# A Systematic Review of All-Ceramic Crowns: Clinical Fracture Rates in Relation to Restored Tooth Type

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***Purpose:*** The objective of this systematic review was to evaluate the clinical fracture incidence of tooth-supported all-ceramic crowns according to restored tooth type. ***Materials and Methods:*** An electronic search of clinical trials published in English and Chinese was performed using four databases (Medline/PubMed, EMBASE, Cochrane Library, and the Chinese Biomedical Literature Database) from 1990 to 2011 and complemented by an additional manual search. The annual core and veneer fracture rates of various tooth types were estimated and compared using Poisson regression. Moreover, the 5-year cumulative incidence was calculated. ***Results:*** Of 5,600 titles and abstracts retrieved, 37 publications were included, with a follow-up period that ranged from 36 to 97 months. Based on the calculated results, all-ceramic crowns demonstrated an acceptable overall 5-year fracture rate of 4.4% irrespective of the materials used. Molar crowns (8.1%) showed a significantly higher 5-year fracture rate than premolar crowns (3.0%), and the difference between anterior (3.0%) and posterior crowns (5.4%) also achieved significance. Fractures were classified as either core or veneer fractures. Core fracture rates were calculated as having a 5-year incidence of 2.5%, and a significantly higher core fracture rate was found in the posterior region (3.9%). The overall 5-year incidence of veneer fracture was 3.0%, and no clear difference was found between restored tooth types, with incidences of 2.0%, 2.5%, 1.0%, and 3.0% for incisor, canine, premolar, and molar crowns, respectively. ***Conclusions:*** Within the limitations of this study, current dental ceramic materials demonstrated acceptable 5-year core and veneer fracture incidences when used for tooth-supported single crowns in both anterior and posterior segments. A higher fracture tendency for posterior crowns was the trend for all-ceramic crowns, while molar crowns showed a significantly higher fracture rate than premolar crowns. Moreover, it is recommended that randomized controlled trials with large sample sizes be undertaken to obtain more definitive results. *Int J Prosthodont 2012;25:441–450.*

Over the past few decades, dental ceramic materials have been widely used in prosthetic dentistry because of their excellent esthetics and biocompatibility. Associated with improved microstructure and physical properties, all-ceramic crowns have expanded to the posterior region as an alternative treatment for dental defects, and it has been suggested that they are as reliable as metal-ceramic crowns—currently considered the gold standard.[1] A recent review article stated that most clinical trials for all-ceramic crowns have reported a survival rate of greater than 90% irrespective of the observation period and materials used.[2] In vitro research confirmed that the fracture strength of the core material was sufficient for functional mastication in the posterior region. Research has revealed that the mean in vivo occlusal force values ranged from approximately 120 to 400 N associated with the tooth type and patient sex and presented much lower values than the in vitro fracture strength reported for all-ceramic materials, which ranged from 770 to 1,060 N.[3,4]

However, increased strength of the core material does not completely avoid the possibility of crown

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**Table 1** Inclusion and Exclusion Criteria

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|---|
| **Inclusion criteria** |
| Prospective studies or retrospective studies focused on all-ceramic crowns with patient recall |
| Mean follow-up time ≥ 36 months |
| Details provided regarding characteristics of the materials used |
| Tooth type of the fractured crowns (at least anterior or posterior tooth) reported |
| **Exclusion criteria** |
| Studies based only on questionnaires or patients' charts |
| Case reports or animal or in vitro studies |
| Single crowns based only on an implant abutment (or no differentiation between implant-supported and tooth-supported crowns) |
| Studies only on PFM restorations, partial crowns, veneers, inlays, onlays, or FPDs (or did not distinguish full crowns from the listed restorations) |

PFM = porcelain-fused-to-metal; FPD = fixed partial denture.

fracture. A recent review of clinical studies showed that among the biologic and technical complications noted for tooth-supported all-ceramic single crowns, the most frequent complication was core fracture, with a 5-year incidence of approximately 5.7%, which was responsible for almost 85% of all failures.[1]

One of the most important factors affecting the fracture rates of all-ceramic crowns is the position of the restored tooth in the mouth, which determines the magnitude and direction of the occlusal force. Ferrario et al[5] reported that the greatest force occurred in molars, decreased in premolars, and became only one-third to one-fourth that of the original values for incisors. Additionally, the fatigue phenomenon associated with cyclic occlusal loads of the posterior ceramic crowns decreased the fracture strength significantly.[6,7] Based on the results of a previous review by Goodacre et al,[8] the clinical fracture rates of ceramic crowns were different between restored tooth types, namely 21% for molars, 7% for premolars, and 3% for anterior teeth. However, the authors did not distinguish between the fracture modes (core or veneer fracture) and the types of ceramic materials used.

