ON FAILURES AND COMPLICATIONS OF TOOTH-SUPPORTED FIXED PROSTHESES

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By Mohammed Abdullah Hawthan

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ON FAILURES AND COMPLICATIONS OF TOOTH-SUPPORTED FIXED PROSTHESES

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To my angel mother Neama and idol father Abdullah

To my precious son Turki and beloved wife Alaa

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ABBREVIATIONS AND DEFINITIONS

Au-MC	High-noble gold-based metal–ceramic
CCT	Controlled clinical trial
CD	Complete denture
CI	Confidence interval
CoCr-MC	Cobalt–chromium-based metal–ceramic
CSR	Cumulative survival rate
ECG	Electromyography
E.max	Lithium disilicate glass–ceramic
Empress	Leucite-reinforced glass–ceramic
Empress 2	Lithium disilicate glass–ceramic
FDP	Fixed dental prosthesis
FPD	Fixed partial denture
HR	Hazard ratio
ISR	Interval survival rate
Ni–Cr	Nickel–chromium
NOS	Newcastle–Ottawa Scale
Pd–Ag	Palladium–silver
PSG	Polysomnography
RCT	Randomized controlled clinical trial
RPD	Removable partial denture
SC	Single crown
SD	Standard deviation
SE	Standard error
Ti	Titanium
VIF	Variance inflation factor

ABSTRACT

Loss of tooth structure or loss of the tooth may affect masticatory function, phonetics, a person´s appearance, and might ultimately impair quality of life. Fixed prosthetic rehabilitation in the form of either fixed dental prosthesis (FDP) or single crown (SC) is a reliable treatment alternative to restore lost functions.

Tooth-supported fixed prosthetic restorations (FDPs, SCs) are influenced by multiple combined general and local factors that may affect the risk of complication and failure. Recognizing risk factors is important in treatment planning, and will help the clinician optimize treatment outcomes. This will also be beneficial for both the patient and society from a cost-effective aspect, as a reduction in complications and failures reduces costs. Several factors have been suggested to impact the survival and failure rates of FDPs and SCs, but there is still limited evidence concerning the clinical outcomes of FDPs and SCs when subjected to a combination of multiple factors in a clinical setting.

The aim of the present thesis was to evaluate whether the survival and failure rates of full-coverage tooth-supported fixed prosthetic restorations (FDPs, SC) are influenced by general and/or local factors.

This thesis is based on a systematic review (Paper I) and three retrospective studies (Papers II, III, and IV).

In Study I, PubMed, Web of Science and ScienceDirect databases were searched and manual searches were conducted to identify clinical human studies reporting on full-coverage tooth-supported FDPs and SCs. Cumulative survival rate (CSR) was calculated over the maximal period of follow-up reported, in a life-table survival analysis.

Seventeen studies fulfilled the inclusion criteria. The highest 5-year survival rate was observed for all-ceramic and metal–ceramic SCs on vital teeth 97.8% (95% CI [97.1– 98.5%]), and all-ceramic SCs on non-vital teeth with fiber post 99.1% (95% CI [97.7– 100.4%]). Metal–ceramic SCs on vital teeth 97.5% (95% CI [96.8–98.3%]) showed a statistically significant higher estimated 5-year survival

rate compared to metal–ceramic SCs with cast metal post 94.5% (95% CI [93.3–95.8%], p <0.001) and fiber post 95.1% (95% CI [93.4–96.6%], p <0.007), respectively. For FDPs, the 5-year survival rate was higher for metal–ceramic FDPs on vital abutments 96.9% (95% CI [95.5–98.4%]), compared to FDPs retained by non-vital abutment(s) with cast metal posts 94.3% (95% CI [89.3–99.3%]). The difference was not statistically significant. Tooth vitality is suggested to contribute positively to the survival of SCs. The results are, however, limited by the small number of studies and the presence of uncontrolled cofounding clinical variables.

In the retrospective studies II, III, and IV, dental records archives and the digital journals of all patients at the Faculty of Odontology, Malmö University, Sweden were reviewed to identify patients rehabilitated with full-coverage tooth-supported FDPs and SCs. Cox regression was used to evaluate the associations between clinical covariates and prosthesis failure.

The CSR was similar for FDPs and SCs after 5 years of function. CSR was higher for SCs compared to FDPs after 10, 15, and 20 years of function. Smoking, type of prosthesis material, and bruxism significantly influenced the survival of FDPs, whereas abutment vitality, position of the non-vital abutment, or prosthesis length did not show any significant influence on the occurrence of FDP failure. The survival of SC was influenced by anterior placement, non-vital abutments, and bruxism, while the patient's age and sex, the location of the crowns in relation to the jaws, the type of tooth, the presence of post and core, and the type of crown material, treatment providers, or smoking did not show significant effects on the survival of SC.

In summary, within the limitations of the review and retrospective studies, bruxism, smoking, and type of prosthesis material are suggested to contribute to FDP failure. Anterior placement, non-vital abutments, and bruxism are factors increasing the rate of SC failure.

POPULÄRVETENSKAPLIG SAMMANFATTNING

Skador på tänder och/eller förlust av tänder kan påverka funktioner som tal och tuggning samt utseende och kan därmed påverka livskvaliteten. Rehabilitering med fasta tandersättningar i form av kronor och broar är ett väl beprövat sätt att återställa förlorade funktioner.

Tandersättningars funktion och livslängd påverkas av flera faktorer, generella och lokala, som kan inverka på risk för komplikationer och misslyckande. Kunskap om riskpåverkande faktorer är betydelsefull vid terapiplanering och kan hjälpa klinikern att välja korrekt behandling. Minskad risk för komplikationer reducerar behandlingskostnader vilket är av nytta för både patient och samhälle.

Ett flertal faktorer har påståtts kunna ha påverkan på lyckande respektive misslyckande för tandstödda kronor och broar men det finns fortfarande begränsad kunskap om kronor och broars kliniska utfall när man tar hänsyn till kombinerade multipla faktorer.

Målet med denna avhandling var att utvärdera överlevnad och komplikationsförekomst för tandstödda kronor och broar med hänsyn till multipla generella och lokala faktorers inflytande.

Avhandlingen består av 4 delarbeten, en systematisk översikt (studie I) och tre retrospektiva studier.

I studie I genomfördes sökningar i tre databaser, PubMed, Web of Science och ScienceDirect, plus handsökningar av tidskrifter, för att identifiera kliniska studier som rapporterar om tandstödda kronor resp. broar. Cumulative survival rate (CSR) beräknades över maximal uppföljningsperiod i en life-table analys.

