Review



# Fracture Rate and Causes of Ceramic Crown Fracture: A Systematic Literature Review

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*Review*

# Fracture Rate and Causes of Ceramic Crown Fracture: A Systematic Literature Review

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**Abstract:** To determine the fracture rate of ceramic crowns and causes of ceramic crown failure, this study used keywords—namely "endocrown," "veneered fixed dental prosthesis," "monolithic lithium disilicate (LS2)," and "all-ceramic single crown"—to search for articles published in English from 2005 to 2023 in the PubMed electronic database. Rather than using the Boolean logic algorithm between MESH terms and keywords, we accurately calculated the numbers of final clinically tracked cases with crown fractures from the contents of articles. The titles and abstracts of many related articles focused on implant or abutment fracture, while crown fracture was investigated and mentioned only in the main texts of the articles. Our studies included those crowns as well as having more complete data collection. Our search yielded 228, 93, 404, and 358 articles for the keywords "endocrown," "veneered fixed dental prosthesis," "monolithic lithium disilicate (LS2)," and "all-ceramic single crown," respectively. We used the Newcastle–Ottawa Scale (NOS) to assess article quality, and our inclusion criteria were randomized controlled trials (RCT) and cohort study articles involving more than 3 years of follow-up and more than 20 cases. After reviewing, 16 high-quality articles were selected for analysis. The 4.4% crown fracture rate recommended on the basis of most clinical results was achieved in only 6 of the 16 articles. In these 6 articles, the researchers concluded the following reasons that may cause the crown fractures: the thickness of the veneer ceramic material; the connector dimensions; pontic span of the fixed prosthesis; the type of cement; the treatment of the ceramic surface before luting. Other articles inferred that the computer-aided design libraries that were insufficient for the creation of appropriate anatomically supported frameworks for prostheses with ceramic veneers; the thermal expansion coefficient and fracture toughness of the framework material did not match those of the veneer ceramic, resulting in an insufficient area supporting the ceramic veneer then leads to premature crown failure after a long period chewing. The future prospective for material developing could focus on solving those problems and have better clinical results.

**Keywords:** fracture; chipping; Newcastle–Ottawa Scale; endocrown; veneered fixed dental prosthesis; monolithic lithium disilicate (LS2); all-ceramic single crown

## 1. Introduction

The aesthetics of dental crowns have continually improved as modern crown materials have increasingly been developed. However, early types of crowns were highly prone to breakage and had a short service life. In the preceding 20 years, owing to the development of nanomaterials and testing equipment, numerous new crown materials, including zirconium dioxide ($ZrO_2$) and monolithic lithium dioxide (LS2), have been proposed, and many related clinical trials have been conducted. However, regardless of whether a crown is supported by a natural tooth or an implant, breakage remains a frequently occurring problem. This study used the Newcastle–Ottawa Scale (NOS), which was recently developed by multinational medical research institutions, to review clinical articles reporting the long-term follow-up of dental crowns. The present review highlights the causes of crown damage and measures for avoiding such damage, and the findings could be used

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as a reference for the development of new ceramic materials that are highly suitable for crown fabrication.

## 2. Clinical Application and Material Properties of Dental Crowns

A crown is a type of dental prosthesis. Dental crowns are a type of helmet used to protect what remains of a natural tooth structure when the teeth structure was compromised by large cavities, or to protect the tooth structure after root canal treatment, or be aesthetically defective because of trauma. A dental bridge comprises two or more connected prosthetic restorations that replace missing teeth. When connected prosthetic restorations are performed, the healthy teeth on either side of the prosthesis need to be ground so that they can serve as supporting surfaces for the dental bridge. When a natural tooth cannot function normally and is therefore removed, a dental implant can be used to replace the missing tooth and fulfil the chewing and biting functions of the tooth in that position. In this type of implant restoration, it consists of three components: the implant fixture that is inserted into the jawbone and osseointegrated to provide the support; the abutment that is an object to connect the crown to implant fixture, and the implant crown [1]. Implants can be restored individually or use two or more implants as supports for making a bridge to replace multiple missing teeth.

Chairside Economical Restoration of Esthetic Ceramics (CEREC) is used when the defect in a natural tooth is large and traditional resin will thus easily fall out [2]. In this restoration process, a dentist employs a digital intraoral scanner to obtain images of the defective tooth and measure the size of the cavity. Software is then used to create a shape that will restore the three-dimensional structure of the tooth, and a cutting machine then grinds a ceramic block into that shape. Therefore, the cut ceramic piece (endocrown or all-ceramic crown) fits almost perfectly in the cavity and thus restores the overall structure of the tooth.

Several decades ago, all dental crowns were metal (mainly gold or silver). In recent years, due to the aesthetics required by patients, dental crowns have developed into two types: veneering crowns (metal, glass ceramic, or ceramic as the interior layer; porcelain as the exterior layer) and monolithic all-ceramic crowns. When designing a crown, the aims are to combine aesthetics and fracture resistance. A material with favorable aesthetics is usually used for the anterior area, whereas a bite-resistant material is applied for the posterior area. Monolithic lithium disilicate (LS2; a glass ceramic) has good light transmittance, can be color-matched to natural dentition, and is less likely than other materials to chip or fracture during biting [3]. LS2 is used for veneering or all-ceramic crowns for the anterior teeth. Common brands of LS2 include IPS e.max Ceram, IPS e.max Press, and IPS e.max CAD. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is a composite material obtained by adding $Y_2O_3$ to zirconia. The purpose of this process is to stabilize the 4% volume expansion that occurs when zirconia ($ZrO_2$) shifts from the tetragonal phase to the monoclinic phase during high-temperature sintering and thus to reduce the likelihood of radial cracks developing [4,5]. Y-TZP has higher mechanical strength and is less prone to cracking compared with LS2 [6] but also is less transparent and thus mainly used in all-ceramic or veneering crowns and short-span bridges located in the posterior area. Common brands of Y-TZP include 3M Lava, Cereon, IPS e.max ZirCAD, and IPS e.max Ceram.

## 3. Selection of Study Assessment Tools

In evidence-based medicine, epidemiological and statistical methods are used to strictly filter and review academic articles collected from a large medical database; a systematic literature review and comprehensive analysis are then conducted on these articles, and the results indicate which tools and medicines are most suitable for use by medical staff to promptly diagnose and treat a certain disease. Many countries have empirical research centers located in top universities and research institutions and have established mechanisms and tools for reviewing randomized controlled trials (RCTs) in the medical field to obtain high-quality documentary evidence.

The CASP tool for critical appraisal originated from the work conducted by the Critical Appraisal Skills Programme in Oxford. Work on CASP began in 1993 and was aimed at helping

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health care decision-makers understand scientific evidence [7]. The first CASP International Training week was held in London, United Kingdom, on July 5–9, 1999. The meeting was attended by more than 20 delegates from 11 countries. The CASP checklist was originally developed as a teaching tool that scholars could use during discussions in seminars. Specifically, scholars could employ this tool to demonstrate the process of critically evaluating academic work and the types of issues worthy of attention. The CASP article review checklist comprises eight categories: the RCT, systematic review, qualitative study, cohort study, diagnostic study, case–control study, economic evaluation, and clinical prediction rule [8]. However, the following aspects of the eight categorical scales commonly cause concern: PICO (standing for patient or population, intervention, comparison, and outcomes), subject representativeness, bias, and whether research results are applicable to local ethnic groups.

