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REVIEW ARTICLE

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Longevity of ceramic onlays: A systematic review

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Abstract

Objective: This systematic review aimed to evaluate the longevity of ceramic onlays and identify the factors that influence their survival.

Materials and methods: An electronic search was conducted through PubMed (MEDLINE), Google Scholar and Cochrane Library, up to August 2017. The literature search aimed to retrieve all the clinical studies on the longevity of ceramic onlays. Ceramic onlay was defined as any partial ceramic restoration that covers at least one cusp.

Results: A total of 21 studies met the selection criteria and were deemed suitable for this review. The medium-term studies (2–5 years) indicated a survival rate of 91-100%, and the long term studies (more than 5 years) showed a survival rate of 71–98.5%. The most common reason of failure was fracture, followed by debonding and caries. The most common patterns of deterioration were loss of margin integrity and discoloration. Onlay longevity can be enhanced if the preparation allows for at least 2 mm occlusal ceramic thickness and incorporates additional retentive features. Restoring teeth that are nonvital, teeth in a more posterior region, or teeth for patients with parafunctional habits appears to be associated with greater ceramic failure. Fabrication materials and methods, and adhesive bonding system did not seem to influence onlay longevity.

Conclusions: The clinical performance of the ceramic onlay appears acceptable regardless of the follow-up duration. Fracture of the ceramic onlay is the predominant cause of failure, and the most observed form of deterioration was associated with the restoration margin.

CLINICAL SIGNIFICANCE

Ceramic onlay appears to be a reliable option to restore posterior teeth. The most common pattern of failure is fracture of the ceramic material. The risk of ceramic onlay failure seems to increase if the restored tooth is nonvital and the patient demonstrates parafunctional habits.

1 | INTRODUCTION

Despite the outstanding performance of metal onlays and crowns,[1–3] their unappealing appearance discourages patients from choosing them. Over the last 20 years, ceramic restorations have become very popular and routinely used in clinical practice. This is further driven by the significant developments that have improved the mechanical and optical properties of ceramic materials available for dental restorations.[4–6] In addition, the development of modern manufacturing techniques has reduced the risk of internal flaw development within the ceramic material, which can further enhance its performance.[7,8] In parallel to ceramic improvements, there have been advances in adhesive and cementation agents that combine enhanced bonding between the tooth and the ceramic material and ease of use.[9–11] Consequently, a new range of conservative, tooth-colored and durable restorative options are available.[7,8,12,13] Contemporary ceramics have been used to restore teeth with inlays, onlays, crowns, or even fixed partial dentures.

The clinical studies have confirmed the successful use of ceramics as dental restorative materials.[14,15] However, due to the considerable variation, it can be challenging to compare outcomes between studies, materials and restoration types. A number of reviews have collated this information to identify the success and survival of different ceramic restorations and also identify the biological and technical complications that exist.[16–20] However, to the authors' knowledge, there are no reviews collating the clinical outcomes specifically of ceramic onlay

TABLE 1 Inclusion criteria

Human clinical study conducted in University, private practice or public clinic setting
Clinical study on ceramic onlay or partial ceramic restoration that covers one cusp up to all cusps
Peer-reviewed journal article
Adult participants
Study that clearly outlined the outcome of ceramic onlays
Retrospective or prospective study
At least, 2 years duration study
English language study

restorations, where the partial ceramic restorations cover all or some of the cusps. The choice to place a ceramic onlay is driven by the need for protecting the tooth with cuspal coverage whilst trying to avoid a traditional crown which has been shown to significantly affect the amount of remaining tooth structure.[21,22] Detailed analysis on the longevity of ceramic onlay restorations is necessary as it will further confirm the suitability of this conservative option. Subsequently, this qualitative systematic review was undertaken to (1) evaluate the longevity of ceramic onlays and (2) identify the factors that influence the survival of a ceramic onlay.

2 | MATERIALS AND METHODS

In August 2017, a detailed electronic literature search on ceramic onlay longevity was completed by the two reviewers. The search aimed to retrieve all the clinical studies that evaluated the longevity of ceramic onlays. No year limit was applied. For the purpose of this systematic review, any partial ceramic restoration that covers at least one cusp was considered a ceramic onlay. This may include partial crown or overlay restorations. The search was conducted through PubMed (MEDLINE), Google Scholar and Cochrane Registrar of Controlled Trials. The Boolean operator of the PubMed dataset was implemented to combine the following mix of key words: ("onlay" OR "partial crown" OR "partial coverage" OR "occlusal veneer" OR "restoration") AND ("ceramic" OR "porcelain") AND ("clinical" OR "longevity" OR "evaluation" OR "survival" OR "performance") AND ("dental" OR "dentition") NOT ("implant" OR "bridge" OR "denture"). The Cochrane Database was searched to retrieve all the articles related to ceramic and porcelain. The Google Scholar search engine was utilized to retrieve additional studies by combining key words such as "ceramic," "porcelain," "onlay," "partial crown," "longevity," and "clinical." No year limit was applied for the literature search.

The selection of the articles was performed in three stages: (1) selection according to the relevance of the title, (2) selection according to the relevance of the abstract, and (3) full text analysis and cross-matching against inclusion criteria (Table 1). After selection of the relevant studies, their bibliographies were searched for additional possible relevant studies. The two reviewers independently screened the retrieved articles, and the agreement level (Cohen's kappa coefficient) was calculated. To reach a consensus, any disagreement was resolved by discussion and referring to the inclusion criteria.

Critical Appraisal Skills Programme (CASP) guidelines were used to evaluate the methodological quality of the selected articles.[23] The CASP guidelines aim to ensure the study's trustworthiness, importance of the study's results and the study's relevance to the area of practice. This was achieved by asking 12 questions for every article (Table 2). For each guideline question, a score of 1 was given if the answer was yes. If the answer was no or unclear, a score of 0 was given. Therefore, according to this assessment, the highest score that can be achieved is 12. An overall quality rating for each study was determined as high (12-10), high-moderate (9-8), moderate (7-5), moderate-low (4-3) and low (2-0).

TABLE 2 Critical appraisal skills programme (CASP) guidelines and scoring system

CASP guidelines		Score
1	Did the study address a clearly focused issue?	Yes (1)—No/Unclear (0)
2	Was the cohort recruited in an acceptable way?	Yes (1) —No/Unclear (0)
3	Was the exposure accurately measured to minimise bias?	Yes (1) —No/Unclear (0)
4	Was the outcome accurately measured to minimise bias?	Yes (1) —No/Unclear (0)
5	Have the authors identified all important confounding factors?	Yes (1) —No/Unclear (0)
6	Have the authors taken account of confounding factors in the design and/or analysis?	Yes (1) —No/Unclear (0)
7	What are the results of the study? (Are they clear?)	Yes (1) —No/Unclear (0)
8	How precise are the results?	Yes (1) —No/Unclear (0)
9	Do you believe the results?	Yes (1) —No/Unclear (0)
10	Can the results be applied to the local population?	Yes (1) —No/Unclear (0)
11	Do the results of the study fit with other available evidence?	Yes (1) —No/Unclear (0)
12	What are the implications of this study for practice? (Is the study clinically relevant?)	Yes (1) —No/Unclear (0)

TABLE 3 The excluded studies and the reasons of their exclusion

Study (year)	Reason of exclusion
Kramer et al. (1999)[30]	Reported the combined outcome of inlay and onlay restorations
Frankenberger et al. (2000)[27]	Reported the combined outcome of inlay and onlay restorations
Posselt and Kerschbaum (2003)[32]	Reported the combined outcome of inlay and onlay restorations
Schulte et al. (2005)[37]	Reported the combined outcome of inlay and onlay restorations
Federlin et al. (2006)[24]	Earlier study of an included paper by the same research group[52]
Federlin et al. (2007)[25]	Earlier study of an included paper by the same research group[52]
Frankenberger et al. (2008)[28]	Reported the combined outcome of inlay and onlay restorations
Kramer et al. (2008)[31]	Reported the combined outcome of inlay and onlay restorations
Zimmer et al. (2008)[40]	Reported the combined outcome of inlay and onlay restorations
Guess et al. (2009)[29]	Earlier study of an included paper by the same research group[55]
Silva et al. (2009)[38]	Reported the combined outcome of inlay and onlay restorations
Tagtekin et al. (2009)[39]	Reported the combined outcome of inlay and onlay restorations
Schenke et al. (2010)[35]	Earlier study of an included paper by the same research group[58]
Schenke et al. (2012)[36]	Earlier study of an included paper by the same research group[58]
Santos et al. (2013)[33]	Reported the combined outcome of inlay and onlay restorations
Federlin et al. (2014)[26]	Earlier study of an included paper by the same research group[58]
Santos et al. (2016)[34]	Reported the combined outcome of inlay and onlay restorations

3 | RESULTS

3.1 | Literature search

The electronic search disclosed a total of 2 262 articles. Title analysis led to the exclusion of 2 202 articles. After reading the abstracts, additional 26 articles were excluded. Therefore, 34 articles were analyzed by reading the full-text and cross-matching against the inclusion criteria. The reviewers' agreement had Cohen's kappa value of 92.3%. In situations where multiple follow-up papers were published by the same research group, the most recent paper was selected. This led to the exclusion of an additional 17 articles (Table 3).[24–40] Reviewing the references of the remaining 17 articles disclosed additional 4 articles suitable for inclusion. Therefore, a total of 21 articles were deemed suitable for inclusion in this review (Table 4).[14,41–60] Nine studies (42.9%) were retrospective and 12 studies (57.1%) were prospective. Four of the prospective studies were split mouth studies.[48,52,55,58] Because of the inevitable heterogeneity of the included studies, whenever possible, the relevant information on failure pattern and deterioration pattern were extracted. Further, the relevant information on the variables that can influence onlay longevity were reported.

