THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

Effect of cement type on the clinical performance and complications of zirconia and lithium disilicate tooth-supported crowns: A systematic review. Report of the Committee on Research in Fixed Prosthodontics of the American Academy of Fixed Prosthodontics

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ABSTRACT

Statement of problem. Zirconia and lithium disilicate have been commonly used as materials for tooth-supported complete-coverage restorations. Adhesive and conventional cements have been suggested for cementation of these restorations. However, evidence on the effect of cement type on the clinical outcomes of teeth restored with zirconia or lithium disilicate restorations is unclear.

Purpose. The purpose of this systematic review was to evaluate the clinical outcomes of teeth restored with zirconia or lithium disilicate restorations when adhesive or conventional cements are used.

Material and methods. This systematic review adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement and was registered at the international prospective register of systematic reviews (PROSPERO) (CRD42018096493). An electronic search was performed in 2 databases (MEDLINE-PubMed and Cochrane Central), and a manual search, from January 2008 through January 2018. The primary clinical question was framed according to the Problem/Patient/Population, Intervention/Indicator, Comparison, Outcome (PICO) approach. The following question was the primary clinical question: "For patients requiring a single tooth-supported complete-coverage ceramic restoration, does adhesive cementation, as compared with conventional cementation, improve the clinical performance and limit the complications of this restoration?" The search included articles published in peer-reviewed journals in English and was limited to randomized clinical trials and prospective and retrospective clinical studies.

Results. Seventeen clinical studies met the eligibility criteria and were included for qualitative analysis. Included studies had 1280 participants who received 2436 zirconia and lithium disilicate crowns. The survival rates for adhesively cemented zirconia crowns ranged from 83.3% to 100%, whereas those reported for conventionally cemented zirconia crowns ranged from 82.0% to 100%. Survival rates for adhesively cemented lithium disilicate crowns ranged from 83.5% to 100%, whereas the survival rate reported for conventionally cemented lithium disilicate crowns was 98.5%. Commonly reported clinical complications included fracture of the veneering ceramic, crown fracture, and loss of crown retention. The mean follow-up time ranged from 25.5 months to 121.2 months. The studies that were assessed for risk of bias showed poor quality of evidence.

Conclusions. Based on the available evidence and within the limitations of this systematic review, zirconia and lithium disilicate tooth-supported crowns exhibited comparable survival rates and complication patterns after adhesive or conventional cementation. (J Prosthet Dent 2019;121:754-65)

Lithium disilicate and zirconia are 2 of the most popular restorative materials. Lithium disilicate has better optical properties but lower mechanical properties than zirconia.[1] Both materials can be veneered with feldspathic porcelain or used as a monolithic restoration.[2-4] A recent systematic review showed that lithium disilicate and zirconia single crowns have similar 5-year survival rates compared with metal-ceramic crowns.[5]

Resin bonding is necessary for low- and medium-strength ceramics that are not supported by a core, especially if the preparation is minimally invasive or is lacking retention form.[6-8] However, resin bonding or conventional cementation of lithium disilicate and zirconia complete-coverage restorations has been a controversial topic.[6-8] Most of the existing knowledge on the topic is based on in vitro studies that have shown that

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Clinical Implications

Conventional cementation of zirconia and lithium disilicate tooth-supported crowns may be considered an acceptable alternative to adhesive cementation, which is more clinically demanding. However, existing evidence has a high risk of bias, and well-designed randomized controlled clinical trials are required in the future.

adhesive resin cementation increased the retention of lithium disilicate crowns,[9] improved the fracture strength and reduced the marginal leakage of alumina crowns,[10] improved the fracture resistance of lithium disilicate crowns,[11] and increased the fatigue resistance of zirconia crowns.[12] In contrast, another study showed that the retention of zirconia crowns did not differ between a resin-modified glass ionomer cement and resin cements.[13] Also, other studies reported no difference in the fracture resistance of zirconia fixed partial dentures and crowns,[14-16] retention of zirconia crowns,[17] and fracture resistance of pressed or milled lithium disilicate crowns after adhesive or conventional cementation.[15,18,19] Two clinical studies based on the same cohorts of participants compared the failure rates and complications of short-span lithium disilicate fixed partial dentures when conventional or adhesive cementation was used and reported no difference after 8 and 10 years.[20,21]

Resin bonding involves a technique-sensitive multi-step procedure that could be problematic with subgingival crown margins or when the intraoral conditions cannot be controlled adequately.[8,20,21] Conventional cementation may be an attractive option due to technique simplicity. Given the increase in popularity of lithium disilicate and zirconia restorations, a review and synthesis of current data related to the clinical outcomes of these restoration materials when cemented with resin cements as opposed to conventional cements is necessary. The purpose of this systematic review was to analyze the clinical performance of tooth-supported ceramic crowns and to describe the complications/failure characteristics when adhesive or conventional cementation is used. The primary question being addressed was framed by using the Problem/Patient/Population, Intervention/Indicator, Comparison, Outcome (PICO)[22] format: "For patients requiring a single tooth-supported complete-coverage ceramic restoration, does adhesive cementation, as compared with conventional cementation, improve the clinical performance and limit the complications of this restoration?"

MATERIAL AND METHODS

This systematic review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[23,24] and was registered at the international prospective register of systematic reviews (PROSPERO; registration number: CRD42018096493). In relation to the framed primary PICO question, "adhesive cementation" included cementation with total-etch, self-etch, or self-adhesive resin cements. "Conventional cementation" included cementation with glass ionomer, resin-modified glass ionomer, or zinc phosphate cements. The following were the secondary PICO questions: "For patients requiring a tooth-supported complete-coverage zirconia restoration, does adhesive cementation, as compared with conventional cementation, improve the clinical performance and limit the complications of this restoration?" "For patients requiring a tooth-supported complete-coverage lithium disilicate restoration, does adhesive cementation, as compared with conventional cementation, improve the clinical performance and limit the complications of this restoration?"

