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Laboratory Technician Assessment of the Quality of Single-Unit Crown Preparations and Impressions as Predictors of the Clinical Acceptability of Crowns as Determined by the Treating Dentist: Findings from the National Dental Practice-Based Research Network

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Abstract

Purpose: In-laboratory assessment by laboratory technicians may offer insight to increase clinical success of dental crowns, and research in this area is lacking.

Materials and Methods: Dentists in the National Dental Practice-Based Research Network enrolled patients in a study about single-unit crowns; laboratory technicians evaluated the quality of tooth preparations and impressions. The primary outcome for each crown was clinical acceptability (CAC), as judged by the treating dentist. A secondary outcome was “Goodness of Fit (GOF),” a composite score of several aspects of clinical fit, also judged by the study dentist. A mixed-effects logistic regression was used to analyze associations between laboratory technician ratings and the CAC and GOF.

Results: Dentists (n = 205) evaluated 3731 crowns. Technicians ranked the marginal detail of impressions as good or excellent in 92% of cases; other aspects of the impression were ranked good or excellent 88% of the time. Regarding tooth preparation, about 90% of preparations were considered adequate (neither excessive nor inadequate reduction). Factors associated with higher CAC were more preparation taper, and use of optical imaging. Factors associated with better GOF

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were higher impression quality, greater occlusal reduction, more preparation taper, and optical imaging.

Conclusions: Overall quality of preparations and impressions was very high, as evaluated by laboratory technicians. Several clinical parameters were associated with higher CAC and GOF. Clinicians who struggle with crown remakes might consider less conservative tooth preparation, as well as using digital impression technology.

Keywords

Crowns; Dental Laboratory; Practice-Based Research; Impressions; Preparations

Despite careful attention to detail and the use of current techniques and materials, dentists still must remake crowns that do not fit clinically; the remake rate approaches 4%.¹ Such remakes require additional time and effort from the dentist, patient, and laboratory. It is often difficult to know why one particular crown must be remade, yet the next one—fabricated using the same laboratory and techniques—may fit nicely on the next patient. Possible sources of error which could cause a crown to be clinically unacceptable include (1) inadequate detail in the impression; (2) insufficient occlusal reduction; (3) insufficient axial reduction; (4) distorted impressions; (5) poor mounting in laboratory, or incorrect interocclusal record; (6) improper preparation design; (7) poor laboratory work; and (8) unknown factors.

The quality of impressions submitted to dental laboratories has been criticized in the literature, with as many as 90% of impressions having an error.² One study of 1157 impressions found that 86% of impressions had at least one error, with over half having to do with the preparation finish line.³ Errors were caused by tissue over the finish line, voids in the impression, and occlusal stops in dual-arch trays. In a U.K. study that considered both single-unit crowns and fixed partial denture impressions, 44% of impressions were judged unsatisfactory.⁴ This was echoed by an earlier study that found a high percentage of flexible plastic trays were used for impressions (72%), and that quality of the impressions was poor.⁵ Similarly, a sample of 136 impressions revealed over half had clinical errors, including indefinite finish lines, distortion of the impression, and inadequate communication on the laboratory prescription.⁶ Other problems may be noted as well, such as questionable material choice and infection control standards, and these concerns have existed for some time.^{7,8} These findings are in contrast to Mitchell et al, who evaluated the quality of 1403 impressions and rated 85% of them good or excellent.⁹ She also noted a high use of dual-arch impression trays, 73%. Beier et al also found a high level of clinically acceptable impressions; of 1466 impressions evaluated in this University setting, only 3% were clinically unacceptable.¹⁰ Findings from another University suggest a similar low incidence of unacceptable impressions at 4%.¹¹ None of these studies correlated the quality of the impressions to the clinical fit of the crowns made from these impressions.

