THE JOURNAL OF PROSTHETIC DENTISTRY

CLINICAL RESEARCH

Survival analysis up to 7 years of 621 zirconia monolithic single crowns with feather-edge margins fabricated with a cast-free workflow starting from intraoral scans: A multicentric retrospective study

Marco Valenti, DDS,[a] Alessandro Valenti, DDS,[b] Johannes H. Schmitz, DDS, PhD,[c] Davide Cortellini, DDS, DMD,[d] and Angelo Canale, CDT[e]

ABSTRACT

Statement of problem. Clinical studies on the fabrication of monolithic zirconia restorations with a feather-edge tooth preparation from digital scans and a cast-free fully digital workflow are lacking.

Purpose. The purpose of this retrospective multicentric study in private practices was to evaluate the outcomes of monolithic zirconia crowns fabricated with feather-edge margins and a cast-free approach.

Material and methods. A total of 621 teeth were prepared with feather-edge margins and restored with monolithic zirconia crowns fabricated with a fully digital cast-free workflow. Data were analyzed by using the Kaplan–Meier test and descriptive statistics. The clinical evaluation adopted the California Dental Association–modified criteria after recalling all patients between April and July 2021.

Results. The clinical survival of 619 of 621 crowns, including recemented crowns placed in 427 patients (217 men, 220 women) over 5 years (2014 to 2019 with crowns in service between 12 and 85 months), was analyzed. The 2 excluded crowns were delivered to patients who dropped out of the study. Of the 619 crowns, 5 failed during the follow-up period: 4 teeth were extracted because of fracture and 1 restoration fractured. No other technical or biological failures were observed. The mean overall survival time was 84.4 months (standard error, 0.255; 95% confidence interval for the mean, 83.92 to 84.92). The overall survival probability was 99.1% up to 85 months.

Conclusions. The clinical outcomes of the monolithic zirconia crowns with feather-edge margins evaluated were comparable with outcomes reported using other margin designs and materials. (J Prosthet Dent 2022;■:■-■)

Zirconia has excellent mechanical properties, including high strength and fracture toughness and good biocompatibility.[1-3] Layered zirconia-ceramic restorations have been reported to exhibit better esthetics than their metal-ceramic counterparts,[4,5] but veneer chipping of zirconia-ceramic crowns has been reported.[6,7] Monolithic zirconia crowns were developed to overcome this problem.[8,9]

The esthetic outcome of monolithic zirconia restorations has improved since the introduction of translucent blanks in different shades[10] and multilayer zirconia blanks.[11] Nonetheless, for maxillary anterior restorations, veneering of the labial surface improves the esthetic outcome.[12]

A shoulder, a chamfer, or a light chamfer marginal finish line has been recommended by manufacturers of zirconia restorations. Despite the recommended guidelines, monolithic ceramic crowns with feather-edge preparation margins have been reported to be clinically

[a]Private practice, Pordenone, Italy.
[b]Private practice, Pordenone, Italy.
[c]Private practice, Milan, Italy.
[d]Private practice, Riccione, Italy.
[e]Dental Lab Owner, Rimini, Italy.

Clinical Implications

A fully digital workflow with the use of an intraoral scanner for monolithic zirconia single crowns is a reliable procedure. The cast-free workflow implies fewer steps and fewer errors, improving efficiency, and providing similar or better clinical outcomes in terms of survival probability than an analog workflow.

effective.[13-16] Tooth preparations with feather-edge finish lines are more conservative than a shoulder or a chamfer finishing line and facilitate impression making, providing good marginal fit.[15-17] The feather-edge can more easily provide a protective ferrule effect in endodontically treated teeth with a post-retained core.[18]

The use of intraoral scanners (IOSs) has been reported to improve clinical efficiency,[19-21] with accuracy comparable with, or even better than, that of conventional impressions.[22-27] A fully digital workflow without a conventional cast has advantages that improve workflow accuracy.[28-30]

In this retrospective analysis, the clinical performance of 621 feather-edge zirconia monolithic restorations placed in 3 private dental practices from 2014 to 2020 and cemented with self-adhesive resin-based cement was reviewed. An IOS was used for digital scans, and a computer-aided design and computer-aided manufacturing (CAD-CAM) cast-free workflow was used in the dental laboratory.