17 studier uppfyllde inklusionskriterierna. Högst 5-års överlevnad observerades för metallkeramiska och helkeramiska singelkronor på vitala stödtänder, 97.8% (95% CI [97.1– 98.5%]), och helkeramiska singelkronor på icke-vitala (rotfyllda) tänder med fiberstift, 99.1% (95% CI [97.7– 100.4%]). Metallkeramiska kronor

på vitala stödtänder uppvisade en statistiskt signifikant högre 5-års överlevnad jämfört med metallkeramiska kronor på rotfyllda stödtänder med gjutna metallstift 94.5% (95% CI [93.3 – 95.8%], p <0.001) eller fiber-stift 95.1% (95% CI [93.4 – 96.6%], p <0.007). För broar var 5-års överlevnaden högre för metallkeramiska broar på vitala stöd 96.9% (95% CI [95.5–98.4%]) jämfört med broar med icke-vitala stöd med gjutna metallstift 94.3% (95% CI [89.3–99.3%]) Skillnaden var inte statistiskt signifikant. Vitala stödtänder förefaller vara en positiv faktor för överlevnaden för singelkronor. Resultaten påverkas dock av att de är baserade på få studier där det kan finnas okontrollerade variabler.

I de retrospektiva studierna, II, III och IV, genomsöktes journalarkivet vid Odontologiska fakulteten, Malmö universitet, för att identifiera patienter som fått tandstödda kronor och/eller broar. Cox regressionsanalys användes för att utvärdera eventuella samband mellan kliniska variabler och kron-/bro-överlevnad.

CSR var jämförbar för broar och kronor efter 5 år i funktion. CSR var högre för singelkronor än broar efter 10, 15 och 20 års funktion. Kronors överlevnad påverkades av anterior placering, icke-vitala stödtänder och bruxism medan patienters ålder och kön, vilken käke kronan var placerad i, på vilken typ av tand, förekomst av stiftpelare, typ av material i kronan, om behandlaren var specialist eller allmäntandläkare samt rökning inte hade signifikant påverkan. Rökning, typ av material och bruxism hade signifikant påverkan på broars överlevnad. Stödtänders vitalitet, position av icke-vitala stöd samt brospann, hade inte någon påverkan på broars överlevnad.

Sammanfattningsvis konstateras, inom studiernas begränsningar, att bruxism och rökning samt typ av material kan ha betydelse för risken för misslyckande med tandstödda broar. Anterior placering, rotfyllda stödtänder och bruxism kan ha betydelse för risken för misslyckande med tandstödda singelkronor.

LIST OF PUBLICATIONS

Paper I

Hawthan MA, Larsson C, Chrcanovic BR. The longevity of fixed prosthetic restorations on vital and non-vital teeth: A systematic review. Journal of Prosthodontics, Submitted, 2022 September 9.

Paper II

Hawthan MA, Chrcanovic BR, Larsson C. Long-Term Retrospective Clinical Study of Tooth-Supported Fixed Partial Dentures: A Multifactorial Analysis. Journal of Prosthodontic Research. 2022 Aug 27. doi: 10.2186/jpr. JPR_D_21_00222. PMID: 36031347

Paper III

Hawthan M, Chrcanovic BR, Larsson C. Retrospective Study Comparing Clinical Outcomes of Fixed Dental Prostheses in Matched Groups of Bruxer and Non-bruxer Patients. International Journal of Dentistry. 2022, Mar 27; 2022:6818170. doi: 10.1155/2022/6818170. eCollection 2022. PMID: 35386548

Paper IV

Hawthan M, Chrcanovic BR, Larsson C. Retrospective clinical study of tooth-supported single crowns: A multifactor analysis. European Journal of Oral Sciences. 2022 Aug;130 (4): e12871. doi: 10.1111/eos.12871. Epub 2022 May 25. PMID: 35613306

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THESIS AT A GLANCE

STUDY	AIM	KEY FINDINGS
(I) The longevity of fixed prosthetic restorations on vital and non-vital teeth: A systematic review.	To evaluate and compare the survival and failure rates of full-coverage fixed prosthetic restorations (FDPs, SCs) on tooth abutments with different vitality conditions, taking into consideration the potential influence of three main factors: Tooth vitality, presence and type of post, and type of prosthetic restoration material.	Preserved tooth vitality is suggested to contribute positively to SC survival. The present results should be interpreted with caution as presence of uncontrolled confounding variables among included studies could increase the risk of bias.
(II) Long-term retrospective clinical study of tooth-supported fixed partial dentures: A multifactorial analysis.	To evaluate and compare the survival rates of fixed partial dentures (FPDs) retained by vital and non-vital teeth, considering multiple combined factors.	Smoking contributes to FPD failure irrespective of abutment vitality, as observed in multivariate analysis. The type of prosthesis material contributed to FPD failure irrespective of abutment vitality, as observed in a separate univariate analysis.
(III) Retrospective study comparing clinical outcomes of fixed dental prostheses in matched groups of bruxer and non-bruxer patients.	To evaluate and compare the failure rates and technical and biological complications of FDPs in a group of patients presenting bruxism in comparison with a matched group of non-bruxers with respect to several clinical factors.	Bruxism is suggested to contribute to FDP failure due to an increased prevalence of technical and biological complications.
(IV) Retrospective clinical study of tooth-supported single crowns: A multifactor analysis.	To investigate the survival rates and technical and biological complications of tooth-supported SCs with respect to several clinical factors.	Anterior placement, non-vital abutments, and bruxism are factors increasing the rate of SC failure.

AUTHOR CONTRIBUTIONS

Paper I

Conceptualization: Mohammed Hawthan, Christel Larsson, Bruno Chrcanovic; **Methodology:** Mohammed Hawthan, Bruno Chrcanovic; **Software:** Mohammed Hawthan, Bruno Chrcanovic; **Validation:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Formal analysis:** Mohammed Hawthan, Bruno Chrcanovic; **Investigation:** Mohammed Hawthan, Bruno Chrcanovic; **Resources:** Christel Larsson; **Data curation:** Mohammed Hawthan, Bruno Chrcanovic; **Writing—original draft preparation:** Mohammed Hawthan; **Writing—review and editing:** Bruno Chrcanovic, Christel Larsson; **Visualization:** Mohammed Hawthan, Christel Larsson, Bruno Chrcanovic,; **Supervision:** Bruno Chrcanovic, Christel Larsson; **Project administration:** Mohammed Hawthan; **Funding acquisition:** Mohammed Hawthan.