Other factors associated with crown fit and longevity are resistance and retention form.¹² These are impacted by preparation height, taper (total occlusal convergence), and smoothness of the preparation. Of these factors, taper seems most discussed in the literature. Of interest, the proposed ideal of a 5% tapered wall promoted in early prosthodontic

literature¹³ has been relaxed to a more realistically achievable 10% to 20%,^{12,14} a figure in line with manufacturer's recommendations for all-ceramic crowns.¹⁵ Generally, dental schools appear to be teaching a taper in line with the 10° to 20° guideline.^{16–23} This can be clinically difficult to achieve, both for dental students and experienced clinicians, however.^{24,25} Tiu et al conclude that taper in practice is greater than 20%, and may even be double that number, especially for molar preparations.¹⁵ Variation in taper depending on the tooth position in the arch is noted in other studies.^{14,20,26}

In contrast to taper, which is typically higher than published recommendations, axial wall reduction is frequently cited as too conservative. This can lead to difficulties with material fracture due to insufficient material to support occlusal loads.¹² In one study, only 7.5% of teeth were prepared with an adequate axial reduction. Other studies also document deficient axial wall reduction.^{15,16,25} Similarly, it is important to achieve adequate reduction at the finish line of the preparation. This area is also frequently under-reduced in clinical practice.^{16,27} The amount of reduction needed of course varies by material choice, but adequate space for material strength is critical for restoration success.^{12,27} When considering all of these factors, an assumption is made: impressions and tooth preparations which fall into accepted guidelines produce a better crown. Perhaps the crown fits better, or has more retention, or lasts longer in the mouth due to superior resistance form. However, scientific evidence of this correlation is largely limited to clinical experience. In an effort to enable clinicians to make more decisions based on evidence-based dentistry,^{28–30} the purpose of this study was to compare in-laboratory technician ratings to the treating dentist's judgment about clinical acceptability.

Materials and methods

The methods for this study have been previously reported.¹ They are repeated here in part for the convenience of the reader, and expanded in sections that pertain specifically to this report. This study represents Stage 2 of a 2-part investigation of successful single-unit crowns. Stage 1 was based on data collected from a questionnaire administered to 1777 dentists regarding clinical techniques and practices for making single-unit crowns.^{31–34} All dentists were members of the National Dental Practice-Based Research Network (“network”). The network is a consortium of dental practices and dental organizations focused on improving the scientific basis for clinical decision-making.³⁵ Detailed information about the network is available at its web site.³⁶ All activities for these investigations were approved by the Institutional Review Boards governing each of the six regions encompassing the network.

Stage 2 was a prospective cohort study focused on the clinical acceptability of crowns (CAC) at the time of insertion made in routine clinical practice. Network Regional Coordinators (RCs) were asked to recruit 200 dentists to participate in Stage 2 from among those who completed the Stage 1 questionnaire. Data were collected on each practitioner using the network's Enrollment Questionnaire, during which practitioners reported information about themselves, their practice(s), and their patient population. This questionnaire is publicly available at <http://nationaldentalpbrn.org/study-results/factors-for-successful-crowns.php>. Questionnaire items, which had documented test/re-test reliability,

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were taken from our previous work in a practice-based study of dental care.³⁷ Dentists enrolled in the network were eligible for the Stage 2 study if they met all of these criteria: (1) completed an Enrollment Questionnaire; (2) were currently practicing and treating patients in the United States; (3) were in the network's "limited" or "full" network participation category; (4) completed the Stage 1 questionnaire; and (5) reported doing at least seven crowns in a typical month. Practitioners were required to complete IRB training required by their region and were asked to secure the participation of at least one dental laboratory for technical evaluation of crown preparations done in the study.

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Once agreeing to participate in the study, dentists were trained by RCs who visited each office, explained the inclusion and study criteria, and answered questions regarding the study. If the office was remotely located, the training was done by telephone and/or virtually using the computer. The training included role-play scenarios, informed consent education, and review of study forms. Once a clinician began the study, he/she was asked to complete patient enrollment within 3 months. Each clinician was asked to enroll 20 patients. Dentists or their practice were remunerated \$50 for obtaining consent, enrolling the patient, and completing the applicable data forms. They also received another \$25 for completing the data forms related to the insertion of the crown. All data forms are publicly available at <http://nationaldentalpbrn.org/study-results/factors-for-successful-crowns.php>.

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Clinicians recruited patients from among their family of patients who needed a single-unit crown. Clinicians were asked to recruit all eligible patients serially, and to record the number of eligible patients who were recruited for the study, eligible patients who declined to participate, and, if so, the reason for not participating. Eligible patients met the following criteria: (1) 18 years old or older; (2) able to provide informed consent; and (3) in need of a single-unit crown on a natural tooth. Retainers for fixed bridges were not permitted in this study, nor were patients who needed multiple single-unit crowns done in a single appointment. This was done to eliminate the possibility that providing multiple units might affect the impression or ultimate CAC rate at cementation. Patients were asked to complete a short "Patient Characteristics" form, which documented basic patient demographics. All forms are available for inspection on the Network website at <http://nationaldentalpbrn.org/study-results/factors-for-successful-crowns.php>.