The purpose of this multicentric cross-sectional retrospective clinical study was to evaluate the clinical performance of monolithic zirconia crowns fabricated with an entirely cast-free digital workflow where different clinicians were following an identical clinical protocol. The research hypothesis was that the clinical outcome of monolithic zirconia fabricated with a fully digital workflow would be satisfactory up to 7 years and comparable with the outcomes of other clinical studies.

MATERIAL AND METHODS

Three clinicians (D.C., J.S., M.V.) conducted this retrospective cross-sectional study while working separately but with a shared clinical protocol in their own general dental practices in Pordenone, Riccione, and Milan, Italy. This study was performed by following the principles of the Helsinki Declaration of 1964, as revised in 2013. As required by Good Clinical Research Practice, patients were asked to provide full and informed consent before inclusion, and each participant provided informed consent before the treatment. Crown selection was based on patient need, with no distinction based on age, sex, or function. Table 1 shows the number of crowns and the endodontic treatment distributed by tooth position. A total of 621 teeth that required complete-coverage crowns were prepared with a vertical finishing line between January 2014 and December 2019. The patients were recalled every 3 to 6 months for professional oral hygiene treatment, depending on their periodontal condition at the beginning of the treatment.

All participating clinicians used the same armamentarium and followed the same clinical protocol for tooth preparation to provide adequate reduction along the axial walls in the margin area with diamond rotary instruments (862 shape: 862.12, 862.16, 8862.12; Brasseler–Komet) and at the occlusal surface. To maintain gingival health and tooth position, interim crowns were prepared and cemented with a eugenol-free[31] interim cement (TempBond NE; Kerr Corp).

The interim restoration technique for gingival diplacement[32] was performed 2 weeks after tooth preparation, and the definitive digital scan was made with an IOS (TRIOS 2; 3Shape A/S) from 2014 to 2017 and a more recent IOS (TRIOS 3; 3Shape A/S) from 2017 to 2019. Both IOSs had been updated with the most recently released software version. In June 2019, a major IOS (TRIOS 2 and TRIOS 3; 3Shape A/S) software update added a tool called specific patient motion, allowing the authors to record mandibular movements: this tool was used for every patient from June 2019.

All crowns were designed by the same dental laboratory technician (A.C.) with a computer-aided design software program (Dental System; 3Shape A/S) and fabricated with a cast-free workflow according to the manufacturer's instructions. The following zirconia presintered blanks were used: Blank A 1125 MPa (ML KATANA Zirconia; Noritake) until 2018, Blank B 1125 MPa (HTML KATANA Zirconia; Noritake) available from 2019, and Blank C 748 MPa (STML KATANA Zirconia; Noritake). The choice regarding the type of zirconia blanks was made in relation to the available occlusal clearance and the color of the abutment. Blank C was the choice for patients with an occlusal reduction between 1.2 and 1.5 mm, for both molars and premolars; if the reduction was between 0.8 and 1.2 mm, Blank C was used only for premolars, and molars were restored with Blank B. Blank B tetragonal zirconia was always used to mask discolored abutments, whereas Blank C cubic zirconia was used for natural-looking or slightly discolored teeth.

Each crown was assessed for proximal contacts, occlusal relationships, shade matching, and marginal adaptation. Where necessary, clinicians performed minor occlusal adjustments before luting.

Before cementation, the operative field was isolated with cotton rolls and high-velocity evacuation (Pneumatic Aspirator Air Care; Cattani Air Technology). The restorations were cleaned with universal cleaning paste

Table 1. Initial crown distribution and endodontic treatment

Crowns Provided		Tooth			
Location	Total	First Premolar	Second Premolar	First Molar	Second Molar
Maxillary	315 (173)	68 (32)	66 (32)	114 (69)	67 (40)
Mandibular	306 (153)	59 (26)	64 (29)	126 (66)	57 (32)
Total	621 (326)	127 (58)	130 (61)	240 (135)	124 (72)

Number of crowns on endodontically treated teeth in parentheses.

