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State-of-the-Art for metal free cantilever bridges: a literature review

INTRODUCTION

Replacing a single tooth, whether in the anterior or posterior region, presents a significant clinical challenge. Traditional solutions, such as fixed dental prostheses (FDP), while effective, often require extensive tooth preparation. Tagami *et al.* (2021)[1] report that a full cap results in a 63-72% reduction of the healthy tooth, increasing the risk of endodontic treatment and associated complications. In response to these limitations, less invasive adhesive alternatives such as resin bonded bridges have emerged. Historically, Rochette (1973)[2] introduced a bonded bridge with perforated metal fins, improved in 1982 by the Maryland bridge (1982, Livaditis *et al.*)[3], featuring electrolytically etched solid fins. Although more adhesive, debonding remains the primary cause of prosthesis failure. Hussey and Linden (1996)[4] demonstrate the value of cantilever RBFDPs, which are evolving towards all-ceramic versions, combining aesthetics and biocompatibility. According to Mines *et al* (2021)[5], these restorations offer clinical performance comparable to conventional FDPs, with superior tissue preservation. Cantilever RBFDPs show excellent survival rates[6 7 8 9], particularly in the anterior sector (95.4% at 15 years and 81.8% at 18 years) [10], while posterior zirconia versions achieve a 100% survival rate over 53 ± 39 months of observation.[11] However, success depends on frame design and bonding protocol, aspects still under discussion for all-ceramic RBFDPs. While randomized clinical trials remain the gold standard for evaluating these restorations, they are time-consuming, expensive and subject to variability. In this context, biomechanical testing, including *in vitro* testing and finite element analysis (FEA), is an essential alternative for characterizing mechanical performance, optimizing framework design and defining minimally invasive preparations adapted to new materials. This systematic review aims to take stock of these approaches to better understand their impact on the strength and durability of RBFDPs, in order to improve their clinical integration and long-term reliability.

MATERIAL AND METHODS

Search strategy

This systematic review followed the structural protocol provided by PRISMA (Preferred Reporting Items or Systematic Review and Meta Analyses Protocols).[12]

The search strategy was defined according to the PICO framework as follows:

- Population: Patients requiring replacement of a missing anterior or posterior tooth with a cantilever bridge.
- Procedure: Placement of a bonded resin cantilever bridge, using different materials (zirconia, lithium disilicate, reinforced composites).
- Comparison: Different frame designs, materials and tooth areas (anterior vs. posterior).
- Outcome: Biomechanical performance
- Timeframe: *in vitro*, *in silico* studies

Up to November 2024, two online databases, PubMed and Google Scholar, were searched for studies. The present systematic review was conducted for the purpose of addressing the following problem: a comprehensive review of in vitro and digital studies on the performance of cantilever bridges.

The search strategy involved the use of keywords, with minor differences in search strategy depending on the restrictions or characteristics of each

database
(table 1). Google Scholar was used for an additional manual search to gather studies that had not been captured in the initial search.
Selection criteria
Articles that met the following inclusion criteria were included in this review:
• Studies conducted from November 2014 to November 2024:
Most clinical studies show that cantilever design RBFDPs are superior to the two-retention device design in the anterior region.[6 7 13] According to the findings of a systematic review with meta-analysis published in 2016 by Wei Y-R *et al.* [8] cantilever RBFDPs have lower clinical failure than two-retention device RBFDPs in the anterior region. The failure of metal-ceramic RBFDPs is independent of frame design, while the failure of all-ceramic RBFDPs with different designs is still unclear. It therefore seems worth exploring this avenue. Furthermore, in 2014, Sasse and Kern [6] report a 100% survival rate of 42 cantilever bridges in single-fin extension for zirconia frameworks. Sailer and Hammerle [13], Botelho *et al.*[14] point in the same direction.
• published in English,
• full-text studies,
• *in vitro* or *in silico* studies,
• studies on cantilever bridges with non-degraded support.
Articles meeting the following exclusion criteria were excluded from this review:
• studies without quantitative data,
• narrative reviews or expert opinions,
• *in vivo* studies,
• animal studies.
Search results were exported to Zotero (version 7.0.11, Digital Scholar project) to recognise and eliminate duplicate records. Titles and abstracts were then checked and all potential studies were then read in full so as to determine their eligibility.
Method
In each article, the following elements were systematically collected: type of study, main objective, region concerned, number of models, frame design, tooth/teeth preparation, frame materials, surface treatment and bonding system used. The nature of the *in vitro* and FEA tests and the results were then collected. The FEA data processing software was indicated, Young's modulus and Poisson's ratio were checked for each item, and the data were collected in tabular form for easier readability.

