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The workflows of a novel self-glazed zirconia for dental prostheses fabrication: case reports

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ABSTRACT
In the clinical application of ceramic prostheses, micro-leakage, porcelain chipping, low-treatment efficiency and quality uncertainty have appeared as the major problems that dentists encountered. However, the full-contour zirconia monolithic prostheses have the potentials for solving the problems. It appears that the full-contour zirconia monolithic prostheses produced through the fully digital workflow can ensure that the restorations can be closely aligned with the abutment and be easy to adjust and to wear, thus to assure the stability and accuracy of occlusal, which are crucial to the ultimate integration of the full-contour zirconia monolithic prostheses by avoiding unfavourable grinding. The newly developed full digital approach can greatly simplify the previous workflow that involved many manual operations. It improves not only the treatment efficiency but also the reliability of the prostheses by avoiding manual operational mistakes.

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Introduction

In oral clinical practice, to solve various problems of tooth defects and dentition defects encountered, crown and bridge prosthetics are considered to be the good choice in both the aesthetical and functional points of view. Although clinical techniques and repair materials are advancing with time, it is still difficult to meet the clinical repair needs, i.e. the restorations can be closely aligned with the abutment and be easy to adjust and to wear, thus to assure the stability and accuracy of occlusal. In order to achieve this goal, efforts have been made, on the one hand, to adapt new materials; thus, metals and resins have been introduced for preparing prostheses, and lately the porcelain laminated and the all-ceramic prostheses have been used in clinical applications. However, it has been revealed that metal crowns showed more antagonistic enamel wear than natural teeth, and it appears not be the material of choice in a high-aesthetic demand region [1]. Resin crowns demonstrated improved aesthetics, but it is easy to be abraded and collared. Porcelain-fused-to-metal (PFM) and all-ceramic crowns may wear the antagonistic enamel and face a huge risk of porcelain chipping. On the other hand, new manufacturing techniques have been introduced consistently through the years; thus, the production of prostheses has been turned from the previous processes that completely relied on technicians to the more advanced one in which ceramic cores were made by direct CNC milling of pre-sintered zirconia blanks. Nevertheless, as a final layer of porcelain or glaze has to be added manually to restore the correct occlusal, the chipping of surface silicate glass layer is hard to avoid [2]. Studies have shown that the porcelain chipping is the main origin responsible for the failure of all-ceramic restorations [3]. Shen et al. found that the porcelain chipping of all-ceramic restoration is often initiated at the interface between the coping and porcelain layer, which is closely related to its processing procedures [4]. Therefore, developing full-contour monolithic prostheses made of a single material with suitable surface roughness, aesthetics, biocompatibility and mechanical durability is highly desired in order to minimize the clinical adjustment.

Full-contour zirconia monolithic prostheses have been approved as one of the most advantageous candidates for restoration in the posterior regions, primarily because of their mechanical durability [5]. Liu et al. reported that the full-contour zirconia monolithic prostheses have almost the same frictional coefficient as well as polished zirconia surface [6]. That is to say, this new category of zirconia prostheses that is free from veneering porcelain avoided ultimately the risk of porcelain cracking and chipping. And the new grade of full-contour zirconia dental ceramics has no shear stress on the surface that will strengthen the full-contour zirconia monolithic prostheses. With adjustable optical translucency and aesthetic