(Ivoclean; Ivoclar AG) for 20 seconds, rinsed with water, and dried, and the crown was cemented with self-etching, self-adhesive cement (RelyX Unicem 2; 3M ESPE AG). Initial light polymerization was performed for 3 to 4 seconds with a light-emitting diode polymerization light (VALO Grand; Ultradent Products, Inc) in standard power mode (1000 mW/cm^2). Excess cement from the buccal and lingual surfaces was removed with an explorer, dental floss, and a double-edged scalpel blade (surgical scalpel blade No. 12D; Swann-Morton). The final polymerization was performed for 1 minute on the buccal side and 1 minute on the lingual side of the restoration. After cementation, the occlusion was adjusted with cone-shaped diamond rotary instruments with grit sizes of 100 and 125 μm when needed and polished with a polishing kit designed for zirconia (ZR Flash Polishers kit; Brasseler–Komet).

Irreparable failure was determined if the abutment was carious, the core had fractured, or the restoration had partially debonded, exposing tooth structure. The first evaluation was performed at the time of cementation (baseline), and reevaluations were conducted every 3 to 6 months during routine professional hygiene appointments. Every examination was performed with an intraoral mirror, a sharp explorer, a periodontal probe (XP23/OW probe; Hu-Friedy), radiographs once a year, and, in some patients, photographs.

All participants were recalled between December 2020 and February 2021. The crowns were evaluated for changes in structural integrity (chips, cracks, or fractures) and marginal integrity with a sharp dental explorer as per the modified California Dental Association/Ryge criteria (Table 2).[33,34]

A different experienced clinician working in the same practice performed all analyses. For failed restorations, the examiner attempted to determine the cause whenever possible.

A statistical evaluation of the survival rate of the ceramic crowns was performed by using the Kaplan–Meier[35] method with a software program (MedCalc 12.1; MedCalc Software Ltd). The survival time was defined from baseline to when the clinician assessed irreparable failure of the crown. If the crown was considered a failure, it was replaced with a new one, which was not included in the study.

Table 2. Clinical rating of restorations using California Dental Association–modified criteria

Parameter	Rating	Definition
Color match	Alfa	No mismatch in color, shade, or translucency between restoration and adjacent teeth
	Bravo	Mismatch between restoration and adjacent teeth within the normal range of tooth color, shade, or translucency
	Charlie	Evident color discrepancy with esthetically displeasing color, shade, or translucency
Restoration surface	Alfa	Smooth surface (that becomes shiny after air drying)
	Bravo	Dull surface or minor chipping of porcelain that does not impair esthetics or function and does not expose tooth structure
	Charlie	Chipping that impairs esthetics/function or exposes tooth structure; cracks or fissures detectable with an explorer tip within the bulk of the material
Marginal discoloration	Alfa	No discoloration of the margin
	Bravo	Superficial marginal discoloration that does not penetrate in the direction of the pulp
	Charlie	Discoloration that penetrates in a pulpal direction
Marginal integrity	Alfa	No visible evidence of crevice along the margin; there is no catch or penetration of the explorer
	Bravo	Visible evidence of crevice or catch of the explorer along the margin; the explorer does not penetrate
	Charlie	Visible evidence of crevice along the margin with penetration of the explorer tip
	Delta	Restoration is visibly fractured, has become loose, or is completely missing

RESULTS

Between April and July 2021, all the patients who had received 619 (of the initial 621) zirconia crowns were recalled, and the data were collected to complete the statistical analysis. The crowns, all of which used a feather-edge preparation, were placed in 427 patients (217 men and 220 women) over a period of 5 years (2014 to 2019, with crowns in service between 12 and 85 months; Table 3).

Two crowns were excluded because of patient dropout. Of the remaining 619 crowns, 257 were premolars (41.5%, 127 first and 130 second premolars) and 362 were molars (58.5%, 240 first and 122 second molars). Table 1 presents a detailed distribution of the crowns. Most patients received only 1 or 2 crowns (288 and 120, respectively), 26 patients received 3 crowns, 2 patients received 4 crowns each, and 1 patient received 5 crowns.

Two patients (each of whom received 1 crown) dropped out of the study and were lost to follow-up. Of the 619 crowns, 5 failed: 4 because of tooth fracture (Fig. 1) and 1 because of crown fracture (maxillary premolar). The fractured crown was replaced with a new crown (not included in the study). All fractured teeth were extracted and subsequently excluded from the evaluation in Table 3. All 5 failed restored teeth had had endodontic treatment before definitive crown restoration.