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Once enrolled in the study, clinicians prepared the tooth for a crown and completed a data form regarding clinical aspects of the procedure, such as tooth number, reason for crown placement, and impression and preparation techniques that were used. Clinicians were asked to place the crown within 6 weeks of preparation. At the time of insertion, clinicians were asked to inspect the crown on the die (if applicable), and evaluate the crown clinically. Clinicians reported this information on a second data form. RCs maintained contact with clinicians to monitor data quality, compliance with study procedures, and to encourage patient recruitment.

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The primary outcome for this study was CAC, as judged by the treating clinician. A secondary outcome was "goodness of fit" score (GOF), as judged by the treating clinician and reported on the data collection form. Of crowns that were deemed clinically acceptable, clinicians were asked to rank each of the following aspects of the crown fit as Excellent,

Good, or Acceptable: overall fit of the crown on the tooth; marginal fit; proximal fit; occlusion; and esthetics. Responses were coded as 0 for Acceptable; 1 for Good; and 2 for Excellent. Dentists were asked to rank 5 areas of crown fabrication: crown fit on the tooth; marginal fit of the crown; proximal fit of the crown; occlusion of the crown; and esthetics of the crown. Each clinician's response for the 5 questions was summed to give an overall GOF score for each crown, ranging from 0 to 10.

Clinicians were asked to recruit their dental laboratory technicians to participate in this study, if an outside laboratory was used. Along with the materials sent to the laboratory to fabricate the crown (impressions, jaw relation record, etc.) the dentist sent a laboratory evaluation form for the technician to complete. The form captured data regarding the quality of the impression, tooth preparation, and other items such as the jaw relation record. The technicians sent the data form to the RC; under no circumstances was this information provided to the clinicians, to allow the technicians to honestly review and comment on the preparations without concern for irritating a client. All responses were kept anonymous from the participating dentists and results are reported only in aggregate.

For clinicians who used in-office optical impressions and milling, a different work flow was required to capture the data and generate a laboratory evaluation. In these cases, clinicians sent copies of the digital files to a central location in the study. These files were collected and evaluated by a single laboratory technician.

Descriptive frequencies were tabulated without adjustment for clustering. Percentages were calculated based on the available data as the denominator. Associations of responses on the Laboratory data collection form with CAC and GOF category were evaluated using generalized mixed-effects linear models to adjust for the effect of clustering of patients within dentists. CAC was dichotomous, with classifications "Acceptable" and "Not Acceptable." GOF results were stratified into two levels, with scores of 0 to 5 labelled "Acceptable", and scores of 6 to 10 categorized as "Excellent or Good." GOF was analyzed using the generalized linear model with a multinomial distribution. For some analyses of the three-category GOF variable, the estimation algorithm failed to converge due to a lack of observations in some cells of the contingency table. A mixed-effects logistic regression model was used to analyze associations of laboratory form responses with CAC and the dichotomous GOF variables.

Results

The characteristics of the 205 dentists participating in this study have been reported previously.¹ The study enrolled 3847 patients. Of these, network dentists prepared 3828 teeth for crowns, a mean (standard deviation) of 18.7 ± 4 preparations. Of these, 3750 crowns remained in the study until completion. Nineteen crowns were rejected before clinical try-in due to laboratory errors, such as not fitting on the die, open margins on the die, and occlusion errors. The remaining 3731 crowns proceeded to the patient try-in appointment. Of these, 3590 were clinically acceptable, and 141 crowns (3.8%) were rejected.¹

Considering laboratory technician evaluation of impressions (Table 1), the following results were obtained. Technicians reported the vast majority, 92%, of impressions were good or excellent when considering marginal detail in the impression. Additionally, the other areas of the impression were highly regarded, with 88% of impressions scoring good or excellent. The majority (72%) of impressions used a dual-arch technique. Despite the high rankings for marginal detail and general impression quality, signs of distortion in the impression were common, with over 1/3 of impressions classified as distorted.

Considering laboratory technician evaluation of preparations (Table 1), most were ranked as acceptable. Generally speaking, in any category of tooth reduction (axial, occlusal, taper), about 90% of preparations were considered adequate. Some 6% had excessive axial reduction, 9% showed excessive occlusal reduction, and 6% showed excessive total occlusal convergence. Insufficient reduction was less often noted. The finish of the preparation was generally considered good (59%) or excellent (28%).

