Rehabilitation of the worn dentition with glass-ceramic restorations

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Abstract

Severe pathologic tooth wear is perceived internationally as an increasing problem based on growing evidence of risks associated with dental hard tissue damage due to erosion, attrition, and abrasion. The defect morphology of these wear-related lesions is different from that of caries lesions. Modern evaluation systems provide detailed quantitative assessment and classification of tooth wear. Against this background, restorative treatment concepts have become significantly more differentiated in recent decades. Direct composite restorations might be preferred for smaller defects and younger patients as they are less expensive and allow for minimally invasive procedures. Indirect restorations such as those made of glass-ceramics provide better control over the optimal form and esthetics and thus facilitate a safer and more predictable implementation of a physiologic static and dynamic occlusion. 3D treatment planning by means of a 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 in the teeth to be restored. The present article describes the principles of minimally invasive treatment concepts with high-strength silicate glass-ceramic restorations using anterior full veneers and posterior occlusal onlays for the rehabilitation of the worn dentition, provides up-to-date data for scientific evaluation, and presents a clinical case.

Keywords

complex rehabilitation, diagnostic wax-up, full veneers, glass-ceramic, Munich splint concept, occlusal onlays, preparation technique

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Introduction

Tooth wear

Tooth wear is perceived internationally as an ever-increasing problem.[1] The pronounced decline in caries has repeatedly been described as a positive development.[2] Parallel to this, there is increasing evidence of risks associated with dental hard tissue damage due to erosion/biocorrosion, attrition, and abrasion.[3] These effects are further potentiated by the fact that the teeth remain in function for longer.[4]

Treatment options 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 bridges are still considered the gold standard for indirect restorations 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 bridge 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 the patient's life.[7]

Indirect restorative therapy to replace lost dental hard tissue will usually be considered in cases of pathologic tooth wear or where there is 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 instead of a less invasive *direct* procedure. If so, 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. A valid tool for detecting and quantifying tooth wear is the updated Tooth Wear Evaluation System (TWES) 2.0. This system first provides a qualitative tooth-wear *screening* result. If at least moderate tooth wear is detected ("positive" result, TWES grade 2 or higher), the system's more refined *tooth wear status* provides a more detailed quantitative assessment and classification of the tooth wear as well as its pathology and origin.[8,9] On this basis, the progression of tooth wear can be monitored and a well-informed decision made regarding any necessary restorative therapy. Affected patients benefit by having their worn teeth preserved. Furthermore, it has also been demonstrated that patients experience a significantly improved quality of life following a restorative intervention.[10] This improvement is related to reduced pain, overall performance and masticatory function, orofacial appearance, and oral well-being. Therefore, if the *tooth wear status* reveals severe pathologic tooth wear, patients will likely benefit from restorative therapy, which should be as minimally invasive as possible while providing predictable results.[11]

Direct vs indirect restorations

When determining the type of restorative treatment to be performed, *additive* approaches should be preferred to predominantly subtractive ones. Thus, for smaller defects, if possible, *direct* composite restorations should be performed, as these are less expensive and allow minimally invasive procedures.[12] According to a study by Schmidlin et al, the results obtained with direct restorations were initially good.[13] However, clinical follow-ups after up to 10.7 years by the same study team showed that more than 20% of patients experienced unfavorable although mostly repairable events.[14] Another research group determined that nanofilled composite showed less surface degradation and better margin quality than microhybrid composite build-up restorations. Apart from the materials' influence, the survival rate of composites in complex *direct* rehabilitations depends on the position of the teeth, with the most unfavorable being molars.[15] Also, the extent of the restorations has a significant influence on the longevity of the restorations in premolars, as premolars with two cusps replaced had 297% more chance of failure than those with one cusp replaced.[16]

In contrast, *indirect* restorations – such as those made of high-strength silicate glass-ceramic – facilitate a more predictable and thus 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 a higher cost.[12] In recent decades, the invasiveness of indirect restorations has been significantly reduced. This was 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. In comparison, for partial crowns and for occlusal onlays, the tissue loss is only half as extensive.[17] These findings increasingly influence the treatment decision in favor of minimally invasive *indirect* restorations.

Regarding necessary *endodontic* follow-up treatment, devitalization is an important criterion, especially in full crowns. However, in clinical studies on all-ceramic partial crowns and veneers with observation periods of up to 12.6 years, either no devitalization occurred,[18] or the devitalization rate was much lower than in studies of metal-ceramic full crowns.[19] Consequently, a paradigm shift has taken place in fixed prosthetics in recent years in the direction of less invasive treatment concepts, which in turn improves the outcome of these treatments.[20,21] A long-term prospective clinical study with leucite-reinforced glass-ceramic partial coverage restorations in the posterior region with a mean observation period of 12.6 years showed a significantly higher failure rate for nonvital teeth (39%) compared with vital teeth (20.9%).[19] In contrast, in a clinical long-term study with pressed lithium disilicate (LS_2) defect-specific partial-coverage restorations, a high survival rate was found over a 10.9-year period, with an overall failure rate of 0.3% per year, which was limited to the molar teeth.[22]

For the *anterior dentition,* new designs of veneer preparations were introduced in recent years. A circular extension of the veneer preparation to a 360-degree design ("full-wrap" or "full-veneer" design) is advantageous, especially in complex rehabilitations with the need of an increase in the vertical dimension of occlusion (VDO) to cover the worn anterior tooth structure, which in turn is frequently connected to wear in the posterior region. If this is treated by restorative means, it results in a reestablishment of the VDO, which also requires the restoration of the contours of the anterior teeth.