This systematic review used the following inclusion criteria: clinical prospective, clinical retrospective studies, and clinical trials; articles published in the English language in peer-reviewed journals; studies with at least 25 months of mean follow-up time; the follow-up needed to include a clinical examination of the participants; studies that examined lithium disilicate or zirconia tooth-supported single crowns; studies that evaluated monolithic or veneered restorations; studies that reported details regarding the type of cement and cementation technique used for the insertion appointment; and studies that reported restoration survival/success rates and complications/failure data.

Exclusion criteria were the following: studies not meeting the inclusion criteria stated previously; in vitro, case series studies, literature reviews, or expert opinions; studies based on questionnaire, surveys, or chart reviews only; studies with fewer than 25 months of mean follow-up time or not reporting mean follow-up time; studies with part of data/participants duplicated in other included studies; studies that did not allow extraction of the required data; studies including endocrowns, partial coverage, inlay, onlay, veneer, minimally invasive, or implant-supported restorations only; studies reporting only on metal-ceramic restorations or other ceramic restorations besides those stated in the inclusion criteria; and studies on fixed partial dentures or multiple unit crowns.

Relevant studies were identified through the MEDLINE-PubMed and Cochrane Central electronic databases. In addition, the contents pages of the following journals were hand searched to identify potentially pertinent articles: *International Journal of Prosthodontics*, *Journal of Prosthetic Dentistry*, and *Journal of Prosthodontics*. The search included articles published between January 1, 2008, and January 31, 2018, and the last search was conducted in February 2018.

Table 1. Exclusion of studies after full-text review

Article Excluded	Year	Applied Exclusion Criteria
Güncü et al[32]	2015	Did not meet inclusion criteria
Dhima et al[35]	2014	
Monaco et al[37]	2013	
Silva et al[43]	2011	
Vanoorbeek et al[48]	2010	
Mansour et al[52]	2008	
Yang et al[31]	2016	Fewer than 25 months of mean follow-up time or mean follow-up time not reported
Pihlaja et al[36]	2014	
Poggio et al[42]	2012	
Fasbinder et al[45]	2010	
Groten and Hüttig[46]	2010	
Cehreli et al[49]	2009	
Rauch et al[28]	2017	Part of data/participant population duplicated in other included studies
Valenti and Valenti[34]	2015	
Reich and Schierz[38]	2013	
Reich et al[47]	2010	
Valenti and Valenti[51]	2009	
Teichmann et al[29]	2017	Did not allow extraction of required data
Tartaglia et al[33]	2015	
Örtorp et al[41]	2012	
Tartaglia et al[44]	2011	
Örtorp et al[50]	2009	
Cortellini et al[40]	2012	Minimally invasive preparations
Olley et al[27]	2018	Studies on metal-ceramic restorations or other ceramic restorations besides those stated in inclusion criteria
Van de Beemer et al[30]	2017	
Beier et al[39]	2012	

The electronic search strategy included combinations of the following search terms: "ceramic crown" AND "cement"; "zirconium oxide" OR "yttria stabilized tetragonal zirconia" AND "crowns" AND "dental cements"; "lithia disilicate" OR "zirconium oxide" AND "yttria stabilized tetragonal zirconia" AND "crowns" AND "dental cements"; "zirconia" AND "cement"; "lithia disilicate" OR "lithium disilicate" AND "cement"; "crowns" AND "dental cements" AND "ceramic"; "ceramics" AND "crowns" AND "dental cements". The medical subject headings of these terms were also searched. All retrieved articles were inserted in a citation manager software program (EndNote X7; Thompson Reuters), and all duplicates were removed.

The search process was completed in 3 stages. During stage 1, two investigators (G.M. and E.D.K.) independently screened titles. Any titles not excluded by both the investigators were discussed. In situations where disagreement was not resolved, the titles were included for abstract screening. During stage 2, the investigators independently screened and analyzed the abstracts. Any abstracts not mutually excluded were discussed. In situations where a disagreement was not resolved and the application of the exclusion criteria was not certain, the abstracts were included for full-text screening. During stage 3, the full-text articles were scrutinized for eligibility, and after the exclusion criteria were applied, the remaining articles were included in the definitive list for the qualitative synthesis. The reference lists of the retrieved articles were searched to identify potentially relevant articles that might not have been included. In situations where a study reported on several types of restorations, only the data for restorations of interest were extracted. In addition, when a study had unclear data, the corresponding author of the pertinent study was contacted by means of e-mail to clarify. When this data extraction was not possible, the study was excluded.

The following data were extracted from the definitive list of publications: author(s), year of publication, type of study design, number of participants receiving the restoration(s) under investigation, mean age of participants, number of single anterior tooth-supported restorations, number of single posterior tooth-supported restorations, total number of restorations, restorative material, type of restoration (layered, monolithic), cementation technique used, location of the study (private practice, university), participant dropout rate, mean follow-up time, survival/complication-free rate, number and type (major, minor) of complications, restoration fracture incidence, and loss of retention incidence. Qualitative and quantitative data were extracted in an electronic data sheet by one investigator (G.M.) and evaluated by a second investigator (E.D.K.). Any disagreements were resolved with discussion.

In this systematic review, a major complication was defined as any complication that resulted in the loss of the restored tooth or the removal and remake of the restoration. A minor complication was defined as any complication that did not require the removal/remake of the restoration, such as changes in tooth sensitivity, endodontic treatment through the crown, periodontal complications not resulting in tooth extraction, repairable secondary caries, loss of crown retention when the crown could be recemented, fractures of the veneering ceramic, or minor ceramic fractures that could be polished or repaired. The Cochrane Collaboration tool was used to assess the risk of bias of the included randomized clinical trials.[25] Risk assessment of included nonrandomized clinical trials and cohort studies was performed with the Risk of bias in nonrandomized studies−of interventions (ROBINS-I) tool.[26] After collection of the data and because of qualitative differences across the studies, no meta-analysis was prepared.

