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Standardizing Failure, Success, and Survival Decisions in Clinical Studies of Ceramic and Metal-Ceramic Fixed Dental Prostheses

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Abstract

“Nothing worthwhile is ever without complications.”

– Nora Roberts

The recent increase in reports from clinical studies of ceramic chipping has raised the question of which criteria should constitute success or failure of total-ceramic prostheses. Terminology such as minor chipping[1], partial chipping, technical complications[2, 3], and biological complications have crept into the dental terminology and they have complicated our classification of success and failure of these crown and bridge restorations. Some journals have permitted the reporting of fractures as “complications” and they are not necessarily classified as failures in the study. One study has attempted to classify chipping fractures according to their severity and subsequent treatment.[4] This is a promising approach to resolve the challenges to the classification of chipping fracture.

The term ‘chipping fracture’ is more descriptive than ‘chipping’ since the latter term tends to imply an event of minor consequence. Two types of statistics are reported routinely in these studies, i.e., percent success, which is a measure of restorations that survive without any adverse effects, and percent survival, which is a measure of all restorations that survive even though they may have exhibited chipping fracture or they may have been repaired. Why has this scenario occurred? One possible explanation is that many of these types of fractures are very small and do not affect function or esthetics. Another reason is that corporate sponsors prefer to use the term chipping since it does not connote failure in the sense that the term fracture does. In any event, we need to be more precise in our scientific observations of fracture and classifications of the various types of fracture including details on the location of fracture and the prosthesis design configuration. Because of the lack of standardized methods for describing chipping fractures, materials scientists are unable to properly analyze the effect of material properties and design factors on the time-dependent survival probability of ceramic fixed dental prostheses (FDPs). Based on the review of clinical trials and systematic reviews of these trials, the present study was designed to develop guidelines for classifying the functional performance, success, survival, and susceptibility to chipping fracture, and subsequent treatment of ceramic and metal-ceramic restorations.

Objective—To develop comprehensive descriptive guidelines and a clinical reporting form to assist dental scientists in their analyses of chipping fracture behavior of metal-ceramic and all-

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ceramic prostheses with particular emphasis on veneered-zirconia restorations. These guidelines are required to optimize the recording of fracture features that can be used to differentiate ceramic chipping fracture from bulk fracture and to assist dentists in identifying subsequent treatment that may minimize the need to replace affected restorations.

A recording form for clinical fracture observations must be sufficiently clear and complete so that dental health professionals can translate the most relevant information in a context that allows their patients to fully understand the potential risks and benefits of treatment with ceramic restorations. It should clearly allow a clinician to determine whether or not a ceramic fracture constitutes a failure, which requires replacement of the prosthesis, or whether the fracture surface is relatively small or located in a nonfunctional area, i.e., one that is not contribute to occlusion, aesthetics, proximal contacts, or food impaction.

To accomplish this task, a review of the relevant publications of clinical trials was necessary to identify the variability in reporting of fracture events. The reviews were focused on clinical research studies of zirconia-based FDPs and PFM FDPs, which had been monitored through recall exams for three years or more. These reports and systematic reviews of all relevant publications were published in English dental journals between 2004 and 2010. The primary focus in this review was on the susceptibility to chipping fracture or bulk fracture of veneered zirconia-based fixed dental prostheses (FDPs) and metal-ceramic FDPs, which are also referred to in this paper as porcelain-fused-to-metal (PFM) FDPs.

1. Introduction

The survival, and to a certain extent, the success of clinical prostheses with a ceramic component are reported as probabilities. Only in very rare circumstances will restorations exhibit 0% successes and 100% failures over a period of 5 years or more. In general, restoration success is defined as the demonstrated ability of a restoration (including a prosthesis) to perform as expected. Restoration failure may be defined as any condition that leads to replacement of a prosthesis. Conditions that constitute restoration failure include secondary caries, irreversible pulpitis, excessive wear of opposing tooth surfaces, excessive erosion and roughening of the ceramic surface, ditching of the cement margin, unacceptable esthetics, cracking, chipping fracture, and bulk fracture. For the present paper, only fracture-related phenomena are considered.