Paper II

Conceptualization: Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Methodology:** Mohammed Hawthan, Bruno Chrcanovic; **Software:** Mohammed Hawthan, Bruno Chrcanovic; **Validation:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Formal analysis:** Mohammed Hawthan, Bruno Chrcanovic; **Investigation:** Mohammed Hawthan, Bruno Chrcanovic; **Resources:** Christel Larsson; **Data curation:** Mohammed Hawthan; **Writing—original draft preparation:** Mohammed Hawthan; **Writing—review and editing:** Bruno Chrcanovic, Christel Larsson; **Visualization:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Supervision:** Bruno Chrcanovic, Christel Larsson; **Project administration:** Mohammed Hawthan; **Funding acquisition:** Mohammed Hawthan.

Paper III

Conceptualization: Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Methodology:** Mohammed Hawthan, Bruno Chrcanovic; **Software:** Mohammed Hawthan, Bruno Chrcanovic; **Validation:** Mohammed Hawthan, Bruno Chrcanovic,

Christel Larsson; **Formal analysis:** Mohammed Hawthan, Bruno Chrcanovic; **Investigation:** Mohammed Hawthan, Bruno Chrcanovic; **Resources:** Christel Larsson; **Data curation:** Mohammed Hawthan; **Writing—original draft preparation:** Mohammed Hawthan; **Writing—review and editing:** Bruno Chrcanovic, Christel Larsson; **Visualization:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Supervision:** Bruno Chrcanovic, Christel Larsson; **Project administration:** Mohammed Hawthan; **Funding acquisition:** Mohammed Hawthan.

Paper IV

Conceptualization: Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Methodology:** Mohammed Hawthan, Bruno Chrcanovic; **Software:** Mohammed Hawthan, Bruno Chrcanovic; **Validation:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Formal analysis:** Mohammed Hawthan, Bruno Chrcanovic; **Investigation:** Mohammed Hawthan, Bruno Chrcanovic; **Resources:** Christel Larsson; **Data curation:** Mohammed Hawthan; **Writing—original draft preparation:** Mohammed Hawthan; **Writing—review and editing:** Bruno Chrcanovic, Christel Larsson; **Visualization:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Supervision:** Bruno Chrcanovic, Christel Larsson; **Project administration:** Mohammed Hawthan; **Funding acquisition:** Mohammed Hawthan.

INTRODUCTION

Background

The loss of natural teeth has been reduced due to regular follow-up prophylactic visits.[1] Nevertheless, tooth damage and loss due to caries, trauma, and periodontal disease still occur.[2, 3] The severity of tooth loss varies from single to multiple missing teeth or even involving the entire dentition. Loss of coronal tooth structure or complete tooth loss can affect aesthetics, phonetics, efficacy of mastication, patients' nutrition, and may negatively influence quality of life.[4, 5]

Missing teeth can be replaced by different fixed or removable treatment options to restore oral functions and aesthetics.[6, 7] Fixed treatment options involve natural teeth and/or dental implants as abutments.[7-11] Restorable natural teeth, vital or non-vital, with loss of coronal structure are still commonly used as abutments for fixed dental prostheses (FDPs) and single crowns (SCs) despite the increased use of osseointegrated dental implants in the last years.[12] Implant treatment modality shows high survival rates and high levels of patient satisfaction.[7, 13, 14] However, in certain medical conditions, dental implant treatment could be contraindicated,[15]such as in the case of insufficient bone volume and/or irradiated bone and patients with osteoporosis treated with intravenous bisphosphonates,[16] or when known risk factors for dental implant failure such as heavy smoking and/or bruxism is present.[17-21] Natural teeth have advantages over implants, most notably periodontal tissue around natural teeth works as shock absorber that reduces and distributes the occlusal forces transmitted to supporting bone.[22, 23] This is not present around implants, where the inflexible ankylotic connection between implant and surrounding bone prevents the distribution of occlusal load to the surrounding bone[22, 23] which has been suggested to increase the risk of implant loss during overloading forces.[23] Higher occurrence of technical complications have been found among implant-

supported restorations than in tooth-supported restorations.[24] Therefore, maintaining natural dentition is among the major goals of dental care.[25]

Full-coverage tooth-supported FDPs and SCs belong to the most reliable treatment alternatives and have been successfully used for decades to restore oral functions and aesthetics.[6, 26, 27] The estimated survival rates of FDPs at 5 and 10 years have been reported to be 93.8% %–89.2%, respectively.[28] Over the long term, up to 18 years of function, the survival rates of FDPs have been reported to be 78%.[29] The short and medium-term survival rates of SCs, up to 5 years, have been reported to range between 93.3%–96.6%,[11, 26] and 85.4% after 25 years of function.[30]

Despite high overall survival rates for tooth-supported FDPs and SCs, clinical performance is still not without some technical and biological complications which affect the treatment outcome.[6, 27] The risk of complications and failures of tooth-supported FDPs and SCs could be influenced by several general and local factors.[31] Recognition of these factors by treatment providers during treatment planning and decision-making may reduce the risk of complications and failures, and increase the survival of tooth-supported FDPs and SCs.

Reported complications for tooth-supported fixed prosthetic restorations (FDPs and SCs)

Biological complications

Secondary caries

In previous systematic reviews, dental caries was reported as a cause of FDP and SC loss.[10, 11, 27, 28] For FDPs, the 5-year risk of caries at abutment and FDP levels were reported with a range of 1.4%–4,8% and 1.6%–2.1%, respectively.[10, 28] The 10-year risk of caries at abutment and FDP levels were reported with higher percentages of 9.5% and 2.6%, respectively.[27] In a systematic review on SCs, a 5-year complication rate of secondary caries of 1% and 0.4% was reported for abutment and SC levels, respectively.[11]

Loss of tooth vitality

Another main biological complication for FDPs and SCs in addition to caries is loss of vitality.[6, 10, 11] In FDPs, the cumulative 5-year complication rate of loss of abutment vitality was reported to be 2.2% and 6.1% in two different systematic reviews.[10, 28] At 10 years, the risk of loss of vitality for abutments supporting

FDPs was 10%.[27] The risk of loss of tooth vitality was reported for SCs with a rate of 1.8% after 5years of function.[11]