RESULTS

The initial electronic search yielded 2571 titles. After removing duplicates, 1362 remained. Of these, 1302 titles were discarded because they did not meet the inclusion/exclusion criteria. The remaining 61 titles were considered for abstract review. After further evaluation and

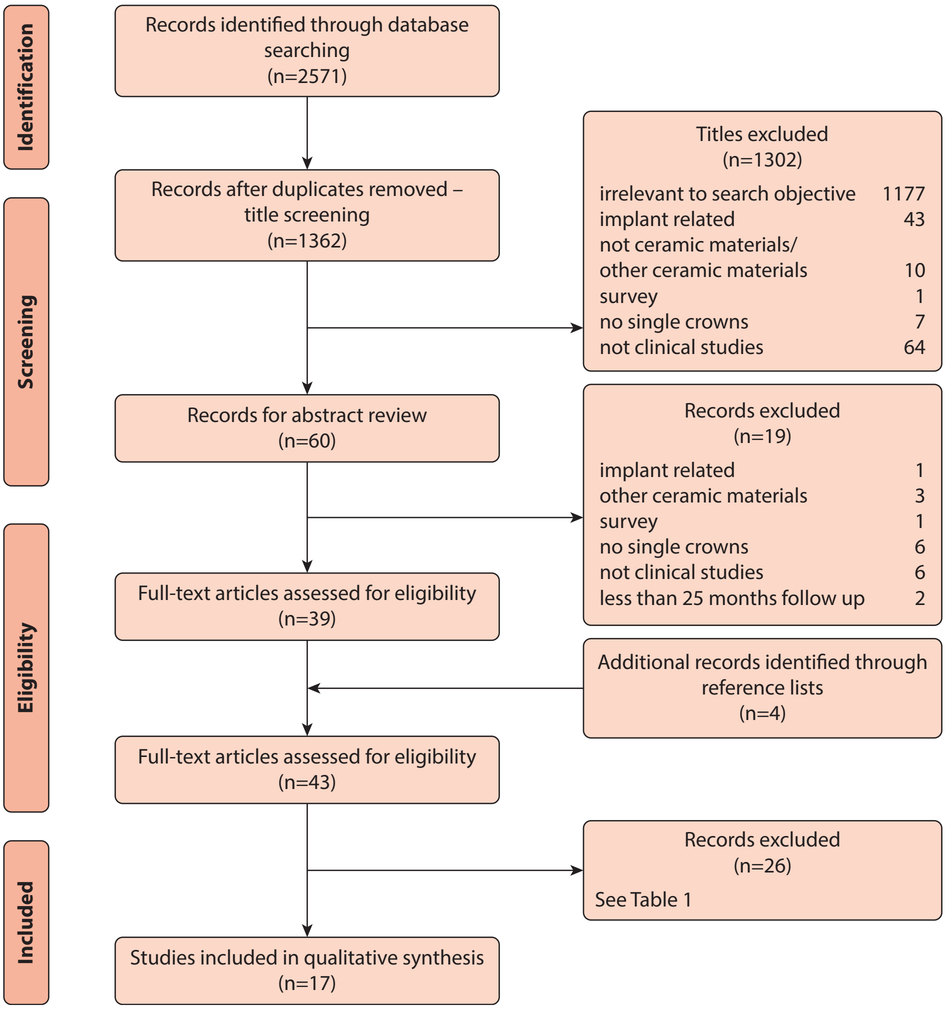

Figure 1. PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

taking into consideration additional potential articles identified through reference lists, 43 articles were included for full-text review. After further evaluation, 26 articles were excluded (Table 1),[27-52] and 17 articles met the criteria for inclusion in this systematic review (Fig. 1).[53-69] Of the excluded articles, 2 had part of a patient population[34,51] that was also included in a later publication,[55] and these 2 articles were excluded after communication with the corresponding author. Also, part of the patient population of 1 study[57] was included in a later publication,[55] and thus, after communication with the corresponding author, this part of the population was excluded. Any articles that contained data for adhesive and conventional cementation, which could not be extracted separately for each cement type after full-text review and author communication, were excluded from the definitive list.[29,41,50]

Data from the included articles were extracted (Tables 2-4). Of the included articles, 5 were randomized clinical trials,[58,63,65,66,68] 1 was a nonrandomized trial,[64] 6 were prospective uncontrolled clinical studies,[53,54,56,60,67,69] 1 was a retrospective cohort study,[57] and 5 were retrospective clinical studies.[55,59,61,62] The included studies involved 1280 participants who received 2436 ceramic crowns. Of the 17 included articles, 6 reported on zirconia single crowns,[54,62,65-67,69] 10 reported on lithium disilicate single crowns,[53,55-57,59-61,63,64,68] and 1 reported on zirconia and lithium disilicate single crowns.[58] In 2 articles, only anterior teeth were restored.[54,69] In 7 articles, only posterior teeth were restored.[53,55,57,58,63,66,68] In 7 articles, posterior and anterior teeth were restored.[56,59-62,64,67] In 1 article, the location of the restorations was not reported.[65] Monolithic restorations were used in 3 articles,[53,55,57] layered restorations were used in 10 articles,[54,59,60,62,64-69] and either monolithic or layered restorations were used in 4 articles.[56,58,61,63] In 12 articles, the crowns were cemented with adhesive cement.[53-56,58-63,65,68] In 4 articles, the crowns were cemented with a conventional cement.[57,66,67,69] One article reported adhesive resin and conventional cementation in the same study.[64] One article included only vital teeth.[66] In 9 articles, vital teeth and endodontically treated teeth were included.[53,56,58-61,64,67,69] In 7 articles, inclusion

