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Restorative options for moderate and severe tooth wear: A systematic review

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A R T I C L E I N F O

Keywords:
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Restorative treatment
Survival
Outcomes
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Systematic review

A B S T R A C T

Objectives: This systematic review aimed to evaluate the failure of different types of restorative treatments for tooth wear.
Study design: A search was conducted in Medline, Cochrane, Web of Science, SCOPUS, and Embase (October 2023) with no limits for publication year or language. Randomized and non-randomized studies comparing restorative options to treat moderate to severe tooth wear were included. Two reviewers independently selected studies, extracted data and assessed the risk of bias. Failure data was obtained from each study and organised into either 'major failure,' with the need to replace the restoration, or 'minor failure,' where the restoration was repaired or refurbished. Studies that did not bring comparisons or sufficient data to calculate failures were excluded.
Results: 3977 articles were found; 43 studies were eligible for analysis. For RCT studies ($n = 6$), direct composite showed a mean annual failure rate (AFR) of 10.54 % for minor failures and 8.38 % for major failures. For non-RCT studies ($n = 37$), these were 3.97 % and 0.4 % respectively. For RCT studies, indirect composite showed a mean AFR of 12.84 % for minor failures and 10.41 % for major failures. For non-RCT studies, these were 2.9 % and 0.15 % respectively. For RCT studies, indirect ceramic showed a mean AFR of 0.09 % for minor failures and 0.13 % for major failures. For non-RCT studies, these were 0.83 % and 0.33 % respectively.
Conclusion: Indirect restorations demonstrated lower failure rates; however, they can be more invasive and require more operator time than alternatives. Direct methods showed greater failures but offer a minimally invasive modality. (CRD42022358586)
Clinical Significance: This study will provide clinicians with a more informed view of the success, survival and failure rates of materials when deciding how to restore tooth wear.

1. Introduction

Tooth wear is the incremental loss of tooth tissue through mechanical or chemical breakdown of the enamel and dentine [1,2]. Tooth wear can present physiologically as part of normal function throughout the lifetime of a patient. Conversely, it can be pathological where the rate and severity of active wear is atypical and can impact on the patient's oral health-related quality of life and ultimately on tooth survival [3–7]. The incidence of this destructive process is increasing; however, the progression of tooth wear is amenable to prevention [8–13]. The preferred management approach for patients exhibiting moderate to severe tooth wear where restorative treatment is not indicated or not clinically necessary involves the implementation of counselling and an appropriate monitoring protocol [3,14]. This needs to be balanced against the risk of the condition worsening, which could potentially result in a less optimal result due to a decrease in the more favourable enamel substrate for bonding [3,5].

The potential impact of tooth wear as well as the costs and challenges associated with the rehabilitation of the severely worn dentition underpins the importance of a timely diagnosis and effective prevention, which may be delivered by dentists, patient education and government healthcare initiatives [15].

Moderate to severe tooth wear can manifest with a variety of effects, such as a reduced vertical dimension of occlusion, and symptoms, which

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include, tooth sensitivity, pain, discomfort and aesthetic complaints due to shortening of anterior units [16]. Under such circumstances, the provision of restorative treatment should aim to prevent further tooth tissue loss, protect the pulpal tissues from insult and improve function and aesthetics [7]. These clinical objectives will collectively contribute to the survival of the tooth, thereby maintaining a natural dentition for as long as possible [17].

Indirect prosthodontic approaches manage the residual worn dentition through conventional preparation of full crowns relying on resistance, partial occlusal coverage or backings which rely on adhesive bonding. Both may require preparation through the subtractive instrumentation of dental hard tissue. In contrast, direct approaches utilise adhesive bonding, often undertaken in a minimally invasive additive manner, without reducing tooth volume further [5]. The latter approach is cost-effective, protects the remaining tooth tissue and provides a restorative approach that is 'sustainable' in terms of restoration replacement without further compromising tooth volume [15]. The merits and advantages of this approach were recognised as part of a European Consensus Statement on Management Guidelines for severe tooth wear [3]. The conjecture between the decisions to restore adhesively, or through conventional means centres on the relative merits of each modality and its effect on the outcome. If aesthetics and durability offered by indirect restorations is found to be superior, their prescription requires balance, where natural tooth tissue is irreversibly damaged to produce the outcome. Conversely, direct resin restorations may be more labour intensive, technically challenging to achieve, require greater maintenance but are otherwise biologically more tolerable due to reduced invasiveness and more economical allowing access to wider socioeconomic groups [18].

Previous systematic reviews examining the variety of approaches through the restorative management of tooth wear have highlighted numerous weaknesses in the available evidence. These included the need for prospective studies, the absence of appropriate clinical details and baseline information, the lack of clear assessment criteria, management of bias and the presence of inadequate follow-up periods [19–23]. As such, formal statistical analysis has been confined to the calculation of Annual Failure Rates (AFRs) or Annual Intervention Rates (AIRs) without meta-analysis of randomised controlled trials [21,22]. Since the publication of the latter investigations, many further longitudinal studies examining the use of a variety of techniques to manage moderate to severe tooth wear have become available in the contemporary literature. These may provide further evidence to better inform and support material selection, as well as the method of treatment execution (full coverage or partial coverage restorations), and the mode (direct or indirect) of treatment delivery.

This study aimed to systematically search the literature for all available studies examining interventions (i.e. failure rates) for the restorative treatment of moderate to severe tooth wear, analyse the data, and provide recommendations on treatment approach and material selection.

2. Methods and materials

2.1. Study design

This systematic review was based on the guidelines of Cochrane Handbook for Systematic Reviews of Interventions and reported based on PRISMA Statement [24]. The systematic review protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO CRD42022358586), on September 13, 2022. An amendment was made to the registered version of the present study, namely the inclusion of monitoring as a group to be compared with restorative approaches and the inclusion of single-arm studies as part of the prospective and retrospective studies.

2.2. Eligibility criteria

The literature search has been established to address the research question phrased as follows in the PICO framework: *Population*: adult patients diagnosed with pathological moderate to severe tooth wear; *Interventions and Comparisons*: any treatment, this could involve the comparison of monitoring and a restorative treatment or restorative treatments (direct/indirect) with any type of dental material (ceramic, resin composite, etc.); *Outcome*: Restoration survival and success.

Studies that enrolled adults (age ≥18 years) diagnosed with moderate to severe tooth wear were considered for inclusion in this study. Studies including patients with temporomandibular disorders, bruxism, or orofacial pain were also eligible for inclusion. According to the literature, interventions for the treatment of tooth wear are widely variable and can be divided into the following groups: (1) indirect: any indirect material technique available e.g. porcelain veneers, ceramic crowns and onlays, indirect resin composite, indirect ceramic/composite, metal onlays, metal palatal veneers and polymer-infiltrated ceramic network (PICN); (2) direct: any direct material. Studies that have included both indirect and direct materials in the same patient were also included. Any study evaluating any of the interventions listed above was retained for inclusion in the review. Analysis was conducted according to dental restoration material type as only studies that compared restorative treatments were included in the review.

The following study types were included according to the eligibility criteria: controlled clinical trials, single-arm clinical trial, case series, randomized clinical trials, prospective clinical trials, and retrospective clinical trials. Case reports, in vitro studies, or clinical studies evaluating materials or techniques for restoring non-carious cervical lesions were excluded.

2.3. Information sources

A systematic literature search was conducted to select retrospective and prospective clinical studies that evaluated or compared management options to restore teeth with moderate to severe tooth wear. The search was conducted in Medline via Pubmed, Embase, Scopus, Web of Science and Cochrane Database of Systematic Reviews with no limits for publication year or language to identify clinical studies. The main outcome assessed was Annual Failure Rate for the studies that included treatment with restorations. The review was conducted between September 2022 and October 2023.

2.4. Search strategy

For this systematic review, a comprehensive search of the databases was conducted using a predefined search strategy (September 2022 and updated in October 2023; Table 1).

2.5. Study selection and data process

In Zotero, all the duplicates were removed by one independent

Table 1
Search terms used for the systematic review.

Database	Search terms
Pubmed	("Tooth Wear"[Mesh] OR Tooth Wears[All fields] OR Wear, Tooth [All fields] OR Wears, Tooth[All fields] OR Dental Wear[All fields] OR Dental Wears[All fields] OR Wear, Dental[All fields] OR Wears, Dental[All fields]) AND ("Clinical Study"[Publication Type] OR "Observational Study"[Publication Type])
Scopus	(tooth wear) AND (clinical study)
Web of Science	ALL=((tooth wear) AND (clinical study))
Embase	'Tooth wear' AND 'treatment'
Cochrane Library	(tooth wear) AND (treatment)

reviewer (IK). The remaining studies were all uploaded in Rayyan [25]. Following this, based on the inclusion and exclusion criteria, three independent reviewers (TC, IK and AA) analysed the titles and abstracts of the articles. Articles and abstracts against the inclusion criteria were excluded by each reviewer. A pilot was performed with a subsample for consistency until consensus was obtained. The same strategy was applied after finishing the first 1000 articles. A disagreement lower than 5 % was achieved. After analysing all the included articles, disagreements about eligibility were resolved through discussion. Next, full texts of all the potentially eligible studies were retrieved. The same reviewers (TC, IK and AA) read the full texts of the selected articles, reviewing the inclusion and exclusion guidelines.

2.6. Data items

A form for data extraction was piloted prior to formal recording. Subsequently, the data was extracted by one reviewer (AA) and a second reviewer (IK) checked the proceedings. The following data were extracted: authors, title, type of study, sample size, number of restorations, age, aetiology, continent, location, time of follow-up, type of tooth, type of failure, materials, outcome, success rate, survival rate, major and minor failure rate and assessment method. Data was entered into an Excel spreadsheet, and, in case of missing information, the authors were contacted twice; in the absence of a response, the study was subsequently excluded.

2.7. Risk-of-bias and quality analysis

Included randomised controlled trials (RCT) were assessed for risk of bias using the Cochrane RoB 2.0 risk of bias according to the Cochrane Handbook for Systematic Reviews of Intervention and considering the assessment at the study level. The RoB 2.0 assessment has five domains, as follows; (1) bias arising from the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in measurement of the outcome; and (5) bias in selection of the reported result. In the assessment of RoB 2.0, one independent reviewer (TC) assigned scores to each domain in the randomized controlled trial's, categorizing them with (1) low risk of bias, (2) some concerns, or (3) high risk of bias. When completed, the outcome was discussed with the other two reviewers (IK, AA) and disagreements were resolved by consensus.

For studies that were not randomized controlled trials, two independent reviewers (IK, TPC) utilized the Risk of Bias in non-randomized Studies of Interventions (ROBINS-I) tool. Seven domains of bias were assessed: (1) bias due to confounding, (2) bias in selection of participants into the study, (3) bias in classification of interventions, (4) bias due to deviations from intended interventions, (5) bias due to missing data, (6) bias in measurement of outcomes, and (7) bias in selection of the reported results. Based on those individual domain judgements, the studies overall risk of bias was assessed by categorizing them with: (1) low risk of bias, (2) moderate risk of bias, (3) serious risk of bias, (4) critical risk of bias, or (5) no information.

To assess the quality of case series, the 'Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Case Series' tool was used [26].

2.8. Effect measurements

The initial aim was to conduct a meta-analysis of randomised studies having split them into three distinct groups; direct vs. direct, indirect vs. direct and indirect vs indirect restorations. This division seemed adequate as these were the major comparisons found in literature and also targeting a meta-analysis. Ultimately, a meta-analysis was not performed because even after separating RCTs in more similar groups, revision of the methods showed that designs were highly variable to meta-analyse.

The main outcome measure of this study was the calculation of the annual failure rate for both the RCT's and non-RCT studies. Once AFR was calculated success and survival for each cohort of materials from each study was also calculated.

The data was extracted in the following way. First, the number of patients according to the authors was considered, both at the start and at the end of the study. If no losses were reported, we considered the initial number of participants. Then, the mean time of follow-up or the estimate reported in the paper was recorded.

The next stage was implementing the utilization of F1, F2 and F3 indices which categorises the failure of restorations for tooth wear [6]. The analysis focused on the clinical acceptability of restorations in terms of; was the restoration replaced (F1), was the restoration repaired (F2), or was the restoration refurbished by polishing after material chipping (F3). Due to the majority of studies not recording failure results in a manner that could be categorised into the three groups, the outcomes were subsequently categorised into either minor failure, where the restoration was either repaired or refurbished through polishing or adjustment (F2+F3), or major failure, (F1), where the restoration required complete replacement. Once reported outcomes were converted into the major (F1) and minor (F2+F3) failure nomenclature AFR was then calculated. The AFRs of the investigated restorations were then calculated according to the formula: $(1\ \_y)z = (1\ \_x)$, in which 'y'_expresses the mean AFR and 'x' _the total failure rate at 'z'_years.