Periodontitis

Loss of abutment teeth and entire prostheses due to periodontal disease progression have been reported for FDPs.[10, 27] The 5-year risk of loss of FDP due to periodontitis was reported to be 0.4%.[28] In a more recent review, the 5-year risk of FDP loss because of recurrent periodontitis was 1.2%.[10] In one review from 2004, the 10-year recurrent periodontitis which lead to FDP loss was reported to be 0.5%.[27] Periodontal breakdown has been reported to occur less frequently for SCs compared to FDPs, with approximately 0.2% reported in one study, irrespective of medium or long term follow-up.[32]

Technical complications

Loss of retention

The most frequent technical complication in FDPs is loss of retention.[27, 28] The reported rate of complication varies from 3.3% to 6.4% over 5–10 years of function.[27, 28] In a more recent systematic review, the cumulative 5-year complication rate of loss of FDP retention was 3.1%.[10] Loss of retention is not a common complication for SCs, except for zirconia-based crowns ,where a 5-year complication rate of 4.7% has been reported.[11]

Framework fracture

Framework fracture has been reported in all different types of FDP materials. The 5-year complication rates of framework fracture ranged between 0.6%–12.9% in one report.[10] Highest percentages were reported for reinforced glass–ceramic and glass-infiltrated alumina FDPs, while lowest 5-year complication rate was reported for metal–ceramic FDPs.[10] The 5-year risk of framework fracture for SCs varied between 0.03%–6.7%, with fewer occurrences for metal–ceramic SCs compared to all-ceramic ones.[11]

Abutment tooth fracture

Abutment tooth fracture has been reported as a common reason for FDP failure.[29] The estimated 5-year complication rate for abutment tooth fracture was 0.9%.[10] The overall 5-year complication rate of abutment tooth fracture for all types of SC material was 0.9% but occurred less frequently in all-ceramic SCs compared to metal–ceramic SCs.[11]

Ceramic veneer chipping or fracture

Complications affecting the ceramic veneer of a restoration are referred to as chipping or fracture.[11] Ceramic chipping was defined in a previous review as any chipping in the veneer ceramic that would need chair side polishing, while the term fracture was used when the damage was such that it led to FDPs or SCs needing to be repaired or replaced.[11]

For FDPs, the reported 5-year complication rate of ceramic chipping for different types of FDP material was 12.7%.[10] Ceramic fracture was reported as the second most common technical complication for all types of FDP material, with a 5-year complication rate of 7.5%.[10] As with framework fractures, there is an influence of type of material where zirconia-based FDPs have showed higher incidence of ceramic veneer fracture compared to other types of FDP materials, with a 5-year complication rate of 14.5%.[10] A retrospective study, however, reported ceramic fracture as one of the most common technical complications for metal–ceramic FDPs.[29] Chipping has also been reported to be the most common technical complication for metal–ceramic SCs, with a 5-year complication rate of 2.6%.[11] For all-ceramic SCs, the 5-year complication rates were reported to be between 1.2%–3.5%, depending on type of ceramic material.[11] Ceramic fracture was also observed as one of the technical complications for all types of SCs material with 5-year complication rate of 0.7%.[11]

Factors with suggested influence on the survival of tooth-supported fixed prosthetic restorations (FDPs, SCs)

Tooth vitality

In previous studies, loss of tooth vitality has shown a significant negative influence on the survival of FDPs and SCs.[33, 34] For FDPs, reported failure rates were significantly higher when abutments were non-vital compared to vital abutments.[34] A high rate of failure was also observed for SCs on non-vital teeth compared to SCs on vital teeth.[33] However, conflicting results have also been reported in previous studies, where loss of tooth vitality showed no negative influence on the survival of FDPs and SCs.[32, 35] In yet another study, similar survival rates were observed for SCs on vital and non-vital teeth, when a high quality of endodontic treatment was performed.[36]

Post and core

A post and core is used to retain a prosthetic restoration (FDP and/or SC) if the remaining tooth structure is not sufficient for retention, and the tooth has received

endodontic treatment.[37] The clinical performance of endodontically-treated teeth may however, be influenced by presence of post and core.[38] A post could increase the stress in the root surface and increase the risk of fracture.[39] The survival rate for FDPs supported by vital abutments has been reported to be significantly higher, at 77.4%, compared to FDPs with at least one non-vital abutment with post and core, at 56.7%.[2] In another study by the same authors, failure rates differed significantly between vital and non-vital abutments with post and core, where significantly more failures occurred in the latter group.[40] Similar results have been reported for SCs where the presence of a post showed an increased risk of SCs failure and complications.[33] The chance of SCs retained by cast metal post and core to be free of failure after 10 years of function was lower, at 75.9%, compared to SCs on vital and non-vital teeth without post and core, at 89.3% and 85.8% respectively.[33]

On the other hand, contradictory findings were observed in previous retrospective studies where the presence of a post showed no negative influence on the survival of SCs.[2, 41] There is therefore no general consensus among authors regarding the influences of tooth vitality, or presence and type of post as variables on the survival of FDPs and SCs.[42] Therefore, it would be of interest to evaluate and investigate the effect of these factors on the survival of FDPs and SCs.

Area of placement and tooth position/type

Both anterior and posterior teeth can be used as abutments for FDPs and SCs. The magnitude of occlusal forces increases from anterior teeth toward the molars with greater force distribution in the molar region, followed by premolar and anterior regions.[43] The ability of different types of teeth to withstand occlusal forces, and successfully function as abutments may differ.

De Becker et al. found an influence of area of placement on the survival of FDPs.[40] FDPs placed in the anterior region (incisors and canines) had higher survival rates compared to FDPs placed in posterior or overlapping areas (canine to premolars or molars); 85% and 63.6%, respectively.[40] On the other hand, a contradictory finding was observed for SCs in another study, where a higher survival rate was found for SCs on posterior teeth with cast metal posts compared to SCs on anterior teeth with cast metal posts.[44] Yet another study did not suggest any influence of tooth position, as the survival rates of SCs on the different types of teeth (anterior, premolar, molars) did not differ significantly.[41]

The location of the prostheses in relation to the jaws, maxilla vs. mandible, has not showed significant influence on survival rates in some studies[2, 29, 40, 41] while one study reported a significantly higher mean life-span for FDPs in the mandible compared to FDPs in the maxilla.[45] There is thus no general agreement regarding the positive or negative influence of area of placement and tooth position factors

on the survival of FDPs and SCs. For that reason, further investigation of these factors is of interest.

