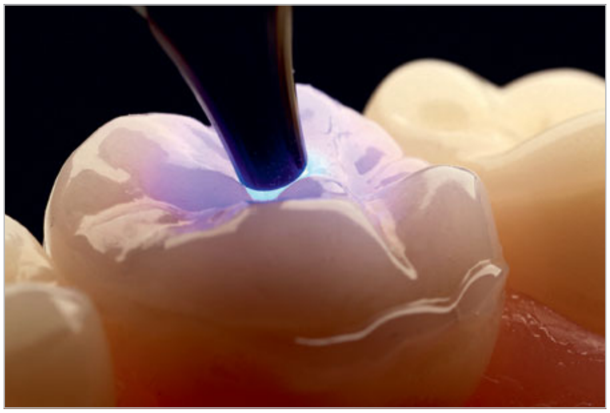

Fig 10 The onlays were cemented adhesively with the matching, strictly light-curing adhesive resin (Variolink Esthetic LC, color: warm; Ivoclar Vivadent). During placement, the use of a so-called "pin-point attachment" for the polymerization lamp (here: Bluephase Style 20i; Ivoclar Vivadent) has proven favorable. It ensures a pin-point initial polymerization in the central fissure for stabilizing the position, without curing excess adhesive near the edge or interproximally.

Monobond Plus, exposure time 60 seconds; Ivoclar Vivadent) is applied, which establishes a chemical bond between the adhesive and the silicate ceramic. Applying heat significantly increases the priming effect, as the heat allows the adhesive molecules to condense on the ceramic surface. This can be achieved with a common hair dryer.[48] Self-etching primers such as Monobond Etch & Prime (Ivoclar Vivadent) also showed positive results in exploratory in-vitro studies.[49] When using a low-viscosity adhesive such as Variolink Esthetic or Vitique, no further adhesive bonding agent needs to be applied to the restoration. This also eliminates the need to protect the preconditioned occlusal onlays from light. In addition to *total etch and rinse* systems, universal adhesive systems with selective enamel etching provide a reliable bond as they condition the prepared tooth surfaces.

These preparatory steps should be followed by additional mechanical cleaning of the preparation surfaces with brushes and fluoride-free pumice paste. If placing rubber dam is difficult, for example in the case of an intrasulcular preparation, the use of non-impregnated gingival retraction cords (such as UltraPak size #000; Ultradent) is recommended. These are placed into the sulcus below the preparation margin. For more extensive core build-ups, additional roughening with a coarse-grained diamond grinding instrument at low speed (2,000 rpm, red angled handpiece) without irrigation is recommended. A beneficial alternative is the use of an intraoral airborne particle–abrasion instrument (Dento-Prep microblaster, Rønvig Dental), which can also be used for the silica-coating of surfaces (Cojet Sand, 3M Espe).[50]

Occlusal onlays are usually made of a material with a high degree of translucency (such as IPS e.max Press HT, Ivoclar Vivadent) because they primarily replace translucent enamel and their shade benefits from the high chroma of the underlying dentin. Up to a thickness of 1 mm, they can be inserted without problems with strictly light-curing, low-viscosity adhesive resins (such as Variolink Esthetic LC, Ivoclar Vivadent, or Vitique, DMG) can be used. The adhesive resins can be applied to the prepared surfaces as well as to the internal surfaces of the restoration.[51]

To keep the occlusal onlays from "floating" on the tooth surface (as a contact lens would), an initial spot exposure (for example with Light Probe Pin Point 6 > 2 mm, Bluephase Style 20i; Ivoclar Vivadent) is recommended for topical polymerization after placement, position checking, and initial excess removal. In this way, positional changes of the non-retentive occlusal onlay are avoided without completely curing the excess and thereby making it difficult to remove (Fig 10). Initial local light-curing for only a few seconds transforms the adhesive resin excess into a gel-like state so that it can be removed with a scaler and Super Floss while stabilizing the positions of the restorations with a spherical plugger.

