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Survival Rate of CAD–CAM Endocrowns Performed by Undergraduate Students

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Clinical Relevance

Computer-aided design–computer-aided manufacturing (CAD–CAM) endocrown restorations could be carried out by undergraduates on posterior endodontically treated teeth with a low risk of failure. A minimum 2 mm ceramic thickness and a rigorous bonding protocol are two key prerequisites for the success of these restorations.

SUMMARY

Objectives: This study aimed to evaluate the success of computer-aided design–computer-aided manufacturing (CAD–CAM) endocrown restorations of endodontically treated teeth (ETT) performed by supervised undergraduate students. The study also intended to identify possible factors that may lead to failures.

Methods and Materials: This observational open cohort study was based on clinical data from endocrown restorations performed by residents and undergraduate students in their 4th, 5th, and 6th year from July 2011 to May 2018. The presence of a tooth with an endocrown on the arch was the main criteria used to calculate the survival rate of restored teeth. The quality of the remaining endocrowns was evaluated referring to the FDI criteria. The cases of failure were categorized into either favorable or unfavorable.

Results: A total of 343 ETT were restored with endocrowns in 315 patients. Among them, 199 patients encompassing 225 endocrowns were followed during a 56 ± 26 month period. The survival rate of restored teeth was found to be 81.8%, the estimated Kaplan–Meier survival rate being 71.8% at 9 years. Among the 41 failed cases, 32 were favorable (debonding and/or ceramic fractures) and 9 were unfavorable.

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Conclusion: Endocrown restorations of posterior ETT using CAD–CAM technologies could be carried out by undergraduates with a low risk of failure. Teacher supervision could be reinforced, covering all steps of each endocrown procedure in order to avoid failures due to insufficient thickness or loss of retention.

INTRODUCTION

Training in the restoration of severely damaged posterior teeth remains a key area of interest, particularly in the treatment of endodontically treated teeth (ETT). Previously, the most common proposal was the use of a complete crown with a radicular anchorage (including cast and prefabricated post and cores). However, in the long term, high risks for tooth fracture were reported.[1] Direct restorations, full or partial crowns, offer alternative proposals to radicular anchorage. Two reviews reported that there was insufficient reliable evidence to determine which treatments would be more effective.[2,3]

In 1995, Pissis proposed an original indirect restoration designed as a monobloc crown, in order to eliminate the radicular anchorage.[4] The concept was then improved by Bindl and Mörmann, who labelled the "endocrown" as an adhesive monolithic ceramic restoration anchored in the pulp chamber, exploiting the mechanical retention properties of the pulp chamber walls.[5] Several studies reported that the design for endocrown preparations was compatible with computer-aided design–computer-aided manufacturing (CAD–CAM) system applications.[5,6] Many evaluations of this new type of restoration have been carried out;[5,7-9] but all studies were difficult to compare due to differences in materials, tooth type, or procedure. Recently, a systematic review was conducted to state whether endocrowns were an appropriate restorative option with a predictable outcome for extensively damaged ETT.[10] Eight clinical studies were included, reporting survival rates varying between 69% and 100%, depending on tooth type (molar or premolar) and a mean follow-up period ranging from 6 to 116 months.[10]

Recent studies reported optimistic long-term results for CAD–CAM endocrowns[8,9] that suggested such treatments would be furthered developed for the treatment of severely damaged posterior ETT. Therefore, it seems necessary to train both undergraduates and postgraduates on how to use these new technologies. In the latest studies into endocrown evaluations, the operators were experienced practitioners, and there was no evidence of students (especially undergraduates) possessing the clinical competencies required in order to successfully provide endocrown treatment. Introducing new procedures during the clinical stage of dental studies raises the issue of quality of care, even if students treat patients while under the teachers' supervision. Particularly in the case of prosthodontic care, failures occurred late, usually when students had completed their studies. That could lead to insurance claims and requests for reimbursements from the establishments. Indeed, assessing the quality of endocrowns would help to update information about the quality of prosthodontic care, which should be readily available to patients treated by dental students.

In this way, this study aimed to evaluate the success of CAD–CAM endocrown restorations of root-filled teeth carried out by supervised undergraduate students and to search for possible factors that may lead to failures.

METHODS AND MATERIALS

Type of Study

This was an observational open cohort study based on clinical data from therapeutic procedures, the use of which was authorized by the local ethics committee. All patients were informed about the study and gave their consent to participate. From July 2011 to May 2018, any adult patient attending the University Dental Hospital of Clermont-Ferrand was invited to participate if he or she had received indication to restore a permanent posterior ETT with an endocrown. After enrolment, the patient was given an appointment for the tooth restoration procedure.

Procedure

Operators — CAD–CAM technologies for prosthodontics are organized as a routine procedure. Residents and undergraduate students in their 4th, 5th, or 6th year worked under the supervision of four teachers who checked each of the six following steps: 1) indication for the endocrown restoration; 2) dental preparation; 3) digital scan; 4) computer designs of the restoration; 5) bonding and sealing; and 6) occlusal adjustment and polishing.