At the time of the clinical evaluation, 614 of 621 crowns were available (5 crowns failed, 2 dropouts). Nine

Table 3. Crown survival and failure distribution according to follow-up (months)

	Maxillary Arch		Mandibular Arch	
Follow-Up	Premolar	Molar	Premolar	Molar
15-24	23 (2) C (15m), B (18m)	32 (1) E (6m)	20 (0)	34 (2) C (18m, 20m)
25-36	32 (0)	52 (2) A (18m, 31m)	29 (0)	51 (2) A (24m), D (30m)
37-48	25 (0)	35 (2) A (7m, 23m)	31 (0)	45 (2) F (48m), A (47m)
49-60	20 (0)	23 (0)	14 (0)	17 (0)
61-72	20 (1) A (37m)	20 (0)	7 (0)	22 (1) F (71m)
73-84	13 (0)	17 (1) A (58m)	18 (0)	10 (0)
85+	1 (0)	2 (1) A (49m)	4 (0)	4 (0)
Failures	2	1	–	4

A, decementation (not considered failure) n=10; B, crown fracture n=1; C, tooth fracture n=3; D, root fracture n=1; E, periapical lesion (not considered failure) n=1; F, dropout n=2.

Figure 1. Mandibular left second molar extracted after 20 months.

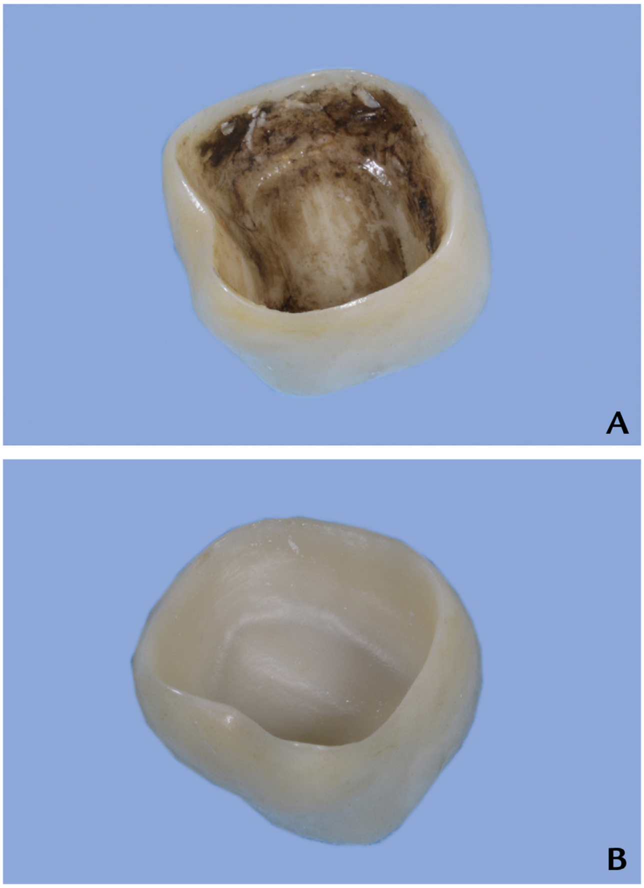

Figure 2. A, Intaglio surface of decemented crown. B, Crown airborne-particle abraded before recementation.

Figure 3. Representative first maxillary molar monolithic zirconia crown with good esthetics and periodontal response.

Table 4. Clinical rating of 614 zirconia monolithic crowns

Parameter	Alfa	Beta	Gamma	Delta
Color	197	287	97	33
Surface	438	131	45	0
Margin discoloration	580	34	0	0
Margin integrity	607	7	0	0

crowns (1 maxillary premolar, 3 mandibular, and 5 maxillary molars) had decemented at 7, 18, 23, 24, 30, 31, 37, 49, and 58 months. The restorations were airborne-particle abraded (Fig. 2) and recemented with a self-adhesive cement (RelyX Unicem 2; 3M ESPE). At the most recent evaluation, the crowns were still functioning and were not considered a failure.

Of the 614 crowns evaluated, 607 were rated excellent for marginal integrity, 580 for marginal discoloration, 438 for surface, and 197 for color (Table 4); 484 crowns scored alfa or beta for color (Fig. 3). Only 33 crowns scored delta for color, and none scored delta for the other 3 parameters.