Table 2. Study characteristics of included articles

Author (y)	Type of Study	Participants No.	Participants Mean Age (y)	No. of Restorations Anterior	No. of Restorations Posterior	No. of Restorations Total	Restoration Material	Restoration Type	Cement	Setting	Dropout (Participants)
Rauch et al[53] (2018)	Prospective uncontrolled	31	55.4	0	31	31	Lithium disilicate	Monolithic	Adhesive	University/ private practice	9%
Dogan et al[54] (2017)	Prospective uncontrolled	18	44.5	20	0	20	Zirconia	Layered	Adhesive	University	6%
Schmitz et al[55] (2017)	Retrospective	335	NR	0	627	627	Lithium disilicate	Monolithic	Adhesive	Private practice	NR
Huettig and Gehrke[56] (2016)	Prospective uncontrolled	45	43.0	176	151	327	Lithium disilicate	Monolithic/ layered	Adhesive	NR	22%
Schmitz and Beani[57] (2016)	Retrospective cohort	76	NR	0	133	133	Lithium disilicate	Monolithic	Conventional	Private practice	0%
Seydler and Schmitter[58] (2015)	RCT	60	44.7	0	60	60	Lithium disilicate/ zirconia	Monolithic/ layered	Adhesive	Private practice	0%
Simeone and Gracis[59] (2015)	Retrospective	106	52.0	106	169	275	Lithium disilicate	Layered	Adhesive	Private practice	NR
Toman and Toksavul[60] (2015)	Prospective uncontrolled	34	NR	98	23	121	Lithium disilicate	Layered	Adhesive	University	3%
Fabbri et al[61] (2014)	Retrospective	312	19-71	231	197	428	Lithium disilicate	Monolithic/ layered	Adhesive	University/ private practice	NR
Gherlone et al[62] (2014)	Retrospective	70	45.9	13	73	86	Zirconia	Layered	Adhesive	NR	NR
Esquivel-Upshaw et al[63] (2013)	RCT	24	>18	0	24	24	Lithium disilicate	Monolithic/ layered	Adhesive	Private practice	3%
Gehrt et al[64] (2013)	NRCT	41	34.0	74	20	94	Lithium disilicate	Layered	Adhesive/ conventional	University	10%
Sagirkaya et al[65] (2012)	RCT	42	38.0	NR	NR	74	Zirconia	Layered	Adhesive	University	0%
Vigolo and Mutinelli[66] (2012)	RCT	39	32.0	0	39	39	Zirconia	Layered	Conventional	Private	3%
Beuer et al[67] (2010)	Prospective uncontrolled	38	50.9	15	35	50	Zirconia	Layered	Conventional	University	0%
Etman and Woolford[68] (2010)	RCT	NR	20-60	0	30	30	Lithium disilicate	Layered	Adhesive	University	0%
Schmitt et al[69] (2010)	Prospective uncontrolled	9	42.1	17	0	17	Zirconia	Layered	Conventional	University	10%

NR, not reported; NRCT, nonrandomized clinical trial; RCT, randomized clinical trial.

of any endodontically treated teeth was unclear.[54,55,57,62,63,65,68] Participants with parafunctional habits/temporomandibular disorders were excluded in 6 articles.[53,54,58,63,64,68] In 3 articles, participants with only excessive parafunctional activity were excluded.[60,65,67] Excessive parafunctional activity was defined by 1 out of these 3 articles,[67] based on the system of Research Diagnostic Criteria for Temporomandibular Disorders.[70] In 6 articles, inclusion of participants with parafunctional activity was unclear,[55-57,62,66,69] and 2 articles included such participants in the study population.[59,61] Besides recording biologic and technical major/minor complications, most articles assessed the clinical quality of the restorations based on the criteria established by the United States Public Health Service/California Dental Association.[53-61,63,65,66,68,69] In addition, some articles assessed parameters such as bleeding index,[64,67,69] gingival index,[58,64,65,68] plaque index,[58,64,65,67-69] probing depths,[58,67] tooth mobility,[58,67] tooth vitality,[58,64,68] and occlusion.[64,67] One article evaluated only technical complications.[62]

A domain-based risk of bias assessment was completed for 7 of the included articles and is presented in Figures 2 and 3. Overall, the 5 assessed randomized trials showed poor quality of evidence.[58,63,65,66,68] The assessed nonrandomized clinical trial and cohort study were at serious risk of bias.[57,64]

Adhesive resin cementation was reported for 210 zirconia crowns in 4 of the included articles.[54,58,62,65] The range of participant mean follow-up time was 25.3 to 49.0 months. The range of crown survival rate was 83.3% to 100%, whereas the complication-free rate ranged from 69.8% to 83.3%. The most common complication reported was technical and involved fracture of the veneering ceramic.[62,65] The incidence of catastrophic crown fracture ranged from 0% to 2.7%, with only 1 article reporting this type of complication.[65] No incidents of loss of crown retention were reported. Other reported complications included abutment tooth fracture,[54] alterations in abutment tooth sensitivity,[58] need for endodontic treatment,[58,65] and periodontal complications.[58]

Conventional cementation was reported for 106 zirconia crowns in 3 of the included articles.[66,67,69] The range of participant mean follow-up time was 35.0 to 48.0 months. The range of crown survival rate was 82.0% to 100%, whereas the complication-free rate ranged from 64.0% to 100%. The most common complication

Table 3. Summary of articles reporting on clinical performance of zirconia restorations after adhesive or conventional cementation

	Restoration				Mean Follow-Up (mo)	Survival Rate (%)	Complication-Free Rate (%)	Number and Type of Complications		Restoration Fracture Incidence (%)	Loss of Retention Incidence (%)
Author (y)	Material	Type	No.	Cement				Major	Minor		
Adhesive cementation											
Dogan et al[54] (2017)	NobelProcera; Nobel Biocare	Layered	20	RelyX Unicem; 3M ESPE	49.0	100.0	NR	1 tooth fracture	0	0	0
Seydler and Schmitter[58] (2015)	IPS e.max ZirCAD; Ivoclar Vivadent AG	Layered	30	Multilink Automix; Ivoclar Vivadent AG	25.3	83.3	83.3	0	1 tooth sensitivity; 1 endodontic treatment; 3 periodontal	0	0
Gherlone et al[62] (2014)	Lava; 3M ESPE	Layered	86	RelyX Unicem; 3M ESPE	36.0	NR	69.8	0	26 veneer fractures	0	0
Sagirkaya et al[65] (2012)	Multiple products	Layered	74	Panavia F; Kuraray America Inc	46.3	93.6	NR	2 crown fractures; 1 extraction due to endodontic reasons	1 veneer fracture	2.7	0
Conventional cementation											
Vigolo and Mutinelli[66] (2012)	NobelProcera; Nobel Biocare; Lava; 3M ESPE	Layered	39	Ketac Cem; 3M ESPE	48.0	82.0	64.0	3 veneer fractures; 4 unspecified	14 unspecified	NA	NA
Beuer et al[67] (2010)	IPS e.max ZirCAD; Ivoclar Vivadent AG	Layered	50	Ketac Cem Aplicap; 3M ESPE	35.0	100.0	100.0	0	0	0	0
Schmitt et al[69] (2010)	Lava; 3M ESPE	Layered	17	Ketac Cem; 3M ESPE	39.2	100.0	NR	0	1 veneer fracture	0	0

NA, not available; NR, not reported.

reported was technical and involved fracture of the veneering ceramic.[66,69] No incidents of catastrophic crown fracture or loss of retention were reported. These results are summarized in Table 3.