Tooth Preparation — Endocrowns are restorations guided by conservative principles[11,12] that preserve the maximum amount of tooth surface for bonding. Tooth preparation consisted of a circular cervical butt margin and a central retentive cavity in the pulp chamber, without root anchoring (Figure 1).[5] Intraradicular extension of the endocrown preparation negatively

affected both the marginal adaptation and the internal fit of the final restoration.[13] Endocrown pulp chamber extension depth was not greater than 2 mm.[14] A minimum thickness of 2 mm had to be achieved under the entire occlusal surface in order to create sufficient space for the restorative material in a full cuspal coverage objective. The axial preparation was carried out to permit continuity between the access cavity and pulp chamber, with a total occlusal convergence angle of 7; and, always in the interest of maximum preservation of residual tissue, any undercut would be filled with a resin composite to avoid unnecessary overpreparation of the cavity. The use of a small resin composite supply may be useful to provide enhanced geometry and remove undercuts from the endodontic preparation.[15] All internal line angles were rounded. The endocrown restored the occlusal surface and occlusal part of the dental walls, as is also achieved with an overlay. There was no peripheral preparation. The preparation was to be supragingival to facilitate digital scanning and bonding. If the occlusal part of the residual walls was less than 2 mm thick, the walls were then reduced in height until reaching 2 mm.

Endocrown Materials — Two reinforced glass-ceramics from Ivoclar Vivadent (IPS Empress CAD [with leucite crystals] and IPS e.max CAD [with lithium disilicate]) were used for milling endocrowns, depending on the supervisor indications.

Milling — For the duration of the study, a Bluecam system with Cerec 3D and Cerec SW 4, then an Omnicam system with Cerec Omnicam 4.4 and Cerec Omnicam SW 4.5 were used for digital scanning and endocrown milling. Crystallization was achieved within 20 minutes for IPS e.max CAD restorations (Programat CS, Ivoclar Vivadent). IPS Empress CAD pieces were oven glazed.

Etching — After milling, ceramic pieces were etched with 9.5% hydrofluoric acid (Porcelain Etch, Ultradent), according to the manufacturer's recommendations, for different durations (60 sec for IPS Empress CAD, 20 sec for IPS e.max CAD). A silane was then applied to the intaglio surface of the endocrown (Monobond Plus, Ivoclar Vivadent).

Bonding — Two bonding procedures were followed. For cases being treated without the use of a rubber dam, a selective etching was made, limited to enamel, and an auto-adhesive cement (RelyX Unicem, 3M Oral Care) was used for sealing the endocrown. For teeth being treated using a rubber dam, enamel was etched for 30 seconds and dentin for 15 seconds. A dual cure adhesive (Excite DSC, Ivoclar Vivadent) and a resin cement (Variolink II, Ivoclar Vivadent) were used for bonding and sealing, respectively.

Finishing — Proximal contacts were checked with dental floss. Control for occlusion was made with finishing burs and using 200 µm occlusion paper.

Study Criteria

Primary Criteria — The presence of the tooth with the endocrown was the main criteria used to calculate the survival rate of restored teeth. Survival was defined as the tooth remaining in the arch and the restoration of the tooth with or without modifications made during the observation period.[16]

Secondary Criteria — The quality of the surviving endocrowns was evaluated, referring to the FDI criteria.[17] Two independent investigators assessed according to the FDI calibration procedure, adapted for a visual assessment. They proceeded to the evaluation of 14 of the 16 FDI criteria at each control session. At each step of evaluation, the investigators were blinded from the operator, the materials and procedures, and the follow-up duration.

FDI criteria are grouped into three categories: 1) Aesthetic properties (condition surface, surface coloring, color and translucency stability, and anatomical shape); 2) Functional properties (fracture and retention, marginal adaptation, contouring occlusal and wear, proximal contact point/food blockage, radiographic examination, and the patient's point of view); and 3) Biological properties (postoperative hypersensitivity and pulp vitality, recurrent decay/erosion/abfraction,

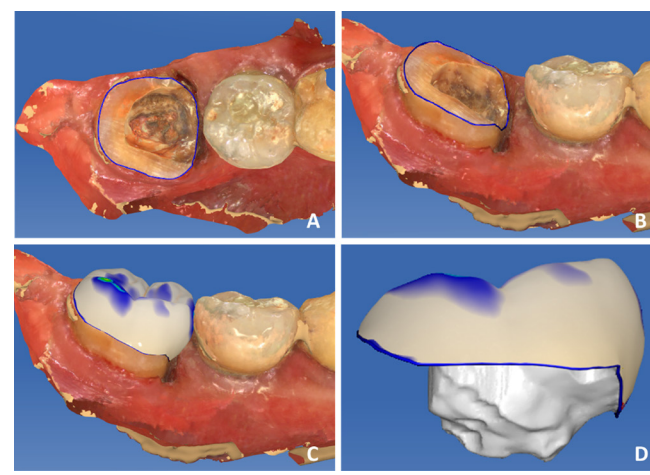

Figure 1: *Cerec screenshots for computer design of the endocrown: A) Occlusal view of the preparation; B) buccal view of the preparation; C) buccal view of the Cerec endocrown model before milling; D) endocrown model before milling.*

tooth integrity, periodontal response, adjacent mucous membrane, and oral or general health). The criteria for postoperative/pulp vitality and for occlusal contour/wear were not applicable in this study. Each criteria was scored from 1 to 5—the highest values signifying poor quality (score 1 is "clinically excellent/very good", score 2 is "clinically good", score 3 is "clinically sufficient/satisfactory", score 4 is "clinically unsatisfactory," and score 5 is "clinically poor.").