The University of Oxford established the Oxford Centre for Evidence-Based Medicine (CEBM) and released the first version of its "Levels of Evidence" in 1998 for clinical academic use. These levels were slightly modified in 2009, and the latest version was released in September 2011[9]. In the approach of the CEBM, clinical problems are divided into diagnosis, prognosis, benefits of interventional treatment, harms of interventional treatment, and early diagnosis. Evidence obtained through systematic literature reviews and blinded RCTs is considered strong, whereas that obtained through non-RCTs and case reports (even those involving several years of follow-up) is considered weak[10]. After the Oxford CEBM released the first version of its evidence level table, the Academy of Medical Royal Colleges and Faculties in Scotland developed the Scottish Intercollegiate Guidelines Network (SIGN 50), in which clinical evidence is classified from high (levels 1++ and 1+; e.g., evidence from systematic literature reviews and RCTs with low risk of bias) to low (levels 2− to 4; e.g., evidence from case reports and expert opinions)[11]. The academy also designed a checklist for six major categories of articles: systematic reviews and meta-analyses, RCTs, cohort studies, case–control studies, studies of diagnostic accuracy and economic evaluation, and other[12].

Australia's Joanna Briggs Institute (JBI) has established an evidence-based practice full-text literature database (mainly related to nursing research) comprising articles of five types—namely evidence summaries, evidence-based recommended practices, best practice information sheets, systematic reviews, and systematic review protocols—and also has established evidence levels for evaluating the literature in its database[13]. Similar to the Oxford CEBM Levels of Evidence and SIGN 50, the JBI evidence levels of systematic reviews and RCTs are high (level 1a), whereas those of case studies and cross-sectional studies are low (level 4c). Regardless of the impact factor of the journal in which an article is published, engineering, in vitro testing, and other bench-based research studies can be classified only as obtaining the lowest level of evidence (level 5).

Regarding the development of tools for systematic literature review, in 1996, Jadad and several scholars from the Pain Relief Centre and Department of Anesthesia of Oxford University developed a systematic literature review scale (later named Jadad Quality Scale) for evaluating the quality of RCTs and the effectiveness of blinding methods used in RCT experiments [14]. The first version of this evaluation scale covered three major aspects: (1) Is the study described as randomized? (2) Is the study described as a blind trial? (3) Does the article describe the reasons for the withdrawal and expulsion of patients from follow-up? The revised version, released in 2001, comprises eight indicators, including whether inclusion and exclusion criteria are described, whether adverse reactions are evaluated and described, and whether statistical analysis methods are described [15]. However, Hempel et al. [16] noted that the Jadad scale had some limitations; for example, the double-blind standard is employed in less than 20% of academic articles. Even in the modified Jadad scale, questions related to blind testing account for 25% of the overall score. Hempel et al. proposed that when reviewing an RCT or non-RCT article, different quality aspects should be developed for application to the specific research topic and research field. For example, the quality criteria recommended by the Cochrane Back Review Group were found to correlate with effect sizes in RCTs related to back pain interventions. Therefore, on the basis of the nine-item Delphi list and three-item Jadad criteria, the Hempel research group's Editorial Board began developing a list of 11 criteria for assessing the internal validity of RCTs to meet anticipated needs for back pain treatment trials.

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No review tool suitable for evaluating the article quality of nonrandomized studies, such as cohort studies and case–control studies, was available until the publication of the NOS, which was jointly developed using the Delphi process by scholars from Newcastle University in the United Kingdom and the University of Ottawa in Canada in 2009 [17]. Because of differences in the directions that an evaluation can take, NOS adopts only one blind test question, which contains fewer blind test-related questions than the Jadade scale, making it more objective. The NOS comprises three parts—subject selection, comparability, and result measurement—and a total of eight questions. Each question covers three or four evaluation criteria. A star is awarded for only one or two of these criteria, and if a second control factor is present in the question, one more star is awarded. The higher the number of stars awarded, the higher is the quality of the article. The comparability part requires reviewers to answer the most important and secondary control factors after reading the article.

The present study employed the following keywords: "veneered fixed dental prostheses," "monolithic lithium disilicate (LS2)," and "all-ceramic single crowns." These keywords were used by Spitznagel et al. [18] in their systematic review. The present study also used the keyword "endocrown," referring to a type of crown often used for local repair after endodontic treatment. In the PubMed electronic database, we searched for academic articles published from 2005 to 2023 without using the Boolean logic algorithm between MESH terms and keywords. A total of 1083 articles were obtained. These articles included those reporting RCTs, cohort studies, short-term and multiyear case series, and bench research. We preliminarily read the abstracts and tables of all 1083 articles and found that many of the articles did not report the results of an experimental group and a control group in RCTs, the performance of single-blind trials, or the evaluation of adverse reactions. Therefore, we used the relatively inclusive traditional NOS to review articles from a range of categories. In addition, we did not compare patient satisfaction levels in relation to the modified United States Public Health Care (USPHS) criteria or California Dental Association (CDA) criteria, nor did we analyze the discoloration and marginal adaptation of dental crowns after years of use [3,19,20].

### *3.1. Inclusion and exclusion criteria for reviewed articles*

Many articles regarding clinical functional evaluation have reported that the acceptable chip or fracture rate for ceramic crowns after 5 years of use is 4.4% [21–23]. This rate corresponds to a fracture or chip in less than 1 in 20 crowns. If this study had included articles reporting on the follow-up of 20 crowns or fewer, the failure rate could easily be as high as 10%–30% [24,25], namely considerably higher than the clinical acceptance rate of 4.4%. Scholars such as Scherrer et al. [26] have proposed the use of Weibull life prediction theory for predicting the service life of a dental crown that is more than 5 years on the basis of results obtained after 3 years. Our inclusion criteria for the present review are described as follows: (1) the cohort study or RCT had more than 3 years of follow-up, (2) the final number of participants was greater than 20, and (3) the cohorts in the study were clearly identified in the article itself or the sample could be divided into an experimental group and a control group.

Regarding our exclusion criteria, because we used the NOS tool for assessing cohort studies, nonclinical research articles such as in vitro bench studies and animal studies were naturally excluded. In addition, long-span bridges covering five or more adjacent fixed dental prostheses (FDPs) may place an excessive load on the abutment and periodontal area, and such a load can directly lead to stress fatigue and bridge fracture or indirectly cause a fracture in the FDPs [27,28]. Ceramic fracture has been confirmed to be more likely in FDPs spanning more than five units. Therefore, the present study excluded articles that discussed only long-span FDPs; articles including data regarding three-, four-, or five-unit FDPs were still included in the review. Finally, articles not written in English and those that did not meet the inclusion criteria were also excluded.