RESULTS
Search and selection process
Figure 1 outlines the search strategy and selection process. The two databases initially yielded 544 results, of which 534 remained after elimination of duplicates. After screening titles and abstracts, 19 studies were assessed for eligibility and submitted for full-text review. Thirteen articles [15 16 17 18 19 20 21 22 23 24 25 26 27] met the inclusion criteria. Six studies [28 29 30 31 32 33] were excluded for the following reasons :
– Variation in bone support (n=1),
– Materials (n=1),
– Variable previously reconstructed tooth (n=1),
– Particular cantilever bridge (n=3).
Tables 2.1 and 2.2 present the selected articles chronologically and divided into two groups: single- or double-wing bonded bridges (comparative analysis of the two types of bridge) for the anterior region and posterior bonded bridges with full or partial coverage, supported by one or two abutments.

Characteristics of items that meet the eligibility criteria.

All selected articles analysed the stresses in cantilever bonded bridges. Seven articles focus on anterior cantilever bridges [15 16 17 18 19 20 21], six on the replacement of a maxillary lateral incisor [15 16 17 18 19 20] and one on the replacement of a mandibular lateral incisor.[21]
Six articles focus on posterior mandibular cantilever bridges. [22 23 24 25 26 27]
Five articles carried out *in vitro* tests [19 23 24 25 27], while twelve studies mentioned FEA analysis. [15 16 17 18 19 20 21 22 23 24 25 26]
FEA softwares used included:
– ANSYS: five studies [16 18 19 20 21],
– TRI/3D-BON-FCS (Ratoc System Engineering Inc.) [15] : one study,
– Voxelcon (Quint) [17] : one study
– NX Nastran (MSC Software) [22] : one study,
– ABAQUS [26] : one study,
– 3D CAD SolidWorks (Dassault Systèmes) [23 24 25] : three studies.
Four studies mention pre-processing of dental surfaces. [19 23 24 25]:
• Malgaj *et al.* [19]:
– AM (As Machined): Surface left as is after machining.
– APA (Airborne-Particle Abraded): Abrasion with 50 µm alumina particles, at a pressure of 0.1 MPa for 15 seconds, at a distance of 10 mm
– NAC (Nanostructured Alumina Coating): Immersion in aluminate solution, boiling for 10 min, calcination at 900°C for 30 min.
– NAC-APA: NAC coating on the bonding surface of the RBFDP and particle abrasion on the tooth surface
• Kasem *et al.* [23]:
– Surfaces sandblasted with 50 µm Al2O3 powder at 25 MPa, then cleaned and dried. The internal surface is then coated with a primer containing MDP (CLEARFIL Ceramic Primer Plus).
• Kasem *et al.* [24]:
– Ultrasonic bath: 5 minutes, leave to dry for 10 minutes.
– Prepare teeth with 37% phosphoric acid (K-etchant, Kuraray Noritake) for 30 seconds and dentine for 15 seconds.
– Water spray
– Conditioning of teeth with an adhesive system containing MDP (Panavia)
• Kasem et al. [25]:

– Abrasion by suspended particles with 50 µm Al_2O_3 powder at 0.25 MPa, followed by cleaning by ultrasonic bath and application of primer containing MDP.

To facilitate analysis and comparison, data on framework designs, dental surface preparations, and materials used were compiled into a table. This structured presentation allows for a comprehensive evaluation of the influence of these parameters on the biomechanical performance of RBFDPs. (Table 3.1 and Table 3.2)

To enhance readability and facilitate the comparison of results from in vitro tests and FEA, all data were synthesized into tables. This structured presentation provides a clear overview of the performance of various materials and designs of RBFDPs, highlighting observed trends and the consistency between experimental findings and numerical simulations. (Table 4)

DISCUSSION

The aim of this systematic review was to assess the effect of different non-metallic frame designs (ceramic or fibre-reinforced composites) and tooth surfaces, based on the intrinsic qualities of modern materials, for the fabrication of two-unit cantilevers in terms of mechanical performance. Focusing on *in vitro* and *in silico* studies, our analysis revealed that various aspects could influence performance. Given that two-unit RBFDPs are considered a less invasive technique for replacing a missing tooth, it is essential to assess which modification increases fracture resistance and reduces the risk of catastrophic failure. In the following section, we will discuss related articles that present a comparison between the use of one or two fins, connector size, choice of tooth receiving the retainer, use of surface treatment, impact of preparation, framework, aging and materials.