The causes for failure were categorized into two types[18,19]: i) Unfavorable or catastrophic failure—the tooth was lost or unrestorable due to fracture below the height of bone level simulation; ii) favorable failure—the endocrown was partially or totally lost (debonding), but the tooth was still restorable with another endocrown or other type of restoration, or the endocrown was fractured without fracture of the tooth.

For each unfavorable failure case, Cerec computer designs of the restorations were collected and analyzed by the blinded investigators. The minimal thickness of each piece was measured using the "cut" and "measure" tools of the Cerec software. Thickness default was recorded for the pieces with a minimal thickness of lower than 2 mm. The continuity of the peripheral limit, which was selected to proceed to milling, was analyzed. The defaults in limits position were checked in accordance with the literature.[20]

Follow-up

The first evaluation was carried out during the endocrown bonding session for the cases without rubber dam use and one week later for the cases bonded under rubber dam. The one-week delay was related to the use of rubber dam, which could alter the degree of rehydration in the tooth and, in turn, its color. The clamp could also induce gingival bleeding. This could influence evaluation of the corresponding FDI criteria: "color and translucency stability," "periodontal response," and "adjacent mucous membrane". The patient was then scheduled for further appointments 6 months post-treatment, and every year thereafter. Clinical examinations were conducted to assess the survival of the tooth at the arch, the presence of the endocrown, and, where relevant, its quality using FDI criteria.

Investigators

Two investigators were trained on an online training and calibration site (www.e-calib.info) in December 2011 (MLMS, ND). Each of them evaluated each restoration independently at each study step. After both evaluations, the scores were compared. When evaluations ranged from 1 to 3, both the values were averaged. When at least one investigator scored 4 or 5, a consensual value was then obtained after re-examination of the patient.

Statistical Analysis

The statistical tests were carried out with the software SPSS 22.0. The survival probabilities were estimated with Kaplan–Meier method. The FDI score criteria were compared between the first and the last evaluation, with paired student's *t*-test.

To evaluate the impact of the follow-up duration, data for the FDI criteria being significant after student's *t*-test were subcategorized into four equivalent quartiles based on the values of the follow-up duration. ANOVA was applied for intergroup comparisons. Log-rank testing was applied to compare survival probabilities, according to tooth type and the rubber dam utilization linked with the bonding system used.

RESULTS

From July 2011 to May 2018, 343 root-filled molar or premolar teeth were restored with endocrowns in 315 patients. Among them, 199 patients were included in the cohort. Fifty-seven patients were lost to follow-up, one patient was deceased, and 56 missed the last appointment. The flow diagram of the cohort is presented in Figure 2.

Overall, 225 endocrowns were evaluated during 56.11 ± 25.94 months, 113 being recalled from 6 months to 4 years and 112 being recalled from 5 years to 9 years. The distribution of endocrowns per student year was 18.7% in 4th year, 41% in 5th year, 20.9% in 6th year, and 19.4% were residents. The distribution of endocrowns per student gender was 43.9% male students and 56.1% female students.

The survival rate of restored teeth was of 81.8%. The estimated Kaplan–Meier survival rate was 71.8% at 9 years (Figure 3). The survival rates were not affected by tooth type, use of rubber dam, or bonding system. The estimated Kaplan–Meier success rate was 58% at 9 years (Figure 4).

The comparisons of mean scores for FDI criteria between initial and final evaluation in the group of successful endocrowns are presented in Table 1. A statistically significant degradation could be noted for the criteria "surface staining," "color stability and translucency," and "patient's view," whereas the "anatomic form" and "oral and general health" criteria showed a statistically significant improvement over time. Color stability and translucency was the single variable varying differently with follow-up duration