Where possible, survival and success rates were also calculated. Success was considered as those restorations that had not presented with F1, F2 or F3 as a percentage of restorations remaining in the study during the mean time of follow-up, whereas survival was considered those restorations that did not present with F1 as a percentage of restorations remaining in the study during the mean time of follow-up.

2.9. Certainty of the evidence assessment

The quality of evidence for the outcome was graded by two independent reviewers (IK, TPC), using the instrument developed by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) working group of evidence, the GRADEpro GDT. The following aspects were considered: study design, risk of bias, inconsistency, indirectness, and imprecision.

3. Results

3.1. Study selection

In total 5764 studies were identified from the database and 14 studies via hand search. After removing the duplicates, 3977 studies remained for reviewing of the titles and abstracts. Three authors (AA, TC, IK) reviewed the titles and abstracts, resulting in 78 eligible studies. The same authors reviewed the full texts.

35 articles were excluded (reasons in Fig. 1, Supplementary material A). Of note, 7 papers were identified that examined the monitoring of tooth progression; however these were excluded as they did not meet the inclusion criteria. Consequently, the results presented in this review pertain to the comparison of restorative treatment options. Overall, 43 studies met all the inclusion criteria for the qualitative analysis, as depicted by Fig. 1.

3.2. Study characteristics

Table 2 provides an overview of the characteristics of the 43 investigations which satisfied the full inclusion criteria. They comprised six RCTs and 37 Non-RCTs. Non-RCTs were subsequently subdivided into 18 prospective, 15 retrospective and 4 case series studies.

Twenty-one of the 43 studies included in this investigation reported the performance of direct resin composite restorations, 12 indirect resin composite restorations, whilst 13 were indirect composite and 20 were indirect ceramic materials, with some studies presenting more than one

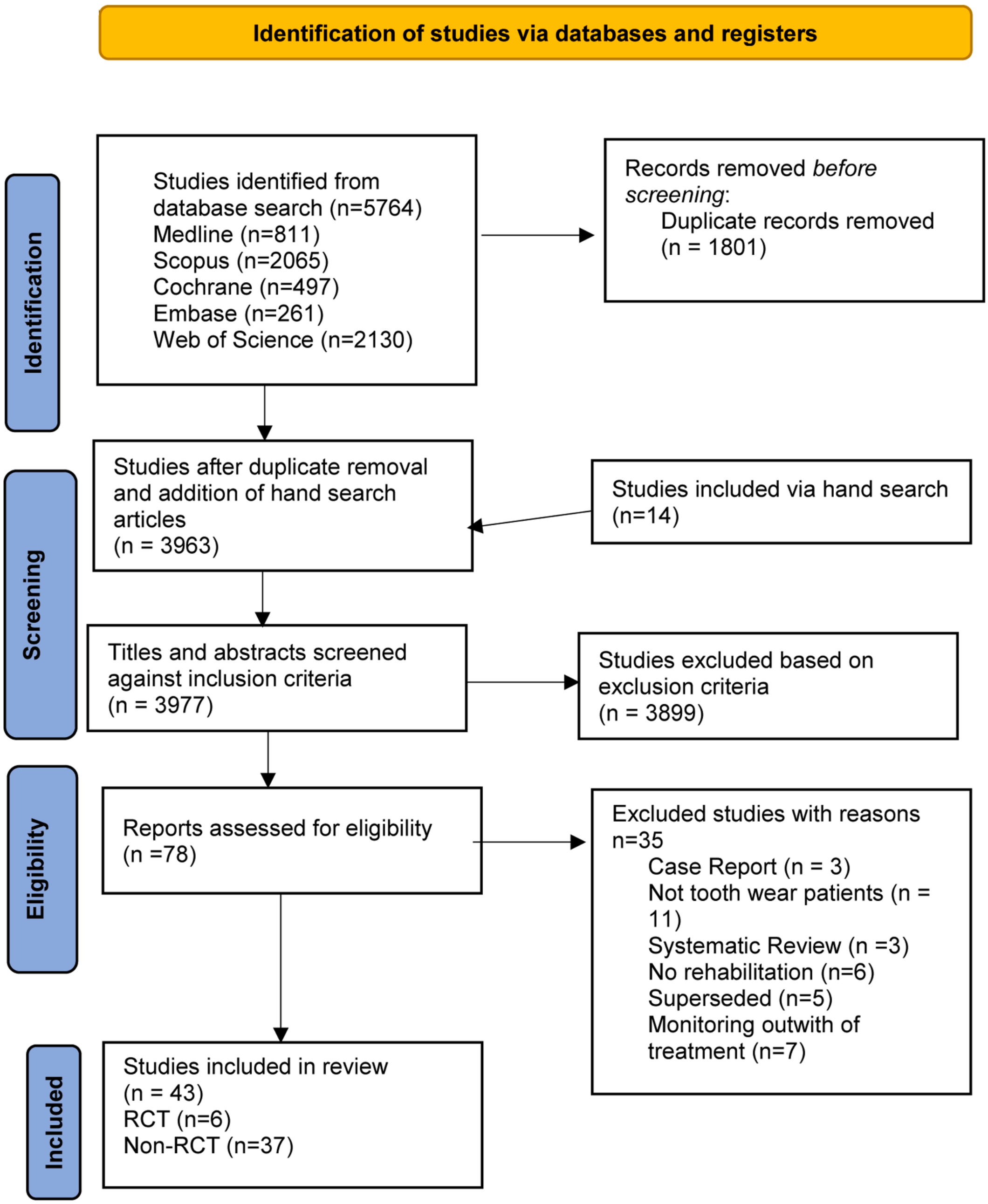

Fig. 1. Study flow diagram.
From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71 [24]. For more information, visit: http://www.prisma-statement.org/

comparison/material. Of the 43 studies, 13 examined different materials in different cohorts. One study examined different materials to restore different anatomical aspects of the same tooth.

3.3. Risk of bias assessment

3.3.1. Randomized controlled trials

The six included RCTs were assessed for risk of bias (Figs. 2 and 3).

Some concerns were found in the majority of the included RCTs, primarily due to bias arising from the randomization process and due to deviation from intended intervention.

3.3.2. Non-randomized studies

For the prospective (Figs. 4 and 5) and retrospective (Figs. 6 and 7) studies, half presented a low risk of bias in most domains, and half were at a high overall risk of bias. In general, two domains were the most affected due to confounding and classification of the interventions, downgrading the risk of bias.

Figs. 8 and 9 provide the results for assessing the risk of bias in the case series. In general, the case series cohort of studies presented a low risk of bias, with one study at high risk due to the lack of clear information regarding inclusion criteria and participant characteristics.

Regarding the certainty of evidence assessed by GRADE (Table 5), there was high certainty of evidence for RCTs and very low for prospective, retrospective studies and case series due to risk of bias and imprecision.

3.4. Annual failure rates, success and survival

Tables 3a, b, c, d show the outcomes of the minor and major AFRs as

Table 2
Characteristics of included studies.

	Author, Year	Location/Setting	Mean Age (SD)	Type of Tooth	Sample Size (Start/End)	Follow Up Years (SD)	Material*
RCT	Alkhayatt et al. 2013 [50]	St George's Hospital, London, UK	58	L/Ant/Mand	18/15	7	Direct composite A Direct composite B
	Bartlett & Sundaram 2006 [27]	Kings's College London, UK	43	L/Post/Max & Mand	16/16 16/16	3 3	Direct composite Indirect composite
	Crins et al. 2021 [51]	Radboud University, Nijmegen, Holland	36.8 (6.6)	L/Ant & Post/ Max & Mand	22/22 20/19	3 3	Direct composite Indirect composite
	Hammoudi et al. 2022 [52]	Department of Prosthetic Dentistry, Karolinska, Sweden	44.8	G/Max & Mand	32/32 32/30	6 6	Indirect Ceramic A Indirect Ceramic B
	Hemmings et al. 2000 [31]	Eastman Dental Hospital and Institute for Oral Healthcare Science, London, UK	33.8	L/Ant/Max & Mand	16/16	2.5	Direct composite A Direct composite B
	Schlichting et al. 2022 [53]	Federal University of Rio De Janeiro, Brazil	30.4	G/Max & Mand	11/11	2.26	Indirect composite Indirect porcelain
Non-RCT Prospective	Burian et al. 2021 [43]	University of Munich, Germany	36.3	G/Max & Mand	6/6	3	Indirect Composite Indirect Ceramic
	Burke 2007 [54]	University of Glasgow, Scotland	37.5	G/Max & Mand	59 End not detailed	3.9	Indirect Ceramic
	Crins et al. 2022 [55]	Radboud University, Nijmegen, Holland	41.7 (10.4)	G/Max & Mand	22/21 22/21	1 year 1	Indirect Composite Direct Composite
	Edelhoff et al. 2019 [56]	University of Munich, Germany	44.3 (6.56)	L/Post/Max & Mand	7/7	7.9	Indirect Ceramic
	Edelhoff et al. 2023 [57]	University of Munich, Germany	44.1 (9.3)	G/Max & Mand	21/21	8.5 ± 2.7 6.7 ± 0.5 years for RC	Indirect Ceramic Indirect Composite
	Gow & Hemmings 2002 [58]	Eastman Dental Hospital and Institute for Oral Healthcare Science, London, UK	36 Range 17–61	L/Ant/Max	12/12	2	Indirect Ceramic
	Gulamali et al. 2011 [17]	Eastman Dental Hospital and Institute for Oral Healthcare Science, London, UK	Range 28–80	L/Ant/Max & Mand	26/26	10	Direct & Indirect Composite
	Koenig et al. 2019 [59]	University of Liege, Belgium	54.34 (15.32)	G/Max & Mand	47/45	2	Indirect Ceramic
	Malament et al. 2021 [60]	Tufts University, USA	62 Range 20–99 Years	Single Unit	304/304	10.9	Indirect Ceramic
	Mehta et al. 2021 [30]	Radboud University, Nijmegen, Holland	35.3 (8.4)	G/Max & Mand	34/34	5.2	Direct Composite
	Milosevic 2014 [61]	University of Liverpool, UK	51.35	G/Max & Mand	30/30	2.82 SD 27.7	Indirect ceramic
	Milosevic & Burnside 2016 [35]	University of Liverpool, UK	44.97 (13.03)	Maxillary Anteriors	164/164	MEDIAN 72 Months	Direct Composite
	Oudkerk et al. 2020 [62]	University of Liege, Belgium	37.7 (12.8)	L/Ant/Max	7/7	2	Indirect Composite
	Raemakers et al. 2015[63]	Radboud University, Nijmegen, Holland	39.9 (5.3)	G/Max & Mand		1.83	Indirect Composite
	Ramseyer et al. 2015 [64]	University of Berne, Switzerland	40.3 Range 31–61	G/Max & Mand	14/14	3.333	Direct composite
	Taubock et al. 2021 [33]	University of Zurich, Switzerland	45 (6) 42 (11)	G/Max & Mand	13/12 13/12	10.7 (0.4) 5.2 (1.4)	Direct Composite A Direct Composite B
	Vailati et al. 2013 [65]	University of Geneva, Switzerland	39.4 Range 27–64	L/Ant/Max	12/12	4.2	Facial Indirect Ceramic Palatal Indirect Composite Palatal direct Composite
	Walls 1995 [66]	Newcastle University, UK	No record	G/Max & Mand	12/9	5	Indirect Ceramic
Non-RCT Retrospective	Aljawad & Rees 2016 [67]	Cardiff University, UK	Mean 39.6 Range 21–70	L/Ant/Max & mand	41/41	2.11	Direct Composite

(continued on next page)

Table 2 (*continued*)