As a consequence of the rapid development of dental ceramic materials during the last decade, it seemed appropriate to provide actual evidence on fracture rates of all-ceramic crowns according to restored tooth type. Therefore, one purpose of this systematic review was to evaluate the fracture incidence of each restored tooth type (incisor, canine, premolar, molar, anterior, posterior, and overall). In addition, the fracture rates between anterior and posterior crowns as well as the incidences between premolar and molar crowns were compared to determine significant differences between them.

## Materials and Methods

### *Literature Search*

A combined electronic search of Medline/PubMed, EMBASE, and the Cochrane Library from 1990 up to and including May 2011 was performed to identify clinical trials of all-ceramic crowns published in English with combinations of the following expanded search terms: "crowns," "tooth prosthesis," "restorations," "ceramics," and "porcelain." A similar search was conducted using the Chinese Biomedical Literature Database (CBM) from 1990 to 2010 for the Chinese literature. To compensate for the delay of updates in the CBM, a search was also performed only for Chinese literature published in 2011 using the China National Knowledge Infrastructure. After that, the electronic search was complemented by a manual search of bibliographies of previous reviews of all-ceramic crowns. Moreover, an additional manual search was conducted in the following journals for the years 2000 to 2011: *The International Journal of Prosthodontics, Journal of Oral Rehabilitation, Australian Dental Journal, Journal of Prosthetic Dentistry, Journal of the Canadian Dental Association, Dental Materials, Clinical Oral Investigations, Journal of Esthetic and Restorative Dentistry, Chinese Journal of Stomatology, West China Journal of Stomatology,* and *Journal of Practical Stomatology.*

### *Literature Selection*

Following the search, titles and abstracts were initially screened for possible suitable articles by two independent reviewers according to the criteria listed in Table 1. This search collected clinical randomized controlled trials (RCTs), prospective cohort studies,

and retrospective studies with follow-up. Case reports and in vitro and animal research studies were excluded. If it could be determined from the titles or abstracts, articles that only reported on implant-supported all-ceramic crowns or restorations other than all-ceramic crowns were excluded. Studies with mean follow-up periods of less than 36 months were also excluded. For this step, previous review articles on all-ceramic crowns were included for reference checking. Any disagreement was solved by discussion. Subsequently, the full text was collected after agreement and screened independently by the same two reviewers on the basis of the inclusion and exclusion criteria. When crucial data were unclear or missing, the authors were contacted via email. If the full text did not agree with the inclusion criteria or with the complementary data obtained from the authors, the article was excluded. Any disagreement was solved by discussion. For the literature search and selection, interreviewer agreement was measured using Cohen kappa coefficients.

### *Data Extraction*

Two reviewers scrutinized the full text independently to extract detailed information on the fractured crowns (material, fracture mode, restored tooth type) using a data extraction table. In this review, the authors only focused on the fracture rates of all-ceramic crowns. Failures that were caused by other factors such as tooth extraction and secondary caries were not taken into consideration. According to previous in vitro and in vivo studies, fracture mode of ceramic crowns may be classified into the following three types: core fracture combined with veneer breakage (core fracture), veneer fracture, and veneer chipping. Veneer chipping was defined as a minor cohesive fracture of the veneering porcelain that did not impair function during the observation period.[9]

### *Statistical Analysis*

The annual fracture rates according to the restored tooth types were calculated by dividing the total number of fractures by the total crown exposure time. Assuming a Poisson distribution for the number of fractures, Poisson regression with a logarithm link function was used to compare the annual fracture rates while attributing the specific weight of each included study.[1,10,11] In the statistical analysis, exposure was defined as the product of the number of crowns at follow-up $\times$ the mean follow-up time, and an offset variable defined as log(exposure) was introduced in the model to balance the different sample sizes and observation times. In this review, the differences of fracture incidence between anterior and posterior crowns as well as the differences between premolar and molar crowns were compared based on the following model:

log(number of fractures) = log(exposure) + intercept + tooth type

Furthermore, the 5-year survival rates were calculated via the relationship between event rate and survival function (S[T] = exp[–T $\times$ event rate]), assuming a constant fracture rate.[12] Thus, the 5-year fracture rates were achieved by subtracting S(T) from 1. This statistical analysis was performed using SAS 8.1 software (SAS Institute), and the level of significance was set at .05.

