CAD/CAM Technology and Zirconium Oxide with Feather-edge Marginal Preparation

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Abstract

Clinical needs and growing patient expectations have forced modern dentistry to focus on finding ever simpler protocols and to develop materials which offer high performance in their mechanical resistance and esthetics.

In recent years, the scientific community has been venturing into the world of CAD/CAM, a significant technological innovation imported from the world of engineering. This innovation has made it possible to exploit a material which has long been noted for its mechanical and mimetic qualities: zirconium oxide. While CAD/CAM is revolutionizing the laboratory work of dental technicians, the white color of zirconium has opened new avenues which may lead not only to new options for proper treatment planning, but also to new opportunities in the choice of materials to be used in prosthetic rehabilitation and variation of the types of preparations possible.

The present paper will analyze the advantages and limitations of these methodologies, which are capable of simplifying clinical protocols and standardizing results. These technologies have instilled great enthusiasm in the profession due to their innovative nature, but this approach needs to be verified by further scientific evidence.

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CLINICAL APPLICATION

Introduction

CAD/CAM is a term borrowed, like the technology associated with it, from the world of engineering and has been applied to clinical dentistry. The end products in the two fields are very different as far as materials, forms, and dimensions are concerned, but the philosophy behind the process remains the same and involves the replacement of manpower with mechanized or robot-powered procedures.\(^1,2\)

The procedures can be divided in two phases: CAD (computer-aided design), whereby the object is designed and created virtually, and CAM (computer-aided manufacturing) which takes the design from the virtual to the production of the designed object.

The precision involved and the ability of this technology to standardize both the process and the finished product make its potential fascinating in itself; in theory it may even be possible to eliminate variables introduced by the operator in the laboratory phase and reduce the clinical steps needed to produce the final prosthesis.\(^3\) Interest for CAD/CAM technology has been expressed by dentists the world over, as this technology makes it possible to work with different materials. Some of these include titanium as base metal alloys, acrylic resins for provisional restorations, and either crystalline or vitreous ceramics. The material with the most applications is a ceramic oxide stabilized with yttrium oxide known as zirconium dioxide (zirconia).\(^4\)

Many questions have arisen about this new method from both clinicians and dental technicians alike; in fact, the laboratory will be most affected by these innovations.

Therefore, the clinician needs to be able to understand how these new CAD/CAM technologies and intraoral optical impressions can be integrated with everyday clinical practice, what type of preparations and prosthetic margins will be compatible with these new materials, and precise information about how to use them.

From a chemical point of view, zirconium is a grey/white hard transition metal, which is not found in nature as a pure mineral. In dentistry, zirconium is not used as a pure mineral but as a ceramic oxide (zirconium dioxide) instead. From a structural point of view, zirconium dioxide comes in three states: cubic, monocline, and tetragonal.\(^5\) All of these states are unstable at room temperature and must be combined with an element to hold the desired form. The tetragonal is one of the most studied forms in published literature\(^6\) and is stabilized with yttrium.\(^7\) This material was used experimentally as early as 1969 in the field of orthopedics.

It is the esthetic and mechanical characteristics of zirconium which makes it such an attractive metal to work with. Indeed, not only is it white in color, but its resistance to fractures is very similar to that of titanium (285 N vs 305 N).\(^8\) In addition, it is not cytotoxic,\(^9\) does not produce mutations of the cellular genome,\(^8,10\) and it induces a modest inflammatory response in tissues, which is less than that of titanium.\(^11\)

Another attractive characteristic of the material is that it has little retention of bacterial plaque. Scarano reported a bacterial covering on the surface of zirconium of 12%, as opposed to 19% for titanium.\(^5\)

Zirconium has multiple applications in dentistry. It can be used as a core for onlays/overlays, as a core for single crowns, as a framework for bridges, as abutments for implants (Fig 1), and as implants themselves.
Despite the material having been well known, the technology was not available. Today, thanks to CAD/CAM, this technological gap has been filled.