	Author, Year	Location/Setting	Mean Age (SD)	Type of Tooth	Sample Size (Start/End)	Follow Up Years (SD)	Material*
	Bartlett & Varma 2017 [29]	Kings's College London, UK	45 Range 24–86	G/Max & Mand	35/35	0.37 Years (Range 0.5–14 Months)	Direct Composite
	Cascales et al. 2023 [68]	University Murcia, Spain	M 45.5 W 50	G/Max & Mand	8/8	5	Indirect & Direct Composite
	Chadwick & Linklater 2004 [36]	University of Dundee, UK	No mention	Not mentioned	NA	No mention	Indirect Ceramic Gold & Oxidized & Blasted & Panavia Gold & Blasted & Panavia Gold & Aquacem
	Chana et al. 2000 [37]	Kings's College Hospital, UK	Range 14–60. Age 10–16=1, 17–29=8, 30–39=6, 40–49=4, 50–60=6	G/Max & Mand	25/25	4	Gold
	da Rocha Scalzer Lopes et al. 2021 [69]	Sao Paulo State University, Brazil	27.5 Range 21–74	G/Max & Mand	43/43	NA	Indirect Ceramic
	Hamburger et al. 2011 [70]	Radboud University, Nijmegen, Holland	44.8 Range 24.1–60.2	G/Max & Mand	18/18	3.98	Direct Composite
	Marchan et al. 2013 [71]	The University of the West Indies, Trinidad	53.6 Range 23–76	L/Post/Max & Mand	23/21	3.5 Years Range 9–75 Months	Gold
	Nohl et al. 1997 [38]	Eastman Dental Hospital and Institute for Oral Healthcare Science, London, UK	Nov-71	L/Ant/Max	48/48	4.7	Gold
	Printzell et al.2016 [72]	University of Oslo, Norway	36.7 Range 17–67	Not recorded	29/29	2.75	Indirect Ceramic
	Smales & Berekally 2007 [73]	Adelaide Dental Hospital, Australia	65.9 (1.8)	G/Max & Mand	17/17	5.0 (3.0)	Direct Composite Indirect Ceramic Gold
	Torosyan et al. 2022 [44]	University of Geneva, Switzerland	45.6 Range 30–73	G/Max & Mand	28/19	6	Direct Composite Indirect Composite
	Malik et al. 2023 [39]	Eastman Dental Hospital and Institute for Oral Healthcare Science, London, UK	Median 51.8 Range 33–73	G/Max & Mand	7/7 20/20 20/20 20/20	5 5 5 5	Direct composite Indirect Cast Implant Amalgam
	Hoekstra van Hout et al. 2023 [74]	Radboud University, Nijmegen, Holland	38.8	L/Post/Max & Mand	9/9	1.25	Direct Composite
Non-RCT Case Series	Attin et al. 2012 [75]	University of Zurich, Switzerland	39(5)	L/Post/Max & mand	6/6	5.5	Direct Composite
	Hansen et al. 2018 [76]	University of Bergen, Norway	56.3 Range 35–67	L/Max & Mand	13/13	1.7	Indirect Ceramic
	Levartovsky et al. 2019 [77]	University of Tel Aviv, Israel	66.1 (3.8)	G/Max & Mand	10/10	2.35	Indirect Ceramic
	Lempel et al. 2021 [78]	University of Pecs, Hungary	26.67	L/Ant/Max	6/6	1.975 1.8	Direct Composite Indirect Ceramic

*Each line represents one of the study arms; if the study was single-armed, only one line will describe all data; if the study had two materials being tested, two lines will be shown with data from each group, according to the material tested.
****G*=Generalised, *L*=Localised, Ant=Anterior, Post =Posterior, Max=Maxilla, Mand=Mandible.

well as the survival and success rates for the included studies, whilst Tables 4a, b, c, d provide a summary of the performance of the pooled total number of restorations.

3.4.1. Randomised studies

For the pooled data of the available randomised studies as summarised in Table 4a, the total number of restorations in either direct composite, indirect composite and indirect ceramic restorations groups were 413, 227 and 485 respectively, with mean observation periods of between 2.8 to 4.8 years. Mean survival rates for the pooled randomised studies for direct composite, indirect composite and indirect ceramic (delivered through either full or partial coverage restorations) were, 87.5 %, 89.5 % and 99.4 %, with respective mean success rates of, 75.1 %, 68.6 % and 98.8 %. Table 4a also provides information relating to the minor and major AFRs for each material type.

3.4.2. Non-randomised prospective studies

Table 4b illustrates the pooled data from the surveyed non-randomised prospective studies. The total number of restorations in direct composite, indirect composite restorations or indirect ceramic were 2947, 1347 and 799 respectively, with a mean observation period of between 3.8 to 6.5 years. Mean survival rates for the pooled data for direct composite, indirect composite and indirect ceramic were, 99 %, 99.6 % and 98.4 %, with mean success rates of, 81.2 %, 94 % and 94 % respectively. AFRs for direct composite were 3.97 % for minor failures and 0.4 % for major failures. AFRs for indirect composite were 2.9 % for minor failures and 0.15 % for major failures. AFRs for indirect ceramic (delivered through either full or partial coverage restorations) were 0.83 % for minor failures and 0.33 % for major failures.

3.4.3. Non-randomised studies retrospective studies

Pooled data of the available non-randomised retrospective studies are shown in Table 4c. The total number of restorations in either, direct, indirect composite, indirect ceramic or gold restorations ranged between 534 and 1642, with mean observation periods of between 3.6 to 6 years. Mean survival rates for the pooled non-randomised retrospective

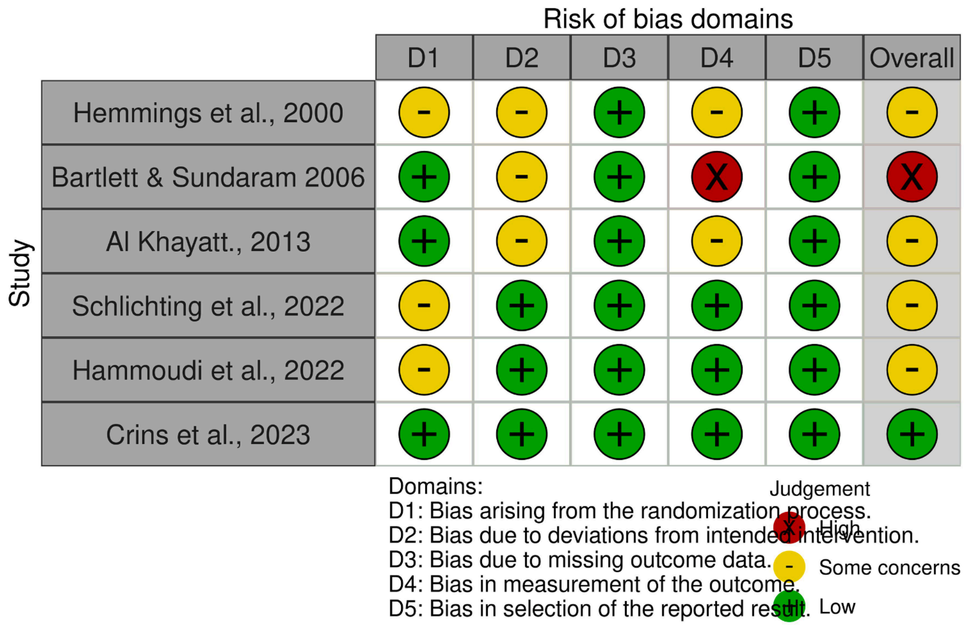

Fig. 2. Risk of bias summary randomised controlled trials: review authors judgements about each risk of bias item for each included study.

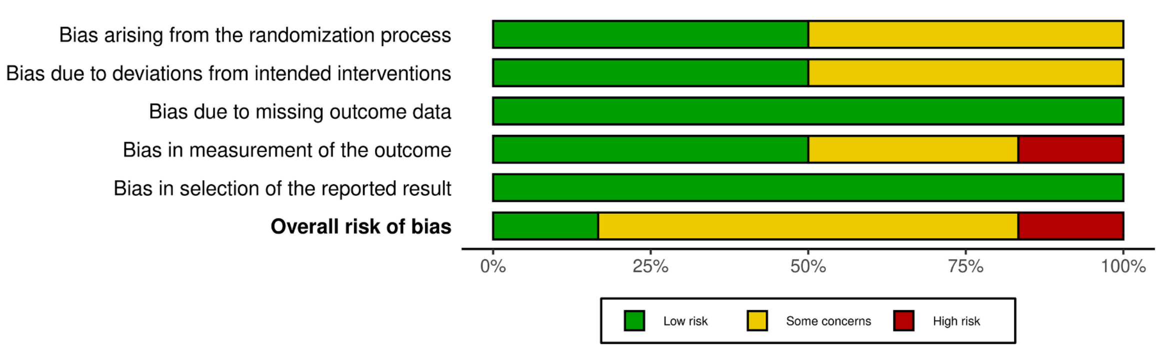

Fig. 3. Risk of bias graph randomised controlled trials: review authors' judgements about each risk of bias item presented as percentages across all included studies.

studies for direct composite, indirect composite, indirect ceramic and gold were, 93.25 %, 100 %, 96.6 and 99.4 %, with respective mean success rates of, 79.9 %, 98 %, 86.3 % and 83.9 %. Mean minor AFRs ranged between 0.4 % (this was one study examining indirect composite) to 5.78 % (direct composite). Major AFRs ranged between 0.8 % (indirect ceramic) to 4.12 % (direct composite).

3.4.4. *Case series*

For the pooled data of the available case series studies as summarised in Table 4d, the total number of restorations in either direct composite or indirect ceramic restorations was $\leq$ 313, with mean observation periods of between 1.95 to 3.74 years. Mean survival rates for the case series studies for direct composite or indirect ceramic were, 100 % and 99.3 %, with respective mean success rates of, 64.5 % and 94.7 %. Table 4d also provides information relating to the minor and major AFRs for each material type.

4. Discussion

The current systematic review was conducted to examine the existing literature and analyze numerous parameters (Minor AFR, Major AFR, Success and Survival) of studies in the provision of restorations for tooth wear. The results of the review illustrated different restorative treatment possibilities, whilst the utilization of monitoring as a treatment modality has not been extensively investigated with the majority of studies measuring the efficacy and accuracy of scanning equipment. Furthermore, the studies did not describe an overall treatment approach where restorations would be placed if it was found that the tooth wear had progressed, nor did they compare monitoring to the provision of restorations in different cohorts. The future of monitoring as a treatment modality may become more significant when considering tooth survival as an outcome, where patients are functioning without negative change in oral health related quality of life (OHRQoL) there may be, on balance, less of a benefit to provide restorations. As such, provision of restorations in moderate cases could reduce, and so the subsequent future restoration burden of maintenance, replacement and complications in these presentations. This may be more relevant where patients may find it difficult to tolerate or finance treatment, such as in the ageing population. Conversely, monitoring where there is a risk of tooth wear progression may result in a more challenging clinical scenario subsequently due to a net reduction in enamel and volume for restoration. As such this can result in increased costs and morbidity to the patient in the future. Future research initiatives on monitoring may include scoping reviews to appreciate how best to improve the evidence base.

With regards to restoration provision the results of the review showed, in general, both commonly prescribed direct and indirect restorative techniques for the treatment of moderate to severe tooth wear displayed high levels of survival and success. Major failures were less frequently observed than minor failures, with direct and indirect composite resin restorations exhibiting higher annual failure rates than