Front cantilevers

Choice of one or two fins: Uraba *et al.* [15] reported that fixed-fixed RDFDPs (Zirconia Y-TZP) tend to show a lower risk of detachment than single-finned RBFDPs and therefore would have a higher survival rate. This FEA study is in line with the *in vitro* study by Narwani *et al* .[35] and Wang *et al.* [21] (IPSe.max CAD and IPS e.max ZirCAD) which demonstrated that fixed-fixed RBFDPs have a higher tensile strength than single-fin RBFDPs. These results are contrary to studies [36 37 38 39 40] concluding that two-unit cantilever RBFDPs (2-unit RBFDPs) often offer better performance than conventional three-unit models. A clinical study by Kern[41] showed that the 5-year survival rate for two-unit RBFDPs was 92.3%, compared with 73.9% for three-unit RBFDPs.

Sareh Habibzadeh *et al.*[42] analyzed and synthesized articles published between 2010 and 2020. In this systematic review, articles that used the two-pillar design with 8- and 10-years follow-up reported a survival rate of 85.3% to 92.6%. Most studies used the cantilever design for all-ceramic RBFDPs and reported a survival rate of 91.7% to 100%. This is partly because two-unit RBFDPs, with a single retaining abutment, reduce the risk of frame detachment, a common problem with three-unit models. In addition, 2-unit RBFDPs have better force absorption, which could reduce the risk of connector failure between pontic and abutment. However, design adaptation is complex due to differences in tooth shape and orientation. Excessive loading on the abutment tooth can cause occlusal trauma, endangering periodontal health and increasing the risk of tooth loss. Kerschbaum and colleagues [43] pointed out that frame loosening of abutment teeth is a frequent failure, often caused by bending of the frame under occlusal loading, which places stress on the adhesive cement. Differences in results may be explained by the nature of the studies: FEA and *in vitro* studies do not take account of differential movements of the abutment teeth, which cause detachment stresses, and the loads applied are quasi-static. The high bond strength [35], observed in RBFDPs with double wings or two abutments in extension may be linked to the increased preparation surface, and hence bonding surface.

Preparing the abutment tooth: RBFDPs are said to be a biologically conservative edentulism treatment. They need a minimal level of preparation and hence are a reversible therapy. When RBFDPs are viewed as a temporary restoration, the preparation of the abutment teeth is based on the viewpoint of a provisional treatment. Nonetheless, in spite of this fact, our literature review indicated a number of perspectives regarding the concept of proper tooth preparation before the placement of RBFDPs. Most of the studies examined mentioned creation of grooves, pits, slots, chamfer and proximal boxes on the lingual/palatal surface of abutment teeth. [15 16 17 18 19 20] Only one study[21] did not mention abutment preparation, which may be a point to consider for future research.

However, it seems that the majority agree on the advantages of minimal preparation without penetrating dentin, using a supra-gingival finishing line and allowing an adequate bonding surface for the material chosen for the prostheses. This is in line with a 2021 integrative review by Mendes JM *et al.* [44] which examined clinical publications to assess survival rates regarding their materials and design: among the 23 clinical publications analyzed, cantilever design showed better 5-year longevity, than two-wing design, at 91.9% versus 85.2% with minimal preparation.

As part of this methodical approach, Attal *et al.* [45] emphasize the importance of maintaining the rigidity of the supporting abutment. In this respect, it is recommended that the supporting preparation be maintained in an intra-amelar position wherever possible.

In various studies, retentive and non-retentive preparation designs have been varied. In four studies[15 18 19 20] proximal boxes/grooves and pinholes were advocated as retention aids, with a view to increasing the longevity of RBFDPs. [8] Proximal boxes allow adequate connector thickness and define an insertion path for correct installation of RBFDPs. Central grooves in the lingual fossa cingulum help optimize framework positioning.