Case presentation

A clinical case is presented detailing the treatment concept in the restoration of a worn dentition with minimally invasive high-strength silicate glass-ceramic anterior full veneers and posterior occlusal onlays. This treatment concept greatly reduces the amount of dental hard tissue that must be removed for indirect restorations.

Baseline

A 25-year-old male presented with generalized erosive and attritive defects of the dental hard tissue and complained about increasing chemical and thermal irritability. He was under the impression that his teeth had become considerably shorter than before and he had developed a diastema, and that both were not acceptable to him considering his young age. Furthermore, he experienced occasional pain in the right and left temporomandibular joints (TMJs) and in the teeth, without being able to identify a single tooth responsible for this pain.

The extraoral impression of esthetic and functional impairment was confirmed by the intraoral clinical examination findings. Almost all the teeth exhibited extensive wear facets. The tooth wear screening based on the TWES 2.0 confirmed the impression, indicating tooth wear grade 3 in the anterior region. Consequently, a tooth wear status was performed, accompanied by assessments of pathology as well as the cause of the situation. The findings per tooth determined generalized moderate and localized severe tooth wear due to the pronounced dentin exposure and loss of one-third of the teeth's clinical crowns. Several signs of pathology as given in TWES 2.0 were present, and the findings indicated that both mechanical and chemical factors were responsible. Considering all these factors, the diagnosis was generalized moderate and localized severe pathologic tooth wear of mechanical and chemical origin.

Regarding the functional situation, the examination of the dynamic and static occlusion revealed anterior and lateral group function in the absence of anterior/canine guidance, along with dynamic mediotrusive premature contacts in the molar region on the non-working side (Fig 1). These findings are clear indicators of parafunctions in the stomatognathic system caused by bruxism, one of the main causes of generalized tooth wear.

Regarding the occasional pain in the right and left TMJs, the functional diagnosis revealed several findings indicative of TMJ overloading resulting in a condylar displacement into the fossa ("compression"). The extraoral findings confirmed a bilateral masseter hypertrophy, and the esthetic evaluation determined a shortened lower third of the face due to a reduction in the VDO, as already described by Goob et al.[23]

Pretreatment

Simulation of occlusion in an individual articulator

Precision impressions (Impregum Super Quick; Solventum Dental Solutions, Seefeld, Germany) of both jaws were taken to produce the working casts. The maxillary cast was mounted in an individual articulator (Artex CR; Amann Girrbach, Pforzheim, Germany) using an arbitrary facebow transfer (Artex Facebow; Amann Girrbach). The mandibular cast was then positioned based on an unforced centric relation (CR) record in order to reestablish a physiologic condylar position. The programming of the individual articulator, aiming to simulate mandibular movement, was performed based on a dynamic registration by means of an electronic instrument.[23]

Laboratory steps and wax-up/mock-up

Based on the patient-specific functional parameters, the new therapeutic CR, and the therapeutic VDO, a diagnostic wax-up was prepared (Carving Wax, grey; Schuler-Dental, Ulm, Germany) to evaluate the esthetics, occlusion, and function in the fully adjustable articulator.

To accurately replicate the diagnostic wax-up, a silicone matrix was prepared

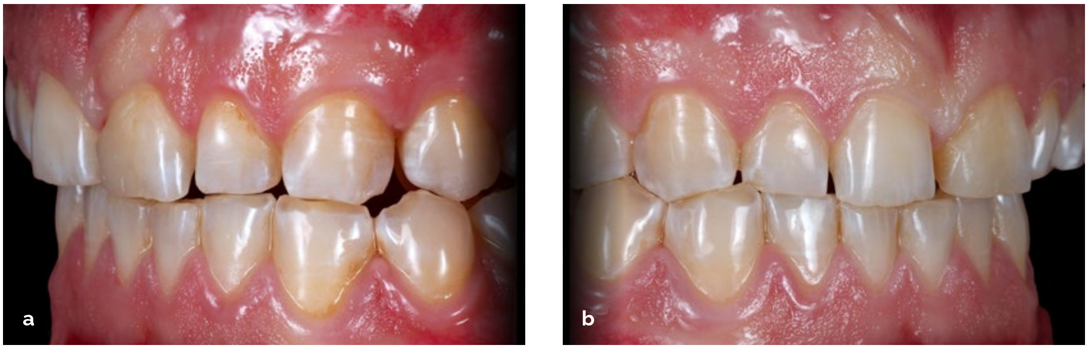

Fig 1a and b Attrition-related worn dentition in dynamic occlusion in a young (25-year-old) male patient exhibiting dentin exposure and loss of canine guidance.