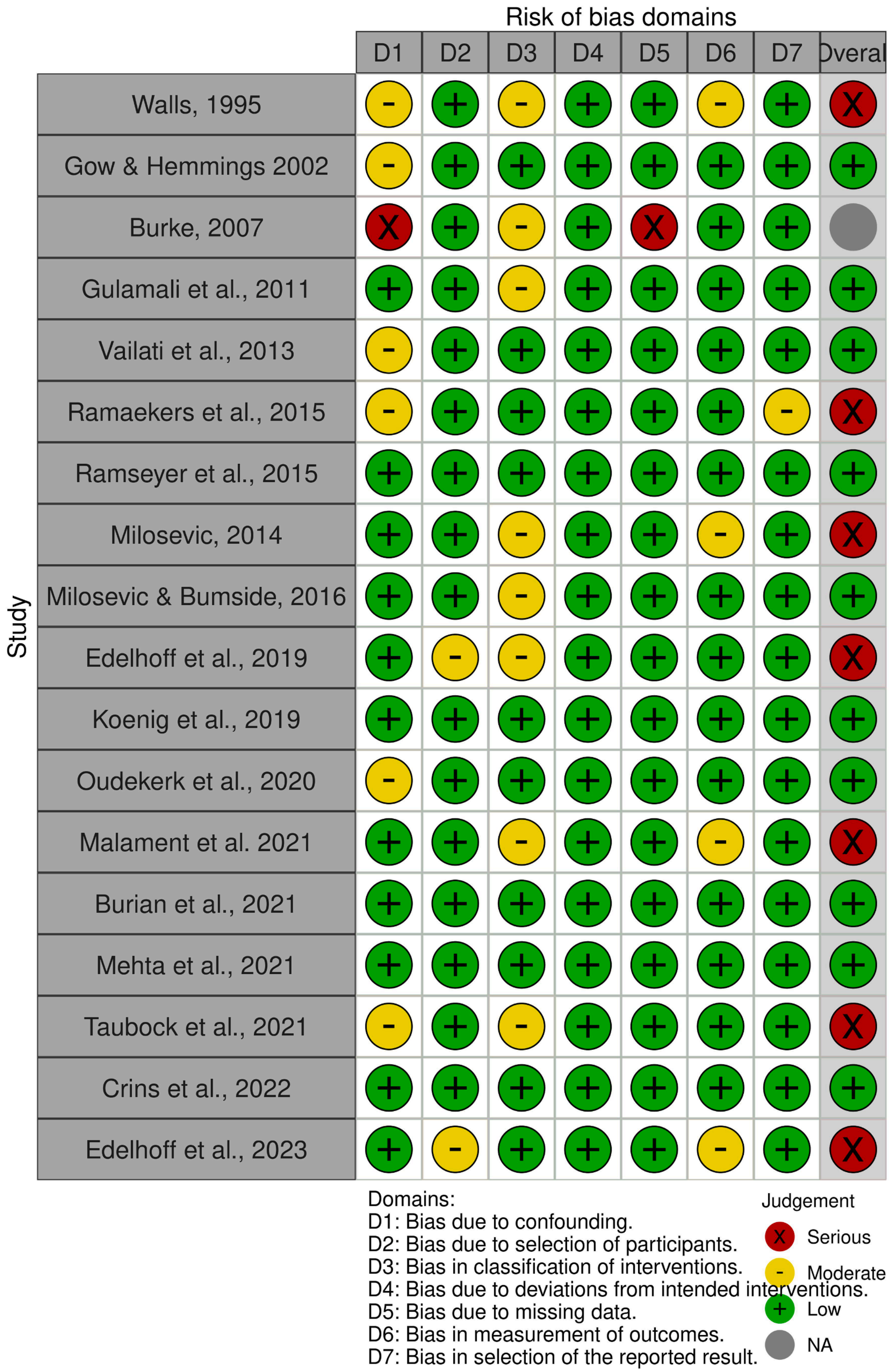

Fig. 4. Risk of bias summary for prospective studies: review authors' judgements about each risk of bias item for each study.

other forms of indirect restorations. The data also alluded to an overwhelming proportion of worn restored teeth surviving, without the need for a dental extraction. The latter was regardless of the mode or method of treatment. This may highlight the relative importance of tooth survival over restoration survival, where the unchecked progression of tooth wear, without treatment, can result in the unwanted and detrimental need for tooth removal.

With the advent of additive restorative techniques in the last 30

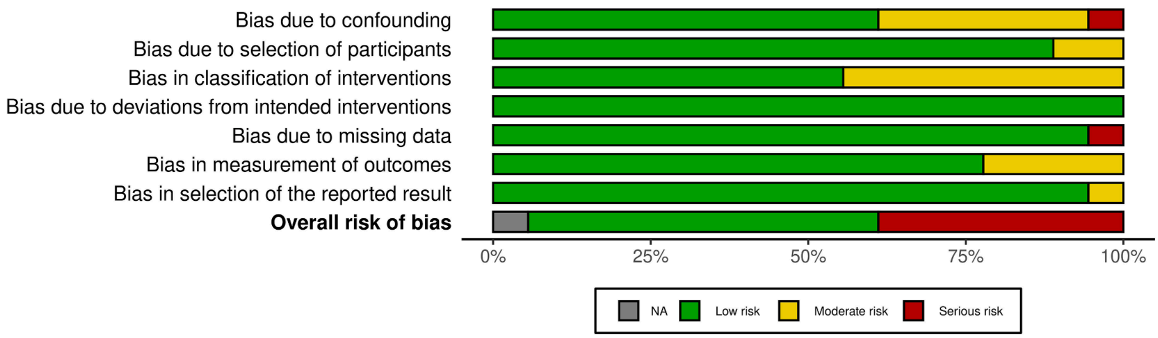

Fig. 5. Risk of bias graph prospective studies: review authors' judgements about each risk of bias item presented as percentages across all included studies.

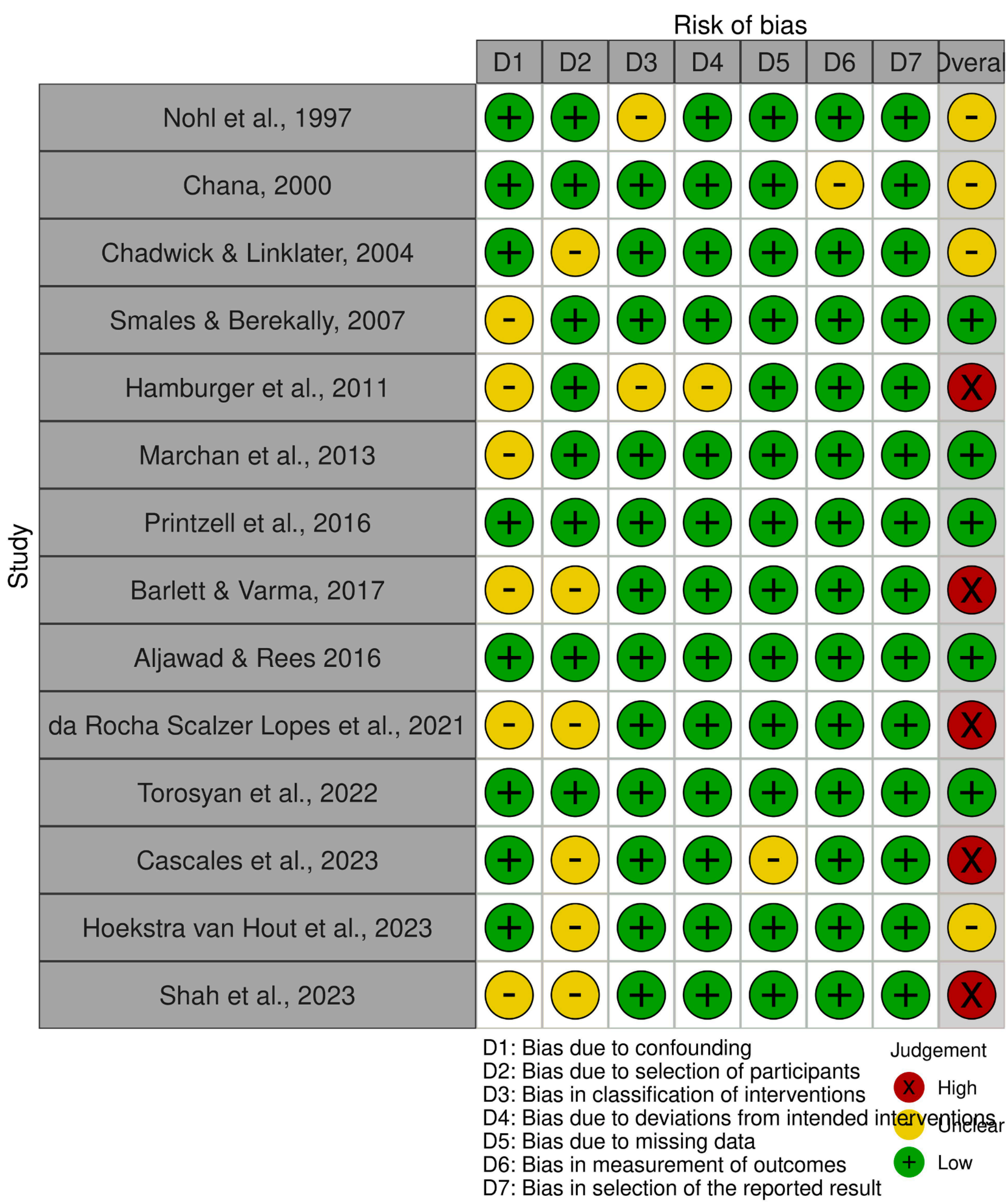

Fig. 6. Risk of bias summary for retrospective studies: review authors' judgements about each risk of bias item for each study.

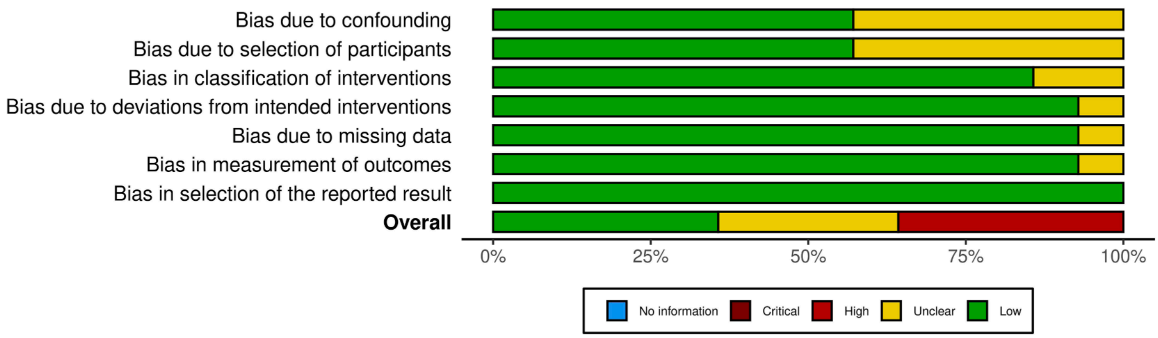

Fig. 7. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

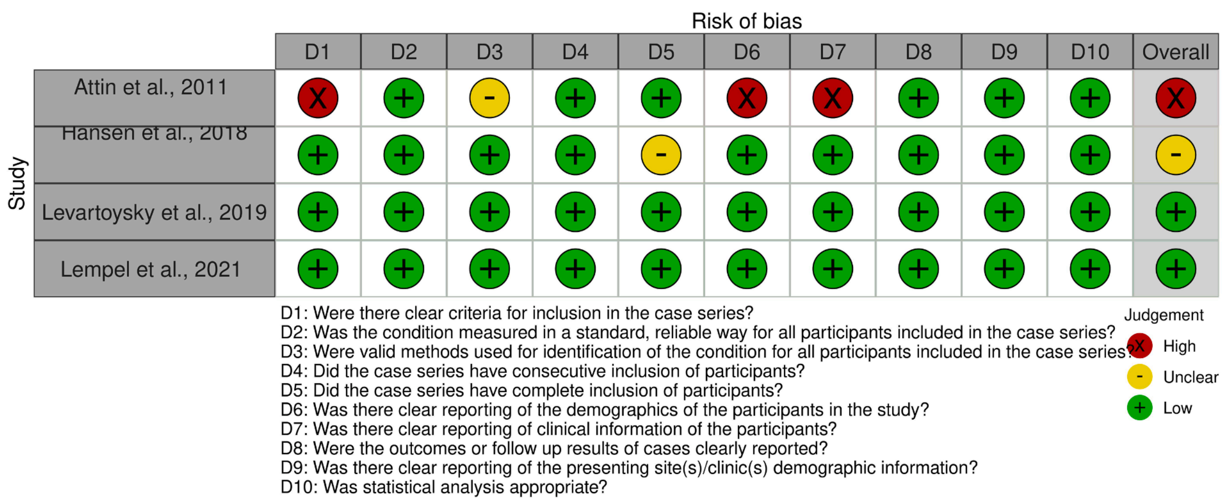

Fig. 8. Risk of bias summary for case series: review authors' judgements about each risk of bias item for each study.

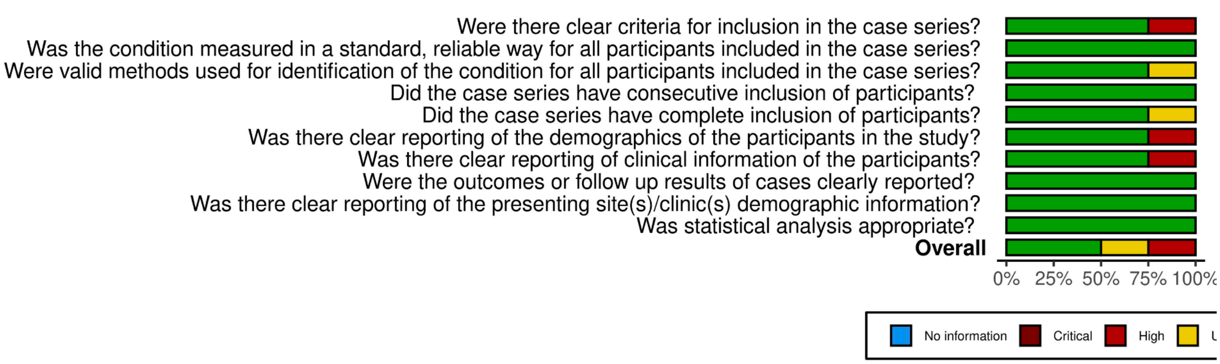

Fig. 9. Risk of bias graph case series: review authors' judgements about each risk of bias item presented as percentages across all included studies.

years, clinicians are faced with the choice of monitoring with preventive advice, providing restorations that are either minimally invasive, or those that remove tooth tissue to create space for the subsequent direct or indirect restoration. This decision-making process places the patient at the center of the need to embark on treatment and accept the risk associated with complications that may arise. 43 studies were identified for this review, with 40 of these having been published from the year 2000 onwards. This may signify growing awareness and populational need in the management and restorative treatment of tooth wear.