## 4. Results of Article Review

This study searched for articles published from 1998 to 2023 in the PubMed medical database. When using the single keywords "endocrown," "veneered fixed dental prosthesis," "monolithic lithium disilicate (LS2)," and "all-ceramic single crown," we retrieved 228, 93, 404, and 358 articles,

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respectively. After reading the abstracts and tables of each full-text article and excluding all articles with nonclinical applications, 12, 25, 61, and 75 articles remained, respectively. We then employed the NOS for cohort studies and RCTs, and after excluding all articles involving samples of a single type, samples of more than three types, a follow-up of <3 years, and FDPs longer than five units, we retained 2, 6, 4, and 4 articles, respectively (Table 1). Although the article published by Konstantinidis et al. [29] did not meet the review criteria (because the FDPs investigated in that study had four to six units), we still adopted their definition of control and experimental groups: the crown bonded to the implant (implant-retained crown) served as the experimental crown, and the crown bonded to the tooth (tooth-retained crown) served as the control crown. This definition was applied to all articles that did not indicate experimental and control groups; our goal was to increase the number of articles that could be included. The articles rescued through this definition of experimental and control groups were all awarded seven to nine stars and found to have high evidence quality (Table 1).

**Table 1.** Numbers of articles in each stage of the review.

| keywords | Pubmed database | After delete nonclinical articles | Final review by NOS |
|---|---|---|---|
| endocrown | 228 | 12 | 2 |
| veneered FDP | 93 | 25 | 6 |
| monolithic lithium disilicate (LS2) | 404 | 61 | 4 |
| all-ceramic single crowns | 358 | 75 | 4 |

The number of articles that could be included decreased sharply after context checked because many reports of dental cohort studies and RCTs were not written in accordance with the logic of medical RCTs or the standards of clinical trials. Research in the medical field emphasizes single-blind or double-blind testing and predetermined control factors; however, this logic is not applied in most clinical dental studies. Consequently, many of the obtained articles did not contain blind independent evaluation data in their statistics sections (only one star could be awarded on the basis of the records tables), making it impossible to identify the main control factor for comparability. Furthermore, when we used the Version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB 2) [30] for assessing the risk of bias in the articles, we discovered that most of the RCTs and retrospective articles regarding ceramic crowns were rated as high risk. Because the research designs of these articles did not mention the generation of the allocation sequence, blinding of participants and researchers, or whether deviations were balanced between groups [31]. In addition, although we had 16 candidate articles after our final review (Table 2), even when we used the same keywords to re-review them, these articles did not have completely consistent control factors; thus, we could not integrate these articles to draw a forest plot or perform a meta-analysis. Some of the candidate articles appeared to classify experimental or control groups by either dental implant, abutment, or FDP, but they included crowns made from three different materials. For example, if we wanted to analyze the fracture rate and causes of ceramic crown fracture (the main focus of the present study) in the RCTs conducted by Horsch et al. [32], Moráguez et al. [33], Vigolo et al. [34], and Malament et al. [35], we would have been unable to distinguish the experimental crowns from the control crowns; thus, we had to exclude these long-term follow-up articles. When selecting control factors and other control factors for each candidate article, we concluded that a minimum ceramic thickness at the occlusal surface of 1.5–2.0 mm [36–39], good periodontal health [19,38], and the absence of evident bruxism [5,40,41] were the most commonly used control factors (Table 3).

**Table 2.** Results of Newcastle–Ottawa Scale quality assessment of selected studies.

| Keywords | Article Resources | Selection | | | | Comparability of cohorts on the basis of the design or analysis [1)] | Outcome | | | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Representativeness of the exposed cohort | Selection of the non exposed cohort | Ascertainment of exposure | Demonstration that outcome of interest was not present at start of study | a) study controls * b) study controls for any additional factor | Assessment of outcome | Was follow-up long enough for outcomes to occur (≥ 3years) | Adequacy of follow up of cohorts | |
| Endocrown | Fages et al. [37] | ☆ | ☆ | ☆ | - | ☆☆ | ☆ | ☆ | ☆ | 8 |
| Endocrown | Bindl et al. [42] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| Veneered FDP | Esquivel-pshaw et al. [36] | ☆ | ☆ | ☆ | - | ☆☆ | ☆ | ☆ | ☆ | 8 |
| Veneered FDP | Sailer et al.[40] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| Veneered FDP | Nicolaisen et al. [39] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| Veneered FDP | Naenni et al. [43] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| Veneered FDP | Esquivel-pshaw et al. [44] | ☆ | ☆ | ☆ | - | ☆☆ | ☆ | ☆ | ☆ | 8 |
| Veneered FDP | Pelaez et al. [19] | ☆ | ☆ | ☆ | - | ☆☆ | ☆ | ☆ | ☆ | 8 |
| Monolithic lithium disilicate (LS2) | van Erp et al. [45] | ☆ | ☆ | ☆ | - | ☆☆ | ☆ | ☆ | ☆ | 8 |
| Monolithic lithium disilicate (LS2) | Gardell et al. [38] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |



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|---|---|---|---|---|---|---|---|---|---|---|
| Monolithic lithium disilicate (LS2) | Sulaiman et al. [46] | ☆ | ☆ | ☆ | ☆ | - | ☆ | ☆ | ☆ | 7 |
| Monolithic lithium disilicate (LS2) | De Angelis et al. [47] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| All-ceramic single crowns (SCs) | Koller et al. [48] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| All-ceramic single crowns (SCs) | Monaco et al. [49] | ☆ | ☆ | ☆ | ☆ | - | ☆ | ☆ | ☆ | 7 |
| All-ceramic single crowns (SCs) | Güncü et al. [50] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |
| All-ceramic single crowns (SCs) | Zembic et al. [41] | ☆ | ☆ | ☆ | ☆ | ☆☆ | ☆ | ☆ | ☆ | 9 |



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**Table 3.** First control factor or other control factors for each study.

| Authors and year of article publication | First control factor or other control factors |
|---|---|
| Fages et al.[37] (2017) | (1) Nonbruxism, nonpsychological disorders<br>(2) Minimum of 1.5-mm occlusal reduction, oriented parallel to the occlusal plane for a peripheral crown<br>(3) Occlusal preparation consisting of a circular butt margin with a reduction of at least 2 mm in the axial direction for an endocrown |
| Bindl et al. [42] (1999) | (1) Circular cervical butt margin with a width of 1.0 to 1.2 mm<br>(2) Bottom-wall angles of the cavity walls of 90° ± 4°<br>(3) Depth of the central retention cavity ranging from 1 to 4 mm |
| Esquivel-Upshaw et al.[36] (2020) | (1) Control veneer ceramic thickness, connector radius of curvature, and connector height<br>(2) No active caries, no periodontal disease, and no periodontal pocket depths greater than 4 mm<br>(3) Missing at fewest three teeth in the posterior area |
| Sailer et al.[40] (2018) | (1) No periodontal disease and no evident signs of bruxism<br>(2) Same treatment procedures for both types of fixed dental prostheses (FDPs) following clinical procedures for metal–ceramic reconstructions |
| Nicolaisen et al.[39] (2016) | (1) Need for replacement of a second premolar or first molar<br>(2) Moderate to large fillings in the teeth neighboring the edentulous area<br>(3) Vertical dimensions at the treatment site allowing for 2-mm occlusal reduction and maintaining 4-mm height<br>(4) No bleeding upon periodontal probing and no pocket depths exceeding 4 mm |
| Naenni et al. [43] (2015) | (1) Periodontally healthy (plaque indices and bleeding on probing below 20%)<br>(2) No evident signs or symptoms of bruxism or clenching<br>(3) Abutment teeth requiring reconstruction<br>(4) Insufficient remaining tooth structure |
| Esquivel-Upshaw et al.[44] (2014) | (1) No active caries, no periodontal disease, and periodontal pocket depths less than 4 mm<br>(2) Missing at fewest three posterior teeth<br>(3) Adequate bone height (>6 mm) and width in areas for which implants are proposed<br>(4) Adequate interocclusal distance to accommodate the prosthesis (>6 mm) |