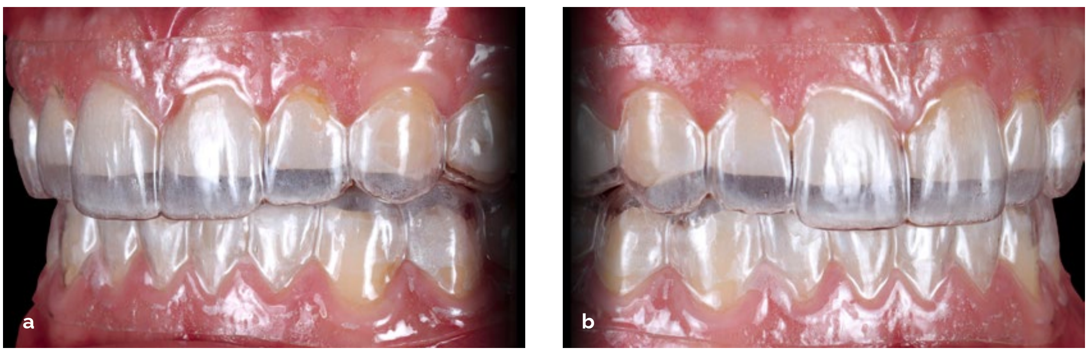

Fig 2a and b The wax-up was transferred by the dental technician into a thermoforming sheet (Duran transparent, 0.5 mm) to create a direct mock-up.

Fig 3a to c Intraoral esthetic and phonetic evaluation using a direct mock-up. Preoperative situation (a). Half mock-up (b). Full mock-up (c).

from a double layer of silicone (Duplicate Silicone Precision, 22 Shore; Briegeldental, Sauerlach, Germany) over the wax-up and hardened in a pressure pot to increase the accuracy of the mock-up. Next, as the basis for later thermoforming, the waxed-up model was duplicated. Subsequently, from the duplicate model, an outer thermoforming foil (eg, Duran transparent, 0.5-mm thickness; Scheu-Dental, Iserlohn, Germany) was derived. This, in turn, was then filled with light-curable temporary crown and bridge composite resin (eg, Protemp 4; Solventum Dental Solutions), placed on the respective teeth, and light cured through the foil (Fig 2). This allowed a precise assessment in advance from both a functional and esthetic perspective, enabling both the dentist and patient to determine the final design prior to treatment (Fig 3). In the present case, further corrections and adjustments for function, esthetics, and phonetics were not deemed necessary.

Fig 4 Transfer of the modified wax-up into a bimaxillary removable CAD/CAM-fabricated simulation splint made of tooth-colored polycarbonate (Munich splint concept).

Fabrication of a simulation splint

Subsequently, the diagnostic wax-up served as a functional and esthetic guide for the creation of a simulation splint. Therefore, the diagnostic wax-up with probable changes during the mock-up appointment as well as the master cast of the initial situation were scanned at the dental laboratory (S900 ARTI scanner; Zirkonzahn, Gais, Italy) and superimposed with the data recorded intraorally. For the splint design, the diagnostic wax-up served as a functional and esthetic guide. In the CAD/CAM workflow, an anatomically oriented wax-up tooth shape design selected from the dental database was utilized for the construction of the Munich splints (Zirkonzahn.Modellier software V.6173-6843-x64; Zirkonzahn).[24] To examine the digitally constructed occlusion, the static and dynamic occlusion were then reexamined in the digital articulator of the CAD software regarding occlusal stability and anterior/canine guidance, as planned, and the occlusal contours were refined, as needed.

Based on these preparations, the maxillary and mandibular splints were then milled from a high-performance polycarbonate (Temp Premium Flexible; Zirkonzahn) using a 5-axis CNC milling machine (Milling Unit M1; Zirkonzahn; Fig 4).

Finally, the splints were reexamined in the individually programmed analog articulator for their static and dynamic occlusion, then polished.

Functional and esthetic evaluation with the splints

Intraorally, the maxillary and mandibular simulation splints (Munich positioning splints) fitted well and without problems, with adequate retention and without unpleasant tension (Figs 5 and 6). On examining the static occlusion with Shimstock foil, the contacts were found to be uniformly tight in the posterior region and reduced in the anterior region. No changes to the static occlusion were required. The patient described the new CR and VDO as appropriate and comfortable. The dynamic occlusion showed harmonious anterior/canine guidance, without any balancing or hyperbalancing contacts in the posterior region. No early contacts in the posterior region were detected during phonetic testing. The patient was not aware of any irritating factors and was pleased with the esthetics, phonetics, and function.