A recent study[5] of the failure of ceramic-based FDPs confirmed a previous estimate that less than 85% or more of fixed dental prostheses were still functional after 10 years in service. However, there was considerable variability in the number of parameters that were reported as well as the extent of details on the failures that had occurred. Even for studies in which a standardized evaluation system such as the USPHS criteria or modified Ryge criteria was used, there was great uncertainty in the determination of whether or not repairable fractures were failures or merely “technical complications.” In addition there was uncertainty on whether the identified causes were directly or indirectly associated with the treatment procedures, for example, during replacement of previous prostheses.[5] Based on this previous review, it was concluded that there is an urgent need to develop a comprehensive classification system for identifying clinical prosthesis failures, technical complications, and biologic complications. The authors also recommended that procedures for making impressions that capture the fracture surface details be clearly described to facilitate fractographic analysis and identification of the most likely cause of fracture.

2. Limitations of Clinical Studies of Ceramic-Base Prostheses

There are many ceramic materials that can be used for single-unit or multiple-unit restorations. The so-called “gold standard” for performance of ceramic restorations is the

metal-ceramic or PFM restoration. Survival estimates for PFM fixed dental prostheses are typically about 97% over seven years or more. Thus, an excellent measure of the performance of all-ceramic prostheses is a clinical trial in which a well-established PFM system is used for control restorations. Unfortunately, very few studies of this type have been reported. Nevertheless, it is important to evaluate the potential significance of the outcome variables that have been reported.

Because of the multifactorial nature ceramic-ceramic and metal-ceramic restorations, researchers may conclude that it is futile to seek correlations between in vitro fracture data with clinical performance data. However, a significant reason why these correlations are not fruitful is that details on the ceramic fractures that occurred in clinical trials are inadequately described. Essential information on cracks, chipping fractures, and bulk fractures (size, location, patient characteristics, and clinicians' criteria for judging success or failure) are generally lacking in these publications. To address this situation there is a major need to establish reporting guidelines for these clinical trials by starting with a comprehensive list of the details of clinical fractures, including the product description, prosthesis design and dimensions, supporting substructure (dentin, implant abutment, etc.), type of fracture, location, and appearance, and the occlusion conditions under which the failures occurred. Once this information becomes available, designs for well-focused in vitro studies can be established that attempt to replicate the types of ceramic failure that have been observed.[6, 7]

How should we define clinical success and why is it important to define clinical success from a dental materials perspective? Success may be defined as the intact survival of a prosthesis with acceptable surface quality, anatomic contour, and function, and where applicable, with acceptable esthetics. Since the probabilities of success over time are rarely 100% for established prosthodontic treatments, an important question to address is which of the many variables that affect outcomes[5, 8–10] should be included in classifying the performance of ceramic-ceramic and metal-ceramic restorations?

Obviously, the answer to this question can't be addressed completely in this paper without soliciting feedback from the research community on proposed guidelines for describing fracture characteristics more comprehensively. Nevertheless, this article will lead us to acquire a more detailed description of fractures that involve zirconia-based FDPs and PFM FDPs that will allow us to answer many pressing questions. Does the ceramic veneer for zirconia frameworks fracture more frequently than PFM veneers? Does a press-on veneer fracture less frequently than manually layered ceramic veneer? How does the severity of chipping fracture affect survival outcomes? Are we overestimating the survival probabilities of zirconia/veneer restorations because of potential investigator bias in industry-supported studies and clinical research that is being performed in the ideal environments of academic institutions? There is some evidence of underreporting of the type, frequency, and severity of adverse effects, such as chipping fracture, bulk fracture, and surface degradation of ceramics, which have been reported in studies that have been supported by corporate sponsors.[11]

It seems prudent to develop a more detailed reporting system for describing fractures of ceramic-based restorations by reducing the variability in reporting of survival outcomes in this field of study. The development of a standardized reporting format for these clinical trials with a refinement of descriptors and terminology that are currently used in peer-reviewed publications should greatly improve our ability to analyze the outcomes of these studies more critically.

3. Data and Data Analysis: Complexities of Multifactorial Clinical Trials

In medical trials, Taylor et al.[12] challenged the methods used to define the clinical success of surgical revascularization of the lower extremities that has been traditionally limited to graft patency or limb salvage, but the definition failed to consider other intuitive measures of importance. Clinical success was redefined as achieving all of the following criteria: (1) graft patency to the point of wound healing; (2) limb salvage for one year; (3) maintenance of ambulatory status for one year; and (4) survival for six months. Despite achieving acceptable graft patency for 72.7% of the subjects and limb salvage for 73.3% of the subjects at 36 months, the clinical success was only 44.4% when outcome data for all four defined parameters were considered. Thus, in spite of achieving “acceptable graft patency and limb salvage”, fewer than half of the patients achieved success when using a definition that included multiple parameters. In a similar manner, we can define the success of dental restorations on the basis of multiple variables rather than survival percentages alone.