Laboratories used CAD/CAM technology most of the time to fabricate the crowns (Table 1). This included complete milling to finish (54%), and milling with some hand finishing, such as layering with porcelain (15%). Crowns were made by hand work in 31% of cases, such as casting a metal substructure and building up a porcelain crown.

Of the 13 in-laboratory parameters assessed, three were significantly associated with CAC (Table 2): the technician's evaluation of the taper; the method of making the opposing impression; and the method of making the centric jaw relation. Both of the latter methods favored use of optical impression techniques. It is noteworthy that the quality of marginal detail was not significantly associated with CAC, nor were other aspects of impression quality.

Five factors were significantly associated with GOF (Table 3): impression quality other than at the margin; occlusal reduction; taper; and the use of optical impression techniques to make the opposing impression and jaw relation record.

Discussion

While the majority of dentists in this study reported no remakes, others struggled with a remake rate well over 10%.¹ Such clinicians may find the results from this study helpful when considering changes to improve success rates, both in terms of CAC and GOF. Interestingly, some techniques identified in this study may be contrary to other accepted dental principles, such as minimal tooth reduction, or only removing enough tooth structure to permit the required restoration.

For example, both CAC and GOF were higher for crown preparations that had higher amounts of tooth reduction. As occlusal reduction, taper, and axial reduction moved from insufficient to adequate to excessive, acceptability and fit were higher, albeit at the cost of increased enamel and dentin removal. This is possibly due to the lack of interferences to seating associated with tapered walls and thick axial reductions. It may be important to note this may also be associated with lower crown longevity, which was not analyzed in this

study. Nonetheless, at least with regard to seating of crowns, more reduction was associated with more-positive results.

The marginal reproduction completeness did not have an association with the fit of the crown. This would suggest that our techniques are generally very good at capturing margins, even when imperfectly utilized, or that the laboratories are adept at interpreting marginal data. Other aspects of the impression, categorized as “Impression Quality other than Margins” were significantly associated with GOF, suggesting that the axial and occlusal accuracy had more of an impact on marginal adaptation of crowns than the marginal detail itself.

The results of this study suggest laboratories are generally satisfied with the quality of the laboratory work sent to them for single-unit crown fabrication, when considering the representation of the finish line in the impression. This is in contrast to Rau et al, who reported that 86% of impressions had at least 1 detectable error, and many of these involved the finish line of the preparation.³ This could be attributed to differences in laboratory technician examination, compared to a detailed evaluation by a dentist. While the dentist might mark something as an error in an impression, the laboratory technician might evaluate the same impression and rate it is good or excellent, because he or she feels the imperfection will not affect the CAC; and the results from this study would support the conclusion that, at least among those impressions that the dentist actually send to the laboratory, the quality of the impression was not vigorously related to the CAC.

A significant finding from this study has to do with the use of digital technology; its use was significantly associated with both CAC and GOF. While this study did not focus on optical impressions directly, it did record associated techniques, such as using the optical impression to capture the opposing arch and to make the centric jaw relation record. Clearly, these are all combined into the overall “technology” differential. Said another way, improvements associated with the use of digital technology to make the jaw record are confounded by the fact that the clinician made the impression optically. However, taken together, the optical data are compelling. In this study, the use of digital optical techniques was associated with better outcomes.

Laboratories reported a high use of CAD/CAM techniques for making crowns. Including those milled in office, the use of CAD/CAM in whole or in part was about 70%. This marks a strong diversion from the traditional metal-ceramic construction, which was made primarily by hand. This digital change is echoed in findings from a study of United States Navy clinicians, who increased CAD/CAM units from 12% in 2012 to 38% in 2017.³⁸ This trend was supported in a survey of UK and Irish dental technicians, who reported that a majority of technicians use some sort of CAD/CAM technology in their workflow.³⁹ It is possible that digital workflow within the dental laboratory reduces technician time to make the restorations, leading to business efficiencies and standardized quality.⁴⁰