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| | |
|---|---|
| | (5) Overall thickness of the core framework plus veneer ceramic equal to 2.0 mm |
| Pelaez et al. [19] (2012) | (1) No high caries activity, no active periodontal disease, and no bruxism<br>(2) Vital abutments or abutments with sufficient endodontic treatment; abutments not crowned previously<br>(3) Periodontally healthy abutments with no signs of bone resorption or periapical disease<br>(4) Stable occlusion, and natural dentition in the opposing arch |
| van Erp et al. [45] (2023) | (1) No endodontic disease, no periodontal disease, and no restorations<br>(2) No dental disease with poor functional prognosis |
| Gardell et al.[38] (2021) | (1) No high caries activity or active destructive periodontal disease<br>(2) No known history of repeated fracture of fillings or other restorations<br>(3) Tooth preparation at an occlusal reduction of 1.5 to 2.0 mm, an axial reduction of 1.5 mm, and a cervical shape of a 120° chamfer with the depth set to 1.0 mm |
| Sulaiman et al. [46] (2020) | - |
| De Angelis et al. [47](2020) | (1) Edentulous for a minimum of 4 months and participant age > 18 years<br>(2) Full-mouth bleeding score < 15%<br>(3) No temporomandibular disorders, bruxism, clenching, or periodontal disease<br>(4) Nonalcoholism and smoking < 10 cigarettes/day<br>(5) Interproximal and occlusal contact tightness set at 25 μm by software |
| Koller et al. [48] (2020) | (1) Edentulous spaces with ≤3 missing teeth and adequate amounts of horizontal and vertical bone and soft tissue for implants of ≥10 mm in length and 4 mm in diameter<br>(2) Nonsmoker and no oral contraindications for implant treatment<br>(3) No signs of occlusal parafunction such as wear facets, nonfunctional clenching or grinding, or masseteric hypertrophy<br>(4) No active periodontal disease, which would be indicated by probing depths of >5 mm and bleeding upon probing |
| Monaco et al. [49] (2017) | - |
| Güncü et al. [50] (2016) | (1) Upper or lower premolar or molar loss in one quadrant and indication of crown fabrication for the symmetrical vital or devital tooth in the same jaw<br>(2) No contraindications for implant treatment<br>(3) Low caries activity and natural dentition of opposing teeth<br>(4) No active bone resorption, furcation involvement, or periapical pathology |

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| | |
|---|---|
| | (5) Thickness of $ZrO_2$ framework of ≥0.5 mm and veneer thickness layer of 1.0–2.0 mm |
| Zembic et al. [41] (2013) | (1) Successfully osseointegrated implants<br>(2) No systemic diseases or signs of bruxism<br>(3) Abutments screw-retained onto implants with a defined torque of 32 Ncm |

**5. Incidence and Causes of Crown Chips and Fractures**

Fages et al. [37] compared monolithic crowns (n = 212) with endocrowns (n = 235) made of Vita Mark II (Vita Zahnfabrik, Bad Säckingen, Germany) ceramic and installed from 2003 to 2008; their follow-up period was 7 years, but they did not indicate which crowns constituted an experimental group or a control group (Table 4). The types of failures that they observed were partial fracture of the ceramic and partial loss of the restoration. Six fractures were found to occur between 1 and 24 months after installation. Five fractures occurred in a monolithic crown (fracture rate = 2.4%), but no chips occurred; the other fracture occurred in an endocrown (fracture rate = 0.4%), and no further chipping was found. Because most of the fractures occurred in the first year after installation (only one occurred after 2 years), Fages et al. concluded that the fractures were due to problems with the material, occlusion, and design rather than being caused by material fatigue. They also found that the most common location of a monolithic ceramic crown was tooth 36 (n = 92) and that no failures occurred in crowns in this location within 7 years of follow-up; they indicated that this result demonstrated the suitability of feldspathic porcelain as a crown material in the molar area and inferred that this suitability was due to the molar teeth bearing compression stresses, which are easier for bonded ceramics than for other materials to accommodate. However, the research results for endocrowns were not as positive, possibly because endocrowns have always been regarded as suitable for sustainable reconstruction and replacement.

After excluding nonclinical studies and applying the NOS, apart from Fage et al. [37], Bindl and Mörmann [42] was the only case–control study comparing the clinical results of two types of endocrown; however, the total number of endocrowns was only 19. Bindle and Mörmann installed 19 CEREC endocrowns in 13 patients; 13 of these crowns were made of Vita Mark II (Vita Zahnfabrik, Bad Säckingen, Germany), whereas the other 6 were made of In-Ceram Alumina/Spinell ceramic (Vita Zahnfabrik, Bad Säckingen, Germany). The butt edges of each round neck were ground to a consistent width specification of 1.0–1.2 mm. The researchers reviewed endocrown usage in accordance with the USPHS criteria at 26 ± 6 months after installation and found the overall clinical quality of the endocrowns to be excellent. Specifically, a chip occurred in only one crown—a Vita Mark II ceramic crown with a slight chip (chip rate = 7.7%), but no fractures in the endocrown. In one case, the endocrown was lost because of recurrent caries. The scholars reported that after a tooth nerve is removed, the tooth (called a nonvital tooth) provides no sensory feedback during mastication, meaning that the nonvital tooth bears higher chewing pressure and thus can break more easily. Therefore, ceramic endocrowns produced using computer-aided design (CAD) technology can withstand high stress, avoiding the peak horizontal load caused by the fixed struts during traditional root canal treatment. Finally, that study indicated that the meticulous bonding technology plays a key role in ensuring a crown's long service life.

Esquivel-Upshaw et al. [36,44] conducted a 5-year RCT study regarding the clinical survival of three-unit implant-supported (i) veneered ceramic–ceramic (CC) FDPs [pressable fluorapatite glass ceramic (IPS ZirPress, Ivoclar Vivadent, Schaan, Liechtenstein) veneered on Y-TZP (IPS e.max ZirCAD, Ivoclar Vivadent, Schaan, Liechtenstein)] and (ii) control veneered metal–ceramic (MC) FDPs [Pd–Au–Ag alloy (Capricorn, Ivoclar Vivadent, Schaan, Liechtenstein) veneered on glass–ceramic (IPS InLine POM, Ivoclar Vivadent, Schaan, Liechtenstein)]; they published the 3- and 5-year follow-up results in 2014 and 2020, respectively. A total of 68 patients initially participated in their clinical study. The 3-year results showed that fractures originated from the occlusal surface and that

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no pores were evident where stresses could have concentrated below the surface. In total, 7 and 6 fractures occurred in the MC FDPs (fracture rate 14.6%) and CC FDPs (fracture rate 14.6%), respectively **(Table 4)**. We discovered that when the distribution of fractures was calculated in accordance with the veneer thickness (mm), radius of curvature of gingival embrasure (mm), and connector height (mm) defined by Esquivel-Upshaw et al. [44], more than one fracture occurred for each primary factor and secondary factor. The most unfavorable condition was a CC veneer thickness 1.5 mm with radius of curvature of gingival embrasure 0.75mm, which corresponded to 10 fractures. At the final 5-year follow-up, 129 FDPs from 96 participants (no participant had more than two FDPs) were analyzed, namely 65 CCs and 64 MCs. A veneer fracture was discovered in 27 FDPs (CC and MC fracture rates = 24.6% and 17.2%, respectively in **Table 4**). An analysis of all the fracture samples revealed that nearly all of the fractures originated from the occlusal surface. The fracture stress of CC FDPs was found to be 37 ± 12 MPa, whereas that of MC FDPs was 44 ± 12 MPa. The researchers theorized that a fracture of posterior fixed all-ceramic restoration can be caused by one or more factors, including inadequate prosthesis design, low quality of porcelain layering, a mismatch in the coefficient of thermal expansion or cooling schedule between $ZrO_2$ and the veneer material, or an intraoral loading orientation.