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behaviours, the new grade of full-contour zirconia dental ceramics fit particularly for model-free digital workflow of the manufacture of customized. This can avoid conventional manual work of grinding/polishing, veneering and glazing. What is more, further breakthrough in developing full-contour zirconia monolithic prostheses has been achieved by introducing a structural gradient concept so a fine-grain structured surface layer made of also zirconia enabling to mimic the aesthetics of natural enamel is formed inherently during a 3D net-shape additive manufacturing process [7]. The 3D net-shape additive manufacturing is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies [8]. Instead of normal additive manufacturing, the 3D net-shape additive manufacturing is based on hybrid gelation principle [6]. And the 3D net-shape additive manufacturing can improve the mechanical properties by combining 3D printing with hot forging and subsequent heat treatment [9]. Known as Self-Glazed Zirconia, the latter developed full-contour zirconia monolithic family prostheses demonstrated fundamentally improved aesthetics and thus can be applied to the anterior regions. Since the surface of the self-glazed zirconia prostheses remains highly smooth after repeated chewing, the antagonistic enamel wear can be greatly reduced [10]. Stober et al. reported that other ceramic materials demonstrated higher antagonistic enamel wear than monolithic zirconia restorations with polished surface [11]. Therefore, the new full-contour zirconia monolithic prostheses, Self-Glazed Zirconia, is the most desirable restoration material to meet the clinical requirements. In addition, by integration of the digital technologies used in oral medicine, the Self-Glazed Zirconia prostheses may provide cost benefit over other materials besides assuring a more accurate fit by adapting to a full digital approach based on computer-aided design/computer-aided manufacture (CAD/CAM) principles. Using the full digital workflow, one can sufficiently simplify the previous workflow that otherwise involved many manual operation steps. After the tooth preparation, one can use the digital optical scanner to scan the teeth that becomes the base for the CAD design and CAM production of the provisional resin prostheses on chairside. Then, one can adjust the provisional prostheses by using the patient mouth as a live full adjustable articulator and re-scan them when needed. The digital data with corrected occlusal conditions obtained in this way then can be copied for the production of the Self-Glazed Zirconia prostheses based on a 3D net-shape additive manufacturing principle. It is expected that prostheses obtained thereafter can be fixed finally without or with only minimal clinical adjustment .This approach would sufficiently shorten the treatment time. There are other advantages of the full digital workflow that include the accurate control of the counter of the prosthesis, of the adhesive gap and adjacency, of the restoration of the occlusal relationship, and to achieve a more personalized design through improved conversion between the patient and the dentist helped by the provisional prostheses [12]. Through the precise and fine design of the restoration, the full-contour zirconia monolithic prostheses would retain a very smooth occlusal surface by avoiding unfavourable clinical grinding [13,14]. In this way, the treatment efficiency would be improved, so does the patient's satisfaction of the medical care [15].

In this article, two clinical cases are described in detail to illustrate the potentials of the Self-Glazed Zirconia as a new category of full-contour zirconia monolithic prostheses for the anterior and posterior teeth, respectively. The corresponding full digital workflow for preparing and implementing the Self-Glazed Zirconia prostheses by a 3D net-shape additive manufacturing approach is compared with that for preparing the conventional porcelain laminated prostheses or full-contour zirconia monolithic prostheses with a polished or silicate glass glazed surface.

The workflows

The traditional partial digital approach

In a traditional partial digital approach as illustrated in Figure 1, the ceramic prostheses were produced by involving the following steps: (1) after the teeth preparation, the impressions were taken and sent to the dental laboratory; (2) the technicians in the dental laboratory produced the plaster model based on the impressions; (3) then the technicians scanned the models and design the digital cores of the prostheses; (4) the cores of the prostheses were produced by milling of the partially sintered zirconia blanks that were further sintered to full density; (5) a layer of silicate glass, empirically called as porcelain, was manually added to the ceramic cores or the surface the fully densified ceramic prostheses and was manually polished to accomplish the prostheses ready for clinic use; 6) the dentist needs to try the prostheses in the patient's mouth and adjust the prostheses repeatedly. As manual mistakes in this approach are unavoidable, dentists have to try the prostheses in the patient mouth and adjust the prostheses repeatedly that often ended up the ceramic prostheses with a partially damaged surface having a high risk of porcelain chipping.