After removing any excess, but before the final curing step, a glycerine gel (such as Liquid Strip, Ivoclar Vivadent) should be applied to the joints to prevent the formation of an oxygen inhibition layer. For complete polymerization, it is recommended to expose each occlusal, oral, and vestibular surface for 40 seconds (if necessary accompanied by mild air cooling). A powerful polymerization lamp (> 1,000 mW/cm^2) should be used for definitive curing. After curing, the retraction

Fig 11 Monolithic lithium disilicate ceramic occlusal onlays (IPS e.max Press, degree of turbidity: HT, Ivoclar Vivadent) with an occlusal thickness of 1 mm after adhesive cementing (at the time [2008] using Syntac, Total etch, Variolink II, Monobond S; Ivoclar Vivadent). (Laboratory procedures; Oliver Brix, DT, Bad Homburg.)

Fig 12 Follow-up of the restorations shown in Fig 11 after nine years of clinical service (in 2017). The supporting (buccal) cusps of the restorations show marked impressions and wear facets caused by the antagonist dentition (also lithium disilicate ceramics).

cords are recovered and excess resin removed from the sulcus with a scaler.

Following adhesive cementing and excess removal, the static and dynamic occlusion should be re-checked for the presence of interferences and premature contacts. Fine-grained diamond grinding instruments (35 µm peak-to-valley) *with* irrigation are used for a final adjustment of the static and dynamic occlusion. The adjusted surfaces should then be smoothed with a ceramic polisher (such as 9545F.204.110, Komet Dental).

DISCUSSION

The secure adhesive connection to enamel and silicate ceramic restorative materials started significantly influencing, decades ago, the preparation techniques in the posterior region in favor of preserving more healthy dental hard tissue.[32] Restorations of this type are considered to be beneficial because of the low risk of damaging the pulp, better hard-tissue protection, easier impression-taking, a better view of the site during preparation and adhesive fixation, and less interference with the marginal gingiva. Most published long-term clinical studies on all-ceramic partial posterior restorations refer to leucite-reinforced glass-ceramics. Today, however, much more resistant restorations based on lithium (di)silicate ceramics have become available.[22,23,39,40]

Since the introduction of lithium disilicate ceramics such as IPS e.max Press or IPS e.max CAD, which provide more flexural strength and fracture toughness than the classic silicate ceramics, updated guidelines have called for removing significantly less hard tissue during preparation than for glass-ceramics. A minimum occlusal thickness of 1.0 mm is now being postulated for monolithic restorations (staining technique). A further reduction in thickness is currently being discussed for situations where sufficient support from enamel is present.[52-55] Thanks to their enamel-like properties and highly favorable interface behavior, glass-ceramic occlusal onlays appear excellently suited for reconstructing severely abraded and eroded posterior teeth.[56]

It makes sense to distinguish between strictly "occlusal onlays" (covering only occlusal surfaces) and "onlay veneers" (additionally covering vestibular surfaces). The latter can be indicated if cervical defects are to be addressed or if extensive changes in the shade and shape (buccal corridor) are desired in the esthetic zone (premolar area).[57]

With regard to *longevity,* leucite-reinforced glass-ceramic onlays showed satisfactory long-term results in a controlled prospective 12-year clinical study and can be used to rehabilitate extensive dental hard-tissue defects.[40] In another clinical study with an observation period of 12.6 years, a failure rate of 20.9% was determined on *vital* teeth, compared to 39% on *endodontically treated* teeth.[23] Compared to the substantial number of long-term clinical studies available on minimally invasive ceramic materials,[39] there is a lack of valid long-term clinical data for minimally invasive definitive restorations of CAD/CAM polymers.[58,59]

Despite all the euphoria about the possibilities described, it should be noted that these methods are highly technique-dependent in terms of preparation (primarily in enamel), adhesive delivery, and final adjustments to the static and dynamic occlusion.[23,39,60] Adherence to defined guidelines during the various clinical and technical treatment phases is a key factor for achieving long-term clinical success (Figs 11 and 12).

CONCLUSION

The restorative dentist today has many alternatives to the traditional, usually much more invasive, treatment methods. In recent decades, there has been a change in defect morphology due to a decrease in caries incidence and an increase in defects caused by biocorrosion and attrition. Occlusal onlays made of high-strength glass-ceramics represent an interesting contemporary form of restoration for reconstructing the occlusion in patients with pronounced deficiencies of the dental hard tissue. Combined with a supragingival preparation margin, these onlays offer numerous advantages:

- reduced loss of dental hard tissue
- increased availability of enamel
- unobstructed view of the site during preparation
- simpler conventional and digital impressions
- less or no traumatic interference with the marginal gingiva
- well-controlled adhesive cementation.

A prerequisite for success, however, is meticulous adherence to the procedure described.

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