The structures are obtained by subtraction milling a partially sintered zirconium block; this procedure is guided by dedicated software.12

An overview of zirconium and CAD/CAM

It must be borne in mind that the zirconium structure is no longer made by a technician but by the milling center machine which grinds the zirconium block. This requires specific instructions and guidelines in digital form, which can be summarized in three steps:13

1) digitization: transforms the geometry of the scanned object into digital data
2) processing: software processes the data and, if necessary, develops the project
3) realization: technology (not necessarily a milling machine) transforms the data into the desired object.

When using CAM/CAD technology, the classic clinical/technical itinerary (impression, model, waxup, casting) must interface with the digital pathway (Table 1). The transformation of analog information into digital information can take place at various points in the conventional process:

1) The impression is developed in the laboratory. The laboratory forwards the model to the digital service who will digitize it, design the structure (CAD), realize it (CAM), and then send it back to the technician for ceramic stratification (Table 2).
2) The impression is developed in the laboratory. The technician digitizes the model with a scanner and with special software designs the structure (CAD) (Table 3a). Alternatively, the technician can realize a traditional waxup and scan it (Table 3b). In both cases, the laboratory will be able to issue a digital file to the milling center for manufacturing the structure (CAM). The structure is then sent back to the laboratory for ceramic stratification.

3) The impression can take the digital route from its beginning (e.g., using a 3M ESPE video camera or similar). The planning can take place either in the laboratory or in the digital service center (CAD). However, the manufacture of the core (CAM), must take place in the milling center and is then delivered to the laboratory along with a resin model for ceramic stratification (Table 4).

In the authors’ clinical experience, the method that gives the best frameworks/cores for supporting ceramics is that which starts with a conventional waxup of the structure made in the laboratory which is then scanned. This technique allows the creation of an individualized structure, which means that the design can be customized with an adequate cusp and marginal crest. This creates, where necessary, a palatine framework thickening and adequate connection design (Fig 2a and b).
Clinical application

For a fixed prosthesis, the base material of the ceramic crown which is most commonly used and which, according to scientific evidence, guarantees the highest standards of resistance, is a noble alloy (ceramometal technique).

The greatest limitation of this technique is the fact that the metal restoration has limited translucency, which means that esthetically it cannot compete with the standard that can be achieved when integral ceramics are used. Integral ceramics are indicated in cases where excellent esthetic results are required as these materials best imitate the color and luminosity of the natural tooth (Fig 3). One disadvantage however, is that these restorations have low mechanical resistance.

Collarless ceramics supported by a metal core represent a solution that, in theory, combines the advantages of both techniques, eliminating the metal in the marginal portions so as to reduce the umbrella effect. Today there is also a third option, which cuts a middle road and which is increasingly being used: zirconium.
Fig 4a  Discolored natural tooth; the use of a high translucency crown would end in an unsatisfactory result.

Fig 4b  The ceramic crown supported by a zirconia core once cemented. The unfavorable tooth value is partially masked, increasing the core thickness. In spite of that, however, a discolored abutment appears through the marginal tissues anyway.

Fig 5a to c  Manufacturers advise a round shoulder or a chamfer preparation for a zirconia ceramic crown.

Fig 6a and b  A clinical case: the smile before and after treatment.
Fig 7a and b  The initial intraoral situation (a). Final result (b): the four incisors with zirconia crowns cemented. The mandible was rehabilitated with an implant-supported fixed prosthesis.

Fig 8a to d  Maxillary anterior teeth before treatment (a). Four incisors prepared with a marginal chamfer (b). Four zirconia ceramic crowns on the master model (c). The end of treatment; the four upper incisors were reconstructed with zirconia ceramic crowns, the two cusps were restored by ceramic veneering (d).
**Fig 9a and b**  Some details of the crown margins and their tissue integration.

**Fig 10a to c**  In the case of a feather-edge preparation, it is necessary to finish with a metallic margin. When using a zirconia core, the margin should also be well represented, but the white color simplifies the esthetic result.
Zirconium has excellent mechanical and esthetic characteristics. Mechanically, this is observed if the material is used in thickness of 0.5 mm or more. This thickness guarantees excellent mechanical resistance but partially diminishes the esthetic result. In some cases however, the thickness of the structure makes it possible to mask highly discolored prepared teeth, optimizing the esthetic results (Fig 4a and b).