Following the recommendation of the treatment team, the patient wore the splints continually day and night, except when eating and for performing oral hygiene (23-hour splint), for 3 months. Functionally, the patient coped very well with the digitally determined CR and new VDO, and no esthetic or functional adjustments were required during this period. Wear facets in the occlusion of the splints resulting from this "test drive" of the planned occlusion are beneficial and can easily be transferred to the definitive restoration by scanning and subsequent digital superimposition (Fig 7).

Fig 5 Preoperative situation with severe attrition and loss of vertical dimension of occlusion.

Fig 6 Situation after wearing the maxillary and mandibular occlusal splints (Munich positioning splints, manufactured using a snap-on technique) for a period of at least 3 months. The splints enable an esthetic, phonetic, and functional "test drive" in the sense of a long-term registration and can be modified according to the patient's demands.

Fig 7 In the "test-drive" period, wear facets, as a fine adjustment of the occlusion, were generated by the patient (long-term registration). These wear facets were scanned and subsequently incorporated into the design of the final glass-ceramic restoration.

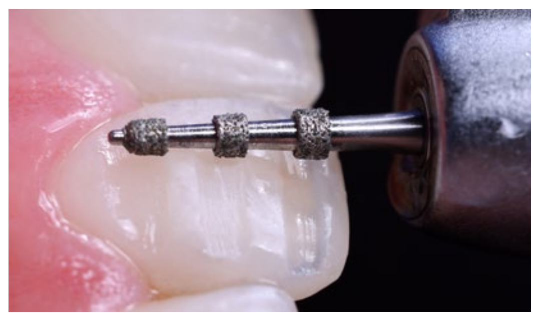

Fig 8 Exemplary clinical presentation of a depth-gauge rotary instrument with a cutting depth of 0.3 mm (instrument shown here: 868BP.314.018; Komet Dental) applied to a worn tooth covered by a mock-up ("third-generation preparation technique").

Transfer to definitive restoration

The transfer to the definitive glass-ceramic restoration could now proceed in stages, in this case using the reciprocal bite-transfer method as described in 2017 by Edelhoff et al.[24]

High-strength silicate glass-ceramic anterior full veneers

Minimally invasive preparation guidelines were performed with a tooth structure removal of a minimum of 0.3 mm cervically and 0.5 mm incisally. To preserve as much sound tooth structure as possible, the preparation was once again guided by the directly placed intraoral mock-up using selected depth-gauge burs (Fig 8).[25,26]

The following preparation burs were employed:

- Depth-marking instruments for 0.3-mm depth markings (868BP.314.018; Komet Dental, Brasseler, Lemgo, Germany).
- Geometrically matching diamond burs for labial preparations and slight chamfer preparations (8856.314.016; Komet Dental) as well as palatal concavity preparations (8379.314.023; Komet Dental) as part of the Perfect Veneer Preparations Set (4686; Komet Dental).

Fig 9 Exemplary presentation of the preparation procedure: Worn posterior teeth, covered by a tooth-colored mock-up. The multiple depth cuts were created with a rounded-tip conical diamond bur and a laser-marked cutting depth of 1 mm. The depth cuts were subsequently highlighted by a graphite pencil with a lead of 0.5 mm diameter, as in veneer preparations. This procedure limits the amount of dental hard tissue removed and at the same time provides sufficient clearance for the restorative material.

Fig 10 Exemplary presentation of the next step in the preparation procedure: Reduction of the mock-up and certain parts of the tooth structure according to the depth markings with the same rounded-tip conical diamond bur and a laser-marked cutting depth of 1 mm (instrument shown here: 855D.314.016; Komet Dental).

- Oscillating instruments (SF8878KM and SF8878KD "half-torpedo" SonicLine tips; Komet Dental) for interproximal chamfer preparations.
- White Arkansas stone burs (modified 649.314.420; Komet Dental) and polishing discs (Sof-Lex XT Pop-On discs, medium grain, 2382 M; Solventum Dental Solutions) for edge breaking, rounding, and finishing of the preparations.

Preparations

Due to their many advantages, the occlusal onlays were planned as minimally invasive partial-coverage restorations featuring supragingival preparations. To ensure an economical removal of the dental hard tissue, additive mock-ups were created based on the procedure described earlier in this article and applied to the defective tooth structures. Additionally, the wax-up on the gypsum model delivered important information for the margin locations according to the dental technician's esthetic and functional analyses. The wax-up color should provide a pronounced contrast (such as gray wax on a white gypsum model) to make the desired extension of the restorations clearly recognizable.

After applying the additive mock-up to the defective teeth, the preparation is initiated by cutting depth markings into the mock-up and/or tooth structure at the depth required to achieve the minimal occlusal thickness for the planned restorative material; for instance, 1 mm in case of monolithic LS_2 ceramics. The present authors 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).

For comfortable placement of the depth markings and the subsequent occlusal preparation, a combination of preparation diamond burs with laser markings 1 mm from the instrument tip can be used (855D.314.016; Komet Dental). If the preparation is based on a mock-up or the tooth surfaces are still in contact with the antagonist teeth, this procedure will create enough vertical space for the occlusal onlays.