The survival analysis was performed on 619 crowns. The total failure rate was 0.81% (5 of 619). The mean survival was 84.4 months. Using the Kaplan–Meier survival estimation method, the overall survival probability of the 619 crowns was 99.1% at up to 85 months. The survival probability was 99.2% for premolars and 99% for molars (Fig. 4).

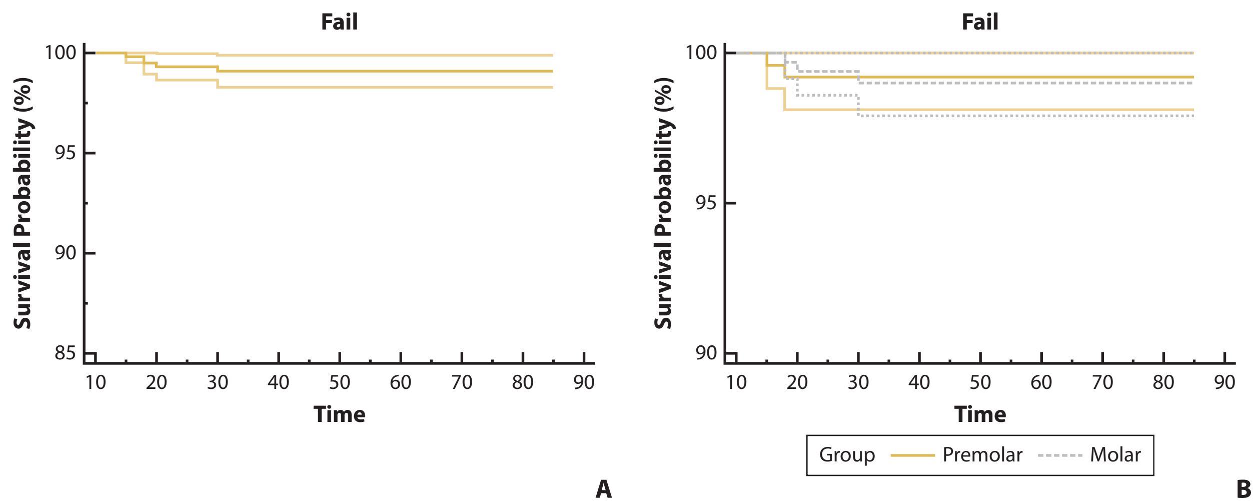

Figure 4. Kaplan–Meier analysis, with 95% confidence interval lines. A, Overall. B, Premolars and molars.

DISCUSSION

The hypothesis of this multicentric cross-sectional retrospective clinical study that the clinical results of monolithic zirconia manufactured with a fully digital workflow would be satisfactory up to 7 years and comparable with those of other clinical studies was accepted. The digital cast-free workflow adopted for this study has the advantage of allowing for the design and fabrication of restorations directly within a virtual environment, with fewer steps and consequently fewer errors, reducing production cost and improving efficiency.[36] The cast-free workflow led to the need for fewer occlusal and proximal contact adjustments as compared with the conventional protocol with impressions and casts (Fig. 5). The cast-free workflow required the dental laboratory technician to define the area of occlusal contacts and proximal contacts with digital waxing. These contacts were not reshaped during the finishing procedures but only airborne-particle abraded at 0.3 MPa and then glazed.

This technique has practical advantages, provided clinical results are comparable with the traditional protocols, as shown in the present study. The authors are unaware of a previous large-scale clinical study on the clinical performance of restorations fabricated by following an entirely digital workflow.[37,38]

The results of the present study demonstrate that the clinical outcome of a fully digital workflow combined with feather-edge preparations for monolithic zirconia restorations were comparable with those obtained using similar preparation designs[13-15] and material.[15,39,40] The same group of clinicians published a similar study[14] on the clinical results obtained with pressed lithium disilicate monolithic crowns. The total number of crowns evaluated and the clinical protocol were similar. In that study, the authors reported a high survival rate in monolithic single crowns fabricated with vertical margins, which was only slightly lower on second and third molars. The monolithic lithium disilicate restorations had a higher score in terms of color matching, being more