3.2 | Description of studies

According to CASP guidelines, the studies' quality scores ranged from 7 to 12. A total of 16 studies (76.2%) had a quality rated as high, 3 studies (14.3%) had a quality rating of high-moderate and 2 studies (9.5%) were rated to have a moderate quality. The included studies evaluated the longevity of ceramic onlays fabricated from glass-ceramic materials such as feldspathic, castable ceramics (Dicor), leucite-reinforced and lithium disilicate ceramics. Only one study included onlays fabricated from polymer-infiltrated ceramic (Enamic).[60] The fabrication methods were: sintering, hot pressing, chairside CAD/CAM and laboratory CAD/CAM. In addition to ceramic onlays, some studies included onlays fabricated from different materials such as porcelain fused-to-metal (PFM), indirect composite resin and gold. Further, some studies included ceramic inlay restorations where no cusp coverage was involved. The number of patients included in the studies ranged from 12 to 110 patients. The patients' age range was 15–81 years. The duration periods of the studies varied from 2 to 15 years.

Several of the included studies evaluated the effect of the following variables on the ceramic onlay longevity: ceramic onlay fabrication materials and methods,[46,47,55,60] vitality of the restored tooth,[14,43,44,54] location in the arch,[14,43,44,46,47,49,50,53] preparation and extension,[14,41,44,46,47,49,54,56] adhesive and cementation systems,[14,43,44,51,53,58] and parafunctional activities.[14,41,43,47,50]

All the included studies measured the survival rate. In addition, most of the studies determined the failure patterns, which were extracted and presented in a stacked column graph. Most of the studies monitored the time-dependent onlay degradation patterns in relation to the following criteria: margin integrity, margin discoloration, anatomic form, color match, caries and sensitivity. The majority of the studies implemented a form of universal index (e.g., USPHS or CDA). For each of the degradation criteria, the proportions of successful, surviving and failing restorations were also calculated and presented in stacked column graphs. Success indicates that the variable fulfilled the highest criteria of the author's standard. Survival reflects that the

TABLE 4 Summary of the included studies

	Study details						Restoration detail					Outcome				
													Degradation			
														Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
Felden et al. (1998)[42]	7	R	University	Median age: 37.9 years (17–66 years)	55 restorations evaluated (Included patients with attrition)	7 years	Variable (cast, pressed, sintered and milled)	Molars and premolars	Vital and non-vital	Different composite cements (light cured, dual cured)	USPHS	74.5				
Felden et al. (2000)[41]	10	R	University	22 patients; Median age: 40 years (26–69 years)	49 restorations included; 42 restorations evaluated (Included patients with attrition)	7 years	Leucite-reinforced, pressed	Molars and premolars	Vital and non-vital	Different composite cements (light cured, dual cured)	USPHS	95.2	Margin integrity	66.7	28.6	4.7
													Margin discoloration	69	31	0
													Caries	97.6	2.4	0
van Dijken et al. (2001)[44]	11	P	University	110 patients; Mean age: 53 years (26–81 years)	182 restorations included and evaluated	5 years	Leucite-reinforced, pressed	Molars and premolars	Vital and non-vital	Dual cured and self-cured composite cements	USPHS	92.9	Margin integrity	30.2	63.2	6.6
													Margin discoloration	83.5	16.4	0
													Color	85.8	13.7	0.5
													Surface	44.5	55.5	0
													Anatomy	86.3	6.6	7.1
													Caries	98.9	0	1.1
Barghi and Berry (2002)[45]	11	P	University	12 patients	21 restorations included and evaluated (Excluded bruxers and patients with severe tooth wear)	4 years	Feldspathic, sintered	Molars and premolars	Vital teeth	Dual cured composite cement	USPHS	100	Margin integrity	90.5	9.5	0
													Color	100	0	0
													Anatomy	95.2	4.8	0
													Hypersensitivity	100	0	0
													Caries	100	0	0
Arnelund et al. (2004)[46]	9	R	Public clinic	Mean age: 48 years (24–78 years)	136 restorations included; 117 restorations evaluated	5 years	Leucite-reinforced, pressed; Feldspathic, sintered	Anterior and posterior teeth	NA	2 different dual cured composite cements	CDA	95.5				

(Continues)

TABLE 4 (Continued)

	Study details				Restoration detail							Outcome				
													Degradation			
														Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
Smales and Etemadi (2004)[47]	7	R	Private practice	50 patients; Age: 15-more than 51 years)	78 ceramic restorations evaluated; 19 PFM restorations evaluated (Included bruxers)	6 years	Feldspathic, sintered	Molars and premolars	Vital and non-vital	Dual cured composite cement	Restoration longevity	Ceramic onlay survival: 73.1 PFM onlay survival: 78.9				
Kaytan et al. (2005)[48]	12	P: Split mouth	University	44 patients'; Age: 23–49 years	47 ceramic restorations included; 44 ceramic restorations evaluated; 47 composite restorations included; 44 composite restorations evaluated; (Excluded bruxers)	2 years	Leucite-reinforced, pressed	Molars	NA	Dual cured composite cement	USPHS	100	Margin integrity (ceramic)	61	39	0
													Margin integrity (composite)	60	40	0
													Margin discoloration (ceramic)	85.3	14.7	0
													Margin discoloration (composite)	83.3	16.7	0
													Color (ceramic)	90.2	9.8	0
													Color (composite)	60	40	0
													Surface (ceramic)	90.2	9.8	0
													Surface (composite)	76.7	23.3	0
													Anatomy (ceramic)	100	0	0
													Anatomy (composite)	100	0	0
													Caries (ceramic)	100	0	0
													Caries (composite)	100	0	0

(Continues)

TABLE 4 (Continued)

	Study details				Restoration detail						Outcome				
												Degradation	Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
Naeselius et al. (2008)[49]	11	R	Private practice	59 patients; Mean age: 50.3 years	130 restorations included; 81 restorations evaluated	4 years	Leucite-reinforced, pressed	Molars and premolars	Vital and non-vital	Dual cured and self-cured composite cements	CDA	93	Margin integrity	59.8	40.2	0
													Margin discoloration	86.6	13.4	0
													Color	75.6	24.4	0
													Surface	29.3	69.5	1.2
													Anatomy	92.7	7.3	0
Otto and Schneider (2008)[50]	11	R	Private practice	Mean age: 37 years (17–75 years)	25 restorations included; 15 restorations evaluated (Included bruxers)	15 years	Feldspathic, chairside CAD/CAM	Molars and premolars	Vital	Dual cured composite cement	USPHS	93.3	Margin integrity	13.3	86.7	0
													Color	53.3	46.7	0
													Surface	26.7	73.3	0
													Contour	40	53.3	6.7
Barnes et al. (2010)[51]	10	P	University	NA	19 restorations included; 13 restorations evaluated	3 years	Leucite-reinforced, pressed	Molars and premolars	NA	2 dual cured composite cements	USPHS	94.7	Margin integrity	92	8	0
													Margin discoloration	92	8	0
													Color	100	0	0
													Anatomy	92	8	0
													Hypersensitivity	100	0	0
													Caries	100	0	0
Federlin et al. (2010)[52]	12	P: split mouth	University	22 patients; Mean age: 37 years (32–44 years)	29 ceramic restorations included; 22 ceramic restorations evaluated; 29 gold restorations included; 22 gold restorations evaluated	5.5 years	Feldspathic, laboratory CAD/CAM	Molars and premolars	NA	The gold onlays were cemented with zinc phosphate; The ceramic onlays were cemented with dual cured composite cement	USPHS	Ceramic onlay survival: 88.8; Gold onlay survival: 93.3%	Margin integrity (ceramic)	63.6	36.4	0
													Margin integrity (gold)	86.4	13.6	0

(Continues)

TABLE 4 (Continued)