Due to a lack of homogeneity, we were not able to perform a meta-analysis; this was in keeping with previous systematic reviews of treatment techniques and materials prescribed for tooth rehabilitation [19,20,22,23]. The authors felt that due to the volume of studies delivering treatment in a similar manner, processing results into salient groups of failure mode would open the opportunity to produce information that could be easily compared between the available studies, as well as different techniques and materials. This approach removed other potentially notable observations, but otherwise less significant such as staining of the margins or discolouration of the main body of the restoration but pragmatically focused on the survival of the restoration and its condition, be it intact or not. Despite this, aesthetic longevity and the need for cosmetic repairs may be important for both clinicians and patients.

Few RCTs are available in the literature, with none comparing direct composite and indirect ceramic. One significant outlier study showed major AFR of 25 % for direct composite and 31.25 % for indirect

Table 3a
Results extracted from the included randomised controlled trials.

	Author, Year	Mean Age (SD)	Type of Tooth	Material	Number of Restorations	Sample Size (Start/End)	Follow Up Time Years	MINOR AFR	MAJOR AFR	SURVIVAL	SUCCESS
RCT	Alkhayatt et al. 2013 [50] **	58	L/Ant/ Mand	Direct composite A	42	18/15	7	**	**	85 %	8 5 %
				Direct composite B	31	18/15	7	**	**	86 %	8 6 %
	Bartlett & Sundaram 2006 [27]	43	L/Post/Max & Mand	Direct composite	16	16/16	3	18.75 %	2 5 %	7 5 %	5 6 %
				Indirect composite	16	16/16	3	25 %	31.2 5 %	68.7 5 %	43.7 5 %
	Crins et al. 2021 [51]	36.8 (6.6)	L/Ant & Post/Max & Mand	Direct composite	220	22/22	3	1.45 %	0.0 0 %	100.0 0 %	95.0 0 %
				Indirect composite	188	20/19	3	6.79 %	0 %	10 0 %	7 8 %
	Hammoudi et al. 2022 [52]	44.8	G/Max & Mand	Indirect Ceramic A	362	32/30	6	0.15 %	0.4 0 %	98.3 3 %	97.5 0 %
				Indirect Ceramic B	92	32/32	6	0.11 %	0 %	10 0 %	9 9 %
	Hemmings et al. 2000 [31]	33.8	L/Ant/Max & Mand	Direct Composite A	52	16/16	2.5	19.95 %	6.7 7 %	82.6 9 %	36.5 4 %
				Direct Composite B	52	16/16	2.5	2 %	1.7 3 %	96.1 5 %	92.3 1 %
	Schlichting et al. 2022 [53]	30.4	G/Max & Mand	Indirect composite	23	11 11	2.26	6.72 %	0 %	10 0 %	8 4 %
				Indirect Ceramic	31	11 11	2.26	0.00 %	0 %	10 0 %	10 0 %

**G*=Generalised, *L*=Localised, Ant=Anterior, Post =Posterior, Max=Maxilla, Mand=Mandible.
** We were not able to extract failure information from this study.

composite [27]. The direct composite provision within this study was micro-filled and applied to molar units, resulting in poor success (56 %) and survival (75 %). This is likely to be associated with micro-filled composites inherent material weakness and support the need for stronger materials posteriorly due to the greater forces being applied than anteriorly [28]. These outcomes identify the need for clinicians to cater selection of materials on evidence of their physical properties, from a biomechanical standpoint, where awareness of subsequent compressive or shear stress and loads can result in complications or failure.

Some of the outlier non-randomised controlled studies warrant further appraisal. Bartlett & Varma presented high failure rates with 24% minor and 16% major annual failure rates for direct composite [29],these findings may have been associated with suboptimal clinical technique, or treatment provided by postgraduate students who had not fully achieved competency in delivery [29]. The severity of pre-treatment wear levels may also have been a significant factor in failure [29]. This latter aspect was addressed comprehensively in a later, larger prospective cohort study which showed higher levels of pre-treatment anterior tooth wear to be significantly associated with higher levels restoration failure [30].

A further outlier showed a significant disparity between different materials provided in the separate arms of the study where microfilled composite produced minor AFR of 20 % and major AFR of 6. 77 % when compared to hybrid composite, which had 2 % and 1. 73 % respectively [31]. This study increased the occlusal vertical dimension for localized tooth wear utilizing a ‘Dahl’ approach. As mentioned previously, the failure rate of the microfilled composite is likely to be associated with inferior compressive strength when compared to other composite formulations. In contrast, the utilization of a hybrid composite produced acceptable outcomes, despite the study being conducted 25 years previously. Since that time the mechanical properties of resin technology has improved but also in tandem that of the bonding agents to both enamel and dentine [32].

Two studies were significant outliers for success and survival of direct resin although these both had the largest follow up time of 10 years and presented comparable minor and major AFR rates to the remaining studies [17,33]. The Gulamali et al. paper [17] examined the provision of restorations which were localized anteriorly at an increased occlusal vertical in a ‘Dahl’ appliance arrangement, producing 65 % survival and 49 % success rates. The authors attributed the outcomes due to the limited mechanical and physical properties of the composite resin and unfavourable dynamic occlusal forces resulting in fracture. The breadth of operator skill and experience may have been wide as postgraduate students may have provided treatment, as previously mentioned. Regardless, patient satisfaction was high and may indicate that patients appropriately informed of the risks and benefits of direct composite will accept the need for future maintenance [17,34]. The Taubock et al. study examined both nanofilled and microhybrid direct composite provision, where the majority of failures clustered within the microhybrid group [33]. Less surface degradation and better marginal qualities was found with nanofilled composite [33]. In comparison two studies produced survival rates of over 90 % and comparably low AFR each examining over 1000 direct restorations [30,35]. The restorations were delivered by experienced operators delivering nano-hybrid or microhybrid composite resin directly. Both papers identified the need to ensure adequate increments of at least 2 mm to ensure strength. One of these studies provided restorations localized anteriorly in a Dahl appliance approach and found that failure rates clustered at the beginning of the observation period when contacts are localized anteriorly, thus concentrating occlusal forces on these restored units, resulting in failure [35]. As contacts re-established posteriorly towards the end of the observation period, the force dissipates amongst more units, resulting in reduced occurrence of failure.

One significant outlier study involved different methods of applying gold restorations where the utilization of glass ionomer cement resulted in an annual failure rate of 55 % and a success of 32 %, the authors stated this was associated with the inferior bonding capacity of glass ionomer in thin sections when compared to resin based cements [36]. Other than the Chadwick & Linklater, outcomes for gold restorations were favorable with over 90 % survival and comparable success rates [36–38]. These observations are likely to be associated with the high compressive strength in thin sections of the material manifesting in low wear degradation, absence of crack propagation and a failure mode that is readily remedied through re-bonding. As such, despite aesthetic shortcomings, gold resin bonded onlays may represent a viable option for

Table 3b
Results extracted from the included non-RCT Prospective Studies.

	Author, Year	Mean Age (SD)	Type of Tooth	Material	Number of Restorations	Sample Size (Start/End)	Follow Up Time Years (SD)	MINOR AFR	MAJOR AFR	SURVIVAL	SUCCESS
Non-RCT Prospective	Burian et al. 2021 [43]	36.3	G/Max & Mand	Indirect Composite	96	6/6	3	0 %	1.0 4 %	9 7 %	96.8 8 %
				Indirect Ceramic	96	6/6	3	0 %	0 %	10 0 %	10 0 %
	Burke 2007 [54]	37.5	G/Max & Mand	Indirect Ceramic	48	59 End not detailed	3.9	1 %	0.5 4 %	9 8 %	93.7 5 %
	Crins et al. 2022 [55]	41.7 (10.4)	G/Max & Mand	Direct Composite	200	22/21	1	4 %	1 %	9 9 %	9 5 %
				Indirect Composite	568	22/21	1	3.87 %	0 %	10 0 %	9 6 %
	Edelhoff et al. 2019 [56]	44.3 (6.56)	L/Post/Max & Mand	Indirect ceramic	103	7/7	7.9	0.09 %	0 %	10 0 %	9 9 %
	Edelhoff et al. 2023 [57]	44.1 (9.3)	G/Max & Mand	Indirect Composite	162	21/21	6.7 (0.5)	0.95 %	0.0 0 %	10 0 %	94.0 0 %
				Indirect Ceramic	274	21/21	8.5 (2.7)	0.35 %	0.0 0 %	10 0 %	97.0 0 %
	Gow & Hemmings 2002 [58]	36 Range 17–61	L/Ant/Max	Indirect Composite	75	12/12	2	6.91 %	0 %	10 0 %	8 7 %
	Gulamali et al. 2011* [17]	Range only 28–80	L/Ant/Max	Direct & Indirect Composite	283 (190 Direct Composite +Indirect Composite 63)	26/26	10	1.68 %	4.2 7 %	6 5 %	49.0 0 %
	Koenig et al. 2019 ** [59]	54.34 (15.32)	G/Max & Mand	Indirect Ceramic	10	47/45	2	1.59 %	4.8 5 %	9 1 %	87.0 0 %
	Malament et al. 2021*** [60]	62 Range 20–99 Years	Localised Single Units	Indirect Ceramic	556	304/304	10.9	0.10 %	0.1 0 %	9 9 %	97.8 4 %
	Mehta et al. 2021 [30]	35.3 (8.4)	G/Max & Mand	Direct Composite	1269	34/34	5.2	4.44 %	0.4 4 %	9 8 %	76.6 7 %
	Milosevic & Burnside 2016 [35]	44.97	L/Anterior/Max	Direct Composite	1010	164/164	2.82	1.2 %	1.3 1 %	9 6 %	93.0 0 %
	Milosevic 2014 [61]	51.35	L/Anterior/Max	Indirect ceramic	161	30/30	Median 6 Years	1.95 %	0.7 4 %	9 6 %	84.4 7 %
	Oudkerk et al. 2020 [62]	37.7 (12.8)	G/Max & Mand	Indirect Composite	192	7/7	2	2.90 %	0 %	10 0 %	9 4 %
	Raemakers et al. 2015 [63]	39.9 (5.3)	G/Max & Mand	Indirect Composite	140		1.83	5.61 %	0 %	10 0 %	9 0 %
	Ramseyer et al. 2015 [64]	40.3 Range 31–61	G/Max & Mand	Direct composite	98	14/14	3.333	3.84 %	0.0 0 %	10 0 %	87.7 6 %
	Taubock et al. 2021 [33]	45(6)	G/Max & Mand	Direct Composite A	56	13/12	10.7 (0.4)	8.76 %	0 %	10 0 %	4 1 %
		42 (11)		Direct Composite B	105	13/12	5.2 (1.4)	5.56 %	0 %	10 0 %	7 5 %
	Vailati et al. 2013 [65]	39.4 Range 27–64	L/Ant/Max	Facial Indirect ceramic	64	12/12	4.2	0.40 %	0 %	10 0 %	9 8 %
				Palatal indirect composite	51	12/12	4.2	0 %	0 %	10 0 %	10 0 %
				Palatal direct composite	19	12/12	4.2	0 %	0 %	10 0 %	10 0 %
	Walls 1995 [66]	No record	L/Ant/ Max&Mand	Indirect Ceramic	43	12/9	5	2 %	1 %	9 5 %	8 6 %

G=Generalised, *L*=Localised, Ant=Anterior, Post =Posterior, Max=Maxilla, Mand=Mandible.

* Unable to separate direct from indirect composite restorations.

** 10 restorations were tooth borne and 85 were implant borne.

*** Restorations were provided for caries and tooth surface loss, unable to separate the groupings.

Table 3c
Results extracted from the included non-RCT Retrospective Studies.