Prosthesis material

Frameworks of FDPs and SCs can be made of different materials, such as noble metal alloys; e.g., high gold, gold (Au), and palladium–silver alloys (Pd–Ag), or base metal alloys; e.g., cobalt–chromium (Co–Cr), nickel–chromium (Ni–Cr), titanium (Ti), and ceramics such as oxide or glass–ceramics.[6, 30, 46-54]

High survival rates of metal–ceramic and all-ceramic FDPs and SCs have been reported by previous reviews and retrospective studies.[6, 10, 11, 55] However, zirconia-based FDPs have demonstrated a higher rate of technical complications such as framework fracture, porcelain chipping, loss of retention, and poor marginal fit compared to metal–ceramic FDPs.[47] For SCs, higher occurrence of technical complications, such as porcelain chipping and loss of retention were reported for zirconia–ceramic SCs compared to metal–ceramic SCs.[11] Therefore, prosthesis material should be included as a potential factor which may affect the survival of tooth-supported FDPs and SCs.

Bruxism

Bruxism is a repetitive jaw–muscle activity represented by clenching and grinding of the teeth and/or by bracing or thrusting of the mandible during wakefulness and sleep.[56]

Bruxism has been reported as a risk factor for FDPs.[57] Technical complications such as loss of retention and material fracture have been reported to occur more frequently in bruxer patients compared to non-bruxers.[58] In one study comparing bruxer and non-bruxer patients, 6 out of 10 bruxer patients were reported to experience technical complications compared to 13 out of 73 of non-bruxer patients.[57] Moreover, the risk of porcelain chipping of SCs has been reported to be three times higher in bruxers compared to non-bruxers.[59] Prevalence of bruxism could affect up to one third of the population.[60, 61] Since the estimated number of people with bruxism is considerable, it is important to investigate the influence of bruxism on the survival of FDPs and SCs.

Number of FDPs units and abutments

Another factor that may influence the long-term survival of FDPs is the length of prosthesis (number of units). Näpänkangas et al. found a significantly lower survival rate for long FDPs (5–11 units) compared to short ones (3–4 units) after a mean follow-up period of 7.5 years.[62] Another study compared two groups of FDPs: short-span FDPs (3–4 units) and long-span FDPs (5–9 units).[63] At 20

years, the estimated survival rate was significantly higher for short-span FDPs (70.8%), compared to long-span FDPs (52.8%).[63]

However, not all studies have confirmed an influence of length of prosthesis on the survival and success rates of FDP.[29] So, some uncertainty still exists regarding the influence of this factor on the survival of FDPs. Furthermore, the presence of a high number of abutments supporting an FDP could increase the complexity of the treatment and the risk of complications, but there is limited information available from similar studies.[63]

Status of the dentition

A high bite force could potentially cause overload on fixed prosthetic restorations and may increase risk of technical and biological complications and this factor could be of interest in an analysis to investigate its influence on the survival of FDPs and SCs. Magnitude of bite force is influenced by two main variables: status of the natural dentition, and presence of dental prosthesis.[64] High number of remaining teeth generally leads to higher bite force.[64] Furthermore, patients with FDPs have a higher bite force compared to patients with removable prosthesis such as removable partial denture (RPD), and complete denture (CD).[64]

General factors

There are other general potential risk factors that could affect the survival of FDPs and SCs, such as patient´s age and sex, smoking, and treatment provider. The magnitude of bite force mentioned above is affected by patient´s age and sex, where male patients show higher bite force than female patients, and young patients show higher bite force than older patients.[43, 64-68] Furthermore, smoking has a detrimental effect on the periodontium because it affects the microbiota composition and immune system and reduces the capacity of periodontium healing around teeth.[69] The treatment provider factor has been evaluated previously in a multivariate model,[70] however, studies involving treatment providers with different clinical experiences, such as dental students, general practitioners, and specialists are limited.

Involving these general factors in the analysis could provide comprehensive information about the relationship of different factors on the survival of FDPs and SCs, and potentially determine whether any factor is strongly related to the outcome of FDPs and SCs.

RATIONALE FOR THESIS

As far as we know, there is still limited evidence concerning the survival of FDPs and SCs when subjected to a combination of multiple factors in a clinical setting. The influence of all aforementioned local and general factors on the survival of tooth-supported FDPs and SCs has been investigated by previous studies, however with different—and sometimes conflicting—results. Most available studies have focused on the influence of a single, or a few, factors. Involving several of the variables in a multifactorial analysis could better reflect the real-life situation, and may provide a better estimation of the potential risk factors on the survival of FDPs and SCs.

Recognizing conditions that place the patient at a higher risk of failure will allow the clinician to make informed decisions and refine the treatment plan to optimize treatment outcomes. Increased knowledge on complications, and how best to avoid them; i.e., how best to eliminate risk factors, will also be beneficial for both the patient and society from a cost-effective aspect.

AIMS

The overall aim of this thesis was to evaluate whether the clinical outcomes of full-coverage tooth-supported fixed prosthetic restorations (FDPs, SCs) are influenced by several general and local factors.

Specific aims

Paper I

To evaluate and compare the survival and failure rates of full-coverage fixed prosthetic restorations (FDPs, SCs) on tooth abutments with different vitality conditions, taking into consideration the potential influence of three main factors:

- Tooth vitality
- Presence and type of post
- Type of prosthetic restoration material

Paper II

To evaluate and compare the survival rates of tooth-supported FDPs retained by vital and non-vital teeth, considering multiple combined factors:

- Sex
- Abutment vitality (vital, non-vital)
- Position of the non-vital abutment
- Length of FDP (number of units)
- Number of abutments
- Location of the FDPs in relation to the jaws (maxilla, mandible)
- Presence or absence of post and core
- Location of post and core (mesial, distal, middle, mesial and distal)
- Area of placement (anterior, posterior, anterior and posterior)

- Type of FDP material
- Smoking
- Bruxism
- Status of the opposing arch (natural dentition, fixed, or removable denture)

Paper III

To evaluate and compare the failure rates and technical and biological complications of FDPs in a group of patients presenting bruxism in comparison with a matched group of non-bruxers with respect to several clinical factors:

- Sex
- Abutment vitality (vital, non-vital)
- Length of FDP (number of units)
- Location of the FDPs in relation to the jaws (maxilla, mandible)
- Presence or absence of post and core
- Area of placement (anterior, posterior, anterior and posterior)
- Type of FDP material
- Smoking
- Bruxism
- Treatment provider

Paper IV

To investigate the survival rates and technical and biological complications of tooth-supported SCs with respect to several clinical factors:

- Sex
- Age
- Abutment vitality (vital, non-vital)
- Location of the SCs in relation to the jaws (maxilla, mandible)
- Presence or absence of post and core
- Crown region (anterior, posterior)
- Tooth type (incisors, canines, premolars, molars)
- Type of SC material
- Smoking
- Bruxism
- Treatment provider
- Status of the opposing arch (natural dentition, fixed, or removable denture)

HYPOTHESES

General hypothesis

The general hypothesis for the present doctoral thesis was a null hypothesis that there is no negative influence of the investigated general and local factors on the survival of full-coverage tooth-supported FDPs and SCs.