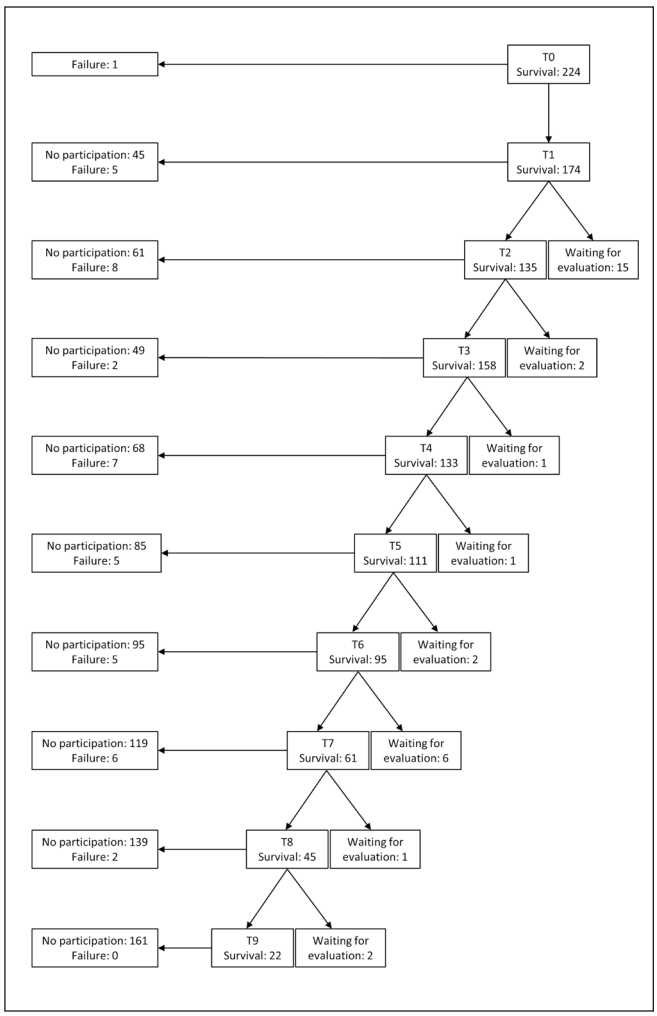

Figure 2: *Flow diagram of the endocrown cohort.*

(Table 2). Mean FDI score value for Quartile 1 with short duration follow-up was significantly lower than the three other groups with longer duration follow-up.

The distribution of the retrospective evaluation results, of 41 cases of failure on captured images in the Cerec system, is presented in Table 3. The analysis of failures showed that almost all failed restorations could be explained by the ceramic thickness or by an error in the preparation limits previously defined by the student on the digital scan.

DISCUSSION

Endocrown restorations of posterior ETT using CAD–CAM technologies could be carried out by undergraduates with a low risk of failure before five years. Exposing the students to the outcome of their work would be a matter to be covered in teaching. However, students who had treated their patients for 2

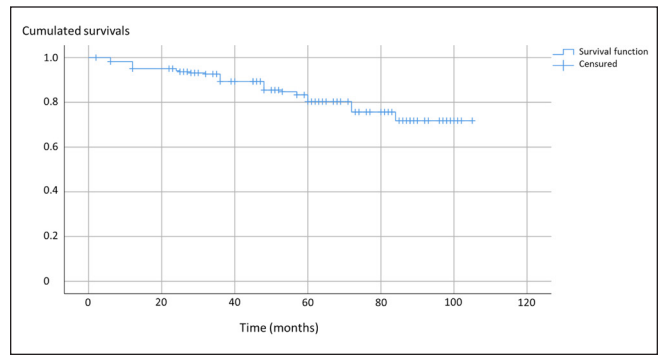

Figure 3: *Survival function of endocrowns carried out by students on root-filled molars and premolars.*

or 3 years and then left university could not experience the long-term results of their prosthetic work. The representations they have of the success, failures, and limits of the dental treatments were not based on self-experimentation. It is, therefore, important to analyze the clinical activities of the students in order for new classes of students to be able to appreciate the possible differences between literature data and the realistic outcome of their activities. Introducing new procedures into the dental curriculum required discussions on several points: i) which improvements the new procedure is supposed to bring to professional practices; ii) are the survival rates of endocrowns performed by students comparable to those of conventional peripheral crowns performed by students and to those of endocrowns performed by experimental operators?; iii) what could be learned from the failure of endocrowns performed by students?; iv) what should be changed in the endocrown operative protocol in order to attenuate the impact of time on FDI criteria and, in particular, on color stability and translucency.

Providing teaching on endocrowns rather than conventional crowns to students has several

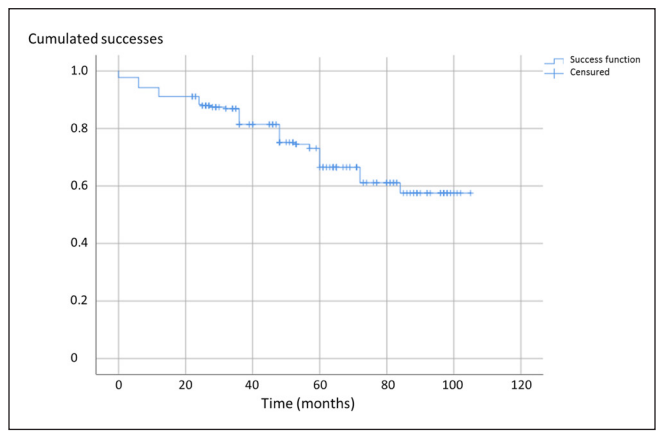

Figure 4: *Kaplan–Meier success curve of endocrowns carried out by students on root-filled molars and premolars.*

Table 1: *Comparison of the Mean FDI Scores Values (±SD) for Each Clinical Criteria Between Initial and Final Evaluation in the Group of Successful Endocrowns (n=184)*