A full digital workflow

In a newly developed full digital workflow as illustrated in Figure 2, the zirconia ceramic prostheses are produced by involving the following steps: (1) to build a three-dimensional digital occlusal model based on intraoral scanning

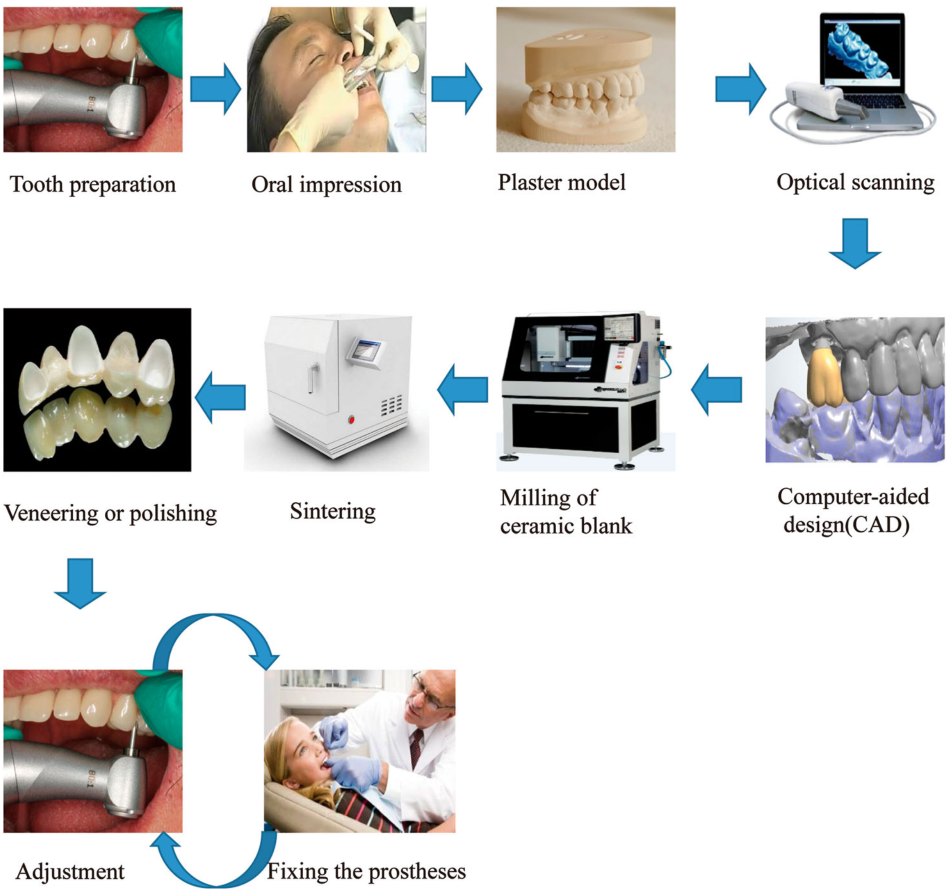

Figure 1. An illustration revealing the steps involved in the traditional partial digital approach of the ceramic prostheses.

data; (2) to design the prostheses by CAD; (3) to produce the provisional prostheses made of resin based on CAM principle on chairside; (4) to adjust the provisional prostheses in the patient's mouth and re-scan them when needed; (5) to make the full-contour zirconia monolithic prostheses by copying the digital data with corrected occlusal conditions based on a 3D net-shape additive manufacturing principle: (6) to fix the prostheses without or with only minimal clinic adjustment.

Comparing with the traditional digital approach, the full digital workflow can essentially simplify the previous digital approach that involved many manual operation steps. It thus would improve not only the treatment efficiency but also the reliability of the prostheses by avoiding manual operational mistakes. The zirconia prostheses prepared in this way of a 3D net-shape additive manufacturing has a glossy surface that imitates the optical appearances of the natural