Highlighting the depth markings on dental hard tissue or a core restoration with a

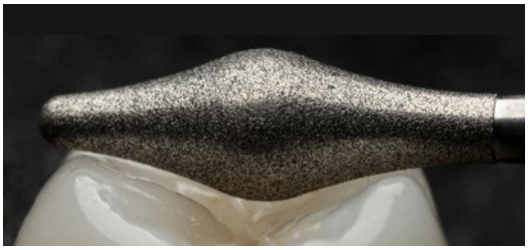

Fig 11 The specific geometry of this instrument creates an anatomically shaped convex cusp support for the future occlusal onlay, while leaving enough space in the central fissure for the dental technician to implement an immediate side shift during dynamic occlusion.

Fig 12 The occlusal plateau for a monolithic lithium disilicate (LS_2) ceramic occlusal onlay was created by an abrasive instrument with a specific geometry (finishing instrument shown here: OccluShaper 8370.340.035; Komet Dental).

graphite pencil or felt-tip pen provides visual control of the subsequent tissue reduction (Fig 9). This ensures that no more hard tissue is removed than is necessary to achieve an occlusal thickness of 1 mm. After removing the mock-up, efficient contouring and leveling of the occlusal surface can be achieved by tilting the same combination instrument shown (Fig 10). This also removes all sharp edges from the occlusal surfaces, which is particularly important if the teeth have been damaged by attrition and biocorrosion, as their shapes may have become very dissimilar to the natural tooth morphology.

For the final shaping of the occlusal surface, the OccluShaper Finishing Diamond 8370 (Komet Dental) introduces a new geometry that provides 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 of the antagonist cusp without premature dynamic contacts (Fig 11). The patented cutting geometry of this instrument allows the dentist to shape the occlusal surface in one step. The different sizes of premolars and molars require the use of different instrument sizes (OccluShaper for premolars: 8370.314.030, OccluShaper for molars: 8370.314.035). To ease the subsequent finishing of the contour, both sizes are also available as finishers (marked in red in Fig 12).

After leveling, shaping, and finishing the occlusal surface, the oral and vestibular surfaces were prepared, contoured, and finished with a rounded chamfer of approximately 0.5 mm in depth. It is important to reach precisely this geometry, which prevents excessive preparation depths and preserves a continuous enamel coverage. To predictably prepare the tooth to this geometry, a special instrument is used which combines a conical diamond instrument with reduced surface roughness with a guide pin at the tip (8849P.314.016; Komet Dental). The guide pin is not diamond-coated and limits the penetration depth for the chamfer to the indented preparation depth of 0.5 mm. 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 (Fig 13).

Fig 13 Preparation design for the full veneers with an equigingival location of the facial margins.

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 to the enamel, wherever possible. A practical alternative for this application is the use of the novel diamond-coated ProxyContour sonic tips (Komet Dental), with one variant each for the mesial (ProxyContour Shaper SFM6) and distal (ProxyContour Shaper SFD6) proximal spaces. These dedicated sonic files are specially contoured for interproximal preparations, on the one hand being extremely thin to limit preparations to the enamel, while on the other hand 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 tip is shaped to produce a marginal geometry, as required for ceramics. The polished surface on the non-preparation side prevents trauma to the adjacent teeth without the need to employ a matrix.

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

Provisionalization and impression

Provisional restorations can be created chairside using a multiple-use diagnostic thermoforming foil in combination with a Bis-GMA–based provisional restorative material (eg, Protemp 4). It is advisable to isolate the surrounding hard and soft tissue 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 (eg, Heliobond; Ivoclar Vivadent, Schaan, Liechtenstein), 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 pellets (Pele Tim; Voco, Cuxhaven, Germany) and Superfloss (Oral B; P&G Braun, Kronberg im Taunus, Germany,) the adhesive layer was cured with a polymerization lamp through the provisional restoration for 30 s.

The technique for the fabrication of the provisionals was also helpful in checking whether enough hard tissue had been removed, as the provisionals precisely represent the thickness of the future ceramic occlusal onlays. Therefore, the provisionals were fabricated before taking the impressions and their thickness (≥ 1 mm) was checked with a measuring instrument.

Prior to taking the precision impressions, the contaminated tooth surfaces were cleaned with rotating nylon cleaning brushes (eg, 9531.204.020; Komet Dental) to avoid any interference with the precision impression material (eg, polyether, Impregum/Permadyne; Solventum Dental Solutions). Next, two retraction cords were placed on top of each other into the sulcus of the intrasulcularly prepared teeth (Ultrapak, size #000 as the first and size #0 as the second filament; Ultradent, South Jordan, UT, USA). In the case of the equi- and supragingival preparations, the single-strand technique using the size #000 retraction cord was sufficient.

The recommended impression technique is a single-stage putty/wash impression in a custom tray or a customized tray

Fig 14 Try-in of the full veneers with Variolink Esthetic Try-In Paste (Ivoclar Vivadent) on the maxillary right canine and right central and left lateral incisors after the adhesive insertion of all posterior occlusal onlay restorations.