	Author, Year	Mean Age (Range)	Type of Tooth	Material	Number of Restorations	Sample Size (Start/End)	Follow Up Time Years (SD)	MINOR AFR	MAJOR AFR	SURVIVAL	SUCCESS
Non-RCT Retrospective	Aljawad & Rees 2016 [67]	39.6 (21–70)	L/Ant/Max & Mand	Direct Composite	296	41/41	2.11	0.97 %	2.1 0 %	9 6 %	93.5 8 %
	Bartlett & Varma 2017 [29]	45 (24–86)	G/Mand & Max	Direct Composite	251	35/35	0.37 Years (Range 0.5–14 Months)	23.79 %	16.3 0 %	9 4 %	84.0 6 %
	Cascales et al. 2023 [68]	M 45.5 W 50	G/Mand & Max	Indirect Ceramic	108	8/8	5	1.33 %	0.0 0 %	10 0 %	94.2 8 %
				Direct Composite	96	8/8	5	2.87 %	0.0 0 %	10 0 %	86.0 0 %
	Chadwick & Linklater 2004 [36]	Not recorded	Not recorded	Gold & Oxidized & Blasted & Panavia	21	NA	No mention	0.00 %	0.0 0 %	10 0 %	100.0 0 %
				Gold & Blasted & Panavia	105	NA	No mention	10.25 %	10.2 5 %	10 0 %	77.0 0 %
				Gold & Aquacem	25	NA	No mention	55 %	5 5 %	10 0 %	3 2 %
	Chana et al. 2000 [37]	Range 14–60. Age 10–16=1, 17–29=8, 30–39=6, 40–49=4, 50–60=6	G/Mand & Max	Gold	135	25/25	4	1.91 %	1.9 1 %	10 0 %	93.0 0 %
	da Rocha Scalzer Lopes et al. 2021 [69]	27.5 (21–74)	G/Mand & Max	Indirect Ceramic	112	43/43	NA	–	1.85 %	10 0 %	9 1 %
	Hamburger et al. 2011 [70]	44.8 (24.1–60.2)	G/Mand & Max	Direct Composite	332	18/18	3.98	0.84 %	0.1 5 %	9 9 %	96.0 0 %
	Marchan et al. 2013 [71]	53.6 (23–76)	G/Mand & Max	Gold	10	23/21	3.5 Range 9–75 Months	0.00 %	0.0 0 %	10 0 %	100.0 0 %
	Nohl et al. 1997 [38]	11–71	L/Ant/Max	Gold	210	48/48	4.7 (Up to 8.17 years)	2.44 %	0.0 0 %	10 0 %	89.0 0 %
	Printzell et al.2016 * [72]	36.7 (17–67)	Not recorded	Indirect Ceramic	60	29/29	5.91	0.00 %	0.0 0 %	10 0 %	100.0 0 %
	Smales & Berekally 2007 [73]	65.9 (1.8)	G/Mand & Max	Direct Composite	202	17/17	5.0 (3.0)	1.26 %	1.1 5 %	8 9 %	77.0 0 %
				Indirect Ceramic	115	17/17	5.0 (3.0)	0.53 %	1.28 9 %	8 8 %	8 3 %
				Gold	28	17/17	5.0 (3.0)	0.00 %	0.3 6 %	9 6 %	96.0 0 %
	Torosyan et al. 2022 [44]	45.6 (30–73)	G/Mand & Max	Direct Composite	149	28/19	6	1.51 %	0.6 8 %	9 6 %	8 7 %
				Indirect Composite	257	28/19	6	0.40 %	0 %	10 0 %	9 8 %
	Hoekstra Van Hout et al. 2023 [74]	38.8	L/Post/ Max&Mand	Direct Composite	18	9 9	1.25	0 %	9 %	8 9 %	8 9 %
	Malik et al. 2023 [39]	Median 51.8 (33–73)	G/Max & Mand	Amalgam	21	20/20	5	15.11 %	4 %	8 1 %	2 4 %
				Direct composite	298	7/7	5	15 %	3.6 0 %	8 3 %	26.1 7 %
				Indirect Cast	172	20/20	5	7 %	1 %	9 5 %	6 3 %

G=Generalised, *L*=Localised, Ant=Anterior, Post =Posterior, Max=Maxilla, Mand=Mandible.
* Unable to separate tooth surface loss from other aetiologies.
** No information on materials used indirectly.

Table 3d
Results extracted from the included non-RCT Case Series.

Attin et al. 2012 [75]	39(5)	Localised/Post/Max & Mand	Direct Composite	75	6/6	5.5 years	19.98 %	0 %	10 0 %	2 9 %
Hansen et al. 2018 [76]	56.3 (35–67)	L/Ant/Max & Mand	Indirect Ceramic	84	13/ 13	1.7 Years	3.61 %	0.7 1 %	9 9 %	93.0 0 %
Levartovsky et al. 2019 [77]	66.1 (3.8)	All teeth	Indirect Ceramic	187	10/ 10	2.35 Years	3.50 %	0.2 3 %	9 9 %	91.0 0 %
Lempel et al. 2021 [78]	26.67	L/Ant/Max	Direct Composite	36	6/6	1.975	0.00 %	0 %	10 0 %	10 0 %
			Indirect ceramic	42	6 6	1.8	0.00 %	0 %	10 0 %	10 0 %

**G*=Generalised, *L*=Localised, Ant=Anterior, Post =Posterior, Max=Maxilla, Mand=Mandible.

posterior units as well as other surfaces where occlusal guidance may be relevant.

One further study examining the rehabilitation of generalized tooth wear presentation documented a minor AFR of 15 % and major AFR of 3.6 % for direct composite with a survival rate of 26 % during a mean 5 year follow-up period [39]. The treatment within this study was delivered by postgraduate students or trainees, which may explain the relative increased failure rate. Thus, all outliers with poorer outcomes identified in this systematic review, regardless of study design, have well-defined reasons for their occurrence. Clearly, material choice played a significant role in the success of treatment, but studies that examined restorations delivered by clinician cohorts that were developing their experience and skill set demonstrated higher failure rates [17,29,39,40].

In total 5002 direct composite restorations, 1831 indirect composite and 1851 indirect ceramic restorations were included in the study. The substantially greater number of restorations within the direct composite group may provide greater significance to their results and outcomes. Within the randomized controlled trials (Table 4a) both direct and indirect composite had comparable mean minor AFR (10.54 %, 12.84 %) and major AFR (8.38 %, 10.41 %). Similarly, the mean survival for direct (87.5 %) was comparable to indirect (89.5 %). Within this cohort of studies indirect ceramic had superior outcomes with negligible mean and major AFR (0.09 % and 0.13 %). Although, these results were not echoed in the prospective studies (Table 4B) where major AFRs were similarly low at 0.4 % (direct composite), 0.15 % (indirect) and 0.33 % (indirect ceramic). The prospective studies may carry greater weight as the number of restorations included was significantly greater than the RCT cohort (5093 vs 1125 in total) with longer mean follow-up times amongst all groups. Within the prospective studies the mean survival rates for direct composite (99 %), indirect composite (99.6 %) and indirect ceramic (98.4 %) were comparable. A discrepancy emerges when looking at success. Composite showing 81.2 % mean success with indirect composite and indirect ceramic both 94 %. This may be associated with relative increased potential for chipping/fracturing of composite when compared to indirect materials, especially in molar teeth, where higher mechanical loads may be expected. However, the use of direct composite, as the initial treatment of choice supported by the European Consensus Statement, Management Guidelines for Severe Tooth wear, 2017 offers the clinician and patient the opportunity to verify planned complex aesthetic and functional changes in a minimally invasive manner, with the scope to adjust restorations by the addition and removal of dental material in the oral environment [3]. Also, post-operative care protocols, including professional monitoring, maintenance visits, and at-home care recommendations, should be considered to extend the longevity of the restorations.

The results illustrate that all materials can provide acceptable outcomes with both direct composite and non-preparation indirect composite requiring less invasive treatment but potentially greater maintenance. In comparison, indirect ceramic achieved better outcomes but are more invasive with less potential future maintenance. Within the indirect ceramic group both partial and full coverage restorations were considered together. Partial coverage restorations may be considered less invasive than full coverage although the parameters for tooth tissue removal in delivery may result in significant volumetric reduction [41, 42]. When considering options patients and clinicians may favor the approaches that do not involve any tissue removal over those that involve preparation, minimal or otherwise, and restoration to ensure sustainability of the underlying tooth tissue and the serviceability of the overlying restoration. Restoration failure with direct composite is easier to repair or replace than different modes of ceramic such as lithium disilicate or the more traditional metal ceramic.

Direct and indirect composite materials posteriorly presented less favorable outcomes than anteriorly, with indirect materials performing superiorly on molar units. Two studies examined cohorts of indirect composite and indirect ceramic producing greater AFR minor and major failures within the indirect composite group, although favorable survival rates [43,44]. This observation is significant in that provision of materials posteriorly that more likely to deteriorate over time can result in occlusal instability resulting in greater risk for anterior restorations. This has also been illustrated in a recent study, not included in the systematic review analysis, showing 0.29 % AFR for anterior units and 2.93 % for molar units [45]. It is worth noting that a greater failure rate for direct resin restorations delivered posteriorly when compared to anteriorly also occurs more generically for situations such as caries management [46]. With occlusal forces being greater posteriorly, due to proximity to the masseter and the lever arm, there is a greater need for material strength on molar units.

As direct composite has shown to have acceptable survival, this should be considered the first choice for all presentations of moderate to severe tooth wear, with the option to replace with indirect materials if minor failures are recurrent on the same unit or major failure results in the need for complete replacement. The utilization of minimally invasive techniques for full mouth rehabilitation provides the opportunity for the clinician to refine occlusal inter-relations whilst also delivering a minimally invasive solution without removing sound tooth tissue or expending more invasive options that can be delivered in the future, if ever required.

One parameter that was not investigated in any of the studies was the economic differences between the utilization of different materials which clearly would play a role for the patient and the clinician. Direct composite is likely to be comparatively cheaper initially at delivery than indirect methods, although the need for greater maintenance may create further costs during the lifetime of the restoration depending on the occurrence of failure and its relative severity [15]. Conversely the provision of indirect full contour crown restorations may result in the loss of vitality due to their invasiveness, which clearly presents significant morbidity and costs in terms of remedial endodontic treatment [47,48]. In addition, when it comes to the patient, their participation is clear as it involves preventive measures and helps ensure successful outcomes. Yet, factors such as lifestyle, compliance with the treatment plan and behavioral changes are known to affect tooth wear onset and development and still need to be included in future studies.

In general, risk of bias varied amongst study designs with groups of studies showing low risk and groups of studies showing high risk of bias. In this specific sample, it appears that the risk of bias did not influence the direction of the results. Still, it is important to note that the certainty of evidence was only high for RCTs, with the other study designs showing very low certainty of evidence due to the design itself and imprecision. Indeed, within the non-RCT studies, over 40 % presented a

Table 4a
RCT Pooled total number of restorations with means calculated for observation periods, annual failure rates, success and survival of included studies.

Material	Total Number of Restorations	Range of Number Restorations	Range Observation Period Years	Mean Observation Period Years	Minor AFR Range %	Mean Minor AFR %	Major AFR Range %	Mean Major AFR %	Range Survival Rate %	Mean Survival Rate %	Range Success Rate %	Mean Success Rate %
Direct composite	413	16–220	2.5–7	4.17	2–19.95	10.54	0–25	8.38	75–100	87.5	36.54–95	75.14
Indirect Composite	227	16–188	2.26–3	2.75	6.72–25	12.84	0–31.25	10.41	68.75–100	89.5	43.75–84	68.6
Indirect Ceramic	485	31–362	2.26–6	4.75	0–0.15	0.09	0–0.4	0.13	98.33–100	99.44	97.5–100	98.83

Table 4b
NON-RCT PROSPECTIVE Pooled total number of restorations with means calculated for observation periods, annual failure rates, success and survival of included studies.

Material	Total Number of Restorations	Range of Number Restorations	Range Observation Period Years	Mean Observation Period Years	Minor AFR Range %	Mean Minor AFR %	Major AFR Rang %	Mean Major AFR %	Range Survival Rate %	Mean Survival Rate %	Range Success Rate %	Mean Success Rate %
Direct composite	2947	56–1269	1–10	5.3	0–8.76	3.97	0–4.27	0.4	99–100	99	41–100	81.2
Indirect Composite	1347	51–568	1–10	3.84	0–6.91	2.9	0–1.04	0.15	97–100	99.6	87–100	94
Indirect Ceramic	799	10–274	2–8.5	6.5	0–2	0.83	0–0.74	0.33	95–100	98.4	84.47–100	94

Gulamali et al. not included as unable to separate direct from indirect composite restorations [17].
Koenig et al. 2019 not included as 10 restorations were tooth borne and 85 were implant borne [59].
Malament et al. 2021 not included as restorations were provided for caries and tooth surface loss [60].
Follow up for Milosevic 2014 not included as median not mean presented **.

Table 4c
Non-RCT retrospective pooled total number of restorations with means calculated for observation periods, annual failure rates, success and survival of included studies.