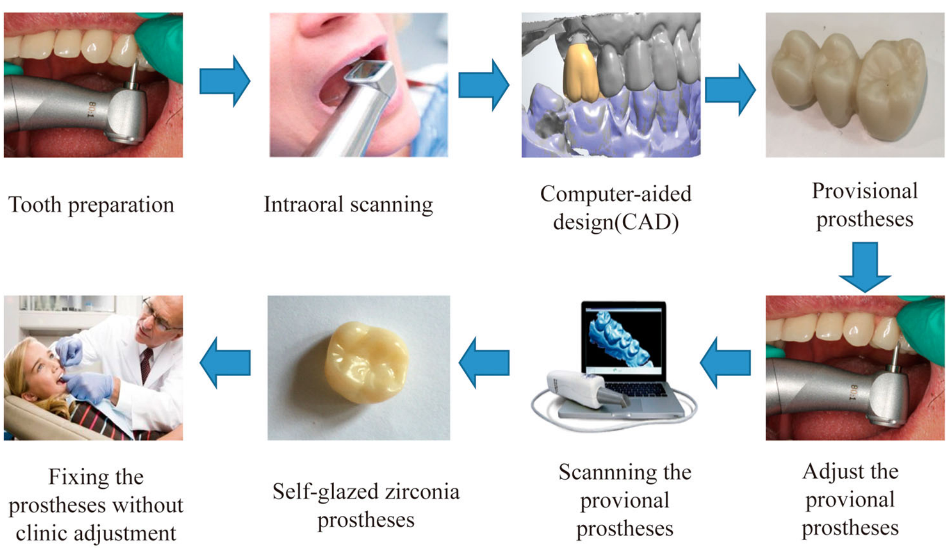

Figure 2. An illustration revealing the steps involved in a full digital workflow of the ceramic prostheses.

enamel. This enamel-like surface is composed of fine zirconia grains of ~150 nm that would remain highly smooth even after repeated chewing, thus to sufficiently reduce the wear of the antagonistic teeth.

Results: two clinical cases

Case 1

A patient suffered an avulsion of teeth 41 and 32 due to a traumatic injury. Figure 3(a) shows the initial intraoral situation with mandible anterior teeth dentition defect. After clinical and radiological assessments, two treatment plans are presented:

1. A restorative procedure with a fixed bridge from 33 to 42.
2. An oral implant treatment to place dental implants at 32 and 41.

The second option is more costly and time consuming but is less invasive to the adjacent teeth. The patient selected the first option.

After the minimally invasive teeth preparation, intraoral scanning was carried out to record the 3D-digital occlusal situation (see Figure 4(a)). Based on this, the digital prostheses were then designed by CAD (see Figure 4(b,c)). In this step, it was essential to draw the edge line of the prepared teeth and to design the bridge with correct occlusal conditions. Thereafter, the provisional prostheses made of resin were prepared by CAM on chairside (see Figure 4(d)). The most accurate occlusal conditions were then obtained by adjusting the provisional prostheses in the patient's mouth (see Figure 3(c)). In this way, the patient's mouth was used just like an alive full adjustable articulator to reproduce more than one movement, i.e. a centric relationship, protrusive and retrusive movement and a left–right lateral maxillomandibular relationship. The repeated adjustment of provisional prostheses would lead to the most comfortable occlusal conditions that will then be re-scanned and used as the base for the production of the full-contour zirconia monolithic prostheses based on a 3D net-shape additive manufacturing principle (Figure 5). By optimizing the occlusal conditions, the full-contour zirconia monolithic prostheses can be fixed without or with only minimal clinic adjustment (Figure 3(d)).

Case 2

Owing to fracture, the tooth #27 of a patient was treated by root canal treatment (see Figure 6(a)). After clinical and radiological assessments, it was suggested that a full crown should be prepared to protect the cracked teeth. The damaged tooth was prepared with minimal invasion (see Figure 7(a)). Intraoral scanning was then carried out to rebuild the 3D-digital occlusal model (see Figure 7(b)). In this case of a single crown, the occlusal conditions can be adjusted digitally to quite a high accurate level (see Figure 7(c,d)) The Self-Glazed Zirconia monolithic prostheses thereafter prepared by using a full digital workflow can be fixed with only minimal clinic adjustment (see Figure 6(b)).

Figure 3. Intraoral photos demonstrating the repairing process of a mandible anterior teeth dentition defect. (a) The initial condition; (b) after the minimally invasive dental preparation; (c) with provisional prostheses; (d) with Self-Glazed Zirconia prostheses fixed without clinic adjustment.