Although the adverse effects of ceramic-based restorations are relatively minor compared to the “quality of life” issues described above, we can draw a parallel when reporting the overall success versus survival of our restorative treatments. However, we need a quantitative *rating scale for clinical fracture resistance* such as the following one:

1. Superior performance: Survival of all FDPs (100%) for at least five years and a success rate of 95 to 100% (surviving FDPs minus altered FDPs based on two of the three grades scale of chipping fractures[4]);
2. Excellent performance: Survival of 95 to 100% all FDPs for at least five years and a success rate of 90 to 95%;
3. Good performance: Survival of 90 to 95% of restorations for at least five years and a success rate of 90 to 95%; and
4. Poor performance: Survival of less than 90% of restorations or a success rate of less than 90%.

For evaluations in clinical trials, investigators have used the traditional four-point scales of the California Dental Association[13] or that used by the U.S. Public Health Service that generally list two categories (Alpha and Bravo and or Romeo and Sierra) for acceptable performance, and two categories for unacceptable performance (Charlie and Delta or Sierra and Tango, respectively). However, to assist biomaterials scientists and dental practitioners with decision-making that is relevant for prosthetic treatments, much more specific information is needed to ensure that our probabilities of success or failure are reasonably accurate and reproducible from one population to another.

A more “sensitive” list of criteria for evaluating the performance of restorative materials has been proposed[14–16] as compared with those developed by the California Dental Association (CDA) in 1973[17, 18] and published in 1977[13], and those later described by Ryge[19, 20]. The CDA system was set up to evaluate restoration quality, but it also covered 14 other components of dental care including history and clinical examination, radiographic examination, diagnosis, treatment planning, and all other aspects of clinical dentistry.

Hickel et al.[14] seem to have ignored or overlooked these broad-ranging objectives of the CDA system that covered many more variables than restoration quality. Hickel et al.[14] criticized the insensitivity and the lack of rigor of previous approaches for evaluating the performance of restorative materials in clinical studies. Instead, these investigators proposed that future clinical studies on new materials and procedures be conducted as randomized, controlled trials with a clear hypothesis and protocol description to allow meta-analyses to be performed. In addition, they proposed three categories (aesthetic, functional, and

biological) to simplify clinical evaluation procedures and to encourage a more detailed analysis of failures. Of greatest significance in this report is the final recommendation that journal editors allow sufficient space for authors of RCTs to report all of the relevant data as outlined in this proposal. As stated earlier, the lack of detailed information on technical complications such as chipping fractures, refinishing, repairs, and bulk fractures represents a major deficiency of previous reports on performance and survival of ceramic and metal-ceramic restorations. Thus, this recommendation should receive the greatest attention in the future. However, the specific allocation criteria for aesthetic, functional, and biological properties outlined in Table 2[14] of their report fall far short of the types of details that are needed to more clearly identify the causes of chipping fracture or bulk fracture of ceramic and metal-ceramic prostheses. Although one of the categories of criteria for clinical observation is focused on “fractures and retention”, there are insufficient descriptive details to ensure that information such as prosthesis dimensions, evidence of bruxing, occlusion, grinding damage, specific location and size of each crack, chip, or fracture will be captured. On the positive side, their criteria included a category called “patient’s view”, for which a rating of a “clinically poor” restoration could lead to a replacement simply solely because the patient may be completely dissatisfied with the restoration.

4. Decision Points for Success or Failure?

The presence of a chipping fracture does not, by itself, represent a failure. However, if the fracture surface cannot be ground and polished without generating heat that can injure the pulp, or the fracture area is in an area of functional stress that does not allow an adequate repair with a resin-based composite, the restoration should be classified as a failure. Although zirconia has one of the lowest thermal conductivities of all dental ceramics, significant heat can still be generated and transferred to the pulp tissue during recontouring of veneering ceramic at chipping fracture sites since relatively long grinding and polishing times may be needed in some cases. The decision to replace rather than to repair a chipped prosthesis with a zirconia core is difficult, especially when a large prosthesis such as an FDP is involved. Replacement may result in potential trauma to more than one tooth because of the time required to cut through the zirconia core ceramic.