Adhesive resin cementation was reported for 1957 lithium disilicate crowns in 10 of the included articles.[53,55,56,58-61,63,64,68] The range of participant mean follow-up time was 26.3 to 121.2 months. Three studies had a mean follow-up period of more than 5 years.[53,60,64] The range of crown survival rate was 83.5% to 100%, whereas the complication-free rate ranged from 71.0% to 96.7%. In this subgroup, the total number of monolithic restorations was 1005, and the total number of layered restorations was 952. The most common complications reported were technical and involved loss of crown retention[53,55,56,61] and catastrophic crown fracture.[53,55,56,59-61,64,68] The incidence of catastrophic crown fracture ranged from 0% to 3.3%, wheras the incidence of loss of crown retention ranged from 0% to 5.5% (Table 4). The cumulative incidence of catastrophic crown fracture for monolithic restorations was 1.3%, whereas that for layered restorations was 1.0%. Other reported complications included abutment tooth fracture,[53,55,60] root fracture,[53,56,61] caries,[53,56] extraction for periodontal or endodontic reasons,[53,56,57,60] alterations in abutment tooth sensitivity,[53,58] endodontic treatment,[53,55,56,59,61,64] fracture of the veneering ceramic,[56,59,60,64] and minor ceramic fractures.[56,61,63] Separate cumulative failure data could be retrieved for 851 monolithic and 678 layered restorations from 9 articles.[53,55,56,58-60,63,64,68] Of 851 monolithic restorations, 37 (4.3%) had a complication, of which 20 (2.4%) had a major complication. Crown fracture was exhibited by 11 (1.3%) monolithic restorations. Of 678 layered restorations, 47 (6.9%) had a complication, of which 18 (2.7%) had a major complication. Crown fracture was exhibited by 7 (1.0%) layered restorations.

Conventional cementation was reported for 163 lithium disilicate crowns in 2 of the included articles.[57,64] One article evaluated 133 monolithic restorations,[57] and the other article evaluated 30 layered restorations.[64] The mean follow-up time was 25.5 to 79.5 months. One article had a mean follow-up period of more than 5 years.[64] Crown survival was reported by one article as 98.5%,[57] whereas another article reported a 87.1% complication-free rate.[64] The most common complication reported was technical and involved catastrophic crown fracture.[57,64] The incidence of catastrophic crown fracture ranged from 1.5% for monolithic restorations to 3.3% for layered restorations. No incidents of loss of crown retention were reported. Other reported complications included caries,[64] extraction for endodontic reasons,[64] and fracture of the veneering ceramic.[64] These results are summarized in Table 4.

DISCUSSION

This systematic review investigated the effect of cement type on the clinical outcomes of zirconia and lithium

Table 4. Summary of articles reporting on clinical performance of lithium disilicate restorations after adhesive or conventional cementation

Author (y)	Restoration: Material	Restoration: Type	Restoration: No.	Cement	Mean Follow-Up (mo)	Survival Rate (%)	Complication-Free Rate (%)	Number and Type of Complications: Major	Number and Type of Complications: Minor	Restoration Fracture incidence (%)	Loss of Retention Incidence (%)
Adhesive cementation											
Rauch et al[53] (2018)	IPS e.max CAD; Ivoclar Vivadent AG	Monolithic	31	Multilink Sprint; Ivoclar Vivadent AG	121.2	83.5	71.0	1 crown fracture; 1 abutment fracture; 1 root fracture; 1 secondary caries; 1 extracted due to apical infection	1 sensitivity change; 1 endodontic treatment; 1 secondary caries; 1 loss of retention	3.2	3.2
Schmitz et al[55] (2017)	IPS e.max; Ivoclar Vivadent AG	Monolithic	627	RelyX Unicem 2; 3M ESPE. Multilink Automix; Ivoclar Vivadent AG	48.2	97.9	NR	9 crown fractures; 3 tooth fractures; 1 extracted due to endodontic reasons	1 loss of retention; 4 endodontic treatment	1.4	0.2
Huettig and Gehrke[56] (2016)	IPS e.max Press; Ivoclar Vivadent AG	Monolithic/ layered	327	Multilink Automix; Ivoclar Vivadent AG. Variolink II; Ivoclar Vivadent AG	30.0	96.8	NR	3 crown fracture; 1 root fracture; 2 secondary caries	2 loss of retention; 2 veneer fracture; 3 minor ceramic fractures; 1 endodontic treatment	0.9	0.6
Seydler and Schmitter[58] (2015)	IPS e.max CAD; Ivoclar Vivadent AG	Monolithic	30	Multilink Automix; Ivoclar Vivadent AG	26.3	93.3	93.3	NR	2 tooth sensitivity	0	0
Simeone and Gracis[59] (2015)	IPS e.max Press; Ivoclar Vivadent AG. IPS Empress 2; Ivoclar Vivadent AG	Layered	275	Multiple products	53.0	98.2	NR	2 core fracture	3 veneer fracture; 15 loss of retention; 1 endodontic treatment	0.7	5.5
Toman and Toksavul[60] (2015)	IPS Empress 2; Ivoclar Vivadent AG	Layered	121	Variolink II; Ivoclar Vivadent AG	104.6	87.1	NR	1 crown fracture; 5 abutment fracture; 3 veneer fracture; 1 extracted due to periodontal reasons	2 veneer fracture	0.8	0
Fabbri et al[61] (2014)	NR	Monolithic/ layered	428	RelyX Unicem; 3M ESPE. Multilink Automix; Ivoclar Vivadent AG	35.5	97.4	96.7	2 core fractures; 1 root fracture	2 loss of retention; 8 minor ceramic fractures; 1 endodontic treatment	0.5	0.5
Esquivel-Upshaw et al[63] (2013)	IPS e.max Press; Ivoclar Vivadent AG. IPS Empress 2; Ivoclar Vivadent AG	Monolithic/ layered	24	Variolink II; Ivoclar Vivadent AG	36.0	100	NR	0	2 minor ceramic fractures	0	0
Gehrt et al[64] (2013)	IPS e.max Press; Ivoclar Vivadent AG	Layered	64	Variolink II; Ivoclar Vivadent AG	79.5	NR	82.0	1 crown fracture	2 veneer fractures; 2 endodontic treatment	1.4	0
Etman and Woolford[68] (2010)	IPS e.max Press; Ivoclar Vivadent AG	Layered	30	Panavia F; Kuraray America Inc	36.0	96.7	NR	1 crown fracture	NR	3.3	0
Conventional cementation											
Schmitz and Beani[57] (2016)	IPS e.max; Ivoclar Vivadent AG	Monolithic	133	VivaglassCEM; Ivoclar Vivadent AG	25.5	98.5	NR	2 crowns fractures	NR	1.5	0
Gehrt et al[64] (2013)	IPS e.max Press; Ivoclar Vivadent AG	Layered	30	VivaglassCEM; Ivoclar Vivadent AG	79.5	NR	87.1	1 crown fracture; 1 secondary caries; 1 extraction due to endodontic reasons	1 veneer fracture	3.3	0