## Results

### *Study Characteristics*

The electronic search resulted in a list of 5,600 records (English: 3,308, Chinese: 2,292). After the initial manual selection on the basis of the titles and abstracts, 137 articles (English: 92, Chinese: 45) remained, with fair interreviewer agreement ($\kappa = 0.67 \pm 0.05$). Following assessment of the full text, 104 articles (English: 62, Chinese: 42) were excluded for various reasons ($\kappa = 0.79 \pm 0.03$). Searching the references of 30 previous reviews on ceramic restorations provided an additional 4 papers.[13–16] Data were extracted from the final 37 articles (English: 34, Chinese: 3) for further analysis.

Among the 37 included publications, only 2 studies fulfilled the requirement of having a randomized controlled design,[17,18] while 25 were prospective cohort studies and 10 were retrospective studies, with a mean follow-up period that ranged from 36 to 97 months. Of these studies, 8 reported on densely sintered alumina crowns (Procera AllCeram [Nobel Biocare]),[9,17,19–24] 10 reported on crowns fabricated using a glass-infiltrated technique (In-Ceram Alumina [Vita Zahnfabrik][16,18,25–29] and In-Ceram Spinell [Vita Zahnfabrik][26,30,31]), 6 focused on feldspathic porcelain (Vita Mark II [Vita Zahnfabrik]),[15,30,32–35] 5 studies reported on glass-ceramic crowns (Dicor [Dentsply],[16,36–39] Cerestore [Coors Biomedical],[16] and Hi-Ceram [Vita Zahnfabrik][16]), 4 reported on crowns fabricated using lithium disilicate–reinforced glass-ceramic (IPS e.max Press [Ivoclar Vivadent][17] and IPS Empress 2 [Ivoclar Vivadent][40–42]), and 6 focused on leucite-reinforced glass-ceramic (IPS Empress [Ivoclar Vivadent][13,14,43–45] and Finesse [Dentsply][46]).