Material	Total Number of Restorations	Range of Number Restorations	Range Observation Period Years	Mean Observation Period Years	Minor AFR Range %	Mean Minor AFR %	Major AFR Range %	Mean Major AFR %	Range Survival Rate %	Mean Survival Rate %	Range Success Rate %	Mean Success Rate %
Direct composite	1642	18–332	0.37–6	3.6	0–23.8	5.78	0–16.3	4.12	83–100	93.25	26.1–96	79.9
Indirect Composite*	257	–	6	6	–	0.4	0	–	–	100	–	98
Indirect Ceramic	567	60–172	5–5.91	5.23	0–7	2.142	0–1.85	0.8	88–100	96.6	63–100	86.3
Gold	534	10–210	3.5–4.7	4.3	0–55	9.9	–	–	96–100	99.4	32–100	83.9

* Only one study.

Table 4d
NON-RCT CASE SERIES Pooled total number of restorations with means calculated for observation periods, annual failure rates, success and survival of included studies.

Material	Total Number of Restorations	Range of Number Restorations	Range Observation Period Years	Mean Observation Period Years	Minor AFR Range %	Mean Minor AFR %	Major AFR Range %	Mean Major AFR %	Range Survival Rate %	Mean Survival Rate %	Range Success Rate %	Mean Success Rate %
Direct composite	111	36–75	1.975–5.5	3.7375	0–20	10	0	0	100	100	29–100	64.5
Indirect Ceramic	313	42–187	1.7–2.35	1.95	0–3.61	3.56	0–0.71	0.47	99–100	99.3	91–100	94.7

Table 5
Certainty of evidence.

Certainty assessment							Summary of findings				
Restorations (studies) Follow-up	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty of evidence	Study event rates (%)		Relative effect (95 % CI)	Anticipated absolute effects	
							With direct resin	With Other restorations		Risk with resin	Risk difference Other treatment
Survival of restorations (follow-up: mean 3.96 years)											
1125 (6 RCTs)	serious[a]	not serious[b]	not serious	not serious[b]	Publication bias strongly suspected, strong association all plausible residual confounding would reduce the demonstrated effect	⊕⊕⊕⊕ High	413 restorations	712 restorations	–	Low not pooled	not pooled
Survival of restorations - prospective (follow-up: mean 4.72 years)											
5649 (18 non-RCTs)	very serious[c]	not serious[c]	not serious	serious[c]	all plausible residual confounding would suggest spurious effect, while no effect was observed	⊕○○○ Very low				Studies compared direct resin, gold, indirect composite, and ceramics. Survival was higher than 91 % (excluding one study with microfilled resin).	
Survival of restorations - retrospective (follow-up: mean 4.28 years)											
3021 (15 non-RCTs)	very serious[c]	not serious[d]	not serious	serious[c]	all plausible residual confounding would suggest spurious effect, while no effect was observed[c]	⊕○○○ Very low				Studies compared direct resin, gold, indirect composite, and ceramics. Survival was higher than 83 %.	
Survival of restorations - case series (follow-up: mean 2.67 years)											
424 (4 non-RCTs)	very serious[e]	not serious	not serious	serious[c]	all plausible residual confounding would reduce the demonstrated effect[d]	⊕○○○ Very low				Studies compared direct resin and ceramics. Survival was higher than 91 %.	

Explanations.
[a] Randomization, intended intervention.
[b] Resin chosen was microffiled.
[c] Missing data, confounders.
[d] risk of bias amongst included studies.
[e] inclusion criteria, demographics.

high risk of bias. This may have manifested in the outcomes, where those cases presenting with a high risk for failure were not entered into the study resulting in inclusion bias.

Due to the quality of reporting within the studies we were not able to report on gender, age, and the aetiology of tooth wear. Males have been reported to have a greater incidence of tooth wear and results from age may have provided insight into progressive wear in the ageing dentition [49]. The type of tooth wear would have given insight into the differences between chemical and mechanical tooth wear. Chemical tooth wear would be expected to have less major and minor failures when compared to patients presenting with mechanical wear, where fractures are more likely [29]. Other patient-related parameters such as caries risk and grinding or bruxism known to influence the longevity of restorations are seldomly reported.

5. Conclusion

Material choice, the materials method of delivery between anterior and posterior units, and operator variables such as experience and knowledge seem to influence the rehabilitation of teeth presenting with moderate to severe tooth wear. Treatment decisions require a balanced, pragmatic approach between the longevity of the restoration and the relative invasiveness and morbidity associated with direct and indirect restorations. A sensible approach is likely to involve the provision of direct materials initially with consideration for indirect materials if a major failure transpires.

CRediT authorship contribution statement

Aws Alani: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Shamir Mehta:** Writing – review & editing, Validation, Methodology, Conceptualization. **Isa Koning:** Validation, Methodology, Conceptualization. **Bas Loomans:** Visualization, Investigation. **Tatiana Pereira-Cenci:** Validation, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

I would like to advise you that we have no conflicts of interest to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2025.105711.

References

[1] W. Hammoudi, M. Trulsson, J.I. Smedberg, P. Svensson, Clinical presentation of two phenotypes of tooth wear patients, J. Dent. 86 (2019) 60–68.

[2] W. Hammoudi, M. Trulsson, J.I. Smedberg, P. Svensson, Phenotypes of patients with extensive tooth wear-a novel approach using cluster analysis, J. Dent. 82 (2019) 22–29.

[3] B. Loomans, N. Opdam, T. Attin, D. Bartlett, D. Edelhoff, R. Frankenberger, G. Benic, S. Ramseyer, P. Wetselaar, B. Sterenborg, R. Hickel, U. Pallesen, S. Mehta, S. Banerji, A. Lussi, N. Wilson, Severe tooth wear: European consensus statement on management guidelines, J. Adhes. Dent. 19 (2) (2017) 111–119.

[4] B. Sterenborg, E.M. Bronkhorst, P. Wetselaar, F. Lobbezoo, B.A.C. Loomans, M. Huysmans, The influence of management of tooth wear on oral health-related quality of life, Clin. Oral Investig. 22 (7) (2018) 2567–2573.

[5] B. Loomans, N. Opdam, A guide to managing tooth wear: the Radboud philosophy, Br. Dent. J. 224 (5) (2018) 348–356.

[6] S.B. Mehta, B.A.C. Loomans, S. Banerji, E.M. Bronkhorst, D. Bartlett, An investigation into the impact of tooth wear on the oral health related quality of life amongst adult dental patients in the United Kingdom, Malta and Australia, J. Dent. 99 (2020) 103409.

[7] S.B. Mehta, B.A.C. Loomans, R.M.F. van Sambeek, T. Pereira-Cenci, S. O'Toole, Managing tooth wear with respect to quality of life: an evidence-based decision on when to intervene, Br. Dent. J. 234 (6) (2023) 455–458.

[8] R.G. Watt, J.G. Steele, E.T. Treasure, D.A. White, N.B. Pitts, J.J. Murray, Adult Dental Health Survey 2009: implications of findings for clinical practice and oral health policy, Br. Dent. J. 214 (2) (2013) 71–75.

[9] K. Yip, P.P.Y. Lam, C.K.Y. Yiu, Prevalence and associated factors of erosive tooth wear among preschool children-a systematic review and meta-analysis, Healthcare (Basel) 10 (3) (2022).

[10] C.M. Kreulen, A. Van 't Spijker, J.M. Rodriguez, E.M. Bronkhorst, N.H. Creugers, D. W. Bartlett, Systematic review of the prevalence of tooth wear in children and adolescents, Caries Res. 44 (2) (2010) 151–159.

[11] A. Van't Spijker, J.M. Rodriguez, C.M. Kreulen, E.M. Bronkhorst, D.W. Bartlett, N. H. Creugers, Prevalence of tooth wear in adults, Int. J. Prosthodont. 22 (1) (2009) 35–42.

[12] N.J. Kassebaum, A.G.C. Smith, E. Bernabe, T.D. Fleming, A.E. Reynolds, T. Vos, C. J.L. Murray, W. Marcenes, G.B.D.O.H. Collaborators, Global, regional, and national prevalence, incidence, and disability-adjusted life years for oral conditions for 195 countries, 1990-2015: a systematic analysis for the Global burden of diseases, injuries, and risk factors, J. Dent. Res. 96 (4) (2017) 380–387.

[13] H. Bronkhorst, E. Bronkhorst, S. Kalaykova, T. Pereira-Cenci, M.C. Huysmans, B. Loomans, Inter- and intra-variability in tooth wear progression at surface-, tooth- and patient-level over a period of three years: a cohort study: inter- and intra-variation in tooth wear progression, J. Dent. 138 (2023) 104693.

[14] T. Donovan, C. Nguyen-Ngoc, I. Abd Alraheam, K. Irusa, Contemporary diagnosis and management of dental erosion, J. Esthet. Restor. Dent. 33 (1) (2021) 78–87.

[15] S. O'Toole, M. Pennington, S. Varma, D.W. Bartlett, The treatment need and associated cost of erosive tooth wear rehabilitation - a service evaluation within an NHS dental hospital, Br. Dent. J. 224 (12) (2018) 957–961.

[16] D. Bartlett, S. O'Toole, Tooth wear and aging, Aust. Dent. J. 64 (1) (2019) S59–S62. Suppl.

[17] A.B. Gulamali, K.W. Hemmings, C.J. Tredwin, A. Petrie, Survival analysis of composite Dahl restorations provided to manage localised anterior tooth wear (ten year follow-up), Br. Dent. J. 211 (4) (2011) E9.

[18] S.B. Mehta, S. Banerji, B.J. Millar, J.M. Suarez-Feito, Current concepts on the management of tooth wear: part 1. Assessment, treatment planning and strategies for the prevention and the passive management of tooth wear, Br. Dent. J. 212 (1) (2012) 17–27.

[19] D. Vajani, T.H. Tejani, A. Milosevic, Direct composite Resin for the management of tooth wear: a systematic review, Clin. Cosmet. Investig. Dent. 12 (2020) 465–475.

[20] E.J. Muts, H. van Pelt, D. Edelhoff, I. Krejci, M. Cune, Tooth wear: a systematic review of treatment options, J. Prosthet. Dent. 112 (4) (2014) 752–759.

[21] M.E. Mesko, R. Sarkis-Onofre, M.S. Cenci, N.J. Opdam, B. Loomans, T. Pereira-Cenci, Rehabilitation of severely worn teeth: a systematic review, J. Dent. 48 (2016) 9–15.

[22] V. Kassardjian, M. Andiappan, N.H.J. Creugers, D. Bartlett, A systematic review of interventions after restoring the occluding surfaces of anterior and posterior teeth that are affected by tooth wear with filled resin composites, J. Dent. 99 (2020) 103388.

[23] K.E. Ahmed, S. Murbay, Survival rates of anterior composites in managing tooth wear: systematic review, J. Oral Rehabil. 43 (2) (2016) 145–153.

[24] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hrobjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, Rev. Esp. Cardiol. (Engl. Ed) 74 (9) (2021) 790–799.

[25] M. Ouzzani, H. Hammady, Z. Fedorowicz, A. Elmagarmid, Rayyan-a web and mobile app for systematic reviews, Syst. Rev. 5 (1) (2016) 210.

[26] S. Moola, Risky business 'mis'interpretation of observational evidence, JBI. Database SyStem Rev. Implement. Rep. 15 (1) (2017) 1–2.

[27] D. Bartlett, G. Sundaram, An up to 3-year randomized clinical study comparing indirect and direct resin composites used to restore worn posterior teeth, Int. J. Prosthodont. 19 (6) (2006) 613–617.

[28] J.L. Ferracane, J.R. Condon, In vitro evaluation of the marginal degradation of dental composites under simulated occlusal loading, Dent. Mater. 15 (4) (1999) 262–267.

[29] D. Bartlett, S. Varma, A retrospective audit of the outcome of composites used to restore worn teeth, Br. Dent. J. 223 (1) (2017) 33–36.

[30] S.B. Mehta, V.P. Lima, E.M. Bronkhorst, L. Crins, H. Bronkhorst, N.J.M. Opdam, M. Huysmans, B.A.C. Loomans, Clinical performance of direct composite resin restorations in a full mouth rehabilitation for patients with severe tooth wear: 5.5-year results, J. Dent. 112 (2021) 103743.

[31] K.W. Hemmings, U.R. Darbar, S. Vaughan, Tooth wear treated with direct composite restorations at an increased vertical dimension: results at 30 months, J. Prosthet. Dent. 83 (3) (2000) 287–293.

[32] M. Cadenaro, U. Josic, T. Maravic, C. Mazzitelli, G. Marchesi, E. Mancuso, L. Breschi, A. Mazzoni, Progress in dental adhesive materials, J. Dent. Res. 102 (3) (2023) 254–262.