Paper I

The null hypothesis for the systematic review was that there would be no difference in survival rates of fixed prosthetic restorations (FDPs, SCs) retained by vital and non-vital abutments irrespective of the presence and type of post and type of prosthetic restoration material.

Paper II

The null hypothesis was that there is no influence of multiple combined general and local factors such as sex, position of the non-vital abutment, length of FDP, number of abutments, location of the FDPs in relation to the jaws, presence and location of post and core, area of placement, type of FDP material, smoking, bruxism, and status of the opposing arch on the survival of tooth-supported FDPs based on the status of the abutments, namely vital, and non-vital, and non-vital with post and core, as well as combinations of these three types of abutments.

Paper III

The null hypothesis was that there is no influence of bruxism on the survival of tooth-supported FDPs with respect to several clinical factors.

Paper IV

The null hypothesis was that there is no influence of the multiple combined factors on the survival of SCs, such as sex, age, abutment vitality, location of the SCs in relation to the jaws, presence or absence of post and core, crown region, tooth type, type of SC material, smoking, bruxism, treatment provider, or status of the opposing arch.

MATERIALS AND METHODS

Study I (systematic review)

The present systematic review followed the PRISMA statement guidelines[71] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO).[72]

The P.I.C.O.S model format was used by the authors to frame the focused questions of the present systematic review.

Participants

Patients who received full-coverage tooth-supported fixed prosthetic restorations (FDPs, SCs) retained by either vital, non-vital, non-vital with post and core, as well as combinations of these three types of abutments.

Interventions

Prosthetic rehabilitation with full-coverage tooth-supported fixed restorations (FDPs, SCs) with different abutment vitality condition (vital. non-vital), with/or without post and core, different types of post (cast metal post, prefabricated fiber post), and different types of prosthetic material (metal–ceramic, all-ceramic) with a minimum observational period of 24 months.

Comparison

Survival rate of FDPs and/or SCs on vital, non-vital, non-vital abutments with post and core, or a combination of these, different types of post (cast metal post, prefabricated fiber post), and different types of prosthetic material (metal–ceramic, all-ceramic).

Outcomes

Success, survival, and/or failure/complications of abutment and/or fixed prosthetic restorations (FDPs, SCs)

Study design

Clinical human studies, either randomized or not, such as randomized controlled clinical trials (RCT), controlled clinical trials (CCT), prospective or retrospective cohort clinical studies, case control and case series studies of full coverage FDPs and SCs retained by vital and/or non-vital abutments and/or a combination of both.

The resulting focused questions were:

Is there a difference regarding survival of full-coverage tooth-supported fixed prosthetic restorations (FDPs, SCs) on vital and non-vital abutments?

Does the presence of post and core have any influence on the survival of full-coverage fixed prosthetic restorations (FDPs, SCs) on non-vital abutments?

Does the type of post and core have any influence on the survival of full-coverage fixed prosthetic restorations (FDPs, SCs) on non-vital abutments?

Does the type of prosthetic restoration material have any influence on the survival of fixed prosthetic restorations (FDPs, SCs) on vital and non-vital abutments?

Search strategies

In September 2020, two authors (MH, BC) independently conducted the search in the electronical databases PubMed, Web of Science, and ScienceDirect databases.

The following terms were used in the search strategy.

Subject: (prosthesis)

AND

Adjective: ("endodontically treated teeth" OR "vital teeth")

Publications were selected based on the aforementioned inclusion and exclusion criteria first by reading titles and abstracts. Full publications were obtained for studies appearing to fulfil the inclusion criteria.

This was followed by 'snowballing', by manually searching the references listed in the included studies to identify additional eligible studies. Discussion between the two authors was undertaken to solve any disagreement regarding inclusion or exclusion of studies.

Complementary search

A complementary search was carried out in December 2022 for studies published during the period from October 2020 to December 2022, by the two authors based on the same databases, search terms, and inclusion and exclusion criteria.

Inclusion criteria

- Full coverage FDPs and SCs retained by vital and/or non-vital and/or non-vital abutments with post and core and/or a combination of all;
- Clinical human studies such as RCTs, CCTs, prospective or retrospective clinical studies, case control and case series studies;
- A minimum observation period of 24 months;
- Studies should report the success or survival rate and/or failure/complications of the abutment and/or fixed prosthetic restorations (FDPs, SCs), abutment vitality condition, presence of post, type of post (cast metal post, prefabricated fiber post), and type of prosthesis material (metal–ceramic, all-ceramic);
- Clinical examination should be provided.

Exclusion criteria

- Non-clinical studies;
- Case reports;
- Pilot studies;
- Animal studies;
- *In vitro* studies;
- Clinical studies not clearly reporting success or survival and/or failure/complications of the abutment and/or prosthetic restorations, abutment vitality condition, presence and type of post, and prosthesis material.

Quality Assessment

The Newcastle–Ottawa Scale (NOS) was used as risk assessment tool [73] to calculate the risk of bias on the basis of three domains:[74]

- Selection of study groups, four stars;

- Comparability of groups, two stars;
- Determination of outcomes, three stars.

A maximum of nine stars/points can be given to the highest quality studies. Studies scored with six points or more were considered high-quality.

Data collection

The following data were collected:

- Year of publication;
- Study design;
- Number of patients;
- Patient sex;
- Patient age;
- Period of follow-up;
- Type of fixed prosthetic restoration (FDP, SC);
- Vitality condition of the abutments (vital/non-vital, and non-vital with post and core);
- Type of post;
- Type of prosthetic material;
- Success/survival and/or failure of the abutment and/or fixed prosthetic restoration.

Statistical analysis:

Prosthesis survival and failure were the dichotomous outcome measures that were evaluated. The statistical units for the outcomes were FDPs and SCs. Outcomes not clearly reported were not used for analysis.