**Table 2** Characteristics of the Included Studies and Fractured Crowns

| Study | Year of publication | Follow-up (mo) | No. of crowns | Material | Location of crowns | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Molar | Premolar | Canine | Incisor |
| Etman and Woolford[17] | 2010 | 36 | 30 | Procera AllCeram | | 30 | 0 | 0 |
| | | 36 | 30 | IPS e.max Press | | 30 | 0 | 0 |
| Sorrentino et al[9] | 2009 | 72 | 128 | Procera AllCeram | 22 | 32 | 18 | 56 |
| Kokubo et al[19] | 2009 | 60 | 101 | Procera AllCeram | 20 | 46 | 9 | 26 |
| Zitzmann et al[20] | 2007 | 55 | 135 | Procera AllCeram | 65 | 38 | 32 | |
| Walter et al[21] | 2006 | 72 | 107 | Procera AllCeram | 20 | 26 | 2 | 59 |
| Zarone et al[22] | 2005 | 48 | 28 | Procera AllCeram | 0 | 0 | 5 | 23 |
| Ödman et al[23] | 2001 | 97 | 71 | Procera AllCeram | 25 | 24 | 3 | 19 |
| Odén et al[24] | 1998 | 60 | 100 | Procera AllCeram | 55 | 28 | 6 | 11 |
| Cehreli et al[18] | 2011 | 40.3 | 51 | In-Ceram Alumina | | 17 | 34 | |
| Kokubo et al[25] | 2010 | 60 | 101 | In-Ceram Alumina | 10 | 27 | 19 | 45 |
| Bindl and Mörmann[26] | 2002 | 39 | 24 | In-Ceram Alumina | 22 | 2 | 0 | 0 |
| | | 39 | 19 | In-Ceram Spinell | 14 | 5 | 0 | 0 |
| Scherrer et al[16] | 2001 | 60 | 68 | In-Ceram Alumina | 10 | 13 | 45 | |
| | | 84 | 30 | Dicor | 9 | 15 | 6 | |
| | | 96 | 30 | Cerestore | 8 | 8 | 14 | |
| | | 72 | 22 | Hi-Ceram | 5 | 8 | 9 | |
| Haselton et al[27] | 2000 | 36 | 74 | In-Ceram Alumina | | 21 | 53 | |
| Pröbster[28] | 1996 | 56 | 596 | In-Ceram Alumina | 40 | 28 | 6 | 22 |
| Scotti et al[29] | 1995 | 37.6 | 63 | In-Ceram Alumina | 14 | 24 | 3 | 22 |
| Bindl and Mörmann[30] | 2004 | 44.9 | 18 | In-Ceram Spinell | 0 | 0 | 2 | 16 |
| | | 44.6 | 18 | Vita Mark II | 0 | 0 | 2 | 16 |
| Fradeani et al[31] | 2002 | 50 | 40 | In-Ceram Spinell | 0 | 0 | 4 | 36 |
| Mao et al[32] | 2008 | 93.3 | 24 | Vita Mark II | 12 | 10 | 0 | 2 |
| Chen and Zhang[33] | 2007 | 36 | 10 | Vita Mark II | 5 | 5 | 0 | 0 |
| Burke[34] | 2007 | 47 | 59 | Feldspathic porcelain | 0 | 2 | 6 | 51 |
| Chen et al[35] | 2006 | 60 | 12 | Vita Mark II | 3 | 9 | 0 | 0 |
| Bindl et al[15] | 2005 | 55 | 70 | Vita Mark II | 37 | 33 | 0 | 0 |
| Erpenstein et al[36] | 2000 | 84 | 173 | Dicor | | 78 | 95 | |
| Malament and Socransky[37] | 1999 | 66 | 1,039 | Dicor | 431 | 257 | 63 | 288 |
| Sjögren et al[38] | 1999 | 73 | 98 | Dicor | 27 | 36 | 2 | 33 |
| Kelsey et al[39] | 1995 | 48 | 101 | Dicor | 61 | 40 | 0 | 0 |
| Valenti and Valenti[40†] | 2009 | 59 | 261 | IPS Empress 2 | 56 | 98 | 21 | 86 |
| Toksavul and Toman[41] | 2007 | 58 | 79 | IPS Empress 2 | 8 | 15 | 15 | 41 |
| Marquardt and Strub[42] | 2006 | 60 | 27 | IPS Empress 2 | 8 | 19 | 0 | 0 |
| Malament et al[14] | 2003 | 60 | 607 | IPS Empress | 26 | 223 | 75 | 283 |
| Fradeani and Redemagni[44] | 2002 | 78 | 125 | IPS Empress | 10 | 22 | 15 | 78 |
| Sorensen et al[45] | 1998 | 36 | 75 | IPS Empress | 13 | 15 | 47 | |
| Studer et al[13] | 1998 | 61 | 142 | IPS Empress | 39 | 36 | 14 | 53 |
| Fradeani and Aquilano[43] | 1997 | 37 | 144 | IPS Empress | 15 | 28 | 12 | 89 |
| Barnes et al[46] | 2010 | 36 | 36 | Finesse | 0 | 7 | 29 | |
| Schmitt et al[47] | 2010 | 39.2 | 17 | Lava Zirconia | 0 | 0 | 0 | 17 |
| Örtorp et al[48†] | 2009 | 36 | 216 | Procera Zirconia | 97 | 71 | 10 | 38 |

a = anterior; po = posterior; m = molar; pr = premolar; c = canine; i = incisor; NR = not reported; – = without veneer layers.
*For Vita Mark II and Dicor glass-ceramic, fracture = core fracture due to the absence of a veneer layer.
†Detailed data were based on personal communication with the corresponding author via email.
‡Core and veneer fractures not distinguished from each other.

| Fractured crowns* | |
|---|---|
| Core fracture | Veneer fracture |
| 1(m) | 1(m) |
| 1(m) | – |
| 2(pr) | 1(i) |
| 1(m), 3(pr) | 1(m), 2(pr), 1(i), 1(c) |
| 1(m) | 6NR |
| 1(a), 3(po) | 1(a), 1(po), 4NR |
| 0 | 1(i) |
| 1(i), 2(pr), 1(m) | 1(m), 4NR |
| 3(m) | 1(m), 1(pr) |
| 2(po) | 0 |
| 2(m), 1(pr), 2(c) | 1(c) |
| 2(m) | 0 |
| 0 | 0 |
| 2(m), 1(pr) | 1(i) |
| 3(m), 1(pr) | – |
| 3(m), 3(pr), 1(i) | 1(m), 1(i) |
| 1(m), 1(i) | 1(pr), 1(i) |
| 1(m) | 1(pr) |
| 0 | 1(m) |
| 1(pr) | 0 |
| 1(i) | 0 |
| 1(i) | – |
| 1(i) | 2(i) |
| 1(m) | – |
| 1(m) | – |
| 2(a), 1(pr) | – |
| 2(m), 1(pr) | – |
| 2(m), 1(pr) | – |
| 23(po), 19(a) | – |
| 92(m), 28(pr), 5(c), 14(i) | – |
| 8(m), 2(pr), 4(i) | – |
| 13(m), 2(pr) | – |
| 2(m) | 2(m), 1(c), 1(i) |
| 1(a) | 2(m) |
| 0 | 2(po) |
| 1(m), 6(pr), 3(c), 5(i)‡ | |
| 3(m), 1(i)‡ | |
| 1(m) | 0 |
| 4(m), 2(pr), 4(c), 4(i)‡ | |
| 2(m), 1(i)‡ | |
| 0 | 0 |
| 0 | 1(i) |
| 0 | 2(m), 1(pr), 1(i) |