Chadwick et al.[21] suggested many factors that affect the survival of dental restorations:

- the type of dentition;
- site of the restoration;
- size of the restoration;
- reasons for placement;
- caries status;
- age, sex and socioeconomic characteristics of the patient;
- oral hygiene;
- age of practitioner, type of salary structure;
- frequency of changing dentists.

Of course, other factors such as the patient’s clenching force, presence of adjacent or opposing teeth, severity of defects produced by the fabrication process, and the patient’s acceptance of treatment also can affect survival. Chadwick et al.[21] proposed outcome measures of restoration longevity and study designs and found that many of the factors reported previously as affecting restoration longevity could not be confirmed using a systematic review protocol that incorporated an objective study design. They indicated that

the determination of failure is very problematic since there is no universally applied standard for dentists to determine the success or failure of restorations. Two possible decision points were identified: (1) failure occurred if the restoration was replaced; or (2) the restoration failed when the decision was based on clearly defined criteria. They also found that the multiplicity of study designs, and reporting methods in the literature made meta-analyses impossible. A proposed approach was suggested to aid the design of future research into the longevity of restorations.

Their review clearly demonstrated that there is considerable disagreement over the conditions for which a restoration needs to be replaced and they emphasized the need for development and clarification of appropriate criteria for replacement of restorations. They claimed that the insensitivity of the original Ryge methods may lead to misinterpretation of the results as good clinical performance in some cases.

Two changes were proposed: (1) a modified clinical testing protocol for controlled clinical trials, and (2) an in-depth description of relevant clinical evaluation parameters, supplemented with 84 references that are primarily related to issues or problems associated with clinical research trials. They claim that these two components comprise a standard for the clinical testing of restorative materials/procedures and provide significant guidance for research teams in the design and conduct of contemporary clinical trials. However, most of their descriptive information and the 84 references are related primarily to direct composite restorations rather than the more complex ceramic-based crown and bridge restorations. However some aspects of the proposed standard are useful in this regard, primarily those that promote the recording of critically important details on the restoration design and those related to describing the deficiencies of “poor” restorations. Two other concerns on the proposed standard are the failure to require acknowledgement of the funding source for the study and the lack of a requirement to exclude the treating dentists (s) from serving as evaluators.

Three basic elements: scientific integrity, patient safety, and investigator objectivity are critically important aspects of any clinical trial. Investigator bias and compromised objectivity are major threats to the quality of any clinical-trial, especially those in which the benefits and risks are each potentially significant. Investigator bias can influence the questions to be addressed or hypotheses to be tested, the study design, the process for retaining research subjects, reporting of adverse events, the methods for data collection and statistical analysis, and the disclosure of financial interests.

A systematic review of the dental implant literature.[11] concluded that, when controlling for other factors, the probability of annual implant failure for industry-supported trials was significantly lower compared with non-industry-supported trials, and this effect may have adverse implications on decisions regarding tooth extraction, research on tooth preservation, and governmental health care policies. In 41 analyzable trials, the funding source was not identified in 63.4% (26/41) of the trials and 65.8% of the trials were considered at a risk for bias. Conflicts of interest statements were made in only two (4.9%) of these trials. The estimated mean annual failure rate of dental implants for all trials was 1.09% (95% CI = 0.84 – 1.42). The mean annual failure rate estimate of non-industry-funded trials was 2.74% (95% CI= 1.14 – 6.55).

Based on an evidence-based review[22] the following question was addressed: “Are scientific articles which are exclusively or partially funded by implant companies more likely to report lower annual implant failure rates compared to articles with non-industry associated sponsorship?” The review suggested that “dental-industry-sponsored research is more likely to report more favorable outcomes than research from non-industry sponsored

research” and that there is a strong need for “more transparency in the sponsorship and declaration of any conflict of interest in all disciplines of dental research.”