For each study, event rates for the prostheses were calculated by dividing the total number of events by the total SC exposure time in years. The five-year survival proportions were calculated using the relationship between event rate and survival function S, S(T) = exp (−T*event rate), by assuming constant event rates. The 95% confidence intervals for the survival proportions were calculated using the 95% confidence limits of the event rates. A meta-analysis for each group was conducted using proportions with inverse-variance weights. The value of 0.5 are added to zero frequencies. Groups were then compared using a z-test. Data were statistically analyzed using SPSS software version 28 (IBM, Chicago, IL, USA). The degree of statistical significance was set at $p < 0.05$.

Studies II, III, IV (retrospective clinical studies)

Ethical Approval

The retrospective record-based clinical studies (II, III, and IV) followed the STROBE guidelines[75] and were approved by the Regional Ethical Committee in Lund, Sweden (Dnr 4,3-2018/422; Dnr 2018/856).

Patients' data

Paper and digital dental records of approximately 4000 patients, from the archives of the Faculty of Odontology, Malmö University, Sweden, were scrutinized by one investigator (MH) in the search for cases that would fit the inclusion criteria of the studies.

Inclusion criteria

- Full-coverage tooth-supported FDPs (limited to three to seven prosthetic units);
- Full-coverage tooth-supported SCs;
- A minimum follow-up time of 6 months after delivery of the prosthetic work;
- Patients attended the school's clinics for follow-up in the last 10 years.

Exclusion criteria

- FDPs smaller or larger than 3–7 units;
- Cantilever FDPs;
- Resin-bonded prostheses;
- Partial-coverage crowns;
- Patients did not attend follow-up appointments;
- Cases with incomplete or lack of information or reported unknown outcomes.

Definitions

Survival

Defined as a prosthesis remaining *in situ* and in function, even though complications might have occurred.

Failure

Defined as a prosthesis that had been removed or replaced.

A tooth was considered a failure if it exhibited extensive alveolar bone loss and/or excessive tooth mobility, extensive caries, or any other complication that would make the tooth unsuitable to function as a retainer for FDP or SC and therefore lead to tooth loss.

Chipping

Defined as loss of veneer substance with or without metal exposure, being classified as minor (managed chair-side) or major (sent to the dental lab for repair).

Anterior located prostheses

FDPs and SCs on incisors and/or canines.

Posterior located prostheses

FDPs and SCs on premolars and/or molars.

Anterior/posterior located prostheses

FDPs abutment/s on incisors and/or canines and another abutment/s in premolars and/or molars.

Cross-arch prostheses

FDPs with abutment/s on premolar or molars from one side to premolars or molars from another side.

Diagnosis of bruxism

All patients included in the present retrospective studies II, III, and IV had undergone clinical examination, including an anamnestic part and self-report questionnaire to identify bruxism. Diagnosis of bruxism based on the diagnostic grading system of "possible", "probable", and "definite" sleep or awake bruxism has been suggested for both clinical and research situations.[56]

Possible sleep or awake bruxism

Based on self-report using questionnaires and/or the anamnestic part of a clinical examination.[56]

Probable sleep or awake bruxism

Based on self-report, together with inspection part of clinical examination.[56]

The information from the self-report plus inspection part of a clinical examination was verified from annotations in the dental records of each eligible patient. Patients were thus classified as "probable" bruxers if such findings were identified.

Data collection

The following data were collected by one investigator (MH) and inserted directly into a SPSS file (SPSS software, version 27; IBM Inc., Chicago, IL, USA)

- Patient age and sex;
- Type of material used for the fabrication of the prostheses (FDPs, SCs) (metal–ceramic, all-ceramic, metal–acrylic, all-metallic). This information was obtained from the dental technician laboratory orders;
- Number of FDP units;
- Type of FDP (with or without cantilever);
- Number of FDP abutments and pontics;
- Tooth vitality (vital, non-vital, non-vital with post);
- Position of the non-vital abutment for FDP (mesial, distal, middle, mesial and distal);
- Situation of the opposing arch (natural dentition, fixed, or removable denture);
- Presence and location of post and core (mesial, distal, middle, mesial and distal, no post and core);
- Type of post and core (cast metal post, prefabricated metal post, fiber post);
- Area of placement and region of FDPs and SCs (anterior, posterior, anterior and posterior, and cross-arch FDPs);
- Location of the FDPs and SCs in relation to the jaws (maxilla, mandible);
- Type of tooth-retained SCs (incisor, canine, premolar, molar);
- Type of cement used for SCs (zinc–phosphate, resin, glass ionomer, resin modified glass ionomer);
- Name of the department where the prosthetic treatment was performed;
- Treatment provider (dental student, general dentist, or specialist);
- Smoking habits;
- Bruxism;
- Complication/s and failure after delivery of the definitive FDPs and SCs, including the date when they occurred.

Information on the occurrence of technical and biological complications was obtained from the records by evaluation of radiographs (when available).

Biological complications

- Caries;
- Loss of tooth vitality;
- Periapical destruction;
- Mobility;
- Bone loss;
- Abutment loss.

Technical complications

- Tooth fracture;
- Loss of retention;
- Framework fracture;
- Minor or major porcelain veneer chipping.

Statistical analysis

Study II and IV (FDPs and SCs)

The data were described with mean values, standard deviation (SD), and percentage for several variables. Interval survival rate (ISR) of the FDPs and SCs was calculated for each follow-up interval of one year, and cumulative survival rate (CSR) was calculated over the entire period of follow-up, in a life-table survival analysis.

Univariate and multivariate Cox regression analyses were used to evaluate the association between the clinical covariates and FDP/SC failure. Hazard ratios (HR) and 95% confidence intervals (95% CI) were estimated using Cox proportional hazards models. In order to verify multicollinearity, a correlation matrix of all predictor variables with a significant HR (p value cut-off point of 0.1) identified in the univariate models was scanned to determine whether there were high correlations among the predictors. Collinearity statistics used to obtain the variance inflation factor (VIF) and tolerance statistics were also performed to detect more subtle forms of multicollinearity.

In the final multivariable Cox regression model, all variables that were moderately associated (p <0.10) with FDP/SC failure were included. For the FDP/SC-level analysis, the clustering of multiple FDPs/SCs within each patient was accounted for in the Cox models using the methods outlined by Lee et al. (1992) and Lin (1994).[76, 77]

Data were statistically analyzed using SPSS software (version 27, IBM Inc., Chicago, IL, USA). Cox models were performed using the Stata software version 15 (StataCorp LLC, College Station, TX, USA). The command *mestreg* was used for the Cox models, in order to take into account clustering of observations in patients. The degree of statistical significance was set at $p < 0.05$.