NA, not available; NR, not reported.

disilicate crowns. Qualitative evaluation of the included articles suggested that either adhesive or conventional cementation resulted in comparable survival rates and complications.

The most common complication reported for either adhesively or conventionally cemented zirconia crowns was fracture of the veneering ceramic—a known concern for layered zirconia restorations[5]—and may not be related

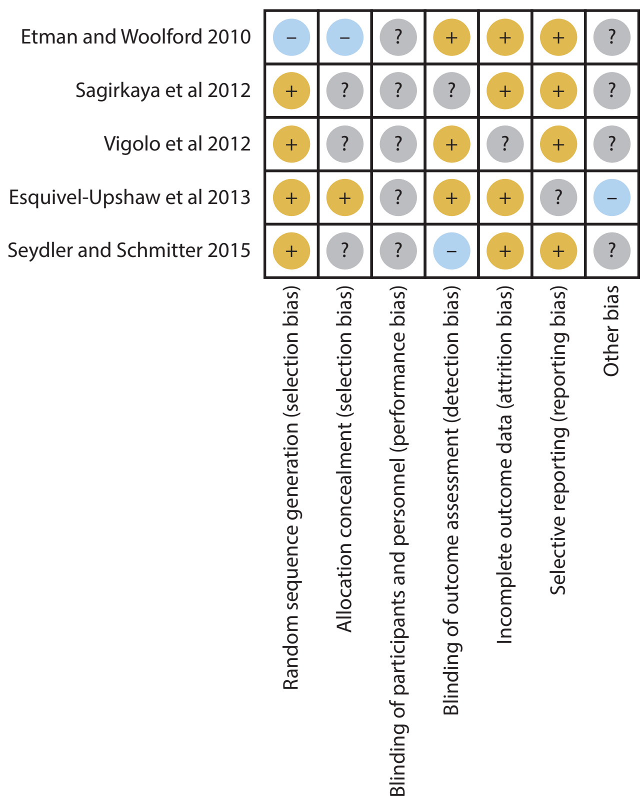

Figure 2. Summary of Cochrane Collaboration Risk of bias assessment tool about each domain for included randomized trials.

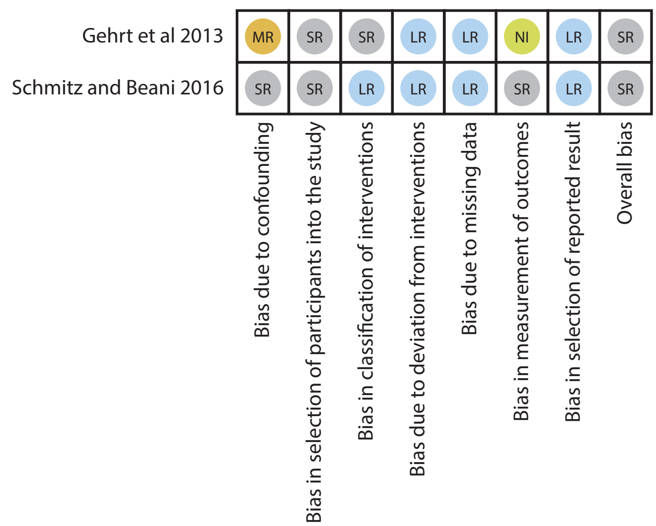

Figure 3. Summary of risk of bias in nonrandomized studies–of interventions (ROBINS-I) assessment tool about each domain for included nonrandomized clinical trial and cohort study. LR, low risk; MR, medium risk; NI, no information; SR, serious risk.

to the type of cement. Instead, this complication could be related to the thickness of the veneering ceramic, the design of the zirconia core, or the core-veneer thickness ratio.[71-74] No information on the zirconia coping design or the veneering ceramic thickness was provided by 3 articles.[58,62,65] The rest of the articles reported a zirconia core thickness of 0.3-0.6 mm; however, they did not mention the exact thickness of the veneering ceramic.[54,66,67,69] In 3 articles, the thickness of the veneering ceramic could be approximately calculated as less than 2 mm based on the described preparation features.[54,66,67]