	Initial Evaluation	Final Evaluation	Comparison (Paired Student's t- Test)
Surface luster	1.08±0.23	1.04±0.21	NS
Surface staining	1.04±0.17	1.11±0.34	p=0.008
Color stability and translucency	1.93±0.63	2.24±0.79	p<0.001
Anatomic form	1.51±0.64	1.32±0.57	p<0.001
Fracture and retention	1.01±0.12	1.04±0.28	NS
Marginal and adaptation	1.51±0.70	1.55±0.66	NS
Contact points			
Mesial contact point	1.37±0.64	1.54±0.88	NS
Distal contact point	1.49±0.82	1.48±0.92	NS
Radiographic examination	1.38±0.85	1.34±0.77	NS
Patient's view	1.08±0.36	1.21±0.66	p=0.008
Recurrence of caries, erosion, abfraction	1.01±0.07	1.03±0.26	NS
Tooth integrity	1.01±0.07	1.01±0.08	NS
Periodontal response	1.23±0.52	1.21±0.51	NS
Adjacent mucosa	1.01±0.08	1.01±0.07	NS
Oral and general health	1.01±0.08	1.00±0.00	p=0.02

FDI criteria scores: 1: clinically excellent/very good; 2: clinically good; 3: clinically sufficient/satisfactory; 4: clinically unsatisfactory; 5: clinically poor.

advantages. Firstly, it could be performed immediately or during the consecutive session following endodontic treatment, reducing the number of patient visits. Moreover, it has been reported that early placement of permanent coronal restoration increases the longevity of ETT.[21] Since the advent of the chairside CAD–CAM system, endocrowns can be bonded in one session. However, conventional crowns take at least 3 sessions. Secondly, compared to conventional restoration with root anchorage and peripheral metal or ceramic crown, the endocrown restoration represents only one single bonding interface. It forms an adhesively luted ceramic restoration–composite cement–residual tooth structure biomechanical unit.[22] Limiting the number of bond interfaces rends the restoration less susceptible to the adverse effects of degradation of the hybrid layer.[23]

The survival rate of endocrowns assessed in the present study (71.8% at 9 years) is similar to that of a recent study on classical peripheral crowns, with or without post, made by 4th and 5th year students in Saudi Arabia (76% at 8 years).[24] The practitioner's experience seems to have an impact on the survival rate of indirect coronal restoration, whatever its type. It was reported that teeth that were treated by 4th year students were more likely to be extracted than those treated by 5th year students.[24] It could be argued that students with less knowledge and/or motor skills have a higher risk of unfavorable or catastrophic failures leading to extractions.

If there was already an impact of the level of experience (between the 4th and 5th year of study) on the survival rate of endocrowns, it, therefore, seems normal to find a noticeable difference between the survival rates of restorations carried out by students and those carried out by experienced practitioners. Endocrown restorations performed by specialized practitioners showed a success rate of 99.8% to 4.5 years on average, which is higher than the results of the present study (81.8% for a similar average follow-up time).[8] This difference is also reflected in the success rate of conventional crown restorations performed by specialists (98.7%) compared to the same restorations performed by students (76%).[24]

Failure cases among endocrowns performed by the students are higher than among those carried

Tables 2: *Comparison of FDI Mean Scores (±SD) for Clinical Criteria Between Initial and Final Assessment at Different Follow-up Duration in the Group of Successful Endocrowns (n=184)*

Quartiles of Follow-up Duration (Months)	**Quartile 1 n=46**		**Quartile 2 n=46**		**Quartile 3 n=46**		**Quartile 4 n=46**		**Comparisons**	
Mean ± SD	29.0±10		51.0±17		71.5±12		133.0±17			
Min – Max	22–36		39–63		64–80		81–105			
Mean scores ± SD for FDI criteria	Initial	Final	Initial	Final	Initial	Final	Initial	Final	F	Risk alpha
Surface staining	1.02 ±0.10	1.08 ±0.26	1.0 2±0.10	1.10 ±0.27	1.00 ±0.00	1.13 ±0.45	1.11 ±0.28	1.14 ±0.34	ns	
Color stability and translucency	1.73 ±0.60	1.87 ±0.62	2.10 ±0.59	2.35 ±0.82	2.12 ±0.73	2.31 ±0.86	1.77 ±0.50	2.42 ±0.75	5.001	p=0.002
Anatomic form	1.28 ±0.47	1.16 ±0.37	1.70 ±0.72	1.40 ±0.57	1.63 ±0.74	1.26 ±0.51	1.43 ±0.53	1.43 ±0.73	2.837	p=0.039
Patient's view	1.01 ±0.07	1.21 ±0.72	1.07 ±0.23	1.15 ±0.43	1.23 ±0.66	1.26 ±0.83	1.02 ±0.10	1.22 ±0.63	ns	
Oral and general health	1.00 ±0.00	1.00 ±0.00	1.01 ±0.07	1.00 ±0.00	1.00 ±0.00	1.00 ±0.00	1.04 ±0.14	1.00 ±0.00	ns	

Abbreviation: ns = not significant.