5. Studies of Ceramic Restoration Survival

A prospective clinical cohort study was performed to determine the success rate of 3- to 5-unit FDPs with zirconia frameworks for posterior fixed partial dentures (FDPs) after 5 years of clinical observation.[2] Forty-five patients who needed at least one FDP to replace 1 to 3 posterior teeth were included in the study. Fifty-seven 3- to 5-unit FDPs with zirconia frameworks were cemented with resin cement. Twenty-seven patients with 33 zirconia FDPs were examined after an observation period of 53 ± 13 months. Eleven patients with 17 of the 57 FDPs were lost to follow-up. After the three-year recall exam, seven FDPs in seven patients were replaced because they had severe biologic or technical complications. The success rate of the zirconia frameworks was 97.8%; however, the survival rate was 73.9% because of other complications. Secondary caries was associated with 21.7% of the FDPs, and chipping of the veneering ceramic occurred in 15.2% of the prostheses. Surprisingly, the authors concluded that zirconia offers “sufficient stability as a framework material” for 3- and 4-unit posterior FDPs in spite of chipping fractures in 15% of the FDPs over the five – year period.

Sailer et al.[3] performed a systematic review of the five-year survival rates and incidence of complications for ceramic fixed dental prostheses (FDPs) compared with those of metal-ceramic FDPs. Poisson regression models were developed to obtain estimates of five-year survival percentages. Nine studies of ceramic FDPs met the inclusion criteria. Data on survival and complication rates of metal-ceramic FDPs were obtained from a previous systematic review[23] and an updated report[24]. The outcomes terminology was defined as follows: **Survival** was defined by percentage of FDPs that remained *in situ* with or without modifications. **Biological complications** consisted of caries, loss of pulp vitality, abutment tooth fracture and progression of periodontal disease. **Technical complications** consisted of framework fracture, fracture or chipping of the veneering ceramic, marginal gap/discoloration, and loss of retention. The 5-year survival of metal–ceramic FDPs was significantly higher (94.4%) than that for all-ceramic FDPs (88.6%). All-ceramic FDPs sustained significantly more material fractures (framework and veneering ceramics) (6.5% and 13.6%, respectively) compared with those of metal–ceramic FDPs (1.6% and 2.9%, respectively). Based on this systematic review of all-ceramic FDPs, significantly lower survival rates at five years were found for metal–ceramic FDPs. The most frequent reason for failure of FDPs made out of glass-ceramics or glass-infiltrated ceramics was fracture of the framework or veneering ceramic. However, when zirconia core ceramic was used, the FDPs failed primarily because of biological and technical complications related to the veneer ceramic.

Sailer et al.[25] reported the survival rates and technical and biologic outcomes of posterior fixed dental prostheses (FDPs) made from zirconia frameworks and those made from metal frameworks. A total of 76 FDPs in 59 patients were used to replace three missing posterior teeth (molars and premolars). The three- to five-unit FDPs were randomly assigned to 38 zirconia-ceramic and 38 metal-ceramic FDPs. The technical outcomes of the reconstructions were examined using the United States Public Health Service (USPHS) criteria. The biologic outcomes were analyzed by assessing pocket depth, attachment level, plaque control, bleeding on probing, and tooth vitality. Fifty-three patients with 67 FDPs (36 zirconia-ceramic, 31 metal-ceramic) were examined after a mean observation period of 40.3 ± 2.8 months. Six patients with nine FDPs were lost to follow-up. The survival of both kinds of FDPs was 100%. No significant differences regarding the technical and biologic outcomes were found. Minor chipping of the veneering ceramic was found in 25% of the

zirconia-ceramic and 19.4% of the metal-ceramic FDPs. Bulk fracture of the veneering ceramic occurred only in zirconia-based FDPs. The authors of this study concluded that zirconia-based FDPs exhibited a survival rate that was similar to that of metal-ceramic FDPs after 3 years.

Pjettersson et al.[26] performed a systematic review of the 5-year survival rates of all-ceramic single crowns and to compare them with the survival rates of metal-ceramic crowns and to describe the incidence of biological and technical complications. A total of 34 studies met the inclusion criteria. Based on meta-analysis, the five-year survival rate for ceramic crowns was estimated 93.3% compared with 95.6% for metal-ceramic crowns. Densely sintered alumina (Procera technique) crowns exhibited the highest five-year survival rate of 96.4%, compared with survival rates of 95.4% and 94.5%, for glass-ceramic crowns and glass-infiltrated-alumina –crowns, respectively. A significantly lower survival rate of 87.5% was calculated for glass-ceramic crowns after 5 years. Based on this systematic review, ceramic crowns used for anterior teeth showed survival rates after five years comparable to those for metal-ceramic crowns. When used for posterior teeth, the survival rate for densely sintered alumina crowns (94.9%) and for the glass-ceramic crowns (93.7%) were similar to those for metal-ceramic crowns. Zirconia-based crowns were not included in this study.