[33] T.T. Taubock, P.R. Schmidlin, T. Attin, Vertical bite rehabilitation of severely worn dentitions with direct composite restorations: clinical performance up to 11 years, J. Clin. Med. 10 (8) (2021).

[34] R.M.F. van Sambeek, R. de Vos, L. Crins, E. Bronkhorst, S.B. Mehta, T. Pereira-Cenci, B.A.C. Loomans, Perception of oral health related quality of life and orofacial aesthetics following restorative treatment of tooth wear: a five-year follow-up, J. Dent. 136 (2023) 104626.

[35] A. Milosevic, G. Burnside, The survival of direct composite restorations in the management of severe tooth wear including attrition and erosion: a prospective 8-year study, J. Dent. 44 (2016) 13–19.

[36] R.G. Chadwick, K.I. Linklater, A retrospective observational study of the effect of surface treatments and cementing media on the durability of gold palatal veneers, Oper. Dent. 29 (6) (2004) 608–613.

[37] H. Chana, M. Kelleher, P. Briggs, R. Hooper, Clinical evaluation of resin-bonded gold alloy veneers, J. Prosthet. Dent. 83 (3) (2000) 294–300.

[38] F.S. Nohl, P.A. King, K.E. Harley, R.J. Ibbetson, Retrospective survey of resin-retained cast-metal palatal veneers for the treatment of anterior palatal tooth wear, Quintessence Int. 28 (1) (1997) 7–14.

[39] J. Malik, S. Shah, K. Hemmings, A. Gulamali, J. Malik, The survival and clinical performance of anterior composite resin restorations and posterior indirect and cast restorations used to treat generalised tooth wear, Res. Sq. (2023).

[40] F.F. Demarco, M.B. Correa, M.S. Cenci, R.R. Moraes, N.J. Opdam, Longevity of posterior composite restorations: not only a matter of materials, Dent. Mater. 28 (1) (2012) 87–101.

[41] D. Edelhoff, J.A. Sorensen, Tooth structure removal associated with various preparation designs for anterior teeth, J. Prosthet. Dent. 87 (5) (2002) 503–509.

[42] D. Edelhoff, J.A. Sorensen, Tooth structure removal associated with various preparation designs for posterior teeth, Int. J. Periodontics Restorative Dent. 22 (3) (2002) 241–249.

[43] G. Burian, K. Erdelt, J. Schweiger, C. Keul, D. Edelhoff, J.F. Guth, In-vivo-wear in composite and ceramic full mouth rehabilitations over 3 years, Sci. Rep. 11 (1) (2021) 14056.

[44] A. Torosyan, F. Vailati, P. Mojon, D. Sierra, I. Sailer, Retrospective clinical study of minimally invasive full-mouth rehabilitations of patients with erosions and/or abrasions following the "3-step technique". Part 1: 6-year survival rates and technical outcomes of the restorations, Int. J. Prosthodont. 35 (2) (2022) 139–151.

[45] E. Maier, L. Crins, T. Pereira-Cenci, E. Bronkhorst, N. Opdam, K. Galler, B. Loomans, 5.5-year-survival of CAD/CAM resin-based composite restorations in severe tooth wear patients, Dent. Mater. 40 (5) (2024) 767–776.

[46] R.A. Baldissera, M.B. Correa, H.S. Schuch, K. Collares, G.G. Nascimento, P. S. Jardim, R.R. Moraes, N.J. Opdam, F.F. Demarco, Are there universal restorative composites for anterior and posterior teeth? J. Dent. 41 (11) (2013) 1027–1035.

[47] G.S. Cheung, S.C. Lai, R.P. Ng, Fate of vital pulps beneath a metal-ceramic crown or a bridge retainer, Int. Endod. J. 38 (8) (2005) 521–530.

[48] W.P. Saunders, E.M. Saunders, Prevalence of periradicular periodontitis associated with crowned teeth in an adult Scottish subpopulation, Br. Dent. J. 185 (3) (1998) 137–140.

[49] T. Pereira Cenci, M.G. Cademartori, L.G. Dos Santos, M.B. Correa, B. Loomans, B. L. Horta, F.F. Demarco, Prevalence of tooth wear and associated factors: a birth cohort study, J. Dent. 128 (2023) 104386.

[50] A.S. Al-Khayatt, A. Ray-Chaudhuri, N.J. Poyser, P.F. Briggs, R.W. Porter, M. G. Kelleher, S. Eliyas, Direct composite restorations for the worn mandibular anterior dentition: a 7-year follow-up of a prospective randomised controlled split-mouth clinical trial, J. Oral Rehabil. 40 (5) (2013) 389–401.

[51] L. Crins, N.J.M. Opdam, C.M. Kreulen, E.M. Bronkhorst, B. Sterenborg, M. Huysmans, B.A.C. Loomans, Randomized controlled trial on the performance of direct and indirect composite restorations in patients with severe tooth wear, Dent. Mater. 37 (11) (2021) 1645–1654.

[52] W. Hammoudi, M. Trulsson, P. Svensson, J.I. Smedberg, Long-term results of a randomized clinical trial of 2 types of ceramic crowns in participants with extensive tooth wear, J. Prosthet. Dent. 127 (2) (2022) 248–257.

[53] L.H. Schlichting, T.H. Resende, K.R. Reis, A. Raybolt Dos Santos, I.C. Correa, P. Magne, Ultrathin CAD-CAM glass-ceramic and composite resin occlusal veneers for the treatment of severe dental erosion: an up to 3-year randomized clinical trial, J. Prosthet. Dent. 128 (2) (2022) 158, e1-158 e12.

[54] F.J. Burke, Four year performance of dentine-bonded all-ceramic crowns, Br. Dent. J. 202 (5) (2007) 269–273.

[55] L. Crins, N.J.M. Opdam, C.M. Kreulen, B. Sterenborg, E.M. Bronkhorst, W. A. Fokkinga, M. Huysmans, B.A.C. Loomans, Prospective study on CAD/CAM nano-ceramic (Composite) restorations in the treatment of severe tooth wear, J. Adhes. Dent. 24 (1) (2022) 105–116.

[56] D. Edelhoff, J.F. Guth, K. Erdelt, O. Brix, A. Liebermann, Clinical performance of occlusal onlays made of lithium disilicate ceramic in patients with severe tooth wear up to 11 years, Dent. Mater. 35 (9) (2019) 1319–1330.

[57] D. Edelhoff, K.J. Erdelt, B. Stawarczyk, A. Liebermann, Pressable lithium disilicate ceramic versus CAD/CAM resin composite restorations in patients with moderate to severe tooth wear: clinical observations up to 13 years, J. Esthet. Restor. Dent. 35 (1) (2023) 116–128.

[58] A.M. Gow, K.W. Hemmings, The treatment of localised anterior tooth wear with indirect artglass restorations at an increased occlusal vertical dimension. Results after two years, Eur. J. Prosthodont. Restor. Dent. 10 (3) (2002) 101–105.

[59] V. Koenig, C. Wulfman, S. Bekaert, N. Dupont, S.Le Goff, M. Eldafrawy, A. Vanheusden, A. Mainjot, Clinical behavior of second-generation zirconia monolithic posterior restorations: two-year results of a prospective study with ex vivo analyses including patients with clinical signs of bruxism, J. Dent. 91 (2019) 103229.

[60] K.A. Malament, M. Margvelashvili-Malament, Z.S. Natto, V. Thompson, D. Rekow, W. Att, 10.9-year survival of pressed acid etched monolithic e.max lithium disilicate glass-ceramic partial coverage restorations: performance and outcomes as a function of tooth position, age, sex, and the type of partial coverage restoration (inlay or onlay), J. Prosthet. Dent. 126 (4) (2021) 523–532.

[61] A. Milosevic, The survival of zirconia based crowns (Lava™) in the management of severe anterior tooth wear up to 7-years follow-up, Oral Biol Dent 2 (1) (2014) 2–9.

[62] J. Oudkerk, M. Eldafrawy, S. Bekaert, C. Grenade, A. Vanheusden, A. Mainjot, The one-step no-prep approach for full-mouth rehabilitation of worn dentition using PICN CAD-CAM restorations: 2-yr results of a prospective clinical study, J. Dent. 92 (2020) 103245.

[63] P.L. Ramaekers, B. Sterenborg, B. Bronkhorst, E. Opdam, N. Huysmans, M, Rehabilitation of severe tooth wear patients using indirect composite restorations , IADR, Boston, 2015, ID: 0868 (2015).

[64] S.T. Ramseyer, C. Helbling, A. Lussi, Posterior vertical bite reconstructions of erosively worn dentitions and the "stamp technique" - a case series with a mean observation time of 40 months, J. Adhes. Dent. 17 (3) (2015) 283–289.

[65] F. Vailati, L. Gruetter, U.C. Belser, Adhesively restored anterior maxillary dentitions affected by severe erosion: up to 6-year results of a prospective clinical study, Eur. J. Esthet. Dent. 8 (4) (2013) 506–530.

[66] A.W. Walls, The use of adhesively retained all-porcelain veneers during the management of fractured and worn anterior teeth: part 2. Clinical results after 5 years of follow-up, Br. Dent. J. 178 (9) (1995) 337–340.

[67] A. Aljawad, J.S. Rees, Retrospective study of the survival and patient satisfaction with composite dahl restorations in the management of localised anterior tooth wear, Eur. J. Prosthodont. Restor. Dent. 24 (4) (2016) 222–229.

[68] A. Ferrando Cascales, S. Sauro, R. Hirata, D. Astudillo-Rubio, R. Ferrando Cascales, R. Agustin-Panadero, A. Delgado-Gaete, Total rehabilitation using adhesive dental restorations in patients with severe tooth wear: a 5-year retrospective case series study, J. Clin. Med. 12 (16) (2023).

[69] G.R.S.V. Lopes, A.F. A, V. Diniz, J.D.M. Matos, V.C. Andrade, M.A. Bottino, R. S. Nishioka, F.M. Chiarelli, A.C.R. Feitosa, S.M.G. Guerra, Incidence of fracture in single ceramic crowns in patients with chronic tooth wear: a clinical follow-up, Int J of Odontostomat 15 (1) (2021) 102–110.

[70] J.T. Hamburger, N.J. Opdam, E.M. Bronkhorst, C.M. Kreulen, J.J. Roeters, M. C. Huysmans, Clinical performance of direct composite restorations for treatment of severe tooth wear, J. Adhes. Dent. 13 (6) (2011) 585–593.

[71] S.M. Marchan, A. Eder, Q.M. Marchan, L. Coldero, A.T. Choon, W.A. Smith, A preliminary evaluation into the performance of posterior resin bonded cast metal restorations (adhesive onlays), Eur. J. Prosthodont. Restor. Dent. 21 (1) (2013) 24–28.

[72] L. Printzell, C.F. Haseid, A. Ekfeldt, C. Hjortsjo, Clinical performance of enamel-dentine bonded all-ceramic restorations: retrospective evaluation in a postgraduate clinic, Swed. Dent. J. 40 (2) (2016) 203–212.

[73] R.J. Smales, T.L. Berekally, Long-term survival of direct and indirect restorations placed for the treatment of advanced tooth wear, Eur. J. Prosthodont. Restor. Dent. 15 (1) (2007) 2–6.

[74] P.M.J. Hoekstra-van Hout, J. Schols, S.B. Mehta, N.J.M. Opdam, T. Pereira Cenci, B.A.C. Loomans, Posterior Dahl: a minimally invasive method for the treatment of localized Posterior tooth wear, J. Adhes. Dent. 25 (1) (2023) 31–38.

[75] T. Attin, T. Filli, C. Imfeld, P.R. Schmidlin, Composite vertical bite reconstructions in eroded dentitions after 5.5 years: a case series, J. Oral Rehabil. 39 (1) (2012) 73–79.

[76] T.L. Hansen, C. Schriwer, M. Oilo, H. Gjengedal, Monolithic zirconia crowns in the aesthetic zone in heavy grinders with severe tooth wear - an observational case-series, J. Dent. 72 (2018) 14–20.

[77] S. Levartovsky, R. Pilo, A. Shadur, S. Matalon, E. Winocur, Complete rehabilitation of patients with bruxism by veneered and non-veneered zirconia restorations with an increased vertical dimension of occlusion: an observational case-series study, J. Prosthodont. Res. 63 (4) (2019) 440–446.

[78] E. Lempel, K.G. Nemeth, B.V. Lovasz, J. Szalma, Adhesive management of anterior tooth wear in combination with the Dahl concept-a 27-month observational case series, Oper. Dent. 46 (6) (2021) 594–608.