A limitation to this study is the potential confounding from dentists using CAD/CAM milling. Roughly 15% of impressions in this study were digital, and many of these were associated with in-office milling. Dentists using in-office milling might be more likely to

accept a crown as clinically acceptable, as people may be more likely to accept their own work. Conversely, dentists using in-office milling might be able to readily produce another crown if the first crown was not acceptable, making them actually more likely to reject a crown and remake it. Or, dentists who have immediate feedback from the milling process might develop greater skills than comparable clinicians and have better clinical results. The study also had other limitations. The primary outcome variable, CAC, and the secondary variable, GOF, are subjective. They can mean different things to different clinicians. This potential bias is moderated statistically by controlling for clustering by clinician. Although network practitioners have much in common with dentists at large,^{41,42} their crown procedures may not be representative of a wider representation of dentists. Network members are not recruited randomly, so factors associated with network participation (e.g., an interest in clinical research) may make network dentists unrepresentative of dentists at large. While we cannot assert that network dentists are entirely representative, we can state that they have much in common with dentists at large, while also offering substantial diversity in these characteristics. This assertion is warranted because: (1) substantial percentages of network general dentists are represented in the various response categories of the characteristics in the Enrollment Questionnaire; (2) findings from several network studies document that network general dentists report patterns of diagnosis and treatment that are similar to patterns determined from non-network general dentists;^{43–46} and (3) the similarity of network dentists to non-network dentists using the 2010 ADA Survey of Dental Practice.⁴⁷

Conclusions

In-laboratory evaluations by technicians of impressions and tooth preparations were generally favorable, with over 85% of impressions classified as excellent or good, and over 86% of preparations adequately reduced and tapered. Less conservative tooth reduction was among the factors associated with clinically acceptable crowns and well-fitting crowns. Optical impressions for opposing casts and jaw records were strongly associated with positive outcomes.

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Table 1

Laboratory technician rating of the preparation, impression, and bite registration of the single-unit crowns enrolled in the study, assessed by the technician while the case was in the laboratory

Parameter that the laboratory technician evaluated	Number (n = 3731)	Percent (%)
Impressions		
Completeness of the Preparation Margin Represented in the Impression		
Excellent (100% reproduced)	1413	40
Good (95% of margin visible)	1835	52
Fair (significant areas missing)	288	8
Poor (marginal detail mostly missing)	23	0.6
Missing data	172	
Quality of the Impression other than the Margin Detail		
Excellent	1152	32
Good	1985	56
Fair	380	11
Poor	41	1
Missing data	173	
Impression Type/Technique Used for this Crown		
Dual Arch (Triple Tray)	2600	73
Full Arch	184	5
Quadrant Tray	251	7
Optical Scan	482	14
Missing data	214	
Type of Dual Arch Tray (if used)		
Rigid Plastic	859	35
Flexible Plastic	1016	41
Metal	603	24
Missing data	122	
Signs of Distortion in the Impression?		
Yes	1314	37
No	2245	63
Missing data	172	
Preparations		
Technician's Evaluation of the Axial Reduction		
Excessive	209	6
Adequate	3250	91
Insufficient	100	3
Missing data	172	
Technician's Evaluation of the Occlusal Reduction		
Excessive	325	9
Adequate	3053	86
Insufficient	182	5

Parameter that the laboratory technician evaluated	Number (n = 3731)	Percent (%)
Missing data	171	
Technician's Evaluation of the Taper		
Excessive	201	6
Adequate	3256	91
Insufficient	105	3
Missing data	169	
Technician's Evaluation of the Finish & Smoothness of the Preparation and Margin		
Excellent	1003	28
Good	2094	59
Fair	442	12
Poor	25	1
Missing data	167	
Other Items		
Technician's Evaluation of the Quality of the Opposing Cast		
Excellent	1029	29
Good	2161	61
Fair	289	8
Poor	73	2
Missing data	179	
Technician's Evaluation of the Quality of the Centric Record		
Good	2921	83
Fair	493	14
Poor	108	3
Missing data	209	
Shade Information		
Simple (single shade given)	3100	88
Moderate (2–3 shades over areas of tooth)	317	9
Detailed (shade map, photographs)	91	3
Missing data	223	
Crown Fabrication Technique Used by Laboratory to Make Crown		
Milled by CAD/CAM	1909	54
Mostly by machine, with additions by the laboratory technician (e.g., layered porcelain)	534	15
Mostly made by the laboratory technician (e.g., lost wax casting, stacked porcelain)	1120	31
Missing data	168	

Table 2

Factors associated with clinically acceptable crowns. Crowns were classified as “clinically acceptable” or not by the study dentist at the cementation visit, and correlated with laboratory technician ratings of various impression and preparation parameters. Significant p values indicate that factor was associated with clinical acceptability of the crown