Using the modified USPHS criteria, Sailer et al. [40] conducted a 10-year RCT to investigate the technical and biological complication rates in three-to-five-unit CC FDPs (Cercon-Ceram-S, DeguDent, veneered on Zirconia, Cercon, DeguDent) and MC FDPs (Duceram-Plus, DeguDent, veneered on gold-alloy, DeguDent U, DeguDent). After the removal of all data regarding patients who had dropped out, 44 patients with a total of 53 FDPs (29 CC and 24 MC FDPs) remained for investigation. The statistical results revealed that the percentage with a minor chip (Bravo level) at 10 years did not differ highly between the CC and MC FDPs (37.9% vs. 33.3%, respectively). However, a major fracture of the veneering ceramic (Charlie level) was found only in CC FDPs (13.8%). Up to the 10-year follow-up, a fracture of the core framework was discovered in two CC FDPs, whereas none of the MC FDPs exhibited a main fracture (fracture rates = 5.9% and 0%, respectively). Pearson's chi-squared test indicated no association between occlusal wear or roughness and the incidence of veneer ceramic chipping for the CC FDPs. Sailer et al. found that the internal gap in the CC FDP framework—including the neck, axial, and occlusal areas—was significantly larger than that in the MC FDP framework; they inferred that the CAD database was inadequate for creating a suitable anatomical support for the framework of a veneering ceramic. Optimizing the parameters of the software by matching the core framework and veneering ceramics of each brand could improve the chipping and marginal secondary caries of CC FDPs.

Nicolaisen et al. [39] conducted an RCT to compare the 3-year clinical outcomes of 17 MC FDPs (Vita VM13, VITA Zahnfabrik) veneered on Au–Pt alloy (BioPontoStar, BEGO) and 17 all-ceramic FDPs (CC FDPs; Vita VM9, VITA Zahnfabrik) veneered on Zirconia (BeCe CAD Zirkon+, BEGO) for replacing a posterior tooth. The veneering ceramic had an overall thickness of 1.0 to 1.5 mm on the axial walls and 1.5 to 2.0 mm occlusally. Chipping of the ceramic veneer was discovered in three cases in the MC FDP group and 5 cases in the CC FDP group (chipping rates = 17.6% and 29.4%, respectively). They concluded that the CC FDP ruptures were related to defects in the veneer layering process or a mismatch in the thermal expansion coefficients of the framework material and veneering ceramic, which would have resulted in the formation of voids at the interface between the framework and veneering ceramic during the sintering process, causing the support area for the ceramic veneer to be insufficient and ultimately leading to premature failure.

Naenni et al. [43] followed the modified USPHS criteria and conducted an RCT to analyze three-unit posterior FDPs; the mean observation period was 36 months. In their initial clinical trial, 20 members each were recruited into an experimental group [Y-TZP $ZrO_2$ framework (IPS e.max ZirCAD, Ivoclar Vivadent AG) veneered with pressed ceramic (IPS e.max ZirPress Ivoclar Vivadent AG)] and a control group [Y-TZP $ZrO_2$ framework (IPS e.max ZirCAD, Ivoclar Vivadent AG) veneered with layered veneering ceramic (IPS e.max Ceram ZirLiner coated on the framework surface, after which IPS e.max Ceram Margin, IPS e.max Ceram Dentin, and Enamel were applied in layers onto the framework)(**Table4**)]. This RCT lasted 3 years, and 36 patients (18 each in the

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experimental and control groups) completed the entire RCT. The researchers observed similar chipping results at 3 years in the Y-TZP $ZrO_2$ FDPs with pressed versus layered veneering ceramic; only the frequency of ceramic veneer chipping differed between the control group (n = 4; chipping rate = 22.2%) and the experimental group (n = 8; chipping rate = 44.4%). They reported that short-span posterior FDPs with a framework made of Y-TZP $ZrO_2$ had the same survival rate after 3 years as corresponding rates revealed in other articles and asserted that Y-TZP $ZrO_2$ is thus highly suitable as a reliable framework material. They also emphasized that in the experimental group, the ceramics were evenly pressed onto the $ZrO_2$ framework. Even when chips occurred, they appeared only on the surface of the veneering ceramic, which can be polished and repaired, rather than at the interface between the framework and the veneering ceramic, which would not require the three-unit FDP to be rebuilt.

In their RCT with a mean follow-up period of 50 ± 2.4 months, Pelaez et al. [19] compared the survival rates and biological and technical complications of three-unit MC [Co-Cr alloy (Heraenium Pw, Heraeus Kulzer) veneered by VITA VM13 (VITA Zahnfabrik; n = 20)] posterior FDPs with those of FDPs with an all-ceramic [CC, $ZrO_2$ framework (Lava, 3M) veneered with Lava Ceram (3M ESPE); n=20]. They concluded that both types of FDP had satisfactory functionality. At the end of the RCT, minor chipping of the veneering ceramic had occurred in two of the CC FDPs (chipping rate = 10%), and no chipping or fracture had occurred in the MC group (**Table 4**). According to the researchers, the main disadvantage of all-ceramic restoration compared with MC-based restoration is the lower fracture resistance of AC FDPs, especially when those FDPs are located in the posterior region, where the connector is weakest. In addition, after consulting the literature, Pelaez provided several reasons for $ZrO_2$ restorations being prone to chipping: (1) The thermal expansion coefficient of the veneer differs from that of the zirconia framework. (2) The elastic strength of ceramic veneers cannot be adjusted. When MC-based restorations are subjected to pressure due to bruxism or chewing, the metal can be penetrated. Plastic deformation occurs to disperse the pressure. By contrast, the elasticity of CC restorations is very low, and the pressure and deformation cannot be dispersed by the ceramic veneers. (3) The facing ceramics have insufficient support. The bracket must be anatomically designed so that the veneering ceramic is adequately supported and so that the risk of chipping of the veneer is thus low. (4) The strength of the bond between the veneer ceramic and the $ZrO_2$ framework is insufficiently high. In such a case, appropriate adhesives and sophisticated bonding techniques can improve the strength of the bond between the ceramic veneer and framework.

A retrospective study conducted by van Erp [45] analyzed 324 patients treated from 2013 to 2018; in total, 924 bilayered maxillary anterior ceramic restorations [heat-pressed lithium disilicate framework (IPS e.max Press, Ivoclar AG) veneered by ceramic IPS e.max Ceram, Ivoclar AG] were performed in these patients, and whether long-term mastication was a clinical manifestation of damage to the incisal edge of the bilayered lithium disilicate (LS2) crown was investigated. Of the 924 restorations, 126 were implant-supported crowns (we define this as the experimental group), and 798 restorations were bonded to natural teeth (562 restorations and 236 complete crowns; we define this as the control group). The mean observation time in that study was 38 months, and no chipping occurred during this period. The results indicated that chipping and fracture of LS2 crowns can be prevented by reinforcing the incisal edges. Only one case of ceramic fracture caused by occlusal dysfunction was observed in control group (fracture rate = 0.12%), and four cases of fracture caused by trauma were reported. The researcher did not specify whether these five fractures occurred in implant-supported crowns or restorations of natural teeth.