Additionally, 2 articles focused on zirconia-based crowns (Lava Zirconia [3M ESPE][47] and Procera Zirconia [Nobel Biocare][48]).

Information on the fractured crowns reported in the 37 included studies is listed in Table 2. For most studies, the definitions of "veneer fracture" and "chipping" were not clearly distinguished. Since both involved only the veneer layer with the core material remaining intact, it was decided to combine and evaluate them as "veneer fracture." Hence, the fractures were classified as core fracture and veneer fracture in the present review (no. of fractures = no. of core fractures + no. of veneer fractures). Only core fractures were considered to be involved for Vita Mark II and Dicor glass-ceramic since crowns were defined as a monoceramic restoration without veneer porcelain (no. of fractures = no. of core fractures). Moreover, 4 of the 6 relevant publications on leucite-reinforced glass-ceramic crowns did not distinguish the glazing technique from the layering technique.[13,14,43,44] Since it was impossible to differentiate the specific veneer fracture mode in these 4 papers, core fracture and veneer fracture were not distinguished from each other for these studies.

### *Statistical Results*

**Fracture Rates.** Based on calculations of the combined data from the 37 included studies, tooth-supported all-ceramic crowns demonstrated an annual overall fracture rate of 1.6% irrespective of the materials used, translating into a 5-year fracture incidence of 7.7%. Evaluating the relationship between fracture rates and location of the crowns, the posterior segment demonstrated a significantly higher annual fracture rate than the anterior segment (posterior: 2.1% vs anterior: 0.9%, $P < .001$). Regarding the restored tooth types, molars showed the highest annual fracture rate of 3.0%, while the incidence dropped to 1.1% for premolars, 1.2% for canines, and 0.7% for incisors. The difference between molar and premolar crowns achieved significance ($P < .001$) (Table 3).

**Core Fracture Rate.** The fracture incidence was then evaluated according to fracture mode. Regarding the core fracture rate listed in Table 3, all-ceramic crowns demonstrated an annual incidence of 1.5%, translating into a 5-year fracture rate of 7.2%. The highest annual core fracture incidence was again associated with molar crowns (2.7%); however, premolar, canine, and incisor crowns showed comparable performances, with annual core fracture incidences of 0.9%, 0.8%, and 0.6%, respectively. Significant differences were found between the anterior (0.8%) and

**Table 3** Annual (5-Year) Fracture Incidence According to Restored Tooth Type

| Material | Fracture mode | Overall | Anterior | Posterior | Anterior vs posterior | |
|---|---|---|---|---|---|---|
| | | | | | *P* | 95% CI |
| All-ceramic systems | F | 1.6% (7.7%) | 0.9% (4.4%) | 2.1% (10.0%) | < .001 | −1.141 to −0.646 |
| | CF | 1.5% (7.2%) | 0.8% (3.9%) | 2.0% (9.5%) | < .001 | −1.280 to −0.683 |
| | VF | 0.6% (3.0%) | 0.4% (2.0%) | 0.5% (2.5%) | .683 | −0.854 to 0.541 |
| Materials excluding glass-ceramic (Dicor, Cerestore, and Hi-Ceram) | F | 0.9% (4.4%) | 0.6% (3.0%) | 1.1% (5.4%) | .001 | −1.053 to −0.258 |
| | CF | 0.5% (2.5%) | 0.2% (1.0%) | 0.8% (3.9%) | .001 | −1.872 to −0.474 |
| | VF | 0.6% (3.0%) | 0.4% (2.0%) | 0.5% (2.5%) | .614 | −0.953 to 0.542 |

F = fracture; CF = core fracture; VF = veneer fracture; CI = confidence interval.

posterior (2.0%) regions ($P < .001$). Moreover, molar crowns presented a significantly higher annual core fracture incidence compared with that of premolars ($P < .001$).