Parameter evaluated by laboratory technician while the case was in the laboratory	Crown clinically acceptable (N and row percentage)	Crown not clinically acceptable (N and row percentage)	Total* (N and column percentage)	p Value
Impressions				
Completeness of the Preparation Margin Represented in the Impression				
Excellent (100% reproduced)	1310 (96)	59 (4)	1369 (40)	**
Good (95% of margin visible)	1727 (96)	64 (4)	1791 (52)	
Fair/Poor (significant areas missing)	262 (96)	12 (4)	274 (8)	
Poor (marginal detail mostly missing)	23 (100)	0	23 (1)	
Quality of the Impression other than the Margin Detail				
Excellent	1073 (96)	47 (4)	1120 (32)	0.28
Good	1873 (97)	65 (3)	1938 (56)	
Fair	342 (95)	17(5)	359 (10)	
Poor	34 (87)	5(13)	39 (1)	
Are there Signs of Distortion in the Impression?				
Yes	1241 (97)	42 (3)	1283 (37)	0.29
No	2082 (96)	93 (4)	2175 (63)	
Preparations				
Technician's Evaluation of the Axial Reduction				
Excessive	205 (99)	3(1)	208 (6)	.13
Adequate	3029 (96)	126 (4)	3155 (91)	
Insufficient	90 (94)	6(6)	96 (3)	
Technician's Evaluation of the Occlusal Reduction				
Excessive	313 (98)	5 (2)	318 (9)	0.06
Adequate	2843 (96)	119 (4)	2962 (86)	
Insufficient	168 (94)	10 (6)	178 (5)	
Technician's Evaluation of the Taper				
Excessive	197(99)	2(1)	199 (6)	0.03
Adequate	3034 (96)	127 (4)	3161 (91)	
Insufficient	94 (94)	6(6)	100 (3)	
Technician's Evaluation of the Finish & Smoothness of the Preparation and Margin				
Excellent	936 (96)	43 (4)	979 (28)	0.54
Good	1963 (97)	70 (3)	2033 (59)	
Fair	405 (95)	21 (5)	426 (12)	
Poor	23 (96)	1 (4)	24 (1)	
Other Items				
Technician's Evaluation of the Quality of the Opposing Cast				

Parameter evaluated by laboratory technician while the case was in the laboratory	Crown clinically acceptable (N and row percentage)	Crown not clinically acceptable (N and row percentage)	Total* (N and column percentage)	p Value
Excellent	954 (95)	52 (5)	1006 (29)	0.055
Good	2025 (97)	72 (3)	2097 (61)	
Fair	265 (96)	10 (4)	275 (8)	
Poor	71 (99)	1 (3)	72 (2)	
How Opposing was Made (not dual arch)				
PVS Impression	152 (94)	9 (6)	161 (5)	0.0001
Stone Cast	212 (94)	14 (6)	226 (7)	
Optical Impression	489 (100)	1 (0.2)	490 (14)	
Technician's Evaluation of the Quality of the Centric Record				
Good	2726 (96)	121 (4)	2847 (83)	0.16
Fair	459 (97)	12 (3)	471 (14)	
Poor	101 (98)	2 (2)	103 (3)	
Type of Centric Record				
Hand Articulated	396 (97)	13 (3)	409 (12)	0.0001
Optical	489 (100)	1 (0.2)	490 (14)	
PVS Record	499 (94)	34 (6)	533 (15)	
Dual Arch Tray	1911 (96)	84 (4)	1995 (58)	
Shade Information				
Simple (single shade given)	2898 (96)	111 (4)	3009 (88)	0.41
Moderate (2–3 shades over areas of tooth)	298 (96)	11 (4)	309 (9)	
Detailed (shade map, photographs)	78 (89)	10 (11)	88 (3)	
Crown Fabrication Technique Used by Laboratory to Make Crown				
Milled by CAD/CAM	1797(96)	66 (4)	1863 (54)	0.57
Mostly by machine, with additions by the laboratory technician	494 (95)	26 (5)	521 (15)	
Mostly made by the laboratory technician	1034 (96)	43 (4)	1077 (31)	

* Due to missing values and rounding, not all columns sum to 100%, and totals may differ among input variables. Missing data values are reported in Table 1.