Study (year)	Study details: Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Restoration detail: Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Outcome: Survival (%)	Degradation: Pattern	Outcome: Success (%)	Survival, excluding success (%)	Failure (%)
													Margin discoloration (ceramic)	54.5	45.5	0
													Margin discoloration (gold)	95.5	4.5	0
													Surface (ceramic)	86.4	13.6	0
													Surface (gold)	81.8	18.2	0
													Anatomy (ceramic)	54.5	31.8	13.6
													Anatomy (gold)	90.9	9.1	0
													Hypersensitivity (ceramic)	95.5	4.5	0
													Hypersensitivity (gold)	95.5	4.5	0
													Caries (ceramic)	95.5	0	4.5
													Caries (gold)	100	0	0
van Dijken and Hasselrot (2010)[43]	11	P	University	105 patients; Mean age: 52 years (26–81 years)	252 restorations included; 228 restorations evaluated; (Included bruxers)	15 years	Leucite-reinforced, pressed	Molars and premolars	Vital and non-vital	Dual cured and self-cured composite cements	USPHS	75.9	Margin integrity	27.8	55.1	17
													Margin discoloration	61.2	38.3	.5
													Color	79.8	18.1	2.1
													Surface	58.5	41.5	0
													Anatomy	75.7	8.1	16.2
													Caries	93.1	0	6.9
Atali et al. (2011)[53]	10	P	University	20 patients	20 restorations included and evaluated	3 years	Leucite-reinforced, pressed	Molars	Non-vital	2 dual cured composite cements	USPHS	95	Margin integrity	80	15	5
													Margin discoloration	95	5	0
													Color	100	0	0
													Surface	80	15	5
													Anatomy	80	15	5

(Continues)

TABLE 4 (Continued)

	Study details						Restoration detail					Outcome				
													Degradation			
														Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
													Occlusal contacts	80	15	5
													Caries	100	0	0
Beier et al. (2012)[14]	8	R	University	Mean age: 46.5 years	213 restorations included; (Included bruxers)	8.5 years	Feldspathic, sintered	Molars and premolars	Vital and non-vital	2 dual cured composite cements	CDA	5 years: 98.9; 10 years: 92.4; 12 years: 92.4				
Murgueitio and Bernal (2012)[54]	11	R	Private practice	99 patients; Mean age: 42 years	210 restorations included and evaluated; (Different occlusal thickness: thin (1.0–1.4 mm), medium (1.5-1.9 mm) and thick (2 mm or more))	3 years	Leucite-reinforced, pressed	Molars and premolars	Vital and non-vital	Dual cured composite cement	USPHS	96.7				
Guess et al. (2013)[55]	11	P: Split mouth	University	14 patients	40 pressed restorations included; 24 pressed restorations evaluated; 40 milled restorations included; 24 milled restorations evaluated; (Excluded patients with parafunction)	7 years	Lithium disilicate, pressed; Leucite-reinforced, laboratory CAD/CAM	Molars	Vital	Light cured composite cement	USPHS	Pressed ceramic onlay survival: 100; CAD/CAM ceramic onlay survival: 97	Margin integrity (CAD/CAM)	54.2	45.8	0
													Margin integrity (pressed)	58.3	37.5	4.2
													Margin discoloration (CAD/CAM)	45.8	54.2	0
													Margin discoloration (pressed)	45.8	54.2	0
													Color (CAD/CAM)	37.5	62.5	0
													Color (pressed)	12.5	87.5	0
													Surface (CAD/CAM)	16.7	75	8.3
													Surface (pressed)	8.3	79.2	12.5
													Anatomy (CAD/CAM)	66.7	33.3	0

(Continues)

TABLE 4 (Continued)

Study (year)	Study details: Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Restoration detail: Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Outcome: Survival (%)	Degradation: Pattern	Outcome: Success (%)	Survival, excluding success (%)	Failure (%)
													Anatomy (pressed)	83.3	16.7	0
													Caries (CAD/CAM)	100	0	0
													Caries (pressed)	100	0	0
Klink and Huettig (2013)[56]	9	P	University	NA	25 restorations included; 23 restorations evaluated	4 years	Feldspathic, laboratory CAD/CAM	Anterior and posterior teeth	NA	Dual cured composite cement and self-adhesive resin cement	CDA	92	Surface	96	4	0
													Anatomy	92	4	4
Ozyoney et al. (2013)[57]	12	P	University	50 patients; Mean age: 28.3 years (16–35 years)	53 restorations included; 50 restorations evaluated; (Compromised molars, excluded patients with parafunction)	4 years	Lithium disilicate, pressed	Molars	Non-vital	Dual cured composite cement	USPHS	92.5	Margin integrity	92	8	0
													Margin discoloration	86	10	4
													Color	86	10	4
													Surface	96	4	0
													Anatomy	98	2	0
													Proximal contact	100	0	0
													Occlusal contact	100	0	0
													Caries	100	0	0
Baader et al. (2016)[58]	12	P: split mouth	University	18 patients; Median age: 41 years (25–59 years)	34 restorations without selective enamel etching included; 18 restorations without selective enamel etching evaluated; 34 restorations with selective enamel etching included; 18 restorations with selective enamel etching evaluated	6.5 years	Feldspathic, laboratory CAD/CAM	Molars and premolars	NA	Self-adhesive resin cement, and self-adhesive resin cement with selective etching	USPHS	Survival without selective etching: 60; Survival with selective etching: 82	Margin integrity (no etching)	18.8	62.5	18.8

(Continues)

TABLE 4 (Continued)

	Study details						Restoration detail					Outcome				
													Degradation			
														Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
													Margin integrity (etching)	22.2	61.1	16.7
													Margin discoloration (no etching)	12.5	37.5	50
													Margin discoloration (etching)	11.1	55.6	33.3
													Surface (no etching)	31.3	68.8	0
													Surface (etching)	22.2	77.8	0
													Anatomy (no etching)	75	18.8	6.3
													Anatomy (etching)	77.8	11.1	11.1
													Hypersensitivity (no etching)	100	0	0
													Hypersensitivity (etching)	100	0	0
													Caries (no etching)	87.5	6.3	6.3
													Caries (etching)	88..9	5.6	5.6
Archibald et al. (2017)[59]	12	R	University	30 patients; Mean age: 52 years (24–80 years)	65 restorations included; 37 restorations evaluated	3.5 years	Lithium disilicate, pressed and chairside CAD/CAM	Molars and premolars	Vital and non-vital	Dual cured composite cement	USPHS	91.9	Margin integrity	32.4	58.8	8.8
													Margin discoloration	47.1	52.9	0
													Color	32.4	67.7	0
													Surface	44.1	53.0	2.9
													Anatomy	76.5	20.6	2.9
													Hypersensitivity	91.2	8.8	0
													Caries	91.2	8.8	0
Lu et al. (2018)[60]	12	P	University	91 patients; Mean age: 37.7 years (18–71 years)	34 ceramic restorations included; 67 polymer-infiltrated ceramic restorations included	3 years	Feldspathic, chairside CAD/CAM; Polymer-infiltrated, chairside CAD/CAM	Molars and premolars	Non-vital	Dual cured composite cement	USPHS	Feldspathic onlay survival: 90.7; Polymer-infiltrated onlay survival: 97.0	Margin integrity (feldspathic)	93.1	6.9	0

(Continues)

TABLE 4 (Continued)

		Study details				Restoration detail						Outcome	Degradation			
														Outcome		
Study (year)	Study quality score (0–12)	Design	Setting	Patient number; Patient age	Restoration number (description)	Duration	Ceramic fabrication materials and methods	Location	Vitality	Cementation material	Evaluation Criteria	Survival (%)	Pattern	Success (%)	Survival, excluding success (%)	Failure (%)
													Margin integrity (polymer-infiltrated)	92.3	7.7	0
													Margin discoloration (feldspathic)	82.8	17.2	0
													Margin discoloration (polymer-infiltrated)	84.6	15.4	0
													Color (feldspathic)	72.4	27.6	0
													Color (polymer-infiltrated)	84.6	15.4	0
													Anatomy (feldspathic)	89.7	10.3	0
													Anatomy (polymer-infiltrated)	89.2	10.8	0
													Caries (feldspathic)	100	0	0
													Caries (polymer-infiltrated)	100	0	0

CDA = California dental association criteria; NA = not available; PFM = porcelain fused-to-metal; P = prospective; R = retrospective; USPHS = United States public health service criteria.

restoration suffered from deterioration that did not necessitate replacement. Failure was considered when the restoration had to be replaced. In situations where the studies included deterioration outcomes at different periods of the study, the deterioration outcome proportions in each evaluation period were calculated.

3.3 | Outcome

3.3.1 | Onlay longevity/survival

According to the medium-term studies (2–5 years) the survival rate had a range of 91–100%.[44–46,48,49,51,53,54,56,57,59,60] The longer term studies (more than 5 years) generally indicated a reduced survival rate (71–98.5%).[14,41–43,47,50,52,55,58] The causes of ceramic onlay failure were grouped as onlay fracture, debonding (loss of retention), caries and other causes such as endodontic complications, periodontal complications and extraction of the restored tooth (Figure 1).