Table 3: *Retrospective Evaluations of 41 Cases of Failures on Captured Images in the Cerec System*

Failure Type	**Criteria**	**Correct**	**Ceramic Thickness Less Than 2 mm (A)**	**Peripheral Limits (B)**	**A+B**
Favorable failure	Endocrown fracture	0	7	4	3
	Debonding	2	2	1	5
	Periodontal failure	1	0	0	0
	Recurrent Carious Lesion	0	1	0	0
	Endodontic Retreatment	1	0	0	2
	Operator's mistake	0	1	0	1
	Dental fracture	0	1	0	0
	Subtotal	**4**	**28**		
Unfavorable failure	Endocrown fracture	0	1	2	0
	Periodontal failure	0	0	1	0
	Recurrent Carious Lesion	0	0	0	2
	Tooth fracture	1	1	0	1
	Subtotal	**1**	**8**		

out by experimental practitioners in previous studies (Table 4). This provided the opportunity to analyze the reasons behind endocrown failures. Reasons for failure were reported in a recent systematic review that included eight studies of variable follow-up period duration: the unsuccessful restorations were mainly due to loss of retention (53%) and fracture (14%).[10] The rate of debonding occurrence varied between 0% and 16%. Generally, insufficient bonding protocol is often evoked to explain ceramic pieces debonding.[10,25,26] It

Table 4: *Survival and Failures Rates of Endocrowns on Endodontically Treated Teeth (ETT) Reported in Previous Studies According to the Sealing Protocols*

Study	Number	Bonding Protocol	Rubber Dam Use	Survival Rate	Follow-up Period (Months)		Failures		
					Mean	Range	Debonding	Fracture	
								Endo-crown	Tooth
Bindl and Mörmann (1999)[5]	19	Tetric Ivoclar Vivadent; Panavia 21 TC, Kuraray Noritake	Yes : 4 cases No: 15 cases	All: 95% M: 93.3% PM: 100%	26±6	14–35.5	5.3%	0	0
Otto (2004)[33]	10	Duo Cement Plus, Coltène	Yes	All: 100%	15±ND	12-16	0	0	0
Bindland others (2005)[7]	86	Tetric Ivoclar Vivadent	No	M: 87.1% PM: 68.8%	52±15	ND	16.3%	0	2.3%
Bernhart and others (2010)[34]	20	Panavia F2.0, Kuraray Noritake	Yes	M: 90%	ND	max: 24 ± 2	0	5%	5%
Decerle and others (2014)[17]	16	RelyX Unicem, 3M	Yes	M: 90.9% PM: 100%	6	ND	0	0	0
Otto and Mörmann (2015)[35]	25	Duo Cement Plus, Coltène	Yes	M: 90.5% PM: 75%	116±ND	109-146	8%	4%	0
Belleflamme and others (2017)[9]	99	Variolink II, Ivoclar Vivadent	ND	All: 99%	44.7±34.6	ND	2%	0	1%
Fages and others (2017)[8]	235	RelyX Unicem, 3M	No	M: 99.8%	55.2±5.13	ND	0	0.43%	0
Present study	178	RelyX Unicem, 3M	No	All: 78.7%	61.0±24.5	2-105	5.6%	9 %	1.7%
	47	Variolink II, Ivoclar Vivadent	Yes	All: 93.6%	37.6±22.9	6-98	0	2.1%	2.1%

Abbreviations: M = molars; ND = no data; PM = premolars.

could be suggested that the use of a rubber dam could influence the survival rate of endocrowns by reducing the number of failures due to debonding. In fact, Table 4 shows that four out of the eight studies reported the use of a rubber dam, but their success rates for endocrown did not differ from those which did not use it. In addition, many studies have not found a causal link between rubber dam use and improvement of performances of direct adhesive restorations.[27-29] The analysis of endocrown failures by fracture reported a variation ranging from 0% to 9%. One recent literature review showed a link between a thickness inferior to 2 mm and failure of ceramic onlay.[25] The present study reports that insufficient preparation thickness is also a cause for fractured endocrowns, when students are operators. Teacher supervision could be reinforced, covering all steps of the endocrown procedures. In particular, captured image analysis for the design of the finish line and the expected ceramic thicknesses could be awarded more attention. Teaching students how to use the digital tools of CAD–CAM software to evaluate the thickness of future restoration could prevent failures.

Among the FDI criteria associated with time, some improved and others worsened between the initial and the final evaluations. The improvement of anatomical form could be explained by physiological wear of the prosthodontic part and/or by the occlusal setting that occurs spontaneously during the first weeks postoperatively. Degradation of the "patient's view" could be linked to the "color stability and translucency" and "surface staining" criteria. It was already shown that the color of root-filled teeth changed with time,[30] and the criteria "color stability and translucency" is time-dependent appearing after several years (Table 2). Three proposals were reported to improve CAD–CAM restoration aesthetics. First, nonvital bleaching carried out before the restoration was recommended to prevent discolorations over time[31]; however, the long-term results are limited. Second, changing the design of the preparation finish line would have more predictable aesthetic results. A shoulder preparation design or the positioning of the circular, cervical butt margin near the gingival margin are described protocals that result in less enamel thickness, in turn, altering the quality of bonding. A 45° bevel design for the preparation finish line resulted in a better esthetic integration limiting the loss of tissue. This design would be more favorable in terms of bonding and resistance.[22] This was indicated for endocrowns where aesthetic requirements are met. Third, when the endocrown was made into composite blocks, a discrete double bevel on both the restoration limit and the enamel border was created with a fine diamond cutting rotary instrument to 1.5-mm thickness. This minimal preparation could then be filled with a resin composite layer in order to improve the aesthetics of the restoration-tooth transition.[32]