Heintze and Rousson[4] systematically analyzed clinical study reports on the frequency of veneer chipping fracture and core bulk fracture of zirconia fixed dental prostheses (FDPs) and porcelain-fused-to-metal (PFM) FDPs to identify possible causes of the fractures. Inclusion criteria for published study reports were: (1) prospective clinical trial of at least two years; (2) report of dropouts; (3) details on technical failures (framework fracture, chipping fracture of the veneer and its extent by recall period); (4) debonding; and (5) replacements and causes (bulk fracture or chipping fracture). Biologic causes of failure were not considered. The principal investigators of in vivo studies of zirconia FDPs were contacted to provide additional information. None of the PFM FDP studies alone satisfied the inclusion criteria of this review. Thirteen clinical studies on zirconia-based FDPs and two studies that included both zirconia and PFM FDPs were found. Recall examination data were retrieved for 595 zirconia and 127 PFM FDPs over a period of approximately three years for both groups.

The innovative aspects of the Heintze and Rousson study[4] were the telephone inquiries to principal investigators that sought additional information on zirconia-based restorations and a classification for chipping fracture treatments. Three grades of chipping fracture treatment were assigned to this classification:

1. Grade 1: Fracture surfaces were polished;
2. Grade 2: Fracture surfaces were repaired with resin-based composite; and
3. Grade 3: Severe chipping fractures required replacement of affected prostheses.

However, no criteria were provided on how the degree of chipping severity was determined. Based on this systematic review[4], the following conclusions were made:

1. The frequency of core fracture was less than 1% in the zirconia group and 0% in the PFM group.
2. When all studies were considered, veneer chipping fractures occurred in 24% of zirconia FDPs and in 34% of PFM FDPs (34%). However, 85% of all chipping fractures occurred in only four studies, and 43% of all chipping fractures occurred in zirconia FDPs.
3. When both types of restorations were included in the studies, chipping fractures occurred in 54% of the zirconia-supported FDPs and in 34% of the PFM FDPs. In

contrast, Silva et al. [27] reported a chipping rate of only 6.1% for zirconia restorations over a four-year period. Their replacement rate of only 2.8%.

4. When all three types of veneer chipping fracture treatments (recontouring/polishing, repair, and replacement) were considered, 97% of PFM FDPs and 90% of zirconia FDPs survived at least three years. Thus, 10% of the zirconia FDPs and 3% of the PFM FDPs were replaced. For both PFM and zirconia FDPs, the frequency of Grades 1 and 2 chipping fractures were significantly higher than for Grade 3.
5. Veneer chipping fractures were significantly fewer in pressed ceramics than in hand-condensed ceramics, for both the zirconia FDPs and the PFM FDPs ($P = .04$).

6. Classification of Chipping Fractures

The three grades of chipping fractures proposed by Heintze and Rousson[4] represent a simple and practical way to express the severity of these fractures. However, unless specific criteria are proposed to determine when a fracture surface should be polished or when it should be repaired, significant variability will occur. Thus, the following criteria for replacement (Grade 3 fracture) are proposed:

1. The fracture surface extends into a functional area and repair is not feasible.
2. Recontouring will result in a significant unacceptable alteration of the anatomic form from the original anatomy.
3. Recontouring will significantly increase the risk of pulp trauma by the generation of heat.
4. Repair with a resin composite will result in esthetic changes that are unacceptable to the patient.

Large defects require more polishing time with concomitant heating of the tooth or implant abutment. An example of a chipping fracture in the buccal surface of a maxillary premolar pontic is shown in Figure 1. Since the fracture is confined to the glass-ceramic veneer and it does not extend into a functional area, it can be classified either as Grade 1 fracture.[4] Thus, the surface needs to be polished, or if it must be repaired with a resin-based composite, it would be classified as a Grade 2 fracture.

A more severe chipping fracture is shown in Figures 2 and 3. The occlusal view in Figure 2 reveals a cleft-type of fracture. The buccal view in Figure 3 represents a more severe condition of the same pontic surface in which the fracture extends across the connector and into the terminal molar crown of this three-unit glass-ceramic FDP. Because of this complex situation, the chipped surface would likely be classified as a Grade 3 fracture. Shown in Figures 4 and 5 are the initial horizontal crack and subsequent incisal fracture in the veneering ceramic of the central incisor pontic of a three-unit glass-ceramic FDP. This result judged as a Grade 3 chipping fracture. The chipping fracture of a metal-ceramic FDP in Figure 6 is confined to the lingual and proximal surfaces. Because the occlusal surface is not involved and the rough surface can be polished, this represents either a Grade 1 chipping fracture.