To the best of our knowledge, the study conducted by Gardell et al. [38] is the only RCT that has performed double-blind testing to compare the clinical performance of lithium disilicate–based (LS2; IPS e.max CAD) and zirconium dioxide–based ($ZrO_2$; Lava 3M ESPE) ceramic crowns in posterior dentition. The dentist performing the RCT did not know which of the two crown materials a patient was receiving; laboratory forms with prerandomized codes representing one of two materials were used. To be able to perform a double-blind test, Gardell et al. specifically controlled the two materials, LS2 and $ZrO_2$, to have the same occlusal clearance (1.5 to 2.0 mm). In total, 43 patients received 59 crowns and were randomly divided into the LS2 group (n = 29) and $ZrO_2$ group (n = 30); their crowns

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were cemented with resin cement. Three years of follow-up (mean duration = 40 months) were included, and the performance of the crowns was evaluated using the modified CDA protocol; the researchers found that no chipping or fractures had occurred in any crown (fracture rate = 0.0%). They believed that in a double-blind RCT, each step must be very precise. Therefore, the two clinicians and dental technicians participating in the project conducted two process calibrations before the project was commenced. Although dentists tend to select the materials that they prefer and although $ZrO_2$ is usually used for lower occlusal spaces, $ZrO_2$ is considerably less translucent than is LS2, and thus distinguishing them with the naked eye should be easy. However, in Gardell et al. [38], materials were blindly selected to be given to the dentist; in other words, the dentist could not choose in accordance with their preferences, and thus the experimental results obtained were considered fair.

A multiyear and two-stage retrospective study was conducted by Sulaiman et al. [46,51], who compiled data regarding the usage of monolithic and layered LS2 crowns in two large dental laboratories that produced ceramic crowns and tracked the number of crowns that had to be remade since 2009 because of fractures; the results of the first phase (2009–2014), covering 21,340 crowns, were published in 2015. The researchers compared single crowns (SCs), veneered crowns, FDPs, and restorations made from $ZrO_2$ ceramic [from Bruxzir (Glidewell Laboratories), Katana HT (Kuraray Noritake), Zirlux (Henry Schein), and Zenostar (Ivoclar Vivadent AG); n = 136,944] and LS2 ceramic-glass (IPS e.max; n = 51,751). The results of the second phase (2010–2017) were published in 2020 and covered 188,695 crowns. Overall, the researchers found relatively low fracture rates in restorations made from LS2 or $ZrO_2$ ceramic during the 7.5-year collection period and discovered a lower fracture rate in monolithic restorations than in layered restorations (**Table 4**). Overall, the fracture rate was relatively low in their survey and considerably below the criteria proposed by Schärer in 1996 [52]. Schärer proposed that the 3- to 5-year survival rate of all-ceramic crowns was 95% (fracture rate = 5%). Sulaiman et al. [46,51] their retrospective study enrolled 27,346 LS2 monolithic single crowns (SCs, IPS e.max), and in these crowns, 262 fractures occurred, corresponding to a fracture rate of 0.96%, which was significantly lower than the rate of 1.26% for layered SCs (171 fractures in 116,836 crowns). Regarding LS2 restorations, the fracture rates in FDPs (monolithic and layered) were significantly higher (3.66% and 2.82%, respectively) than those in crowns and those in veneers (**Table 4**). In total, 77,411 monolithic $ZrO_2$ SCs were enrolled, and 416 fractures occurred, yielding a fracture rate of 0.54%, which was lower than those of layered $ZrO_2$ SCs (2.83%) and monolithic FDPs (1.95%). The fracture rate in layered SCs (2.83%) was higher than that in layered FDPs (1.93%), and the fracture rates in monolithic anterior and posterior $ZrO_2$ restorations were lower (1.23% and 0.75%, respectively) than those in layered anterior and posterior $ZrO_2$ restorations (2.09% and 2.98%, respectively). Posterior monolithic $ZrO_2$ restorations were less likely to fracture than were anterior restorations, whereas posterior layered $ZrO_2$ restorations were more likely to fracture than were anterior $ZrO_2$ restorations.

Sulaiman et al. (2020) reported that the fractures may have been caused by the thickness of the ceramic material in, connector dimensions of, or pontic span of the FDP; the type of cement; or treatment of the ceramic surface before luting. The $ZrO_2$ ceramic employed in the FDPs evaluated in that study contains 3 mol% yttria and has bending strength of 1000–1200 MPa, which is higher than that of the newly developed 5 mol% yttria cubic zirconia with a translucent effect (bending strength = 400–600 MPa). Therefore, to minimize the risk of fracture in FDPs in the long term, dentists may be able to specify the required content or brand of yttrium oxide when making dental crowns and FDPs. The researchers also found lower fracture rates in $ZrO_2$ FDPs than in FDPs made with LS2, and less tooth reduction and smaller connector dimensions were required for $ZrO_2$ FDPs than for FDPs made with LS2. These findings confirmed those of other scholars, namely that an FDP made from $ZrO_2$ has a longer period of utilization (5–10 years) than does an FDP made from LS2.

De Angelis et al. [47] conducted a 3-year cross-sectional retrospective study to compare the clinical outcomes of two types of implant-supported monolithic crown used to replace a single missing posterior tooth: LS2 (IPS e.max; n = 19) and $ZrO_2$ (inCoris TZI; Dentsply Sirona; n = 19). Their follow-up revealed one minor chip in an LS2 crown at 23 months, which could be easily repaired. No

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other crowns were damaged during the entire follow-up period. Therefore, we judged that the final fracture rate in both the experimental group and the control group was zero. De Angelis et al. concluded that if occlusal overloading can be avoided—such as by narrowing the occlusal table, reducing cusp inclination, correcting the load direction, minimizing nonaxial loads, and ensuring light occlusal contact in dental implant restorations—the risk of ceramic crown fracture can be minimized. In addition, Mallmann et al. [53] reported that for three-unit implant-supported FDPs, using screw access channels and mechanical circulation reduces the mean fracture load regardless of the material used as the crown's framework. Therefore, when De Angelis et al. conducted their retrospective study, they arranged the screw entry channel to be as close to the center of the occlusal surface as possible.

Koller et al. [48] conducted a randomized but nonblinded study of dental implants covering the period of 2009–2010. A second-stage surgery was performed 6 months after first-stage implantation, and a monolithic crown (LS2, IPS e.max CAD, Ivoclar Vivadent) was installed. Finally a total of 28 implants in 21 patients ($ZrO_2$ implant, Ziterion Vario Z, n = 14; Ti-alloy implant, Ziterion Vario T, n = 14) were evaluated. The researchers found that at the end of the 80-month follow-up, all $ZrO_2$ and Ti-alloy implants were in good condition without abutment cracks, and the crowns had not chipped or fractured (fracture rate = 0.0%). Koller et al. stated that strict adherence to a clear bonding protocol and an appropriate follow-up plan may be helpful for preventing crown damage; for example, cement is used to connect the crown to the abutment. Material matching is crucial. Titanium alloy implants must be paired with screw-retained titanium abutments; zirconia implants should be fixed under the rubber dam through adhesives, and zirconia abutments should be used. Currently, a microgap is left under the crown when it is supported by a titanium implant, but no microgap is left under the crown when it is supported by a zirconia implant. Because crowns are single restorations in which splints are not used, dentists must be careful during follow-up inspections or measurements to prevent any eccentric occlusal contact.