Connector size: FEA is used to study the distribution of stresses on the various components of the RBFDP, including the adhesive cement and periodontal tissue. Regarding previous RBFDPs, we can highlight several points: Cantilevers with larger connectors (3x4mm) show better stress resistance and less deformation than smaller connectors (3x3mm). [20] Smaller volume connectors (such as 4mm x 2mm x 1mm and 5mm x 2mm x 1mm) give the highest maximum equivalent stress values, exceeding the bending strength of the materials, leading to fractures. [18]

Finite element analysis highlights various points: FEA models show that stress concentration zones are mainly located at connectors and bonding interfaces. [17 18 19 20]

Choosing the tooth to receive the retainer: Dentures using canines as abutments are less likely to detach [20] and damage periodontal tissues than those using the central incisor [15 20].

Surface treatment: APA and nanostructured alumina coating (NAC) are effective in improving zirconia bonding in RBFDPs. NAC offers a non-damaging alternative to APA, particularly beneficial for translucent zirconia materials. The results of the finite element analysis confirmed that the stress concentration zones are mainly located at the bond interfaces and in the connection zones of the prostheses.[16 17 18 19 21]

Materials:

Bonding system: The studies did not compare the different bonding systems.

Frame materials: two materials are highlighted: the connector material has a significant influence on its resistance to applied loads. Zirconia, in particular, shows better performance in terms of fracture resistance under high loads[18] Materials such as IPS e.max ZirCAD and IPS e.max CAD are recommended for their low probability of failure. [21]

Posterior cantilevers:

Articles on posterior RBFDPs focus on optimizing and evaluating fiber-reinforced resin and zirconia cantilever fixed dental prostheses to improve their structural strength, interfacial adhesion and overall clinical performance. [22 23 24 25 26 27]

Impact of substrate preparation and frame design: Chen[26 27] and Kasem[23 24 25] demonstrated the impact of RBFDP preparation and design on the fracture resistance of resin-fixed prostheses. Lingual coverage (LC) and occlusal coverage (OC) designs can be used to design fixed cantilever dentures in the premolar area, while inlay ring (IR), one wing (OW) and two wings (TW) designs should be used with caution due to their inferior performance in terms of fracture resistance.[23]

Another study by Kasem *et al.* evaluated the biomechanical behaviour of zirconia cantilever RBFDPs with different retainer designs and number of inlay boxes. The study found that retainers with lingual and occlusal coverage are effective designs for cantilever RBFDPs, but the use of two inlay boxes decreased fracture loading and increased stress transmission to the tooth, leading to a higher incidence of catastrophic failure. [24]

Impact of artificial aging: Kasem *et al*. have also highlighted the fact that artificial aging [24] (mechanical loading and thermocycling) has an impact on fracture value: the results of a previous *in vitro* study assessed the effect of retainer design on the fracture toughness of FRC RBFDP cantilever glass. The authors reported higher fracture values without an artificial ageing process.[46] The majority of aging studies use a one-year simulation process; Thus, it would be interesting to push this process further to obtain a more reliable interpretation on the effect of fracture value.

Materials: Chen *et al* [26 27] have studied FRC RBFDPs: clinical studies have reported a survival rate of only 60-80% after 5 years, [47] with the main failure modes being delamination, detachment and fracture. The factors determining the performance of FRC RBFDPs have been studied to improve their lifespan. Thanks to numerous load-to-failure tests, the main factors determining the performance of FRC RBFDPs have been reported to be Fiber volume [48], position and orientation. [49] The optimized design features a scoop-shaped cavity preparation and fibers placed close to the occlusal surface of the connector region. This design significantly reduced the maximum principal stresses within the restoration and tooth structure, as well as interfacial tensile stresses, compared with conventional designs. Kasem *et al.* also indicate that FRCs can be used as cantilevered RBFDPs in the premolar region and envisage this as a "promising" solution. [24]

Miura *et al.* [22] used three-dimensional finite element analysis to evaluate different frame designs for zirconia cantilever partial fixed prostheses. The design combining extended frame height and width (Design 4) showed better stress distribution and increased protection of the abutment teeth, resulting in improved long-term stability. In this study, the peripheral preparation is total, and therefore more debilitating. A peripheral coronal preparation leads to a displacement of the support under mechanical stress, which is why traditional dentistry recommended the use of two abutments to stiffen the whole. In addition, Kasem *et al*.[24 25] and Lam *et al*. [50] suggest that zirconia is a reliable alternative for the design of posterior RBFDPs, provided that retainer design considerations and clinical factors are taken into account. According to Attal *et al.* [45], material strength is a determining factor in the bridge's ability to withstand mechanical forces. Consequently, they recommend the use of zirconia for posterior cantilever bridges, a solution that offers optimal strength.