In order to obtain the very best esthetic results, it is necessary to use a thickness of 0.3 mm, as this gives a high degree of luminosity and translucency. It should be noted however, that these characteristics are inferior to those that can be obtained from integral ceramics (light transmission through 0.6 mm thick flat specimens of densely sintered alumina is 72% versus 48% for densely sintered zirconia).

For restorations with a zirconium oxide core, the producers recommend round shouldnedered or chamfered preparations as these are considered to be best for precision, resistance, and esthetic outcome (Figs 5 to 9).

The presence of a margin means that excellent definition is required in the preparation phase and then adequate transferral of that information to the laboratory. These problems are easier to solve with a feather-edge preparation where the finishing line is no longer represented by a line but rather by an area (Table 5).

The advantage of a butt preparation (shoulder or chamfer) is that it allows, from the margin, an adequate thickness of restoration materials (metal-opaque ceramics), reducing as much as possible the unsightliness of a metal border.

However, it is necessary with a feather-edge preparation to have a well-represented and clinically evident metallic margin (Fig 10). This may be considered an esthetic compromise and is usually indicated for complex perio-prosthetic rehabilitations. This limitation can be overcome by using a material such as zirconium, which makes it possible to create a white margin. While being clinically acceptable, this integrates well esthetically with the periodontal tissues without needing to “invade” the dento-gingival sulcus, which would complicate the prosthetic procedures and risk damage to the periodontal attachment.

This led to the idea of combining zirconium oxide with the feather-edge preparation, a solution which, while not advised, is allowed by the producers on the condition that certain fundamental clinical and technical considerations are taken into account.

Why feather-edge marginal preparation?

In the last 10 years, the prosthetic treatment plan has changed due to the introduction of implants. Indeed, it is because of implants that it is possible to treat individual or multiple edentulous areas (Fig 11), without resorting to the preparation of healthy
needed to recover teeth which have been destroyed by decay. The carious lesion, moreover, does not only extend horizontally towards the pulp chamber but follows the line of the dental tubules and often extends apically and involves the periodontal attachment. For this reason, the majority of cases require a crown-lengthening procedure before the prosthetic phase in order to make the residual healthy tissue accessible and to re-establish a correct relationship with these without damaging the periodontal attachment (Figs 12 and 13).

In the same surgical time, it is possible to carry out a feather-edge preparation of teeth and sacrificing sound tissue to accommodate bridges. In the same way, many seriously compromised teeth, which until recently would have been treated in a prosthetic manner with complete crowns, can today be rehabilitated with indirect adhesive restorations.

The indications for a fixed prosthesis have changed, and it is much less frequent that a healthy tooth is rehabilitated with a fixed prosthesis. It is even rarer that the clinician performs endodontic treatment for prosthetic reasons as vital teeth can be treated with restorative therapy. Therefore, prosthetic dentistry almost always follows the endodontic treatment needed to recover teeth which have been destroyed by decay.

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Fig 12a to c  Surgical crown lengthening is frequently necessary to properly rehabilitate a seriously decayed tooth. During the surgery, the tooth is prepared up to the bony crest, and after suturing the temporary is relined. With a feather-edge preparation it is easy to obtain, 4 months after surgery, healthy tissues around the prepared tooth.

Fig 13  The tissues maturing around natural abutments 4 months after periodontal surgery (a). The teeth were prepared once the flap was raised and the final impression was obtained without any further marginal preparation. The zirconia crowns once cemented (b).
the abutments once the flap is raised, while, at the same time, optimizing all other parameters that render the long-term results more predictable. These parameters involve:

- re-establishing biological dimensions
- lengthening short abutments
- recovering the ferrule effect
- correcting root proximities
- eliminating residual concavities following furcation barreling
- bone surgery to eliminate the shallow infra-osseous pockets
- surgery to correct esthetic problems such as a gummy smile or to harmonize unsightly gingival trajectory arcs.