This study had some limitations. Firstly, the return rates of the patients decreased with time, half of the endocrown cohort being lost to follow-up after 5 years. The limited number of trained investigators could partially explain this low rate. Their presence in the service was limited to some days, and some evaluations were probably lost for this reason. However, return rates in open cohorts are often low, particularly for studies conducted on routine care. The ethical frame of studies on routine care did not allow any changes in the organization nor the observed dental procedure. For this reason, it was not possible to recall the patients for evaluation appointments. Secondly, endocrown evaluations were only taken on by calibrated investigators. Comparisons of T0 evaluations between calibrated investigators and students would be possible. Asking the student operator to evaluate the endocrown he/she carried out at T0 would be interesting, as that would allow him/her to use the evaluation criteria, and to then ask themselves what the outcome of the treatment should be. Moreover, this could prepare the students for self-evaluation of professional practices, giving them tools to compare direct or indirect restorations, for example.

CONCLUSIONS

Undergraduate students could be trained to restore root-filled posterior teeth with CAD–CAM endocrowns. Teacher supervision should cover all steps of carrying out endocrown procedures in order to limit the number of failures. The evaluation criteria of this study could be referred to any practitioner or teacher aiming to evaluate the professional practices according to the Deming cycle method.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects' oversight committee guidelines and policies of Comité d'Ethique des Centres d'Investigation Clinique del'inter-région Rhône-Alpes-Auvergne. The approval code issued for this study is CE-CIC-GREN-11/17.

Conflict of Interest

The authors of the present study certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in the present article.

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REFERENCES

1. Raedel M, Fiedler C, Jacoby S, & Boening KW (2015) Survival of teeth treated with cast post and cores: A retrospective analysis over an observation period of up to 19.5 years *Journal of Prosthetic Dentistry* **114(1)** 40-45. https://doi.org/10.1016/j.prosdent.2014.08.017
2. Fedorowicz Z, Carter B, de Souza RF, Chaves C de AL, Nasser M, & Sequeira-Byron P (2012) Single crowns versus conventional fillings for the restoration of root filled teeth *Cochrane Database Systematic Reviews* **5** CD009109. https://doi.org/10.1002/14651858.CD009109.pub2
3. Shu X, Mai Q-Q, Blatz M, Price R, Wang X-D, & Zhao K (2018) Direct and Indirect Restorations for Endodontically Treated Teeth: A Systematic Review and Meta-analysis, IAAD 2017 Consensus Conference Paper *Journal of Adhesives Dentistry* **20(3)** 183-194. https://doi.org/10.3290/j.jad.a40762
4. Pissis P (1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique *Practical Periodontics Aesthetic Dentistry* **7(5)** 83-94.
5. Bindl A & Mörmann WH (1999) Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results *Journal of Adhesives Dentistry* **1(3)** 255-265.
6. Fages M & Bennasar B (2013) The endocrown: a different type of all-ceramic reconstruction for molars *Journal of the Canadian Dental Association* **79** d140.
7. Bindl A, Richter B, & Mörmann WH (2005) Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry *International Journal of Prosthodontics* **18(3)** 219-224.
8. Fages M, Raynal J, Tramini P, Cuisinier FJ, & Durand J-C (2017) Chairside computer-aided design/computer-aided manufacture all-ceramic crown and endocrown restorations: A 7-year survival rate study *International Journal of Prosthodontics* **30(6)** 556-560. https://doi.org/10.11607/ijp.5132
9. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, & Mainjot AK (2017) No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases *Journal of Dentistry* **63** 1-7. https://doi.org/10.1016/j.jdent.2017.04.009
10. Govare N & Contrepois M (2020) Endocrowns: A systematic review *Journal of Prosthetic Dentistry* **123(3)** 411-418.e9. https://doi.org/10.1016/j.prosdent.2019.04.009
11. Dogui H, Abdelmalek F, Amor A, & Douki N (2018) Endocrown: An alternative Approach for restoring endodontically treated molars with large coronal destruction *Case Reports in Dentistry* **2018** 1581952. https://doi.org/10.1155/2018/1581952
12. Lander E & Dietschi D (2008) Endocrowns: a clinical report *Quintessence International* **39(2)** 99-106.
13. Gaintantzopoulou MD & El-Damanhoury HM (2016) Effect of preparation depth on the marginal and internal adaptation of computer-aided design/computer-assisted manufacture endocrowns *Operative Dentistry* **41(6)** 607-616. https://doi.org/10.2341/15-146-L
14. Hayes A, Duvall N, Wajdowicz M, & Roberts H (2017) Effect of endocrown pulp chamber extension depth on molar fracture resistance *Operative Dentistry* **42(3)** 327-334. https://doi.org/10.2341/16-097-L
15. Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, & Giannini M (2014) Influence of no-ferrule and no-post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns *Operative Dentistry* **39(6)** 595-602. https://doi.org/10.2341/13-004-L
16. Vagropoulou GI, Klifopoulou GL, Vlahou SG, Hirayama H, & Michalakis K (2018) Complications and survival rates of inlays and onlays vs complete coverage restorations: A systematic review and analysis of studies *Journal of Oral Rehabilitation* **45(11)** 903-920. https://doi.org/10.1111/joor.12695
17. Decerle N, Bessadet M, Munoz-Sanchez ML, Eschevins C, Veyrune J, & Nicolas E (2014) Evaluation of Cerec endocrowns: A preliminary cohort study *European Journal of Prosthodontics and Restorative Dentistry* **22(2)** 89-95.
18. Sedrez-Porto JA, Rosa WL de O da, da Silva AF, Münchow EA, & Pereira-Cenci T (2016) Endocrown restorations: A systematic review and meta-analysis *Journal of Dentistry* **52** 8-14. https://doi.org/10.1016/j.jdent.2016.07.005
19. El-Damanhoury HM, Haj-Ali RN, & Platt JA (2015) Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks *Operative Dentistry* **40(2)** 201-210. https://doi.org/10.2341/13-143-L
20. Beier US, Grunert I, Kulmer S, & Dumfahrt H (2007) Quality of impressions using hydrophilic polyvinyl siloxane in a clinical study of 249 patients *International Journal of Prosthodontics* **20(3)** 270-274.
21. Yee K, Bhagavatula P, Stover S, Eichmiller F, Hashimoto L, MacDonald S, & Barkley G (2018) Survival rates of teeth with primary endodontic treatment after core/post and crown placement *Journal of Endodontics* **44(2)** 220-225. https://doi.org/10.1016/j.joen.2017.08.034
22. Politano G, Van Meerbeek B, & Peumans M (2018) Nonretentive bonded ceramic partial crowns: Concept and simplified protocol for long-lasting dental restorations *Journal of Adhesive Dentistry* **20(6)** 495-510. https://doi.org/10.3290/j.jad.a41630
23. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, & Van Meerbeek B (2005) A critical review of the durability of adhesion to tooth tissue: Methods and results *Journal of Dental Research* **84(2)** 118-132. https://doi.org/10.1177/154405910508400204
24. Sadaf D (2020) Survival Rates of Endodontically Treated teeth after placement of definitive coronal restoration: 8-Year retrospective study *Therapeutics and Clinical Risk Management* **16** 125-131. https://doi.org/10.2147/TCRM.S223233