Fig 15 Try-in of all anterior full veneers with the try-in paste. All static and dynamic contacts were designed with guidance in LS_2 ceramic. The canine restorations and all the posterior restorations were fabricated with a monolithic design. The central and lateral incisors were partially covered with a veneering ceramic.

Fig 16 *Preoperative* situation: Palatal view of the worn maxillary anterior teeth.

Fig 17 *Postoperative* situation: Palatal view 8 months after the final restoration of the maxillary anterior teeth, including reconstruction of the canine guidance.

with retentions loaded with a polyether adhesive; in this case, M+W Select Rim-Lock, smooth; M+W Dental, Büdingen, Germany.

Try-in and adhesive placement

After removing the provisionals, the sites were cleaned with nylon cleaning brushes and a fluoride-free cleaning paste (eg, Zircate Prophy Paste; Dentsply Sirona, Bensheim, Germany). As in most cases, the temporary adhesives detached as the provisionals were removed from the finished prepared surfaces. On selectively etched enamel surfaces, finishing burs can be used selectively to remove any adhesive and to level the surface locally.

To check the shape and shade of the restorations, they were tried in with colored glycerin gel (eg, Variolink Esthetic Try-In Paste; Ivoclar Vivadent), which is available in colors that correspond to those of the definitive adhesives (warm+, warm, neutral, light, light+). The try-in pastes were used to test whether minimal last-minute shade adjustments to the full veneers were necessary (Figs 14 to 17). Their influence is not very pronounced, but it *increases* with the increasing translucency of the ceramic (usually IPS e.max Press HT; Ivoclar Vivadent) while it *decreases* with higher thicknesses of the ceramic (Figs 18 and 19). An individual opacity selection is required (IPS e.max Press HT, MT, LT, Multi) on the upper areas of the anterior teeth (teeth 12, 11, 21, and 22), In the present case, a color-graded multi LS_2 ingot with individual layering of low-fusing nano-fluorapatite glass-ceramic (IPS e.max Ceram; Ivoclar Vivadent) was chosen for the esthetically relevant anterior region. The marginal fit and occlusion were inspected using a self-mixing A-silicone com-

Fig 18 Minimally invasive preparation design after finishing procedure, including the vestibular areas for functional and esthetic reasons (change of shade and buccal corridor). Across almost all areas of the preparation surface, enamel could be retained for secure and permanent adhesive bonding.

Fig 19 Try-in of the LS_2 ceramic monolithic onlays with a minimum of 1-mm occlusal thickness in the mandibular posterior region.

pound (eg, Fit Test C & B; Voco), which needs to be performed before etching the ceramic.

The internal surfaces of the LS_2 ceramic restorations were then etched with hydrofluoric acid gel (eg, IPS Ceramic Etching Gel; Ivoclar Vivadent) for 20 s. To remove any residual acid, the etched restorations were sprayed with a water–air mixture for 30 s, and the acid was neutralized (IPS Ceramic Neutralizing Powder; Ivoclar Vivadent). Submersion in a container filled with 96% ethanol in an ultrasonic bath for several minutes can be helpful in removing persistent excess material.

Following a visual inspection of the etching pattern, a silane-containing primer (Monobond Plus; Ivoclar Vivadent) was applied to the etched ceramic for 60 s to establish a chemical bond between the adhesive and the silicate ceramic. Applying heat significantly increases the priming effect. The consistency of the *low-viscosity* adhesive (Variolink Esthetic) required no further low-viscosity adhesive to be applied to the restoration.

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

After removing any excess, but before the final curing step, a glycerin gel (eg, Liquid Strip; Ivoclar Vivadent) was applied to the surfaces 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 s using a powerful polymerization lamp (> 1000 mW/cm²), accompanied by mild air cooling.

Following adhesive cementation and excess removal, the static and dynamic occlusion were rechecked for the presence of interferences and premature contacts. Fine-grained diamond grinding wheels (35 µm peak to valley) with irrigation are used for the final adjustment of the static and dynamic occlusion. The adjusted surfaces should then be smoothed with a

Fig 20 Postoperative situation after final adhesive placement of 24 LS_2 ceramic partial-coverage restorations. The anterior teeth in the mandible (teeth 42, 41, 31, and 42) were restored with direct composite restorations.

Fig 21a to c Postoperative situation of the patient 2 weeks after restoration placement.

ceramic polisher (eg, 9545F.204.110; Komet Dental), finalizing the adhesive placement of 24 LS_2 ceramic partial-coverage restorations in the maxillary anterior and all posterior regions. Furthermore, four direct composite restorations were placed in the mandibular incisors (Figs 20 and 21).

Discussion

Treatment indication

The *decreasing* incidence of caries, accompanied by an *increasing* incidence of biocorrosive defects *changed defect morphologies* of the dental hard tissue.[2] This has led to an altered requirement profile for minimally invasive defect-oriented adhesively cemented single-tooth restorations. Today, restorative treatment of the worn dentition focuses more on specific incisal and occlusal (with or without superficial circumferential) defects, seeking to restore adequate function, esthetics, and biomechanics and to help prevent further pathologic wear.