The present approach involves, once the flap has been rised, a feather-edge preparation of the teeth as far as the osseous crest.
In order to be able to benefit from all of the advantages offered by a feather-edge preparation, it is important to not modify this preparation once the surgical phase is over, unless to carry out small adjustments which do not involve the marginal area. Indeed, once the abutment is re-prepared in the impression stage, this may create a reference margin in the marginal finish area which is binding for the final restoration (Figs 14 to 20). When the tissues have matured completely it will be possible to take a definitive impression and finalize the prosthetic restoration (Fig 21).

There is a published technique which makes it possible to exploit the advantages of the feather-edge preparation carried out “blind,” that is, without surgical access.\textsuperscript{19,20} Naturally, each preparation type has advantages and disadvantages. The choice of one rather than another is often guided by the different degrees of difficul-
**Fig 17a to c** The palatal view showing the healthy tissues around the crowns.

**Fig 18** The buccal emergence profile respecting the tissue health.

**Fig 19a to c** Six months after the surgery, when teeth were prepared up to the osseous crest, the abutments were ready for the final prosthetic phase: occlusal (a) and buccal view (b). Cemented zirconium oxide prostheses (c).
Fig 20  The old restorations (a). The abutments once the previous prosthesis was removed (b). The periodontal intervention with the open flap abutment preparation (c). The final abutments 10 months after surgery (d). The red line on the master model represents where the technician placed the apical limit of the restoration after ditching; the black line represents the gingival level (e). The zirconia copings try-in (f). The tracing of the gingival scallop on the zirconia copings (g). Zirconia copings removed after try-in and tracing (the amount of the coping margin positioned into the sulcus is evident) (h). One-year follow-up, the good tissue integration is evident (i).
get is represented by an area and not a line. However, the management of the esthetic zone is more delicate as a short margin would make it impossible to condition the gingival tissues and shape the prosthetic emergence profiles at an interproximal level.

In cases of shoulder or chamfer preparations, the finish line is well defined and is the line that the technician must refer to without any doubt. The margin of the restoration must be unequivocally positioned at this level. On the other hand, with a feather-edge preparation, the prosthetic margin can be positioned at any level in an apico-coronal direction, as long as it respects the periodontal attachment. Once the structure has been realized, it could invade too deeply into the gingival sulcus. In this case, it can be shortened during the trial. In healthy conditions, the interproximal probing depth is approximately 3 mm and it is possible to receive a structure from the laboratory which finishes at this depth. From a clinical point of view, it is often unnecessary to position the prosthetic margin at this level interproximally, as in this zone there are no important esthetic requirements but only the need for tissue conditioning to recreate an adequate emergence profile. This profile is obtainable when the margin is positioned at 1 mm inside the sulcus. Therefore, any invasion by the restoration is unnecessary and could damage the periodontal attachment and make it difficult to remove any cement excess. Furthermore, adjusting the margin and shortening it does not lead to any loss of precision nor will it compromise the esthetic result.

Advantages of feather-edge marginal preparation

- Saves dental tissue: it is therefore indicated for teeth which have suffered serious periodontal damage as a consequence of periodontitis.
- Simplifies the final impression as there is no longer a finishing line but rather a finishing area.
- Relining the provisional is easier and faster. Even in cases where the border of a temporary crown is slightly shortened, no marginal precision is lost as would happen in the case of a “short” provisional margin with a shoulder or chamfer preparation. In fact, the finishing tar-

**Fig 21a and b** The impression is easily obtained in cases of feather-edge preparation; the intra-crevicular part of the prepared tooth appears as a rising margin.
Disadvantages of the feather-edge marginal preparation

The disadvantages of a feather-edge preparation are emphasized in the case of a prosthetic rehabilitation using the ceramo-metal technique:

- The presence of a visible metal collar is necessary to guarantee precision and resistance at the margin. This border, when not hidden in the gingival sulcus, is particularly unattractive and certainly unacceptable in the esthetic zone.
- If a metallic border is not properly formed there is a risk that a horizontal overhang will be created.\textsuperscript{21}