**Veneer Fracture Rate.** When it came to veneer fracture, the overall annual incidence dropped to only 0.6%, with a 5-year rate of 3.0%. Evaluation of the data according to restored tooth type showed that anterior (0.4%) and posterior (0.5%) crowns were found to have comparable annual clinical incidences of veneer fracture, and no significant difference was found between premolar (0.3%) and molar crowns (0.6%) (Table 3).

**Modified Fracture Incidence.** As shown in Table 2, Dicor glass-ceramic crowns demonstrated an extremely high fracture tendency compared with other materials. As a consequence of the significantly reduced physical properties of glass-ceramic, the application of this material for full crown use is no longer recommended.[49] To keep pace with the times and to obtain a more accurate result with current materials, revised fracture rates were calculated excluding the data from the seven publications with specific glass-ceramics (Dicor, Cerestore, and Hi-Ceram).

When comparing the modified results with the original estimates, the annual overall fracture rate and core fracture rate were reduced to 0.9% and 0.5%, translating to a 5-year response of 4.4% and 2.5%, respectively. However, the 5-year veneer fracture rate remained unchanged at 3.0%. Assessing the changes according to restored tooth type, the annual and core fracture incidences were both decreased to some degree for all tooth types (Table 3). Nevertheless, differences in fracture incidences on the basis of the crown position still reached significance; namely, posterior crowns (1.1%) demonstrated a significantly higher annual fracture rate than that of anterior crowns (0.6%) ($P = .001$), and a significantly higher annual fracture rate was also found for molar crowns (1.7%) compared with premolar crowns (0.6%) ($P < .001$). The most remarkable change in the modified results was associated with core fracture. Although molar crowns (0.9%) showed a relatively higher annual core fracture incidence than premolar crowns (0.5%), this difference was not significant.

## Discussion

Two available methodologies were used to calculate the annual fracture incidence: the total number of fractured crowns divided by the total crown exposure or the arithmetic mean of the annual fracture rates of all included studies. After analyzing the normality, the fracture rates of the included studies did not meet normal distribution ($P < .001$, Shapiro-Wilk test). Therefore, it is not appropriate to describe the average level of fracture incidence using arithmetic mean.[50] As a result, it was decided to use the former model in calculation of the fracture rate. However, an inherent shortcoming of this method is that no median or standard deviation is available.

In this study, the role of tooth type of the fractured crowns was emphasized rather than the ceramic system. During data extraction, all 37 included studies were classified based on the ceramic material used, as listed in Table 2. When trying to evaluate the fracture incidence of various materials used for different tooth types separately, most results were calculated based on the data from four or fewer studies. Such a result was considered too small to draw a significant or insignificant conclusion. According to previous reviews, IPS Empress, In-Ceram Alumina, and feldspathic porcelain crowns demonstrated similar clinical survival rates irrespective of their position in the mouth.[11,51,52] Therefore, it was decided to combine the data of multiple materials into one pooled but credible result.

Based on the recommendations of McLean, two criteria should be considered when evaluating all-ceramic systems. First, since all-ceramic systems age, a clinical observation period of at least 3 years and preferably 5 years should be recorded prior to formulating definite claims about the indication for and long-term benefits and performance standards of a new restorative system. Second, the failure rate of

| | | | | Premolar vs molar | |
|---|---|---|---|---|---|
| Incisor | Canine | Premolar | w | *P* | 95% CI |
| 0.7% (3.4%) | 1.2% (5.8%) | 1.1% (5.4%) | 3.0% (13.9%) | < .001 | −1.352 to −0.757 |
| 0.6% (3.0%) | 0.8% (3.9%) | 0.9% (4.4%) | 2.7% (12.6%) | < .001 | −1.226 to −0.574 |
| 0.4% (2.0%) | 0.5% (2.5%) | 0.3% (1.5%) | 0.6% (3.0%) | .128 | −2.001 to 0.200 |
| 0.5% (2.5%) | 1.1% (5.4%) | 0.6% (3.0%) | 1.7% (8.1%) | < .001 | −1.491 to −0.450 |
| 0.3% (1.5%) | 0.4% (2.0%) | 0.5% (2.5%) | 0.9% (4.4%) | .165 | −1.217 to 0.194 |
| 0.4% (2.0%) | 0.5% (2.5%) | 0.2% (1.0%) | 0.6% (3.0%) | .114 | −2.256 to 0.172 |