Adhesively cemented lithium disilicate crowns had restoration fracture and loss of retention as the most common reported complications. The highest crown fracture and loss of retention rates were reported in 3 articles.[53,59,68] Rauch et al[53] reported a 3.2% crown fracture and a 3.2% loss of restoration retention incidence, whereas Etman and Woolford[68] showed a 3.3% crown fracture incidence. The higher incidence rates reported in these articles may be explained by the small number of participants/crowns enrolled in these studies. Simeone and Gracis[59] reported a 5.5% loss of restoration retention incidence; however, in this study, 7 different cements were used, and approximately 73% of the incidents occurred in the same individual. The rest of the articles had low crown fracture (up to 1.4%) and loss of retention (up to 0.6%) incidences. Monolithic and layered restorations showed comparable complication rates. The cumulative incidence of major complications was 2.4% for monolithic and 2.7% for layered restorations. The cumulative incidence of all complications was 4.3% for monolithic and 6.9% for layered restorations. Exact data for monolithic and layered restorations could not be extracted for 1 article; however, this article showed no statistically significant difference in the survival rates between monolithic and layered restorations.[61] Another article that included both types of restorations found no significant differences in the complications between monolithic and layered restorations.[63]

Conventionally cemented lithium disilicate crowns had restoration fracture as the most commonly reported complication.[57,64] Schmitz and Beani evaluated monolithic restorations and showed a 1.5% crown fracture incidence.[57] Gehrt et al[64] evaluated layered restorations and reported a higher crown fracture incidence (3.3%), which may be explained by the small number of participants/crowns enrolled in this study. None of the studies reported any loss of restoration retention incidents.

Of the 2436 restorations in the included articles, 1957 (80.3%) were adhesively cemented lithium disilicate crowns. This subgroup of restorations included more long-term data and demonstrated a wider variety of complications. A total of 10 different major and minor mechanical and biologic complications were described for adhesively cemented lithium disilicate crowns.[50-52,54-57,59,60,64] Adhesively cemented zirconia crowns comprised 8.6% of the total number of restorations, and the included studies described 5 different major and minor mechanical and biologic complications.[54,58,62,65] Conventionally cemented zirconia crowns comprised 4.4% of the total number of restorations, and the included studies described only 1 type of mechanical complication.[66,67,69] Conventionally cemented lithium disilicate crowns comprised 6.7% of the total number of restorations, and the included studies described 4 different major and minor mechanical and biologic complications.[57,64] As a result, the data for zirconia crowns and conventionally cemented lithium disilicate crowns were limited compared with those for adhesively cemented lithium disilicate crowns; this is a limitation of this systematic review.

In addition, the included studies were heterogenous in relation to the participants' characteristics, abutment teeth characteristics, location of restorations, cementation material, and type of restoration. Two studies included a high number of participants with parafunctional activity and found low failure rates in these participants.[59,61] Many other studies included participants with minor parafunctional activity or participants whose parafunctional activity status was unclear.[55-58,60,62,65-67,69] However, this potentially important confounding factor was not controlled for, and this may be another limitation of this systematic review. In 1 article, 70% of the reported failures occurred in participants with parafunctional activity.[60] Of 17 articles, 16 included endodontically treated teeth and vital teeth, or the endodontic status of the abutment teeth was unclear.[53-65,67-69] Of 9 articles that included endodontically treated teeth, 3 did not provide specific information on the distribution or failure patterns of these teeth.[53,61,69] No major complications due to fracture of restored endodontically treated teeth were reported by 3 articles.[58,64,67] In contrast, 1 of the included articles reported that all 5 incidents of material failure were observed on endodontically treated teeth.[59] Another included article reported that the complication rate of endodontically treated teeth (11.7%) was significantly higher than that of vital teeth (2.0%) after 24 months.[56] Finally, Toman and Toksavul[60] evaluated 121 restored teeth, of which 11 were endodontically treated. No crown fractures were noted on the endodontically treated teeth, but 5 of them exhibited abutment fracture. As a result, the reported survival rate of endodontically treated teeth was 53.0%, as opposed to a 91.3% survival rate for vital teeth after 104.6 months.[60] The endodontic status of the abutment teeth could be another important confounding factor affecting mechanical and biologic complications and the survival rate of the restorations. However, most of the included studies did not control for it.

The location of restorations varied among the included studies, which reported restoration of only anterior teeth,[54,69] only posterior teeth,[53,55,57,58,63,66,68] or restoration of either anterior or posterior teeth.[56,59-62,64,67] A total of 18 incidents of major complications could be identified for 750 (2.4%) anterior crowns, and 36 incidents of major complications could be identified for 1612 posterior crowns (2.2%). When all complications were considered, data could be extracted for 506 anterior and 1342 posterior crowns. The cumulative complication incidence was 7.1% for anterior and 6.0% for posterior crowns. It is unclear if variability in restoration location may have influenced the results of this systematic review. However, any included studies that statistically compared clinical outcomes between anterior and posterior crowns found no correlation between restoration position and complication rates,[62] no difference in the overall complication rates,[56] and no difference in the survival rates between anterior and posterior crowns.[60,64]