This is potentially damaging for the periodontal tissues as it can retain bacteria and plaque.\textsuperscript{22-25} The zirconia margin is mandatory in this area especially during cementing and while chewing; in fact, in these conditions there is a high concentration of stress on the margins which could cause ceramic chipping.\textsuperscript{26,27}

In order to create enough space for the restoration material, there is risk of creating an over-tapered preparation. This does not guarantee a retentive and stable form for the restoration unless one resorts to additional retentions.\textsuperscript{28}

All of the above is particularly disadvantageous in cases of:

- patients with a thin gingival biotype in whom the metal borders, even if intra-crevicularly positioned, could show through the gingival margins, resulting in an esthetically unsatisfactory rehabilitation
- short abutments with a high risk of crown debonding. The vertical preparation is considered to be unsightly as the elimination of less dental material gives the technician less space for ceramic stratification and, especially in the anterior teeth, in cases of even minimal gingival recession the metallic margin of the prosthesis is visible. With regard to precision, a vertical preparation (feather edge or bevel) may ensure a better seal than a horizontal one (shoulder or chamfer) before luting. In contrast, after the cementing it provides worse seating. This is due to the difficult defluxion of the cement at the prosthetic margin.\textsuperscript{29,30} The final result therefore, in terms of precision, can be considered totally superimposable and, in any case, clinically acceptable for both types of preparation (vertical and horizontal).\textsuperscript{29,31}

Zirconium oxide and feather-edge preparation

The marginal design recommended by the producers of zirconium oxide is a chamfer or round shouldered margin combined with a preparation that has a slightly increased taper compared to the conventional ones: 4 degrees per side compared to the vertical as opposed to 2 to 3 degrees per side (Fig 22).\textsuperscript{15,26,32} The authors’ clinical experience suggests that zirconium oxide could also be used in vertical preparations, thereby combining a much simpler and much faster preparation with a material which is at least as mechanically resistant as gold, yet more esthetically pleasing.

The design of the zirconium core must not differ from a core for a ceramo-metal restoration in the case of the feather-edge preparation. The emergence profile must respect the periodontium and be easy to
Fig 22a and b  The ideal taper recommended in prosthetic dentistry is 2 degrees on each side (a). The recommended taper in the case of zirconia crowns is 4 degrees on each side (b).

Fig 23  Chipping of the marginal crests: the two zirconia cores were designed in a standard way without considering the necessity of ceramic support in relation to the occlusal contact points.
The main condition to be respected in order to minimize the chipping risk and obtain a successful long-term result, is that the ceramic has to be adequately supported by the underlying structure so that it will work during compression (Figs 23 and 24). The zirconium oxide edge must be 0.5 to 0.7 mm wide in order to guarantee resistance to chipping during insertion and luting phases.

In extended structures, planning the connections is of the utmost importance and should be orientated appropriately: in the molar region the corono-apical sections should be most represented, while in the esthetic zone the vestibular-palatal thickness should be greater.

FIG 24a to d False root realized, creating a forced pathway for the interproximal brush to clean the distal tooth surface.
Conclusions

Although the combination of zirconium and feather-edge preparation requires further randomized clinical studies in the medium and long term, it would seem to
offer an extremely interesting solution from a clinical point of view.

Indeed, the zirconium confers to the restoration excellent esthetic and mechanical characteristics, as long as the plan allows for a rigorously personalized support structure for the overlaying ceramic. Feather-edge marginal preparation adapts well to the increasingly frequent requirement of pre-prosthetic periodontal surgical interventions. Moreover, the possibility of performing the final tooth preparation once the flap is raised reduces the number of interventions and the risk of invading the sulcus and damaging the supra-crestal fibers.

This type of preparation, with its white zirconium borders, does not require that the margins be positioned deeply into the sulcus, as the metal borders do not need to be hidden.

It is therefore possible with this combination to reduce and simplify the clinical steps needed for the final prosthesis, while at the same time guaranteeing greater stability and health of the tissues over time.

This is a simple and time saving technique that could be used on a daily basis by those clinicians striving to obtain an optimal clinical result.

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References