**Table 4** Time of Core Fractures

| Study | Material | Mean exposure (mo) | No. of core fractures | Time until fracture (mo) |
|---|---|---|---|---|
| Kokubo et al[19] | Procera AllCeram | 60 | 4 | 23, 27, 34, 38 |
| Walter et al[21] | Procera AllCeram | 72 | 4 | 3C < 24, |
| Ödman and Andersson[23] | Procera AllCeram | 60–126 | 4 | 1C < 12, 30, 2C > 84 |
| Odén et al[24] | Procera AllCeram | 60 | 3 | 1C < 36, 37, 39 |
| Scherrer et al[16] | In-Ceram Alumina<br>Cerestore<br>Hi-Ceram<br>Dicor glass-ceramic | 60<br>96<br>72<br>84 | 3<br>7<br>2<br>4 | 9, 41, 43<br>8, 18, 19, 26, 30, 40, 52<br>15, 21<br>9, 28, 56, 65 |
| Kokubo et al[25] | In-Ceram Alumina | 60 | 5 | 17, 22, 37, 52, 59 |
| Mao et al[32] | Vita Mark II | 93.3 | 1 | 2 |
| Chen et al[35] | Vita Mark II | 60 | 3 | 3, 6, 36 |
| Studer et al[13] | IPS Empress | 61 | 14 | 4C < 12, 9C < 36 |
| Fradeani and Redemagni[44] | IPS Empress | 78 | 4 | 16, 3C > 72 |

C = crown.

ceramic systems should not exceed 5% over 5 years. A higher failure rate jeopardizes the reputation of the practicing dentist; working time and income are also affected by a high incidence of failure.[53]

In this review, only studies with a mean follow-up longer than 36 months were included, of which 16 studies reported a mean observation period of 60 months or longer.[9,13,14,16,19,21,23–25,32,35–37,42,44,54] There is no current definite delimitation of the length of an observation period for ceramic restorations. In general, observations of less than 3 years were defined as short-term investigations, while those longer than 5 years were usually reported as long-term.[36,55] Whether a mean follow-up of only 3 years is too short to provide credible information on the fracture resistance of all-ceramic crowns was argued by some authors. To evaluate the distribution of core fractures over time, studies with a mean follow-up of 60 months were collected. An interesting result was found that 46 of 56 core fractures occurred during the first 40 months (Table 4). This phenomenon was also reported in the clinical studies of Scherrer et al[16] and Groten and Huttig,[56] and the authors defined it as an early mortality behavior, which implied that most complications seem to occur early in a crown's clinical lifetime. Combining the fatigue theory of all-ceramic restorations, there appears to be a possible explanation for this phenomenon: Long-term and repetitive occlusal loading may cause preexisting subcritical flaws to slowly grow until catastrophic fracture occurs at a level of loading insufficient to cause fracture of the crowns in the absence of fatigue.[6,57] For this reason, those preexisting flaws are the prerequisite to fatigue. Hence, if an inherent weak point does exist, 40 months of occlusal cyclic loading may be sufficient to result in a core fracture. However, this is only an assumption and needs to be supported by further evidence.

In evaluating the results of the 5-year fracture incidence, the highest fracture incidence was seen for molar crowns, with a 5-year core fracture rate of 12.6%, which is well above McLean's recommendation (5%).[53] However, after excluding publications on glass-ceramic materials that are no longer recommended, the modified results showed an acceptable 5-year core fracture rate of only 4.4% for molar crowns. This result confirmed the authors'

assumption that the extremely high fracture tendency of some glass-ceramic materials could have a significant effect on the calculation and should be excluded. Since Dicor glass-ceramic is rarely recommended for full crowns at present, the modified results are a more realistic indication of the fracture incidence of all-ceramic crowns. A high annual fracture rate of 1.1% was found for canine crowns, resulting in a 5-year proportion of 5.4%. This high fracture tendency for canine crowns was also reported in a previous systematic review on IPS Empress crowns.[10] Since most patients had canine guidance during articulation, strong lateral extrusion contacts on crowns resulting from canine guidance were considered to be responsible for overloading and fracture of restorations.[58] This high fracture incidence was more evident for ceramic veneers.[59,60]