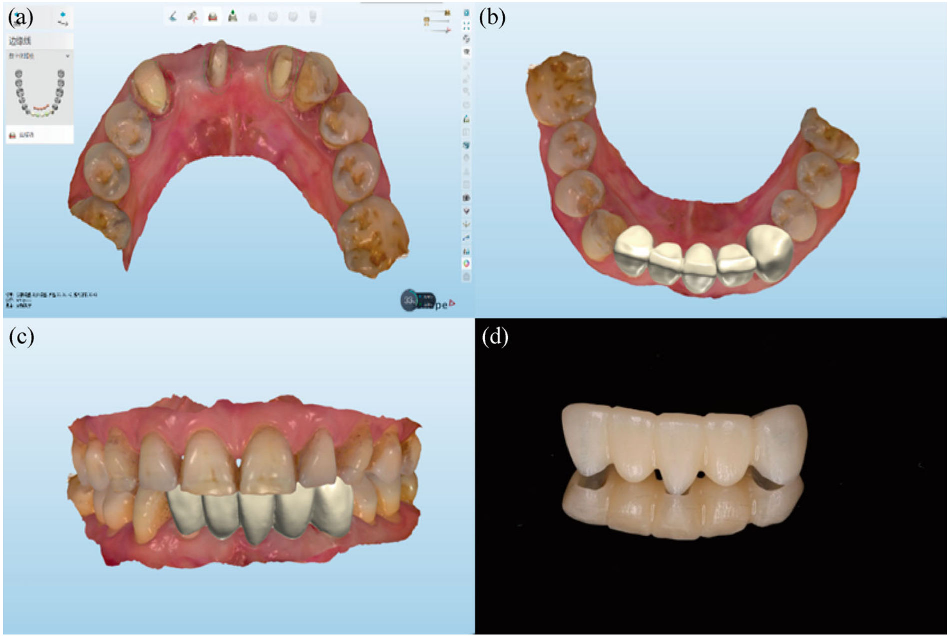

Figure 4. (a) The digital model built based on scanned data; (b) the CAD morphology of the bridge; (c) the CAD of the occlusion; (d) the PMMA provisional prostheses.

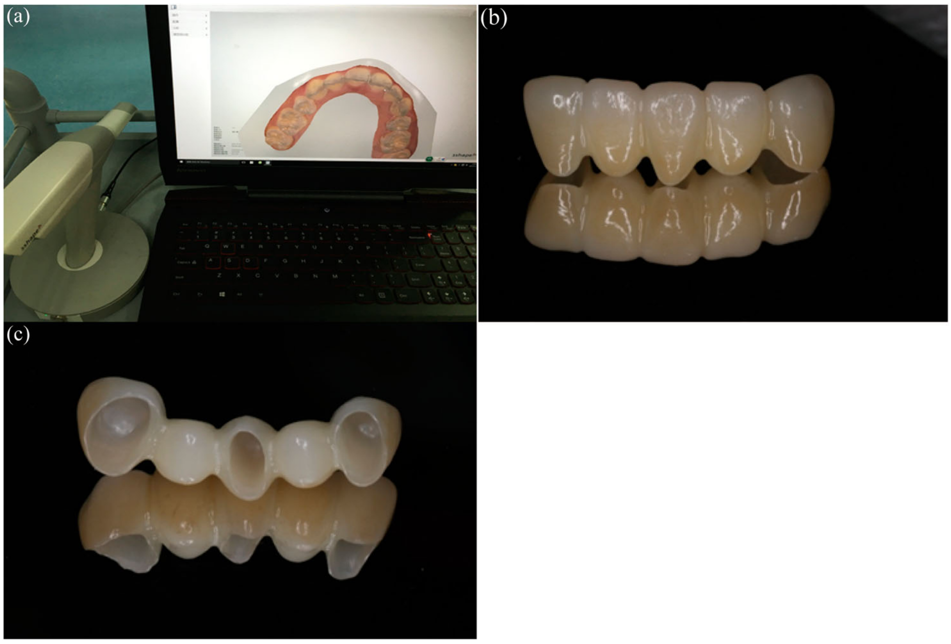

Figure 5. The re-scanned image of the provisional prostheses: (a) the labial view; (b) the intaglio view; (c) the Self-Glazed Zirconia monolithic prostheses.