Monaco et al. [49] conducted a 5-year RCT (average follow-up period = 65.7 months) in which a single crown comprising a reduced-gold ceramic alloy (d.SIGN 91, Ivoclar Vi-vadent; n = 40; MC) veneered with overpressing ceramic (PoM, Ivoclar Vivadent; ZirPress, Ivoclar Vivadent) or the $ZrO_2$ (ZirCad, Ivoclar Vivadent; n = 45; CC) veneered by pressable ceramic (ZirPress; Ivoclar Vivadent) was implanted into a patient's premolars or molars. The service lives and clinical behaviors of these two crown types were then compared. Modified USPHS standards were employed to evaluate the survival rate of the restorations, and one CC crown was found to have suffered a core fracture, whereas one MC crown had failed because of root fracture. Chip fractures of the veneer ceramic were discovered in two MC crowns (chipping rate = 5.0%) and three CC crowns (6.7%). The researchers concluded that the 5-year survival rates of the $ZrO_2$-based and metal-based single crowns were similar. No significant differences were found in aesthetic, functional, or biological outcomes between the two groups. Thus, they concluded that $ZrO_2$-based crowns fabricated with overpressing veneer technology can effectively replace metal-based restorations in the treatment of posterior teeth. In addition, they found that ceramic chipping of the metal-based veneers occurred in the marginal crest of the occlusion area, possibly because of the absence of supportive porcelain veneers in teeth with higher masticatory forces or internal defects introduced during occlusal adjustment. Monaco et al. also concluded that the bond strength between the $ZrO_2$ framework and porcelain veneers was higher than the cohesive strength of the porcelain itself. Therefore, improving the strength of the veneering porcelain could reduce the risk of chipping. We recommend applying the concepts of reinforcement of the incisal edge of the LS2 crown invented by van Erp et al. [45] to Monaco's studies to prevent the outer ceramic of the restoration from chipping.

Because no periodontal ligament exists around dental implants, stress is conducted directly to the bone, and the occlusal stress on a single implant-supported crown may be greater than that on a single tooth-supported crown. The long-term stability of $ZrO_2$ and whether $ZrO_2$ crowns can be used in dental implant systems as a substitute for alloy crowns remain topics worthy of long-term investigation. Güncü et al. [50] compared the 4-year clinical performance of implant-supported (Astra Tech Ossesospeed implants; Astra Tech AB, Mölndal, Sweden; n = 24) and natural-tooth-supported

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(n = 24) single-veneer $ZrO_2$ crowns [LAVA, 3M ESPE, veneering with Vita VM9 (Vita Zahnfabrik, Bad Säckingen)] in the posterior region and performed a CDA quality index evaluation. Their 4-year clinical follow-up study revealed similar restorative and periodontal outcomes in the natural-tooth-supported and implant-supported $ZrO_2$ crowns. However, nonrepairable cohesive failure of an implant-supported porcelain veneer occurred in one maxillary molar (at 2-year follow-up) and one mandibular molar (at 4-year follow-up), whereas that of a tooth-supported veneer occurred in one mandibular molar (at 3-year follow-up). None of the patients in which these failures occurred had bruxism or had a ceramic restoration on the opposing tooth. Güncü et al. inferred that although veneering porcelain can provide an aesthetic advantage when its thickness is 1.0–2.0 mm, it has a fracture toughness value that is 8 times lower than that of general $ZrO_2$, and this may be the main cause of fractures. If aesthetics are not the main concern for a patient, monolithic $ZrO_2$ crowns may be selected for restorations in the molar area. Güncü et al. suggested that the relationship between the thickness of the veneer porcelain and the fracture strength under applied tensile strength should be studied to enable the design of more suitable core frameworks and the minimization of chipping risk.

To compare the survival rates and technical complications between $ZrO_2$ and titanium abutments, Zemic et al. [41] conducted a 5-year RCT and published the results of their 1-year and 3-year follow-up in 2009 (with Sailer et al.) and the clinical results of their 5-year follow-up in 2013. First, a single implant (Brånemark system, Nobel Biocare AB, Gothenburg, Sweden) was placed in a patient's canine and posterior areas; then, 4–6 months later, abutment connection surgery was performed. The patients were randomly fitted with $ZrO_2$ abutments (Procera, Nobel Biocare AB, Carolinsk, Sweden) plus all-ceramic crowns (experimental group; n = 18 over 5 years) or titanium abutments (Procera, Nobel Biocare AB, Carolinsk, Sweden) plus MC crowns (control group; n = 10 over 5 years). Although neither of the two articles resulting from that 5-year study identify the brands of crowns, during a mean follow-up of 5.6 years, the researchers found that none of the all-ceramic crowns connected to a $ZrO_2$ abutment chipped or fractured, whereas three of the MC crowns connected to a titanium abutment chipped (chipping rate = 30%). The researchers praised zirconia abutments but drew no notable conclusions regarding the fractured crowns.

As mentioned, the present study identified 16 high-quality research articles by using the NOS review criteria and, on the basis of these articles' mid- to long-term follow-up results (follow-up of ≥3 years; **Table 4**), found that the fracture rate in 10 of the articles was higher than the post-2010 clinical recommendation of 4.4% or higher than the 5% recommended by Schärer in 1996, regardless of the crown's material or usage. Although new ceramic materials are continually being developed, the results of clinical use do not appear to be improving. The fracture rates in the experimental and control groups were lower than 4.4% in only six articles (**Table 4**). We also found that the greater the number of crowns included in the clinical follow-up, the lower was the fracture rate, such as in the large-scale studies conducted by Fages et al. [37] and Sulaiman et al. [46]. We employed 4.4% as a critical value and summarized the causes of crown fracture in each article and the remedies or future developmental directions suggested by each author. The recommendations described in this paragraph were made in articles reporting fracture rates lower than 4.4%:

- When conducting an RCT or retrospective study, every step must be very precise.

Research group members must perform multistep calibrations before the project is commenced [Gardell, 38]. Sulaiman et al. [46] reported that fracture can occur because of the thickness of the ceramic material in or the connector dimensions or pontic span of the FDP; the type of cement; or the treatment of the ceramic surface before luting. The risk of ceramic crown fracture can be reduced by avoiding occlusal overloading, such as by narrowing the occlusal table, reducing cusp inclination, correcting the load direction, reducing nonaxial loads, and using lighter occlusal contact in dental implant restorations [47]. In addition, matching of the materials of each component and meticulous bonding technology are critical [Koller, 48]. Titanium alloy implants must be paired with screw-retained titanium abutments, and $ZrO_2$ implants should be fixed under the rubber dam through adhesives and be paired with $ZrO_2$ abutments [Koller, 48]. Regardless of the material of the crown framework, the mean fracture load can be minimized by using screw access channels and through

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mechanical circulation of the implant-supported FDP [De Angelis et al. 47]. The screw entry channel should be as close to the center of the occlusal surface as possible, and any eccentric occlusal contact must be prevented during subsequent examinations and measurements [47,48].