7. Proposed Method for Reporting Chipping and Bulk Fractures

Success may be defined as the achievement of treatment planning goals and expectations. Failure represents the inability of a restoration to perform as expected under typical clinical and patient conditions. A complication represents an unfavorable and unexpected outcome

of dental treatment. The most relevant measure of success is the survival of a restoration over a specific time period without any adverse effects or need for corrective action.

Although chipping of ceramic surfaces may seem to be a relatively insignificant event in the field of prosthetic reconstruction, it represents a situation that may lead to unnecessary trauma for patients and an unexpected expenditure of time for dental practitioners. More significantly, it represents an unexplainable phenomenon, which indicates an unacceptable level of uncertainty regarding the quality control capability of procedures for fabricating relatively costly prostheses.

On the other hand, if the chipping fractures are caused by patient factors such as dietary substances or extreme clenching forces, such information should be collected in an attempt to predict conditions that are directly related to chipping fractures. However, since we are unsure of the primary cause or causes of these fractures, a standardized list of information that is potentially linked to these adverse effects should be proposed to ensure that adequate information and details are available for continuing research on this topic.

Summarized in Table 1 is a proposed form for recording relevant information on clinical fractures of ceramic-ceramic and metal-ceramic prostheses. Table 2 represents an example of an actual clinical report for a chipping fracture of a zirconia-based FPD. Note that wear facets and possible evidence of bruxing are reflected in the evaluator's response. Also, the patient indicated that he had a habit of chewing on ice cubes, a factor that may or may not have played role in the fracture process. It took approximately 5 min for the evaluator and dental assistant to complete the form.

7. Discussion and Conclusions

The specific etiology of chipping fractures is unknown, in part because the details of these fractures are limited to superficial descriptions, and also because systematic fractographic analyses have not been typically performed to determine the site of crack initiation and the stresses that caused these chipping fractures. If this information is included in future reports of clinical trials, our ability to determine specific causes of each fracture will be greatly enhanced. In addition, this additional information should lead to preventive measures such as framework design changes, fabrication damage reduction, and thermal processing methods, which can minimize the probability of chipping fractures and increase survival probabilities for ceramic crown and bridge restorations.

The use of the classification system for chipping fracture treatments that was proposed by Heintze and Rousson[4] is strongly recommended for future clinical studies in which the fracture susceptibility of ceramic prostheses will be monitored. However, the classification should be expanded to include quantitative descriptions of fracture area (or dimensions) and location and the criteria for decisions to grind/polish or repair fracture surfaces and those for replacement of the prostheses. In addition the adoption of the fracture reporting form that is shown in Tables 1 and 2 will also enhance our ability to determine fracture causes and to identify corrective actions that can be taken in the future to prevent or significantly reduce the frequency of chipping fractures. The adoption of the proposed changes for reporting of fractures will depend on feedback from the research community, and revisions, if necessary, that may occur as a result of this evolution process.

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Figure 1.

Chipping fracture (shown to the left of the blue arrow) within the buccal surface of a premolar pontic in a three-unit glass-ceramic fixed dental prosthesis FDP. The fracture is classified as a Grade 1 chipping fracture[4] because minor recontouring and polishing of the site will not affect occlusion, mastication, or aesthetics appreciably.

Figure 2. Fracture within the buccal surface of the pontic in a three-unit glass-ceramic fixed dental prosthesis (FDP). Note also the crack across the distal marginal ridge of the molar crown. The fracture classified as a Grade 3 chipping fracture[4] because the fracture surface extends from the pontic (center) to the molar crown (see Figure 3).

Figure 3. View of buccal surface of the same chipping fracture (arrow) shown in Figure 2. Because the fracture extends from the pontic into the distal connector and the surface of the molar, it is classified as a nonrepairable Grade 3 fracture.

Figure 4.
Crack within the incisal region of the pontic of a three-unit glass-ceramic FDP before fracture.

Figure 5. Incisal fracture of the central incisor pontic shown in Figure 4. This should be classified either as a Grade 3 fracture and not a Grade 2 fracture because a repair with a resin composite in a high stress site has a low survival probability.