CAD/CAM vs analog wax-up

Both CAD/CAM and analog wax-ups require the involvement of an experienced dental technician. Due to the detailed emergence profile in the vestibular, interproximal, and palatal areas for phonetics, together with the importance of nonverbal communication that occurs through the color difference between the model and the wax-up, the analog wax-up remains the standard of the present authors and was performed in the case reported here. It allows for constant 3D control, whether by the dental technician when making the wax-up or by the dentist during preparation adjustments.

Another very effective approach is starting with the tooth design early in the digital workflow and continuing with the use of a virtual articulator for dynamic occlusion, which can be enhanced with a facial scan.

Regardless of whether a digital or analog method is used, a wax-up and mock-up are mandatory requirements.

Direct vs indirect restorations

In complex rehabilitations like those involving the reconstruction of the VDO, indirect restorations facilitate a safer and more stable implementation of a physiologic occlusion because they provide better control over the optimal form and esthetics as time progresses.[12] In complex situations where a large number of occlusal surfaces are treated in the rehabilitation, both direct and indirect techniques initially require input from the dental technician for the 3D-treatment planning in the form of a wax-up. However, indirect restorations are associated with higher cost due to the fabrication of the restorations in the dental laboratory. Silicate ceramic materials are considered the materials of choice for such indirect restorations that replace lost enamel due to their similar optical and mechanical properties in single-tooth restorations. Long-term studies indicate that these adhesively cemented glass-ceramic partial-coverage restorations represent a safe treatment modality, both in the anterior and posterior regions.[27,28]

In severely worn dentitions, a circular extension of the veneer preparation to a 360-degree ("full-wrap" or "full-veneer") design on anterior teeth is considered to be advantageous in order to cover the affected tooth structure, mostly damaged as a consequence of traumatic anterior occlusion. This approach also serves to close the space created in the palatal area by the increase of the VDO on the maxillary anterior teeth. Minimal invasiveness is improved by a directly placed intraoral mock-up using selected depth-gauge burs for the preparation. The use of special depth-gauge burs for initial veneer preparation led to significantly lower preparation depths compared with "freehand" preparations.[25]

Longevity in terms of preparation design and materials

In a prospective clinical study investigating the survival and complication rates of anterior full-veneer restorations made of LS_2 ceramic with a mean observation period of 8 years, a 100% survival rate and 12.5% complication rate was reported.[29] A minor technical complication of small repairable chippings in four restorations and one major complication – a crack of one restoration due to trauma – were described. No biologic complications, debonding, discoloration, secondary caries, or postplacement endodontic issues occurred.

In view of the changes in the occlusal contours that occur due to severe wear in posterior teeth, adhesively cemented occlusal onlays made of high-strength glass-ceramics are a more desirable type of restoration than classic full crowns, which are twice as invasive. For decades now, the secure adhesive bonding to enamel and silicate ceramic restorative materials has significantly influenced preparation techniques in the posterior region with a view to preserving more healthy dental hard tissue. Restorations of this type are beneficial because of the low risk of damaging the pulp, improved 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 posterior all-ceramic partial restorations refer to leucite-reinforced glass-ceramics.[19,30] Today, however, much more fracture-resistant restorations based on lithium (di)silicate ceramics are preferred.

Fig 22 Monolithic LS_2 ceramic occlusal onlays (IPS e.max Press, degree of translucency: HT; Ivoclar Vivadent) with an occlusal thickness of 1 mm after adhesive cementing (in 2008) using Syntac, Total Etch, Variolink II, Monobond S (all Ivoclar Vivadent; Laboratory procedures: Oliver Brix, CDT, Bad Homburg).

Fig 23 Follow-up of the restorations shown in Figure 22 after almost 16 years of clinical service (in 2024). The supporting (buccal) cusps of the restorations show marked impressions and wear facets caused by the antagonist teeth (also monolithic LS_2 ceramics) exposing underlying caries-free enamel at one cusp.

Since the introduction of LS_2 ceramics, 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 (see Figs 9 and 10). A further reduction in thickness is currently being discussed for situations where sufficient support from enamel is present.[31,32] However, an adequate material thickness for potential corrections of static and dynamic occlusion and material wear over time, especially in patients with a high functional load, must be taken into consideration (Figs 22 and 23).[33] Long-term clinical studies on occlusal onlays with observation periods of up to 11 years with high survival rates refer to an application of a 1-mm occlusal thickness.[22,34]

Regarding longevity, leucite-reinforced glass-ceramic onlays showed satisfactory long-term results in a prospective controlled 12-year clinical study and can be used to rehabilitate extensive dental hard tissue defects.[30] In another clinical study on leucite-reinforced glass-ceramics with a mean observation period of 12.6 years, a failure rate of 20.9% was determined on vital teeth, compared with 39% on endodontically treated teeth.[19]

The longevity of LS_2 glass-ceramic onlays was reported in clinical studies with observation periods of up to 10.9 years. Malament et al reported a survival rate of 98.3% at 9.8 years, providing an estimated risk of 0.29% per year.[22] In that study, all failures occurred exclusively in the molar region. In another prospective clinical long-term study by some of the present author group, a survival rate of 100% and a complication rate of 10% were identified.[34] Technical complications were associated with four marginal discolorations and one marginal crack formation (Fig 24). No biologic complications occurred. In the subsequent recall period, after article publication in 2019, a repairable loss of retention of an occlusal onlay in the mandibular left second molar after a clinical service period of 138 months occurred (Fig 25).