In most articles reporting a fracture rate higher than 4.4%, CAD libraries were concluded to be insufficient for creating appropriate anatomically supported frameworks for FDPs with ceramic veneers [Sailer,40; Pelaez, 19]. If the thermal expansion coefficient and fracture toughness value of the framework material do not match those of the veneer ceramic, a gap forms at the framework–veneer interface [Esquivel-Upshaw, 36, 44; Nicolaisen, 39; Pelaez ,19]. Finally, an insufficient area supporting the ceramic veneer may lead to premature crown failure after a long period of normal chewing [Bindl and Mörmann ,42; Nicolaisen, 39; Pelaez,19].

**Table 4.** Crown chipping or fracture rate for each group in high-quality articles.

| First author | No. failures of experimental group (E) | Sample size of experimental group | Chipping or fracture rate (%) | No. failures of control group (C) | Sample size of control group | Chipping or fracture rate (%) | Materials and usage of dental crowns |
|---|---|---|---|---|---|---|---|
| Fages* [37] | 5 | 212 | 2.4 | 1 | 235 | 0.4 | E- Vita Mark II / monolithic crown<br>C- Vita Mark II / endocrown |
| Bindl [42] | 1 | 13 | 7.7 | 0 | 6 | 0.0 | E- Vita Mark II / endocrown<br>C-In-Ceram lumina/Spinell /endocrown |
| Esquivel [36] | 16 | 65 | 24.6 | 11 | 64 | 17.2 | E- IPS ZirPress on IPS e.max ZirCAD / Veneered FDP<br>C-PdAuAg alloy on IPS INLine POM/ Veneered FDP |
| Sailer [40] | 11 | 29 | 37.9 | 8 | 24 | 33.3 | E- Cercon-Ceram-S on Ceron / Veneered FDP<br>C- Duceram-Plus on gold-alloy / Veneered FDP |
| Nicolaisen [39] | 5 | 17 | 29.4 | 3 | 17 | 17.6 | E- Vita VM9 on BeCe® CAD Zirkon+/ Veneered FDP<br>C- Vita VM13 on AuPt Alloy / Veneered FDP |
| Naenni [43] | 8 | 18 | 44.4 | 4 | 18 | 22.2 | E- IPS e.max ZirPress on IPS e.max ZirCAD / Veneered FDP<br>C- (1) IPS e.max Ceram ZirLiner, (2) IPS e.max Ceram Margin, (3) IPS e.max Ceram Dentin, (4) Enamel on IPS e.max ZirCAD/ Veneed FDP |
| Esquivel [44] | 6 | 41 | 14.6 | 7 | 48 | 14.6 | E- IPS ZirPress on IPS e.max ZirCAD / Veneered FDP<br>C- PdAuAg alloy on IPS INLine POM / Veneered FDP |
| Pelaez [19] | 2 | 20 | 10.0 | 0 | 20 | 0.0 | E- Lava Ceram on Lava/ Veneered FDP<br>C- Vita VM13 on CoCr alloy/Veneered FDP |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| van Erp* [45] | 0 | 126 | 0.0 | 1 | 798 | 0.1 | E- IPS e.max Ceram on IPS e.max Press / implant-supported crown<br>C- IPS e.max Ceram on IPS e.max Press/ nature teeth-supported crown |
| Gardell* [38] | 0 | 29 | 0.0 | 0 | 30 | 0.0 | T- IPS e.max Ceram on IPS e.max CAD / posterior crown<br>C- Lava 3M / posterior crown. |
| Sulaiman* [46] | 262 | 27346 | 0.96 | 171 | 11683 | 1.26 | E-IPS e.max / monolithic single crown<br>C-IPS e.max on IPS e.max / layered single crown |
| Sulaiman* [46] | 122 | 3337 | 3.66 | 39 | 1382 | 2.82 | E- IPS e.max / monolithic FDP<br>C- IPS e.max on IPS e.max / layered FDP |
| Sulaiman* [46] | 25 | 2170 | 1.15 | 30 | 2488 | 1.21 | E- IPS e.max / monolithic Veneer<br>C- IPS e.max on IPS e.max / layered Veneer |
| Sulaiman* [46] | 416 | 77411 | 0.54 | 849 | 30036 | 2.83 | E-$ZrO_2$ / monolithic single crown<br>C-$ZrO_2$ on $ZrO_2$ / layered single crown |
| Sulaiman* [46] | 320 | 16437 | 1.95 | 252 | 13060 | 1.93 | E-$ZrO_2$ / monolithic FDP<br>C-$ZrO_2$ on $ZrO_2$ / layered FDP |
| Sulaiman* [46] | 72 | 5854 | 1.23 | 433 | 20712 | 2.09 | E-$ZrO_2$ / monolithic anterior restoration<br>C-$ZrO_2$ on $ZrO_2$ / layered anterior restoration |
| Sulaiman* [46] | 664 | 87994 | 0.75 | 668 | 22384 | 2.98 | E-$ZrO_2$ / monolithic posterior restoration<br>C-$ZrO_2$ on $ZrO_2$ / layered posterior restoration |
| De Angelis* [47] | 0 | 19 | 0.0 | 0 | 19 | 0.0 | E-IPS e.max CAD/ implant-supported monolithic single crown<br>C-inCoris TZI/ implant-supported monolithic single crown |
| Koller* [48] | 0 | 14 | 0.0 | 0 | 14 | 0.0 | E-IPS e.max CAD / $ZrO_2$ implant-supported monolithic single crown<br>C- IPS e.max CAD/Ti-alloy implant-supportec monolithic single crown |
| Monaco [49] | 2 | 40 | 5.0 | 3 | 45 | 6.7 | E- PoM on d.SIGN 91/veneered single crown |



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|---|---|---|---|---|---|---|---|
| | | | | | | | C-ZirPress on ZirCad/veneered single crown |
| Güncü [50] | 2 | 24 | 8.3 | 1 | 24 | 4.2 | E-Vita VM9 on Lava/implant-supported crown<br>C- Vita VM9 on Lava/nature tooth-supported crown |
| Zembic [41] | 0 | 18 | 0.0 | 3 | 10 | 30.0 | E- all-ceramic (No brand)/$ZrO_2$ abutment-–supported crown<br>C- metal-ceramic crown (No brand)/Tianium abutment-supported crown |

Note: *: It meant that the crown failure rate of both the experimental group and the control group studied in this article was below 4.4%.



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## 6. Conclusions

Because populations are aging, the number of dental crowns made of ceramic materials is increasing worldwide, and thus whether ceramic crowns can last a long time is a research topic of interest. The present study employed the NOS to evaluate articles reporting clinical research on dental crowns. We discovered that many related articles did not conform to the standards of medical RCTs regarding experimental versus control groups and blind testing. Unfortunately, the clinical results of many articles could thus not be included in the present review. The present review constituted an opportunity to highlight to dentists the necessary precautions for conducting RCTs and retrospective studies and to indicate that studies should be designed with consideration of NOS guidelines in the future. In addition, this paper could enable materials scientists to understand the shortcomings of existing ceramic crowns so that they can develop crowns that are less likely to fracture.

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