In a review by Goodacre et al[8] based on the data from 22 included studies with a mean follow-up period of approximately 4 years (range: 1 month to 14 years), the mean fracture incidence of all-ceramic crowns was calculated to be 7%. The fracture rates for anterior, premolar, and molar crowns were 3%, 7%, and 21%, respectively. Comparing these results with the present outcomes, the 5-year fracture rate had decreased to 8.1% for molars and 3.0% for premolars. In a recent systematic review, Pjetursson et al[1] assessed the overall fracture incidence of ceramic crowns irrespective of tooth type, resulting in a 5-year core fracture rate of 5.7% and a veneer fracture rate of 1.2%. However, the 5-year core fracture rate was reduced to 2.5% while the veneer fracture rate increased to 3.0% in the present research. The lower core fracture proportion could be explained by the exclusion of data for specific glass-ceramic crowns that are no longer recommended. Regarding the veneer fracture, in general, veneer chipping was defined as a minor defect that could be repaired by polishing or left untreated. However, in the present review, veneer chipping was also considered as a type of veneer fracture and was included in the calculation, which might account for the relatively higher proportion.

Over the past 40 years, porcelain-fused-to-metal restorations have proven to be a reliable treatment option and are considered the gold standard for dental restorations.[61] Hence, it is necessary to observe the clinical performance of all-ceramic crowns compared with that of metal-ceramic crowns.[17] According to the results of a previous review, the calculated 5-year incidence of ceramic fracture or chipping of metal-ceramic crowns was approximately 5.7%.[1] Comparing this result with the 5-year veneer fracture rate in this review, a comparable incidence of 3.0% was found for all-ceramic crowns. This may confirm that although metal oxidation and interdiffusion of ions are considered to lead to a greater bond strength for the metal-ceramic interface compared to that of the core-veneer interface for a bilayer ceramic structure,[62,63] the assumption of a superior fracture resistance of veneer porcelain for metal-ceramic restorations is questionable.

Zirconia-based ceramic materials have recently become of considerable interest and widely researched in in vitro studies and clinical trials as a consequence of their greater mechanical properties compared with other ceramics.[64] However, although zirconia has been used clinically during the past decade, few clinical trials reporting on the long-term performance of zirconia-based single crowns are available for comparison.[48] Fractures within the veneering ceramic have been described as the most frequent mode of clinical and laboratory failure for this material.[56] Regarding the data of this systematic review and some short-term clinical trials, core fractures were noticeably infrequently reported in zirconia-based single crowns over 1 to 3 years of follow-up, while the veneer fracture proportion ranged from 0% to 5.9%.[65] More clinical trials on zirconia-based crowns with a follow-up period of longer than 3 years are needed to acquire a more accurate comparison.

The data in Table 2 show great variance between individual studies reporting on the same material and restored tooth type within a similar follow-up period. A clear difference was observed between the studies conducted by Zitzmann et al[20] and Kokubo et al,[19] with the former reporting a core fracture rate of 0% and the latter of 6.5% for Procera AllCeram crowns on premolars. This variance was also found for In-Ceram Alumina crowns[26,28] and IPS Empress crowns.[13,14] This phenomenon may be explained by the relatively small sample size, which can lead to a large deviation and an exaggerated outcome. An additional explanation might be that the technical sensitivity, ie, the difference between clinicians or technicians (eg, selection of indication, tooth preparation design, or lab processing), could result in a highly variable fracture resistance for the same material and tooth type. Hence, it is difficult to compare the clinical performance of restorations based only on observational studies without control groups. Meta-analysis of RCTs would be the most appropriate solution.[66] However, sometimes an RCT design is hard to conduct because of high costs and lack of scientific background.[11] According to the GRADE approach recommended by the Cochrane Collaboration, observational investigations with a large study sample could still achieve a high-quality level of evidence.[67]

In this study, a Poisson model was used to compare the performance between various tooth types. However, the authors had to assume that the probability to observe a fracture remains constant over time. If the early mortality phenomenon does exist, then using the Poisson model in calculating the fracture incidence of restorations should be restricted. Another limitation of this study is that the fracture rate calculated in this review is an average incidence. When interpreting the results, it should be kept in mind that the mean follow-up ranged from 36 to 97 months. Although no clear correlation has been found between a longer observation period and higher mean fracture rate, caution should be used before extrapolating the results.

## Conclusions

Within the limitations of this study's protocol, the current evidence was interpreted to suggest that dental ceramic materials demonstrated acceptable 5-year core and veneer fracture incidences when used for tooth-supported single crowns in both anterior and posterior segments. A higher fracture rate for posterior crowns was the clear trend for single crowns, and molar crowns showed a significantly higher fracture rate than premolar crowns. Clinical trials on zirconia-based crowns with long-term follow-up are still needed. Moreover, to evaluate the comparative performance between various ceramic materials and restored tooth types, well-designed randomized controlled studies with sufficiently large sample sizes should be undertaken.

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