Figure 6. Lingual view of the chipping fracture in a PFM crown of a three-FDP that was made with a palladium-based alloy framework. This is classified as a Grade 1 fracture[4]. This rating is based on the assumption that recontouring and polishing of the site will not increase plaque retention or food impaction. Courtesy of Dr. Josephine Esquivel-Upshaw.

Table 1

Information recording form required to describe and classify details of chipping fractures and bulk fractures to satisfy criteria for comprehensive failure analyses and subsequent treatment decisions

Evaluator Form for Recording Data on Chipping Fracture or Bulk Fracture	
Variable	Response
Funding Sponsor?	Industry ____ Government ____ University ____ Other ____
Product Name (if known)	Core Ceramic: _____ Veneer Ceramic: _____
Product Name (if known)	Core Metal: _____ Veneer Ceramic: _____
Date of cementation	Month/ Day /Year: (_ _ / _ _ / _ _ _ _)
Date of observed fracture	Month/ Day /Year: (_ _ / _ _ / _ _ _ _)
Tooth number of fracture	(1–32 system) _____ (11–48 system) _____
Number of FDP units	Crowns _____ Pontics _____
Tooth/Implant Support?	Natural teeth (nos.) _____ Implant-support (nos.) _____
FDP unit that fractured	Most anterior crown: ____ Most Posterior Crown: ____ Pontic: ____
Crack/Chip/Fracture Site	Occlusal ____ Proximal ____ Marginal Ridge ____ Buccal/Lingual ____
Fracture size (mm × mm)	Occlusal-gingival dimension(mm) ____ × Mesial-distal dim. (mm) ____
Occlusion	Canine-disclusion _____ Group function _____
Functional surface?	Yes _____ No _____
Evidence of wear facets?	Yes _____ No _____
Treatment required	None ____ Grind/polish ____ Composite repair ____ Replace ____
Patient remarks on cause	Hard object contact during chewing ____ Trauma ____ Other ____
Proposed Cause?	Grinding damage ____ Overload ____ Unsupported veneer ____ Diet ____
Did you cement a bridge?	Yes _____ No _____
Impression & Photos?	Yes _____ No _____
Other remarks?	

Table 2

Example of a completed form that for an implant-supported, zirconia-based, three-unit FDP, which exhibited a chipping fracture in the veneering ceramic on the lingual surface of the maxillary left first molar that extended into the proximal area below the distal marginal ridge. Evidence of wear facets and severe wear of cusps extending into dentin are also noted.

Evaluator Form for Recording Data on Chipping Fracture or Bulk Fracture	
Variable	Response
Funding Sponsor?	Industry ☒ Government ☒ University ☐ Other ☐
Product Name (if known)	Core Ceramic: <u>Zir CAD</u> Veneer Ceramic: <u>Zir Press</u>
Product Name (if known)	Core Metal: _____ Veneer Ceramic: _____
Date of cementation	Month/ Day /Year: (/ /)
Date of observed fracture	Month/ Day /Year: (/ /)
Tooth number of fracture	(1-32 system) <u>M #14</u> or (11-48 system) _____
Number of FDP units	Crowns <u>2</u> Pontics <u>1</u>
Tooth/Implant Support?	Natural teeth (nos.) _____ Implant-support (nos.) <u>2</u>
FDP unit that fractured	Most anterior crown: ☒ Most Posterior Crown: ☐ Pontic: ☐
Crack/Chip/Fracture Site	Occlusal ☐ Proximal ☐ Marginal Ridge ☒ Buccal ☐ <u>Lingual</u>
Fracture size (mm x mm)	Occlusal-lingual dimension (mm) <u>5</u> x Mesial-distal dim. (mm) <u>4</u> <u>Buccal-Lingual - 4mm</u>
Occlusion	Canine-disclosure ☒ Group function _____
Fracture in wear area?	Yes ☐ No ☒
Evidence of wear facets?	Yes ☒ No ☐
Treatment required	None ☐ Grind/polish ☒ Composite repair ☐ Replace ☐
Patient remarks on cause	Hard object contact during chewing <u>ice</u> Trauma ☐ Other ☐
Proposed Cause?	Grinding damage ☐ Overload ☐ Unsupported veneer ☒ Diet ☐
Were you the dentist?	Yes ☐ No ☒
Impression & Photos?	Yes ☒ No ☐
Other remarks?	<u>Clinicians unusual mottling on Lingual</u> <u>Bridge UL #14-16</u>