By far, the most frequently reported failure pattern was fracture of the onlay and/or the tooth, which was observed in 16 studies (76.2%).[14,41–44,47,49–52,54–56,58–60] The fracture percentage of all the failures ranged from 29.1 to 83.3%. In fact, some studies found onlay fracture as the only failure pattern.[42,50,51,54,55] The second most common pattern of failure was debonding, which was reported by nine studies (42.9%).[43,44,47,49,52,56–58,60] The percentage of debonding ranged from 12.0 to 60.0% of all failures. The third cause of onlay failure was caries and it was reported by 6 studies (28.6%) (incidence of 6.3% to 40.0% of all failures).[14,43,44,57,58,60]

3.3.2 | Onlay deterioration

Regardless of the onlay restorative material and technique, there was a consistent and time-dependent deterioration of the onlays. The commonly observed deterioration patterns were related to margin integrity, margin discoloration, surface roughness, color match and anatomical form.

The most frequent form of deterioration was associated with margin quality (integrity and discoloration). Fourteen studies (66.7%) reported deterioration of margin integrity (adaptation) in the range of 6.9–86.7% (Figure 2).[41,43,44,48–53,55,57–60] It appears that even at baseline, most of the studies reported minor deficiencies of the margin integrity. As the duration of service increased, the success of margin integrity was markedly reduced. However, the prevalence of unacceptable margin integrity occurred in 0–17.8% of the onlays. Thus, although the margin integrity of ceramic onlays is likely to deteriorate, the prevalence of unacceptable margin integrity was low.

The second most frequent form of deterioration was margin discoloration and this was reported by 13 studies (61.9%).[42–44,48,49,51–53,55,57–60] Relatively high levels of margin discoloration were documented (ranging from 5.0 to 88.2% of the restorations) (Figure 3). However, the prevalence of unacceptable margin discoloration was generally low (0 to 0.5%), except in one study that reported a 44.7% incidence of unacceptable margin discoloration after 6.5 years.[58]

Onlay color match, surface roughness and contour deteriorations were less prevalent. Eleven studies (52.4%) observed deficiency in onlay color match,[43,44,48–51,53,55,57,59,60] that was in the range of 0–75.0% of the onlays (Figure 4). However, unacceptable color match was reported to occur in up to 4.0% of the onlays. Increase in surface roughness occurred in 12 studies (57.1%) and affected up to 4.0–87.5% of the ceramic onlays (Figure 5).[43,44,48–50,52,53,55–59] In general, the rate of unacceptable surface roughness was low (0–10.4% of onlays). Contour or anatomic form was evaluated by 14 studies (66.7%) (Figure 6),[43,44,48–53,55–60] and limitations in the contour were found to be in the range of 0–60.0% on the onlays. The unacceptable contour rate was low and in the range of 0–16.2%. It appears that there were considerable variations in the color match, surface roughness and contour among the studies, even at baseline. Nevertheless, the low incidence of onlay failure due to these variables indicates that they are not major limitations of ceramic onlays.

On the contrary, few papers (23.8%) reviewed the occurrence of hypersensitivity, which was more prevalent at baseline (Figure 7).[45,51,52,58,59] However, the studies consistently reported reduction and disappearance of the hypersensitivity, which indicates that the hypersensitivity after onlay cementation is of a transient nature.

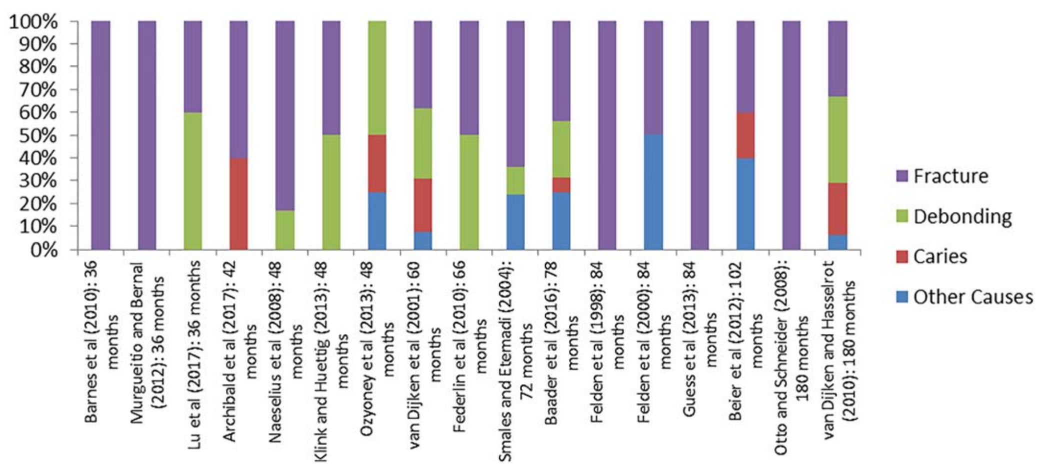

FIGURE 1 Distribution of the failure pattern proportions (%) from the included studies

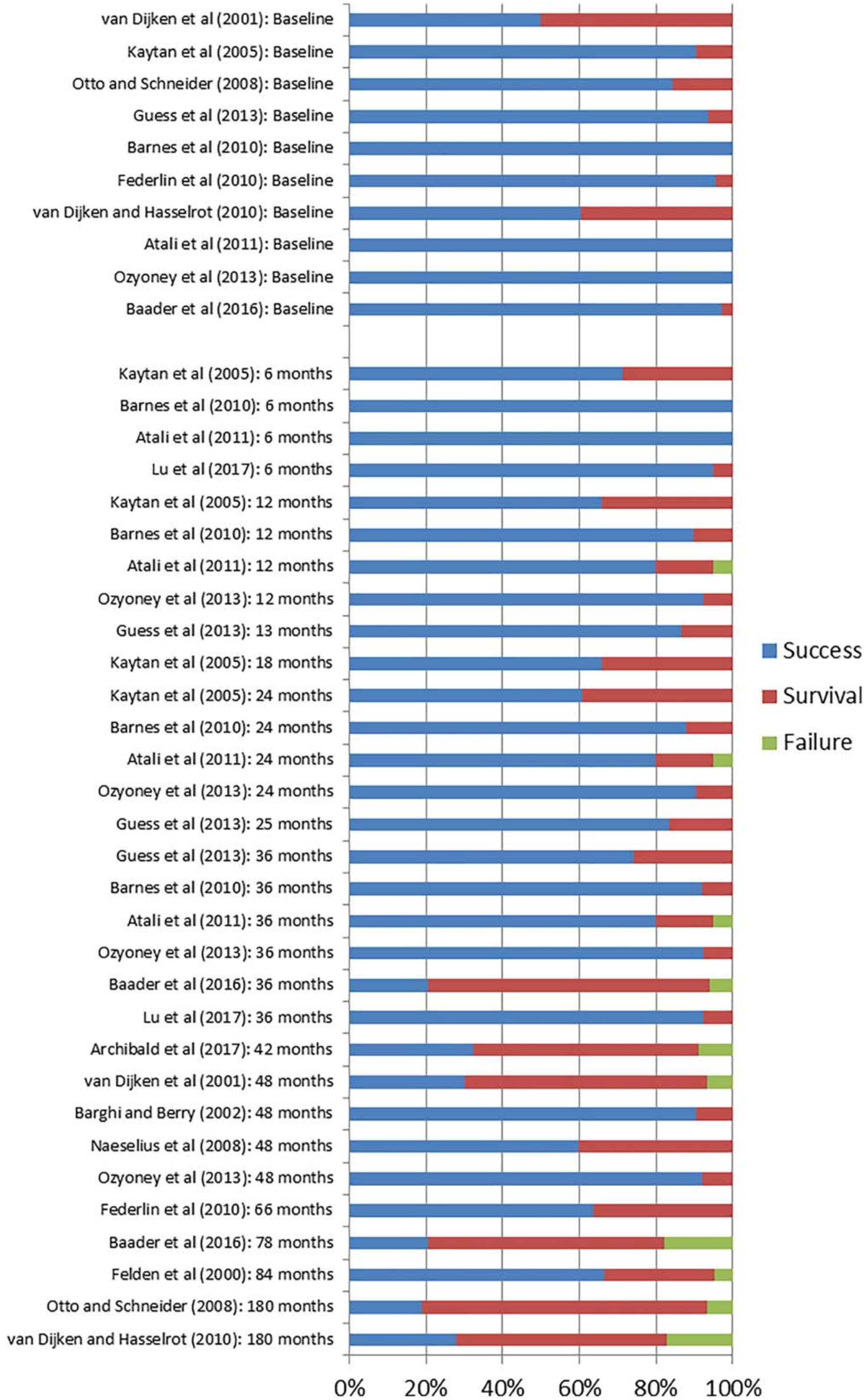

FIGURE 2 Margin integrity

3.3.3 | Factors influencing onlay outcome

Preparation and extension

Three studies (14.3%) evaluated the effect of preparation variables on onlays longevity.[43,47,54] Smales and Etemadi found no clear influence of preparation thickness (2.1–3.2 mm floor depth reduction, and 1.6–2.6 mm working cusp reduction) and taper on fracture of molar feldspathic onlays.[47] van Dijken and Hasselrot evaluated four preparation designs for leucite-reinforced ceramic: (1) partial coverage with no