** Due to clustering, the statistical model did not converge and no *p* value was generated.

Table 3

Factors associated with Goodness of fit (GOF) of crowns. Crown fit was documented by the study dentist at the cementation visit and correlated with laboratory technician ratings of various impression and preparation parameters. Significant p values indicate the factor was associated with clinical fit of the crown

Parameter evaluated by laboratory technician while the case was in the laboratory	Goodness of fit as determined by study dentist at cementation visit (N and row percentage)		Total* (N and column percentage)	p Value
	Excellent or good	Acceptable		
Impressions				
Completeness of the Margin Represented in the Impression				
Excellent (100% reproduced)	1126 (86)	177 (14)	1303 (39)	0.32
Good (95% of margin visible)	1487 (87)	232 (13)	1719 (52)	
Fair (significant areas missing)	217 (83)	44 (17)	261 (8)	
Poor (marginal detail mostly missing)	20 (87)	2 (13)	23 (1)	
Quality of the Impression other than the Margin Detail				
Excellent	925 (87)	141 (13)	1066 (32)	0.03
Good	1607 (86)	256 (14)	1863 (56)	
Fair	289 (84)	54 (16)	343 (11)	
Poor	28 (82)	6 (18)	34(1)	
Are There Signs of Distortion in the Impression?				
Yes	1093 (88)	147 (12)	1240 (38)	0.22
No	1757 (85)	310 (15)	2067 (63)	
Preparations				
Technician's Evaluation of the Axial Reduction				
Excessive	187 (92)	16 (8)	203 (6)	0.54
Adequate	2589 (86)	426 (14)	3015 (91)	
Insufficient	75 (83)	15 (17)	90 (3)	
Technician's Evaluation of the Occlusal Reduction				
Excessive	289 (93)	22 (7)	311 (9)	0.04
Adequate	2431 (86)	399 (14)	2,830 (86)	
Insufficient	131 (78)	36 (22)	167 (5)	
Technician's Evaluation of the Taper				
Excessive	185 (95)	10(5)	195 (6)	0.005
Adequate	2597 (86)	423 (14)	3020 (91)	
Insufficient	71 (75)	23 (24)	94 (3)	
Technician's Evaluation of the Finish & Smoothness of the Preparation and Margin				
Excellent	810 (87)	119 (13)	929 (28)	0.71
Good	1696 (87)	258 (13)	1954 (59)	
Fair	328 (81)	77 (19)	405 (12)	
Poor	20 (87)	3 (13)	23 (1)	
Other Items				
Technician's Evaluation of the Quality of the Opposing Cast				

Parameter evaluated by laboratory technician while the case was in the laboratory	Goodness of fit as determined by study dentist at cementation visit (N and row percentage)		Total* (N and column percentage)	p Value
Excellent	813 (86)	135 (14)	948 (29)	0.93
Good	1742 (86)	273 (14)	2015 (61)	
Fair	224 (85)	41 (15)	265 (8)	
Poor	64 (90)	7 (10)	71 (2)	
How Opposing was Made (not dual arch)				
PVS Impression	120 (79)	32 (21)	152 (5)	0.03
Stone Cast	176 (87)	27 (13)	203 (6)	
Optical Impression	462 (95)	26 (5)	488 (15)	
Technician's Evaluation of the Quality of the Centric Record				
Good	2355 (87)	361 (13)	2716 (83)	0.22
Fair	371 (82)	82 (18)	453 (14)	
Poor	93 (92)	8 (8)	101 (2)	
Type of Centric Record				
Hand Articulated	337 (85)	60 (15)	397 (12)	0.04
Optical	462 (95)	26 (5)	488 (15)	
PVS Record	424 (86)	71 (14)	495 (15)	
Dual Arch Tray	1604 (85)	294 (15)	1899 (56)	
Shade Information				
Simple (single shade given)	72 (92)	6(8)	78 (2)	0.09
Moderate (2–3 shades over areas of tooth)	266 (90)	30 (10)	296 (9)	
Detailed (shade map, photographs)	2471 (86)	413 (14)	2884 (89)	
Crown Fabrication Technique Used by Laboratory to Make Crown				
Milled by CAD/CAM	1556 (87)	238(13)	1794 (54)	0.85
Mostly by machine, with additions by the laboratory technician	438 (89)	56(11)	494 (15)	
Mostly made by the laboratory technician	859 (84)	163 (16)	1022 (31)	

* Due to missing values and rounding, not all columns sum to 100 percent, and totals may differ among input variables. Missing data values are reported in Table 1.