As for the indirect restorative material used, to date there is a lack of valid long-term clinical data for minimally invasive definitive restorations made of CAD/CAM polymers, compared with the substantial number of long-term clinical studies available on minimally invasive ceramic materials. In a randomized split-mouth clinical trial investigating the survival rate and qual-

Fig 24 Follow-up after 11.5 years of clinical service as part of a prospective clinical long-term study. During the recall appointment, a minor fracture at the palatal margin associated with a subcritical crack propagation was observed in the maxillary right second premolar (tooth 15) as well as localized margin discolorations of the monolithic LS_2 partial restorations.

Fig 25 Follow-up after more than 12.5 years of clinical service: Retention loss and marginal discoloration of a monolithic LS_2 onlay restoration in the mandibular left second molar (tooth 37). The composite buildup was still bonded to the internal surface of the restoration, indicating a reliable bond to the glass-ceramic and a weaker adhesion to the dentin areas after more than a decade of service. After cleaning and moderate corundum blasting and tribochemical activation, along with etching and priming of the tooth surfaces as well as the surfaces of the internal ceramic and composite buildup, the restoration was successfully recemented in its original position.

ity of survival of indirect composite resin and ceramic laminate veneers over a 10-year period, significantly better results were reported in the group of ceramic veneers.[35] The cumulative survival after 10 years of the indirect composite resin veneers was 75% and that of the ceramic veneers was 100%. The six failures in the indirect composite resin laminate veneer group consisted of three debondings and three fractures.

A recent article compared the results of two clinical studies in patients with moderate to severe tooth wear.[36] In the one study, pressed LS_2 single-tooth restorations were placed, and in the other study, experimental CAD/CAM composite resin single-tooth restorations were used. The LS_2 single-tooth restorations showed lower long-term failure rates than those made of CAD/CAM composite resin. On the other hand, the composite resin restorations exhibited more material fractures and higher discoloration rates. These findings were confirmed by an up to 3-year randomized clinical trial comparing ultrathin CAD/CAM LS_2 single-tooth restorations and ultrathin CAD/CAM composite resin restorations.[37] Higher surface degradation and minor partial failures (restorable chipping) were observed exclusively in the composite resin group.

Another clinical study compared the wear behavior of LS_2 and composite resin over a time period of 3 years, applied to patients with moderate to severe tooth wear.[38] Significant differences between both groups could be identified. The composite resin restorations showed much higher wear rates compared with the LS_2 ones. The wear rates in both materials differed between the premolars and molars, with higher amounts of wear on the molars. The results suggested that, with increasing time in situ, the monthly wear rates for both materials decreased over time.

In an in vitro study, the thickness of the glaze layer of LS_2 restorations was measured to be 100 to 120 µm, and wear usually occurred within the first months or years of clinical service.[39] A relatively short-term occlusal adaptation by the glaze layer was identified in an in vitro study, which might explain the higher wear rate of the LS_2 restorations in the first compared with the second year.[40] However, after 10^6 cycles of oral wear simulation, the glazed LS_2 specimens showed comparable roughness and volume loss compared with the polished ones.[38,40]

Also, clinical studies on direct composite rehabilitations reported that their survival rate depended on the position of the teeth, with survival rates being most unfavorable in the case of molars.[15] Even though the wear of composite resin restorations was higher, the prosthodontic treatment was less invasive than with LS_2 restorations due to the associated tooth preparation with the latter. Based on these clinical results, more wear-resistant materials in load-bearing areas might be recommendable in patients with higher functional risks.

Despite all the euphoria about the restorative options 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, and therefore require highly skilled dentists to provide the restorations.[41]

Adherence to defined guidelines during the various clinical and technical treatment phases is a key factor for achieving long-term clinical success.[36]

Conclusions

Anterior full veneers and posterior occlusal onlays made of high-strength silicate glass-ceramics represent an interesting contemporary form of indirect restoration for reconstructing the occlusion in patients suffering from pathologic tooth wear. Combined with minimally invasive supragingival or equigingival preparation margins, these restorations offer numerous advantages:

- Reduced loss of dental hard tissue.
- Preservation of enamel for durable adhesive bonding.
- Unobstructed view of the site during preparation.
- Conventional or digital impressions without interference from sulcus fluid and/or undercuts.
- No traumatic interference with the marginal gingiva.
- Well-controlled adhesive cementation.
- First promising long-term clinical results.

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

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