When adhesive cementation was used, a wide range of cements was reported by the included articles, including 3-step adhesive resin cements,[60,63,64] self-etching resin cements,[58,65,68] or self-adhesive resin cements;[53,54,62] multiple types of adhesive cements were also used in the same study.[55,56,59,61] When conventional cementation was used, the included studies used a glass ionomer cement.[57,64,66,67,69] Resin bonding of zirconia is achieved with airborne-particle abrasion of the crown intaglio with aluminum oxide, followed by application of a primer containing 10-methacryloyloxydecyl dihydrogen phosphate.[6] Such a procedure was clearly stated by only 1 of the 3 included articles on adhesively cemented zirconia crowns.[58] Resin bonding of low-to medium-strength glass-ceramics relies on acid etching of the ceramic crown intaglio with hydrofluoric acid, followed by application of a silane-coupling agent.[6] Such a procedure was clearly described by 6 of the 10 included articles on adhesively cemented lithium disilicate crowns[53,58-60,64,68] and implied in 2 articles.[56,61] All included articles on zirconia restorations involved crowns with a zirconia core layered with veneering ceramic; however, the zirconia/layering materials varied among the articles.[54,58,62,65-67,69] None of the included articles reported on the most recent generation of high-translucency zirconia that has different properties.[6] Most of the included studies on lithium disilicate restorations involved monolithic or layered crowns by using a pressed or milled version of the same material (IPS e.max; Ivoclar Vivadent AG).[53,55-58,64,68] An older version of the same material (IPS Empress 2; Ivoclar Vivadent AG) was used in 1 study,[60] and 2 studies used both.[59,63] Similar complication rates were observed between adhesively cemented monolithic and layered restorations. Also, exact information of the ceramic thickness was not provided by the included articles; however, assumptions could be made based on the used tooth preparation features. Reported tooth preparations for zirconia crowns had occlusal reduction that ranged from 1.0 to 2.0 mm and axial reduction that ranged from 1.0 to 1.5 mm. Tooth preparations for lithium disilicate crowns had occlusal and axial reduction that ranged from 1.0 to 2.0 mm. Material thickness could affect the fracture incidence of a crown regardless of the cement used; however, in this systematic review, lower complication rates were not observed when preparation reduction was toward the higher end of the reported range. In addition, the variability of cements and materials used may have contributed to the reported clinical outcomes and complications. Finally, some of the included studies used different criteria to define a restoration as survived/failed or did not report survival rates: 1 study included minor complications in the calculation of survival rate, which may have underestimated the survival rate (83.3% for adhesively cemented zirconia crowns and 93.3% for adhesively cemented lithium disilicate crowns).[58] Two studies reported only complication-free rates for the examined restorations based on the cement type.[62,64]

Unfortunately, long-term clinical data are lacking, and the strength of the existing evidence may be weak. Of the 17 included articles, only 3 had a mean follow-up period of over 5 years,[53,60,64] of which only 1 had a mean follow-up period of over 10 years.[53] All 3 studies examined lithium disilicate crowns. Rauch et al[53] reported 83.5%, and Toman and Toksavul[60] reported 87.1% survival rates for adhesively cemented lithium disilicate crowns. Gehrt et al[64] reported 82.0% complication-free rates for adhesively cemented lithium disilicate crowns and 87.1% for conventionally cemented ones. A previous nonrandomized clinical trial that was not included in the definitive list of articles of this systematic review because the required data could not be extracted showed similar rates.[29] This study examined lithium disilicate crowns and reported an overall 89.7% survival rate after 5 years and 86.1% survival rate after 10 years; it also found that the type of cement had no impact on the survival of the restorations. In addition, survival rates after 5 and 10 years were not statistically different in a nonrandomized trial on 3-unit lithium disilicate–fixed partial dentures cemented with either a 3-step adhesive resin cement or glass ionomer cement.[20]

Most of the included studies were uncontrolled prospective trials that, despite being useful in evaluating the performance of a restorative option, do not allow comparison with an already established treatment alternative (control group).[53,54,56,60,67,69] In addition, most of the included controlled trials did not address the research question directly and were found to have a high risk of bias,[58,63,65,66,68] whereas the rest of the included studies were retrospective.[55,57,59,61,62] Only 1 controlled trial directly compared lithium disilicate crowns cemented with a 3-step adhesive resin or a glass ionomer cement and found that the occurrence of complications was not significantly influenced by the type of cement used.[64] However, in this study, the allocation of the participants to the type of cement was not randomized. Adhesive cementation was used when the abutment teeth were shorter than 4 mm or had an angle of convergence over 10 degrees, which did not allow a fair comparison between the 2 types of cements. To definitively assess the effect of cement type on the clinical performance of zirconia and lithium disilicate single tooth–supported restorations, well-designed standardized studies are required.

CONCLUSIONS

Within the limitations of this systematic review, the following conclusions were drawn:

1. Current clinical data suggest that adhesive and conventional cementation results in comparable clinical outcomes for both zirconia and lithium disilicate tooth-supported single crowns.
2. The quality of available evidence is poor, and more research with long-term randomized clinical trials on the subject is suggested.

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https://doi.org/10.1016/j.prosdent.2018.10.011

Noteworthy Abstracts of the Current Literature

Strength-limiting damage in lithium silicate glass-ceramics associated with CAD-CAM

Romanyk DL, Martinez YT, Veldhuis S, Rae N, Guo Y, Sirovica S, Fleming GJP, Addison O

Dent Mater 2019 Jan;35:98-104

Objective. The fabrication of all-ceramic restorations using Computer Aided Design and Computer Aided Manufacturing (CAD-CAM) most commonly involves subtractive machining which results in strength-limiting, surface and sub-surface damage in the resultant prosthesis. The objective was to explore how clinically relevant machining-process variables, and material variables, affect damage accumulation in lithium silicate glass-ceramics.

Methods. Three commercial lithium silicate glass-ceramics (IPS e.max CAD, Celtra Duo and Vita Suprinity) were selected. For each material, two groups of disk-shaped specimens were fabricated (n=15), using a CAD-CAM process, creating surfaces equivalent to those generated for a dental restoration, or alternatively, using a highly controlled laboratory process generating disk-shaped test specimens with a consistent polished surface. Bi-axial flexure strength (BFS) was determined in a ball-on-ring configuration and fractographic analyses performed. For each material BFS was correlated with machining sequence and with surface roughness.

Results. BFS was significantly influenced by material substrate ($P<0.01$) and by fabrication route ($P<0.01$). A significant factorial interaction ($P<0.01$) identified that the magnitude of changes in BFS when comparing the two specimen fabrication routes, was dependent on substrate type. The polished control specimens exhibited a significantly increased BFS when compared with the CAD-CAM counterparts for all materials. IPS e.max CAD and Celtra Duo showed a 44 and 46% reduction in mean BFS for the CAD-CAM specimens when compared with the polished counterparts, respectively. In contrast, Vita Suprinity showed the least disparity in mean BFS (21%) but the greatest variance in BFS data.

Significance. All CAD-CAM specimens showed evidence of machining introduced damage in the form of median and radial cracks at sites either coincident with, or peripheral to the failure origin. Subtractive machining introduced significant strength limiting damage that is not eliminated by heat treatments applied for either microstructure development (IPS e.max CAD and Vita Suprinity) or annealing/crack blunting (Celtra Duo).