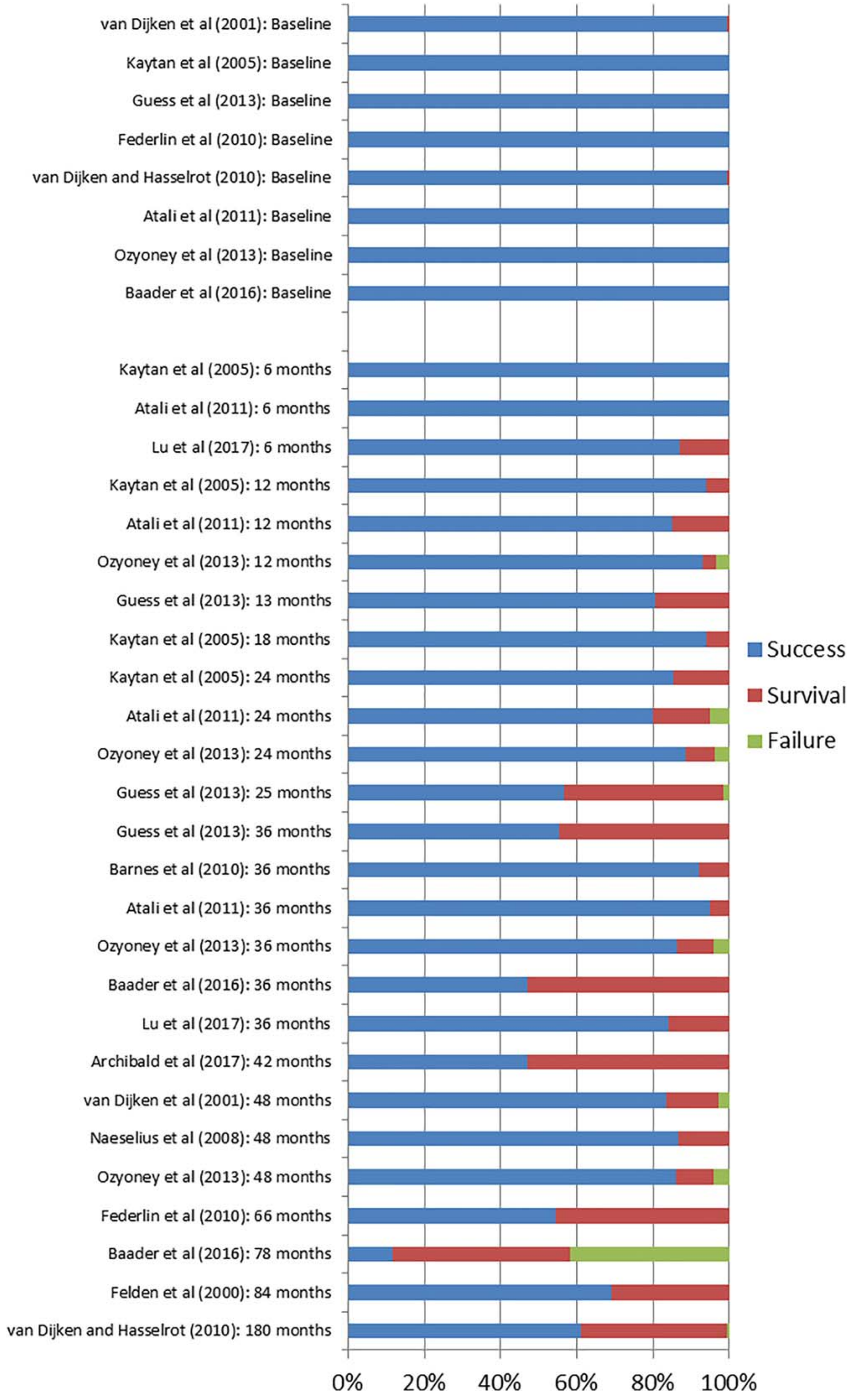

FIGURE 3 Margin discoloration

shoulder, (2) partial coverage with minimal retentive features (shoulder or chamfer), (3) full coverage with minimal retentive features (shoulder or chamfer addition) and (4) endodontically treated teeth with no retention (no post or core).[43] The 4th group had the greatest failure rate (37%), followed by the 1st group (34.5%). The 2nd (18.2%) and 3rd (22.6%) groups were relatively similar and had the most superior outcome. Their results indicated that incorporation of retentive features within the preparation may reduce the failure of onlay restorations.[43]

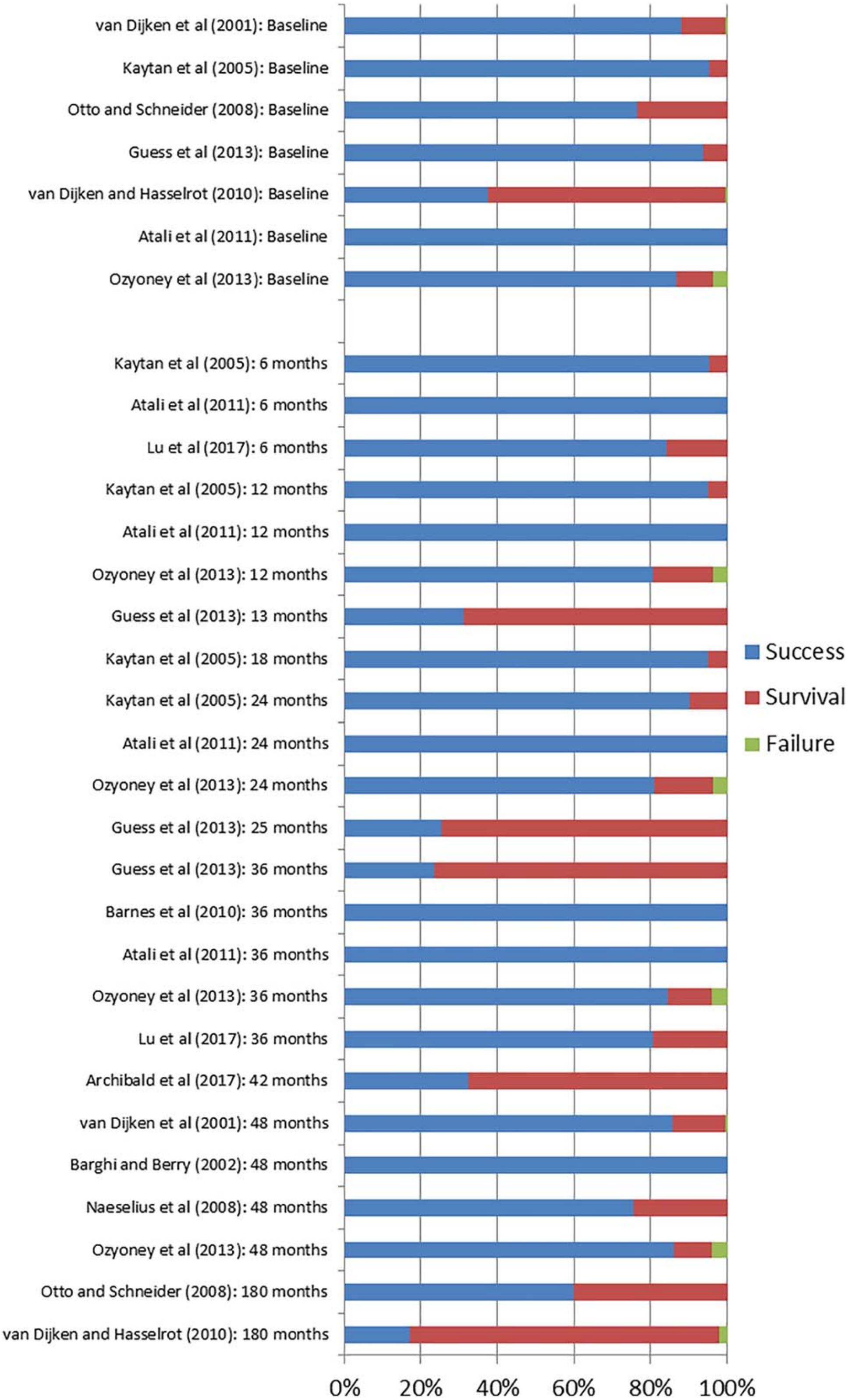

FIGURE 4 Color match

Murgueitio and Brenal evaluated the effect of three leucite-reinforced onlay occlusal thicknesses: thin (1–1.4 mm), medium (1.5–1.9 mm), and thick (2 mm or more).[54] They found that increased leucite-reinforced ceramic onlay thickness reduced the probability of failures, and 85.7% of the fractures were for onlays with thicknesses <2 mm.