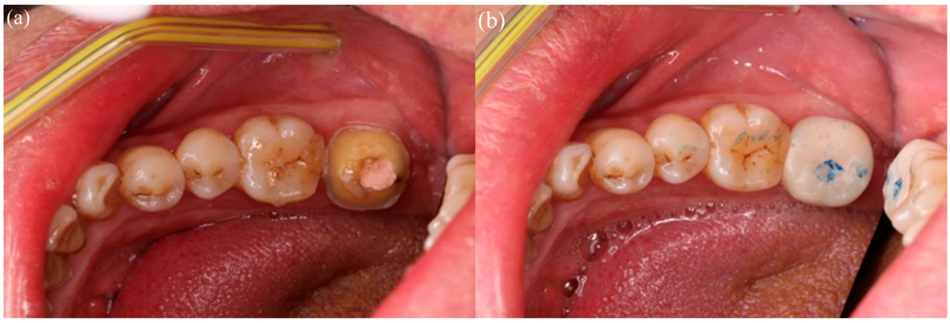

Figure 6. Intraoral photos demonstrating a tooth defect of tooth #27 (a), and the repairing result by a Self-Glazed Zirconia crown after minimal clinical adjustment (b).

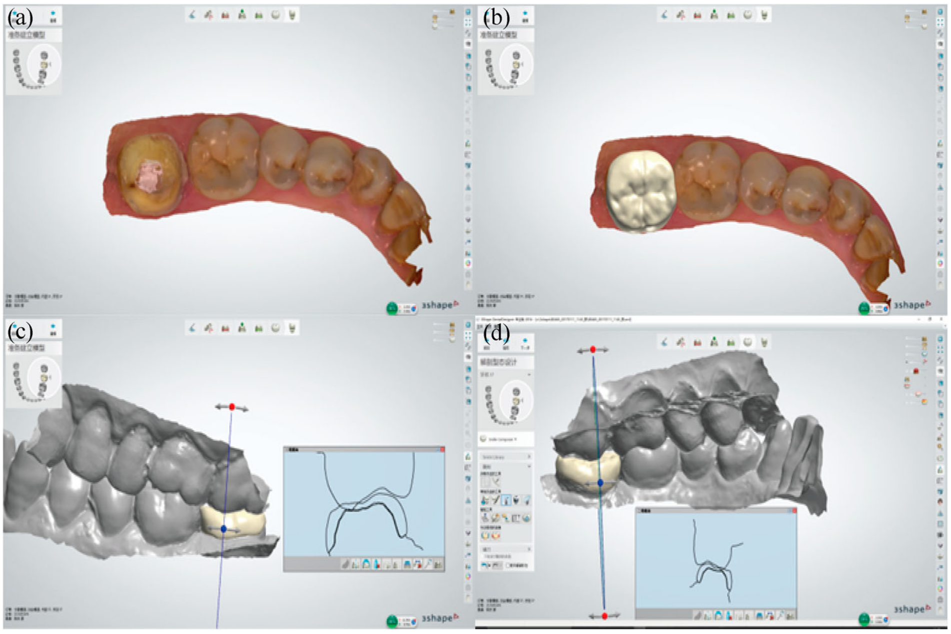

Figure 7. A full digital approach towards the Self-Glazed Zirconia crown. (a) The intraoral scanned image of the tooth #27 prepared with minimal invasion; (b) the CAD of the prosthesis; (c) digitally adjusting the occlusal conditions (the labial view); (d) digitally adjusting the occlusal conditions (the lingual view).