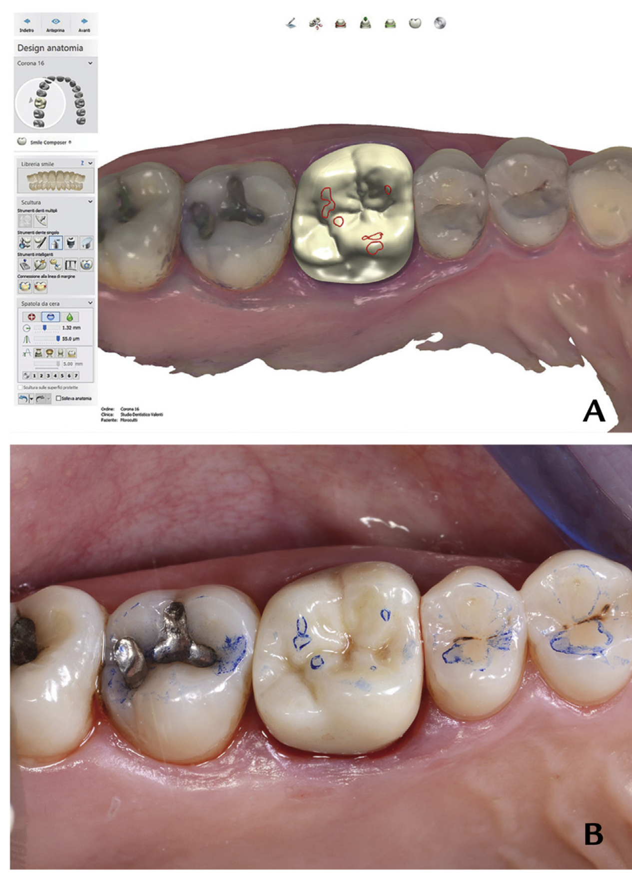

Figure 5. Representative molar crown. A, Digital waxing with occlusal contacts (*red*). B, Cemented crown after cement excess removed with occlusal stops marked (*blue*).

translucent[41] (unlike zirconia, all lithium disilicate crowns had alfa or beta scores and no gamma or delta scores for color), with fewer decementations (1 of 627 versus 9 of 621), but they were more prone to bulk fracture and nonrepairable chipping (9 of 627 versus 1 of 621 crowns). The rate of tooth fracture was similar: 3 fractures with lithium disilicate and 1 fracture with zirconia.

Manufacturers continue to introduce improved monolithic zirconia materials, and the most recent versions have improved the esthetics of posterior restorations, although the more translucent zirconias are weaker, with toughness values similar to those of lithium disilicate.[41] The various kinds of zirconia available should be carefully selected on the basis of their properties, including fracture resistance, translucency, and expected clinical outcome.[42,43]

Limitations of this retrospective study included that the crowns were not placed simultaneously, the limited follow-up evaluations, and the lack of a control group. Further clinical research and randomized controlled trials studies are needed to confirm the results shown in the present study. When analog and digital workflows are compared, studies should evaluate not only IOS accuracy but also the useful information provided by the IOS software program, including the recording of jaw movements, the capturing of interim restoration information,[44] and the precise evaluation of the amount of axial and occlusal reduction during preparation.[45]

CONCLUSIONS

Based on the findings of this cross-sectional retrospective clinical study, the following conclusions were drawn:

1. An overall failure rate of 0.81% was obtained, similar to the failure rate reported for single-crown restorations with other margin designs and different metal-free materials.
2. The cast-free workflow for monolithic zirconia crowns was a reliable process that provided outcomes comparable with those of other kinds of workflows, and the use of IOS software tools allows a precise and efficient evaluation of tooth reduction.

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Corresponding author:
Dr Marco Valenti
Via G. B. Damiani, 5
Pordenone 33170
ITALY
Email: marco@studiodentisticovalenti.com

CRediT authorship contribution statement

Marco Valenti: Conceptualization, Methodology, Writing – original draft, Visualization. **Alessandro Valenti:** Writing – original draft, Writing – review & editing. **Johannes H. Schmitz:** Writing – original draft, Writing – review & editing. **Davide Cortellini:** Conceptualization, Methodology. **Angelo Canale:** Writing – original draft, Writing – review & editing.

https://doi.org/10.1016/j.prosdent.2022.05.029