These studies highlight the importance of optimizing the shape and design of RBFDPs to improve their mechanical performance, longevity and clinical outcomes. The use of advanced materials such as zirconia and FRC, together with innovative design techniques, can significantly improve the efficacy of these dental prostheses.

Interpreting the results of this systematic review has several important limitations:

- Selection of databases: The analysis was limited to only two databases, which may restrict the diversity of articles reviewed.
- Limited number of articles: The number of articles dealing specifically with the subject of cantilever

RBFDPs is relatively small, which may affect the generalizability of the conclusions.
- Variability of experimental methods and conditions: The studies included used various methodologies and different experimental protocols, which makes direct comparison difficult and may introduce bias in the results interpretation.
- Lack of information: Some articles do not provide all the information required for an exhaustive evaluation of the results, which limits the precision of the analysis.

CONCLUSION

According to the performance analysis of cantilever bridges, which is grounded on the *in vitro* and *in silico* research, the development of more conservative and long-lasting solutions to problems related to the prosthetic is significant, which supports the topicality of the given therapeutic method. The findings point to an increasing trend in favour of cantilever RBFDPs, because of their ability to preserve tissue in the dentists, and failure modes that are considered more favourable than those of double retainer counterparts.

As much as some consistency of preparation procedures is evident in the anterior area, greater variation still remains in the posterior areas. Thus, there is no agreement that appears to be coming up on a standard preparation that fulfils all mechanical requirements.

In the anterior part, the literature points towards a minimally invasive preparation, which is optimised by an appropriate connector, to save tooth structures and achieve good stress distribution. Regarding materials, zirconia appears to be chosen in terms of its mechanical and aesthetic performance.

Lithium disilicate still remains in common use, particularly in certain aesthetic applications. When it comes to the tools of analysis, FEAs can be used to obtain useful information as to the stress distribution and material strength; however, *in vitro* mechanical tests do not seem to be as relevant to the current study. The latter would be interesting, say, in the evaluation of thermomechanical ageing and the optimisation of the determination of failure modes. All in all, the findings of *in vitro* experiments support the trends exhibited by *in silico* ones, which makes them valid.

Lastly, the current review may form the basis of further investigation with the introduction of modern optimisation tools like evolutionary algorithms and response surface methods. This would allow the development of designs that are not only mechanically optimised but also able to maximise the clinical life of prosthetic devices.

Abbreviations:

2U RBFDPs: Two-unit cantilever resin-bonded fixed dental prostheses

FEA: Finite-Element Analysis

FDP: Fixed Dental Prostheses

FRC: Fiber- Reinforced Composite

RBB: resin bonded bridge
Y-TZP: Yttrium-oxide partially stabilized zirconia
IC: Incisive, Canine
C: Canine

FF-RBB: Fixed-Fixed RBB

D-CRBB: Distal Cantilever RBB

M-CRBB: Mesial Cantilever RBB

AM: As Machined

APA: Airbone-Particle Abraded

NAC: Nanostructered Alumina Coating

PDL: Periodontal Ligament

SE RBFPD: single-ended resin-bonded fixed partial denture

DE RBFPD: double ended resin-bonded fixed partial denture

OW: One Wing

TW: Two

Wings IR: Inlay

Ring

LC: Lingual Coverage

OC: Occlusal Coverage

D1F: 2-unit cantilevered FRC RBFDP, Inlay ring retainer

D1Z: 2-unit cantilevered RBFDP Zircone , Inlay ring retainer

D2F: 2-unit cantilevered FRC RBFDP, Lingual coverage retainer

D2Z: 2-unit cantilevered RBFDP Zircone, Lingual coverage retainer

LC1: Lingual Cover and 1mesial inlay box

LC2: Lingual Cover and 2 boxes (M. and D.)

OC1: Occlusal Cover and 1 mesial inlay box

OC2: Occlusal Cover and 2 inlay boxes (M. and D.)

mvM: maximum modified von Mises stresses

MSS: Maximum shear stress
MPS: Maximum principal stress

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