Five studies (23.8%) included comparisons between ceramic onlays and ceramic inlays. Felden et al. found significantly lower survival

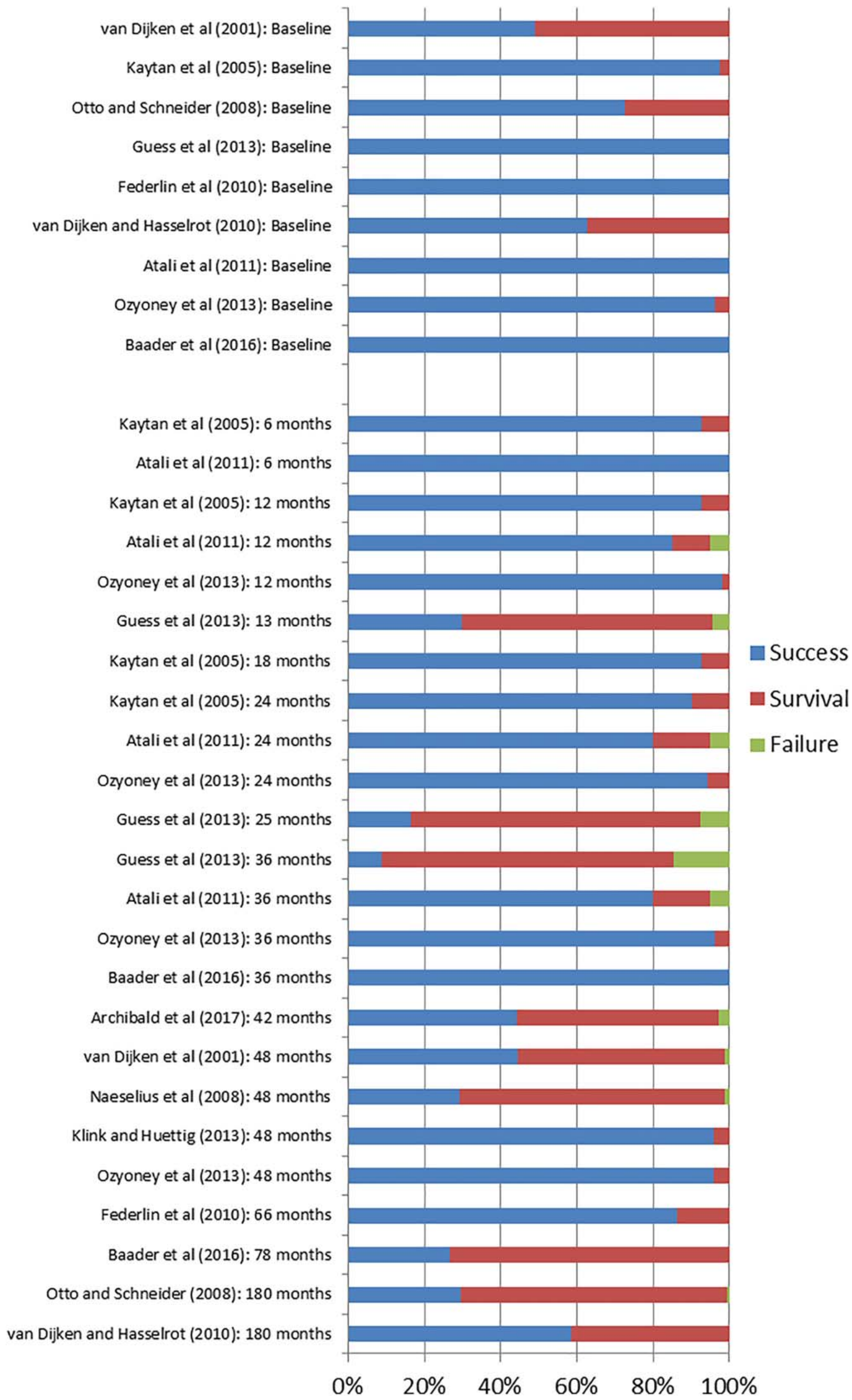

FIGURE 5 Surface roughness

probability for onlays (cast, pressed, sintered and milled) than inlays over a 7-year period.[42] However, they attributed the failures to the inclusion of weak ceramic material such as castable ceramic. On the other hand, three studies found that onlays exhibited better longevity than inlays.[46,49,56] Over 5 years, Arnelund et al. reported an insignificantly higher tendency of failure for inlays than onlays (pressed leucite-reinforced or sintered feldspathic).[46] Likewise, after 4 years, Naeselius et al., and Klink and Huettig had found significantly better survival for

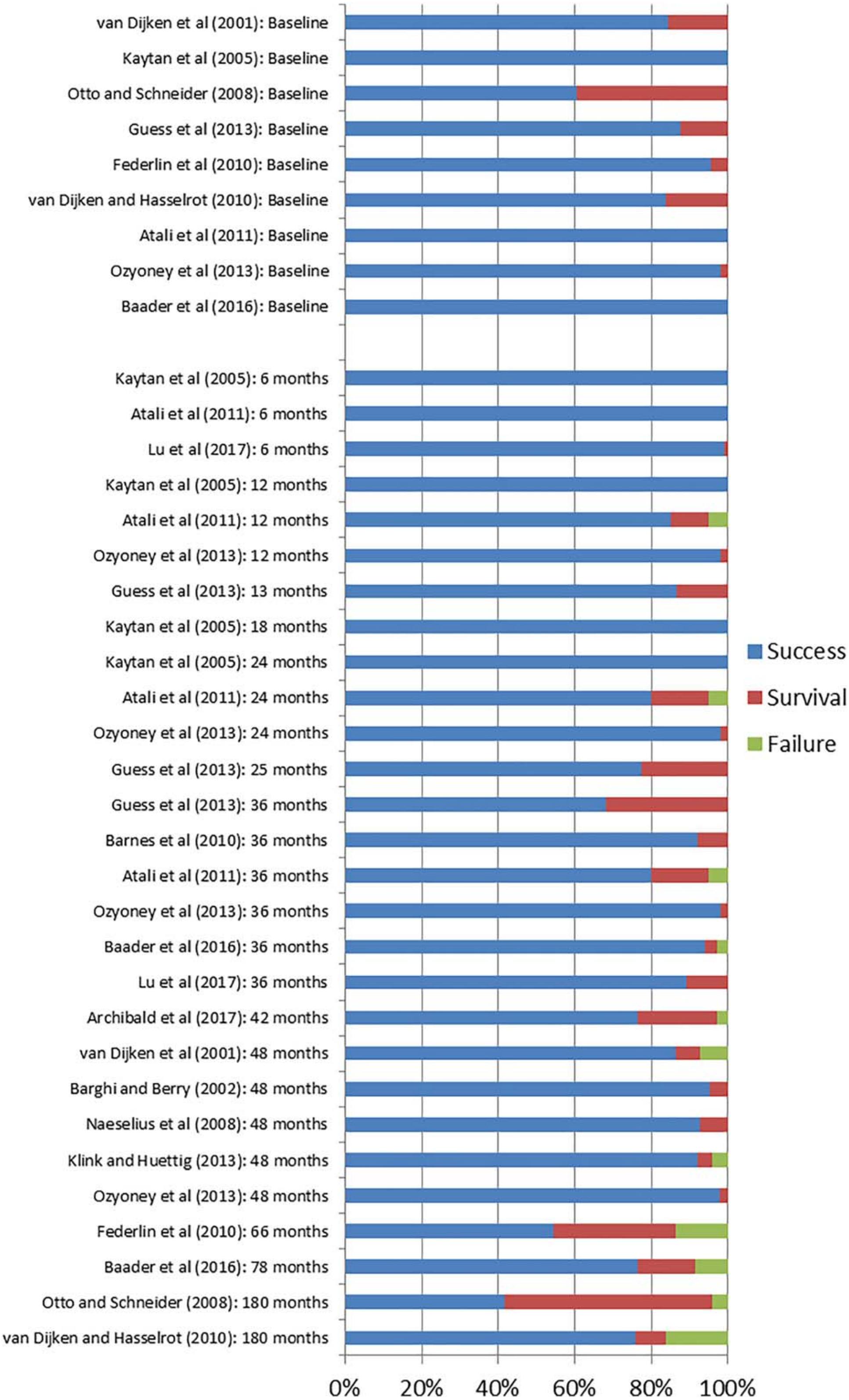

FIGURE 6 Anatomic form

onlays than inlays for pressed leucite-reinforced and feldspathic ceramics respectively.[49,56] However, after 8.5 years, Beier et al. had found no significant difference between onlays and inlays fabricated from feldspathic ceramic.[14]

Therefore, it appears from the available studies, ceramic onlay longevity, specifically fabricated from leucite-reinforced, may be enhanced by providing sufficient occlusal thickness of at least 2 mm. Retentive features appear to have a positive effect. There is tendency for the