Discussions

Micro-leakage, porcelain chipping, low-treatment efficiency and quality uncertainty have appeared as the major concerns of the application of ceramic prostheses. Effects have been made to solve these problems by, for instance, using more accurate impression material/process, using materials with higher strength and improving the techniques of teeth preparation, yet with very limited success achieved. The recent introduction of new grade full-contour monolithic zirconia restorations that are veneer and glazing layer-free has thrown light on solving these problems [16]. Known as Self-Glazed Zirconia, this new family of gradient structured zirconia restorations are formed by a precision additive 3D gel deposition approach that matched perfectly well with a full digital workflow [17]. The as-sintered surface of this novel zirconia is as smooth as the natural enamel and its wear behaviour is similar to that of the finely polished zirconia ceramics [6]. When correct occlusal conditions are established by intraorally adjusting the provisional prostheses made of resin, this smooth surface can be preserved by avoiding further clinical adjustment.

In the current two cases, the Self-Glazed Zirconia monolithic prostheses were used to treat the tooth defects and dentition defects. The benefits of this treatment to dentists are a better clinical result, a smoother procedure with shortened cycle of treatment by avoiding clinical adjustment; the benefits to patient are minimal invasive teeth preparation, short treatment time and increased reliability of the prostheses. In prosthodontic dentistry, the obvious advantages of the full-contour zirconia monolithic prostheses have been recognized [18]. First of all, compared with the traditional PFM or laminated zirconia prostheses, it greatly improved the geometrical accuracy of the prostheses through the digital optical scanning and the digital designing and manufacturing of the prostheses [19]. This achievement made it possible to clinically wear the prostheses with much smooth and high efficiency with no or much less grinding that was unavoidable by using the more conventional prostheses. Second, the application of full-contour zirconia monolithic prostheses can shorten the treatment cycle, making the treatment much more efficient and with significantly improved patients' satisfaction [20]. Finally, the implementation of the full-contour zirconia monolithic prostheses in dental practice allows the dentists, technicians and patients to have a better communication concerning the designing outputs that ensure the accuracy of the restoration while meeting the individual needs of the patients [21]. A further achievement of Self-Glazed Zirconia in producing full-contour zirconia monolithic prostheses by avoiding any manual operation makes this grade of zirconia prostheses match better with a full digital workflow [22]. On the other hand, the anti-fracture properties, permeability, stability and biocompatibility of the full-contour zirconia monolithic prostheses can meet the clinical requirements is an already approved evidence, a further improvement of the geometrical accuracy and surface smoothness in case of Self-Glazed Zirconia would make this family of prostheses even more reliable [23]. The improved aesthetics enabled by increased optical translucency and shade gradient in Self-Glazed Zirconia make the family of full-contour zirconia monolithic prostheses not only fit for the application in the molar region with large bite force but also fit for the applications in the anterior regions where a high-aesthetic demand is crucial [24].

The success demonstrated by the current two clinical cases in the application of a new grade of full-contour zirconia monolithic prostheses known as Self-Glazed Zirconia indicates that the materials process is as important as the materials themselves, if not even important. The potentials of a material have to be explored together with the possible material processes that couple with the advances in clinical treatment procedure. This goal cannot be achieved without the involvement of cross-disciplinary research collaborations by involving experts with different professional backgrounds [25]. It thus appears extremely desire to break the barriers between industries and the boundaries between disciplines to generate a dynamic and open environment for further innovation in prosthodontic dentistry [26].

Conclusions

Two clinical cases were used to demonstrate the potentials of the full-contour zirconia monolithic prostheses in prosthodontic dentistry. Known as Self-Glazed Zirconia, the production of this zirconia prostheses matches well with a full digital dental workflow. It can ensure that the restorations can be closely aligned with the abutment and be easy to adjust and to wear, thus to assure the stability and accuracy of occlusal, which are crucial to the ultimate integration of the prostheses by avoiding unfavourable grinding. The newly developed full digital approach can greatly simplify the previous workflow that involved many manual operations. It improves not only the treatment efficiency but also the reliability of the prostheses by avoiding manual operational mistakes. The success in solving otherwise hard to handle problems by the application of this new grade of zirconia prostheses visualized the value of cross-disciplinary research collaborations by emphasizing the materials processes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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