25. Abduo J & Sambrook RJ (2018) Longevity of ceramic onlays: A systematic review *Journal of Esthetics and Restorative Dentistry* **30(3)** 193-215. https://doi.org/10.1111/jerd.12384

26. van Dijken JW, Hasselrot L, Ormin A, & Olofsson AL (2001) Restorations with extensive dentin/enamel-bonded ceramic coverage. A 5-year follow-up *European Journal of Oral Sciences* **109(4)** 222-229. https://doi.org/10.1034/j.1600-0722.2001.00063.x

27. Brunthaler A, König F, Lucas T, Sperr W, & Schedle A (2003) Longevity of direct resin composite restorations in posterior teeth *Clinical Oral Investigations* **7(2)** 63-70. https://doi.org/10.1007/s00784-003-0206-7

28. Raskin A, Setcos JC, Vreven J, & Wilson NH (2000) Influence of the isolation method on the 10-year clinical behaviour of posterior resin composite restorations *Clinical Oral Investigations* **4(3)** 148-152. https://doi.org/10.1007/s007840000069

29. Daudt E, Lopes GC, & Vieira LC (2013) Does operatory field isolation influence the performance of direct adhesive restorations? *Journal of Adhesive Dentistry* **15(1)** 27-32. https://doi.org/10.3290/j.jad.a28194

30. Greta DC, Colosi HA, Gasparik C, & Dudea D (2018) Color comparison between non-vital and vital teeth *Journal of Advanced Prosthodontics* **10(3)** 218-226. https://doi.org/10.4047/jap.2018.10.3.218

31. Rocca GT & Krejci I (2013) Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns *European Journal of Esthetic Dental* **8(2)** 156-179.

32. Rocca GT, Bonnafous F, Rizcalla N, & Krejci I (2010) A technique to improve the esthetic aspects of CAD/CAM composite resin restorations *Journal of Prosthetic Dentistry* **104(4)** 273-275. https://doi.org/10.1016/S0022-3913(10)60138-2

33. Otto T (2004) Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study *International Journal of Periodontics and Restorative Dentistry* **24(5)** 446-455. https://doi.org/10.11607/prd.00.0601

34. Bernhart J, Bräuning A, Altenburger MJ, & Wrbas KT (2010) Cerec3D endocrowns--two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars *International Journal of Computerized Dentistry* **13(2)** 141-154.

35. Otto T, & Mörmann WH (2015) Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years *International Journal of Computerized Dentistry* **18(2)** 147-161.