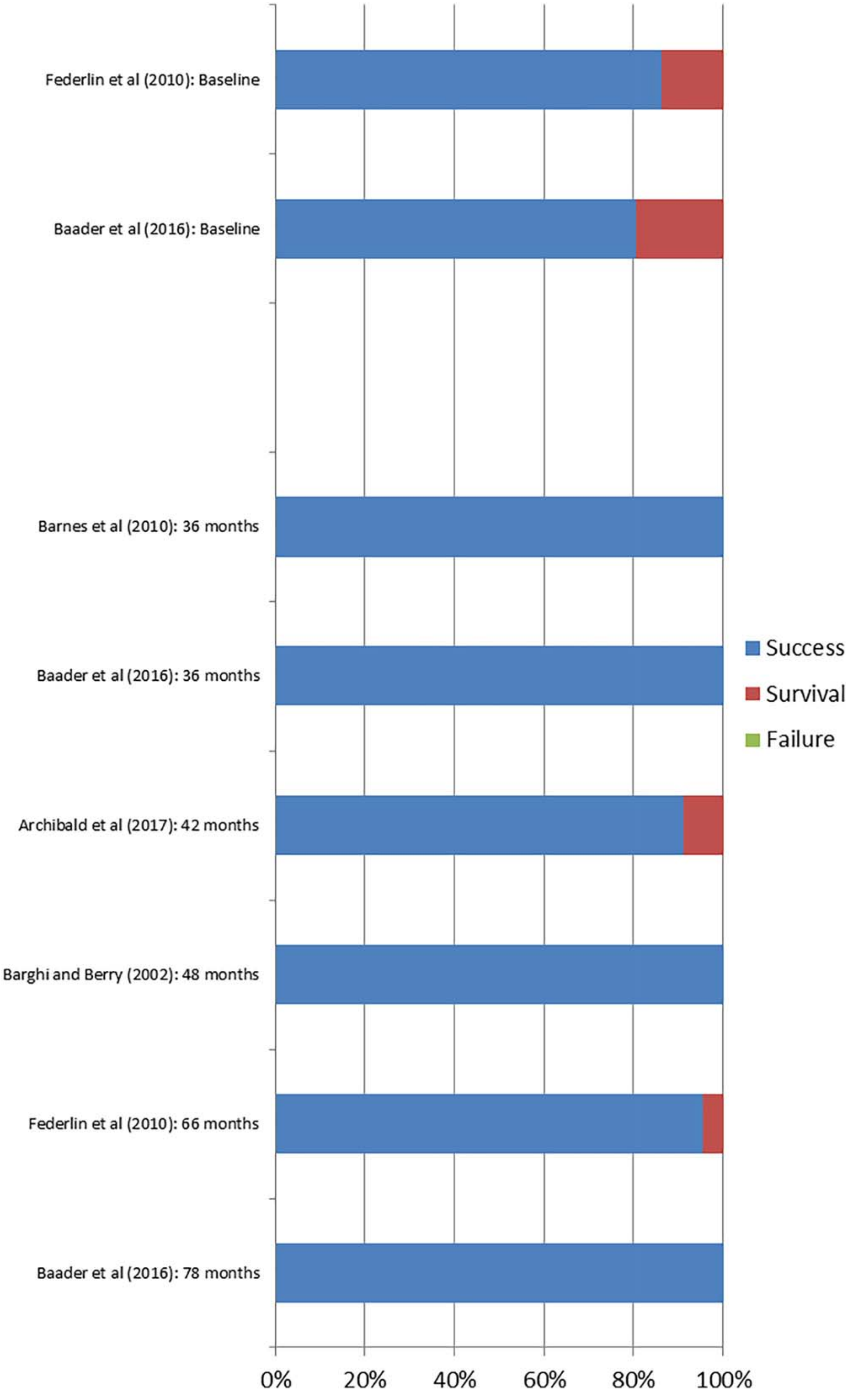

FIGURE 7 Hypersensitivity

ceramic onlays to be associated with a better clinical outcome than inlays. However, more standardized studies are needed to confirm these outcomes.

Fabrication materials and methods

Four studies (19.1%) compared different materials and methods for fabricating the ceramic onlays.[42,46,55,60] After evaluating cast, pressed, milled and sintered ceramics, Felden et al. found 92.9% of the fractures occurred in restorations fabricated from cast ceramics over 7 years.[42] Over 5 years, Arnelund et al. found no difference in the clinical performance of sintered feldspathic ceramic and pressed leucite-reinforced ceramic.[46] After 7 years, Guess et al. found milled leucite-reinforced ceramic and pressed lithium disilicate ceramic onlays to have similar reliability.[55] Interestingly, milled inlays exhibited increased surface roughness and a more deficient color match, which may be attributed to the milling process. A 3 years study indicated that onlays fabricated from chairside CAD/CAM feldspathic and polymer-infiltrated ceramics have similar clinical outcome.[60] Therefore, with the exception of cast ceramic onlays which are not applicable to contemporary dental practice, none of the available studies reported systemic superiority of any material or fabrication method. This is further supported by the rest of the studies that indicated the feasibility of ceramic onlays regardless of the material used and the method of fabrication. Further, the evaluated CAD/CAM systems appear to provide an acceptable outcome.

Three studies (14.3%) compared the longevity of ceramic onlays against alternative onlay materials.[47,48,52] Smales and Etimadi compared feldspathic ceramic onlays and PFM onlays. In general, the two materials demonstrated similar clinical performance over the 6-year period.[47] Kaytan et al. compared ceramic onlays (pressed leucite-reinforced) and composite resin onlays over 2 years.[48] Overall, the two materials were similar, except for the color match, which was superior for the ceramic onlays. Over 5.5 years, Federlin et al. compared ceramic onlays against gold onlays. They found that although the survival was similar for the two onlay materials, ceramic onlays had inferior stability of margin integrity, margin discoloration and anatomic form.[52]

Therefore, studies to date suggest there is no indication that one ceramic material performs better than another, and the fabrication methods appear to minimally influence the ceramic onlay performance. After comparing ceramic onlay materials to indirect composite or cast gold restorations, it appears that the survival rate is similar. However, the gold onlays tend to be more resistant to deterioration, whilst the indirect composite onlays tend to be inferior to ceramic onlays.

Restoration location

Six studies (28.6%) reported the implication of restoration location on longevity.[14,46,47,49,50,54,59] Arnelund et al. indicated that molar onlays were four times more likely to fail than premolar onlays.[46] Similarly, the studies by Smales and Etemadi, and Otto and Schneider found molar onlays had three times more fracture than premolar onlays.[47,50] The other studies found that failures occurred on molars only.[49,54,59] In one of these studies, ceramic onlays on 2nd molars were five times more susceptible to fail than those on 1st molars.[54] On the other hand, Beier et al. did not report significant difference of the survival for ceramic onlays on premolars and molars.[14]

Bonding and cementation agents

Although several adhesives and cementation agents were implemented, overall, the studies did not clearly disclose a preference for one system over another. Five studies (23.8%) evaluated the impact of bonding and cementation agents on ceramic onlays longevity.[43,44,51,53,58] Two studies found no difference between dual-cured and self-cured composite cements.[43,44] Similarly, Barnes et al. and Atali et al. found no difference between different dual-cured composite cements.[51,53] In a cross mouth study, Baader et al. evaluated two different cementation protocols using self-adhesive resin cementation material. Half of the onlays were cemented with selective enamel etching and the other half were cemented without selective enamel etching.[58] Both of the cementation methods experienced deterioration over time with respect to margin integrity and margin discoloration. They observed a significantly higher survival rate after selective etching than without, which led them to recommending selective etching prior to the use of self-adhesive resin cement when covering multiple cusps with reduced retention and tooth structure.

Tooth vitality

Four studies (19.1%) reported the outcome of ceramic onlays on vital and non-vital teeth.[14,43,44,54] The consensus of the studies is that vital teeth have a more favorable outcome and were less likely to fail than nonvital teeth. Nevertheless, three studies were conducted solely on non-vital teeth and the authors reported an acceptable outcome.[53,57,60]

Parafunctional habits

Four 4 studies (19.1%) clearly stated that they excluded patients with parafunctional habits[45,48,55,57] and several studies (57.1%) did not provide any specification.[41,44,46,49,51–54,56,58–60] A total of five studies (23.8%) reported the effect of parafunctional habits on the longevity of onlays,[14,42,43,47,50] and 4 of them showed a negative effect of parafunctional habits on onlay longevity. Felden et al. found all the fractures occurred in patients with signs of attrition.[42] Smales and Etemadi, and van Dijken and Hasselrot reported a greater chance for onlays failure for patients with parafunctional habits.[43,47] Some studies found that patients with multiple fractures had bruxism.[50,59] On the contrary, Beier et al. indicated no greater risk for patients with bruxism.[14]

4 | DISCUSSION

4.1 | Ceramic onlay survival

This review confirms that ceramic onlays have an acceptable medium-term survival (91–100%) and long-term survival (71%–98.5%). This finding is consistent with other reviews assessing survival of ceramic restorations.[16–19] A literature review by El-Mowafy and Brochu identified that survival rates for ceramic restorations ranged from 96% at 4.5 years to 91% at 7 years.[16] Pieger et al. demonstrated that ceramic crowns had a cumulative survival rate of 97.8% at 5 years, and 96.7% at 10 years.[19] More recently, a systematic review by Morimoto et al. showed that the estimated survival rate for the ceramic restorations was 95% at 5 years and 91% at 10 years.[18] Similar to this study, these reviews on ceramic restorations consistently reported that fracture is the most frequent type of ceramic restoration failure,[16–19] which can be attributed to ceramic vulnerability to fatigue and crack propagation from internal or external surfaces.[7]

The second most common cause for ceramic onlay failure is debonding which reflects failure at the cementation interface. Although the use of adhesives is commonplace in the modern dental practice, the procedure for ceramic bonding remains technique sensitive.[9,43] Factors that complicate ceramic adhesion include cement manipulation and adherence to bonding protocol, moisture control and etching.[58] This is even more important for onlays due to the generally less retentive preparation and the greater reliance on the adhesive bonding to retain the restoration. However, from the studies assessed, due to the number of different types of adhesives, cements, treatments of the ceramic surface and variable isolation techniques used, it was impossible to observe a relationship between the cementation procedure and debonding. It was noted that, in one study, the involved clinicians had a different failure rate of ceramic restorations, which may be attributed to different cementation techniques and clinical experience.[44]

In comparison with other indirect onlay restorations (PFM, composite and gold), the limited data illustrates that ceramic onlays yield a generally comparable survival outcome.[47,48,52] While the longevity of ceramic onlays appear to be similar to composite onlays, ceramic onlays have the advantage of being more color stable.[48] Such observations can be due to the stability of ceramic material in the oral environment as opposed to composite resin material which is more prone to surface wear and discoloration.[17,48] On the other hand, according to the present review, ceramic onlays have inferior stability (anatomic form, margin integrity and discoloration) to gold onlays.[52] Earlier published studies assessing survival of gold onlays indicated similar survival to the observed outcome of ceramic onlays. The 10-year survival rates for gold onlays have been reported as 96.1[1], 94.5,[2] and 97%.[3] However, the failure pattern for gold onlay is somewhat different from ceramic onlays. Studer et al. identified in their study that the predominant reasons for failure of the gold onlays being secondary caries and loss of retention.[1] These results for gold onlays, when compared with the results from this review, illustrate that onlay restorations constructed from ceramic are at risk of failing by nature of the ceramic material itself. Because of the vulnerability of ceramic onlays to fracture, it is reasonable for the clinician to consider factors or modify their technique and selection criteria to enhance the outcome of ceramic onlays, which will be discussed later.

4.2 | Ceramic onlay deterioration

The reviewed studies revealed time dependent degradation of the ceramic onlays that was more noticeable in the long-term studies. The most common form of deterioration was associated with the restoration margins.[41,43–45,48–53,55,57,58] Margin integrity and discoloration are most likely influenced by the intimacy of margin fit of the ceramic restoration, and mechanical and chemical degradation of the adhesive cement. Such problems are further accentuated if there is inaccuracy in the margin fit of the ceramic restoration, or failure to seat the restoration due to the viscosity of composite cements. A laboratory investigation indicated a relationship exists between the width of the margin gap and the depth of margin deficiency.[10] Further, an SEM analysis of cemented inlays reported that the wider gap between the ceramic and tooth structure is associated with increased wear of the cementation composite and subsequent development of a margin deficiency.[11] Further, a wider gap will increase the portion of cement that is subjected to water sorption and eventual hydrolysis and plasticing of the polymer contents.[43] In effect, loss of the resin cement at the tooth-restoration interface creates an irregular surface that is susceptible to staining. Whilst this pattern of deterioration did not influence the survival of ceramic onlays, it may have important clinical consequences. In particular, if a patient is driven for an esthetic restoration, staining at the margin may compromise the patient's acceptance of the restoration in the long run.

4.3 | Factors influencing ceramic onlay longevity

Despite the variations in ceramic materials composition and production methods, no relationship was evident between ceramic material and fabrication method, and ceramic onlay failure rate.[42,46,55] This systematic review indicates that more modern technologies for manufacturing ceramic onlays, such as chairside and laboratory CAD/CAM systems, appear to be comparable to conventional methods for producing ceramic onlays. This observation will most likely continue in the future with further advancement in the precision of digital dentistry. The similarity in the outcome of the onlay restorations regardless of the material and fabrication method can be attributed to the "strengthening effect" of adhesive bonding of a glass ceramic material. This applies to feldspathic, leucite-reinforced, and lithium disilicate ceramics, which can be attributed to adhesive cementation compensating for the mechanical differences between the different materials.[18] Thus, while different ceramics exhibit different mechanical properties, the influence on the clinical performance is less obvious. In addition, the partial coverage nature of the ceramic onlays means the durability of the onlay is attained from the remaining tooth structure and the available enamel that can further enhance the adhesive bonding. On the other hand, no study assessed the outcome of densely sintered ceramics, such as zirconia, for onlay restorations. It would be interesting to see how these alternative ceramic materials with improved mechanical behavior would compare to the glass-ceramic materials for onlays.

In terms of tooth preparation, it was stated by Murgueitio and Brenal that inadequate occlusal ceramic thickness was associated with onlay fracture.[54] Occlusal ceramic thickness of at least 2 mm was reported to reduce the risk of fracture for the glass-ceramic leucite-reinforced onlays, which can be attributed to resistance of flexion and crack propagation.[43,54] Further, addition of retentive features to the onlay preparation, such as shoulders or chamfers, was reported to enhance the survival of the ceramic onlays.[43] Such retentive features will increase the bonding interface between the tooth and the ceramic which has the capacity to improve the retention and fracture resistance. Further, the retentive features will provide a defined path of insertion of the onlay which will facilitate seating during cementation and reduce the exposure of the cement at the margin.

Whilst a number of studies identified that loss of tooth vitality negatively influenced the survival of ceramic onlays,[14,43,44,54] it is difficult to conclude that loss of tooth vitality *per se* is a risk factor for ceramic onlay fracture as other studies indicated acceptable outcomes of ceramic onlays when restoring nonvital teeth.[53,57] The inferior survival of non-vital teeth may otherwise be attributed to the lack of remaining tooth structure. Subsequently, in comparison to the vital tooth the restored nonvital tooth may have less capacity to support and retain the ceramic restoration.[43,54]

An observed pattern from this review is ceramic onlays are prone to failure in a high stress environment such as patients with parafunctional habits/bruxism and restorations on teeth further in the posterior region. Overall there is a perception that bruxism is associated with greater ceramic restoration fracture which led some studies to exclude patients with signs of bruxism.[45,48,55,57] Other studies related ceramic fractures to the patient being a bruxist, evidenced with signs of attrition.[14,43,47,50] However, in the studies reviewed, it is challenging to know if the ceramic fracture can be attributable directly with bruxism or alternative explanations such as the material used, clinical techniques and ceramic thickness. Further, it is not yet clear if additional clinical considerations should be implemented prior to placing ceramic restorations for patients with bruxism. The location of the onlay restoration within the dental arch has also been considered as a factor that may influence the longevity of a ceramic restoration. In the studies reviewed, despite a higher number of failures on molar teeth compared to premolars, this was not always significant.[14,46,47,49,50,54] The tendency of greater ceramic onlay failure in the more posterior position in the arch may be attributed to increased occlusal forces on the more posterior teeth.[54] To overcome the sensitivity of ceramic restorations to heavy occlusal forces, it has been suggested that metallic restorations are more ideal in areas where high occlusal forces are anticipated.[13,52]

Although this systematic review provides updated understanding on ceramic onlays, it suffers from several limitations, mainly the limited number of studies and the heterogeneity of the materials and assessments used. Whilst the majority of the studies implemented a form of universal index (e.g., USPHS or CDA), the reporting of the information differed. One of the reasons behind this variation is the subjectivity in restoration evaluation, inevitable operators' differences and the interrelation between these variables.

5 | CONCLUSIONS

Within the limitations of this study, it can be concluded that regardless of the follow-up duration, ceramic onlay restorations exhibited acceptable clinical outcomes. The most common pattern of failure of a ceramic onlay was fracture, followed by debonding. The most observed form of deterioration was associated with margin integrity and discoloration. Tooth preparation, tooth vitality and occlusal force appear to influence ceramic onlay survival. Different modern glass-ceramic materials, manufacturing techniques, and cementation materials have minimal effect on glass ceramic onlay survival. Future clinical research should aim to evaluated more optimized ceramic material and bonding technologies that can overcome the most common patterns of ceramic onlay failure and deterioration. In addition, the clinical studies should be more rigidly designed to isolate the factors that can influence the clinical outcome.

DISCLOSURE STATEMENT

The authors declare no conflict of interest or financial interest with any of the products included in the manuscript.

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