Study III (FDPs in matched groups of bruxers and non-bruxers)

From the group of patients not presenting bruxism, a control group was included with the same number of patients as in the study group. The matching was performed in SPSS software (version 27 software, IBM Inc., Chicago, IL, USA). The matches were selected on the basis of similarities in four factors, namely, patients' gender (equal matching), age of the patients at the day of FDP delivery (tolerance of 10 years of difference), number of prosthetic units of the FDPs (equal matching), and follow-up time (tolerance of 18 months of difference).

The Kolmogorov–Smirnov test was performed to evaluate the normal distribution of the variables, and Levene's test evaluated homoscedasticity. The performed tests for the comparison of mean values between the two groups were the paired-samples t-test or Wilcoxon signed rank test, depending on the normality, and McNemar's test was used in the analysis of contingency tables of categorical data.

RESULTS

Study I (systematic review)

Literature Search

The process of selection is summarized in (Figure 1).

- A total of 2052 papers were identified through electronic databases search (1003 in PubMed, 500 in Web of Science, 549 in ScienceDirect);
- After discarding duplicates, 1680 papers were available for screening on title and abstract level;
- After first screening, 178 articles were identified;
- Sixty-one studies yielded after 'snowball' manual searching;
- After the second screening, 40 potentially relevant studies qualified for full-text analysis;
- In the last step, 23 articles were excluded, a total of 17 articles were finally included in the review.

According to the NOS assessment tool, all included studies scored six points or more, and were considered high quality.

Complementary search

A total of 193 studies were identified through the complementary search (94 in PubMed, 37 in Web of Science, 62 in ScienceDirect). After removing duplicates, title and abstract screening were carried out for 165 papers. Full text review was carried out for 13 potentially relevant papers. No additional studies fulfilled the inclusion criteria (Figure 2).

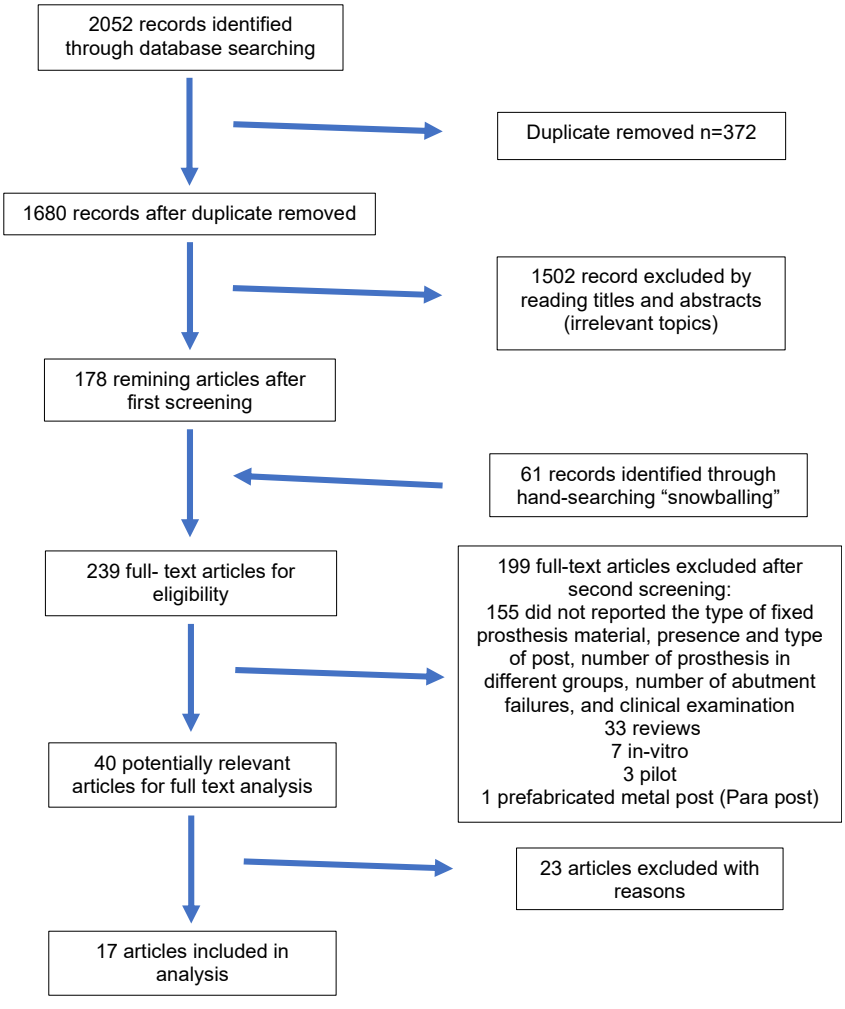

Fig. 1. Study screening process.

Description of the studies

Out of the 17 included studies, 4 were RCTs,[42, 78-80] 1 CCT,[81] 4 prospective,[59, 82-84] and 8 retrospective.[2, 30, 32, 33, 85-88] The number of included SCs and FDPs was 3,945 and 1,333, respectively, retained by vital and/or non-vital abutments and/or a combination of both.

Data of SCs from one study were excluded due to overlap with another study.[30, 32] Four studies included both SCs and FDPs.[2, 32, 59, 83]

Sixteen studies included a total of 2,465 patients. One study did not report the number of included patients.[2] The majority of the publications (n =16) included metal–ceramic SCs[2, 30, 33, 42, 59, 78-81, 83-88] and/or FDPs.[2, 32, 59, 83] Four of them also evaluated all-ceramic SCs[42, 78, 85, 86] and one paper only included all-ceramic SCs.[82]

The clinical outcomes of posts on root canal treated teeth restored with SCs were evaluated in 10 studies[2, 42, 79, 81, 83-88] and in two studies that investigated FDPs.[2, 83] Eight studies assessed the longevity and clinical performance of SCs[30, 33, 42, 59, 78, 80, 82] and/or FDPs[32, 59] retained by vital and/or non-vital abutments, or combination of both. Two studies used the United States Public Dental Health criteria[82] and a modified version (USPHS)[78] to evaluate the clinical performance of SCs. Another study evaluated SCs using FDI World Dental Federation criteria involving aesthetic, functional, and biological properties.[80]

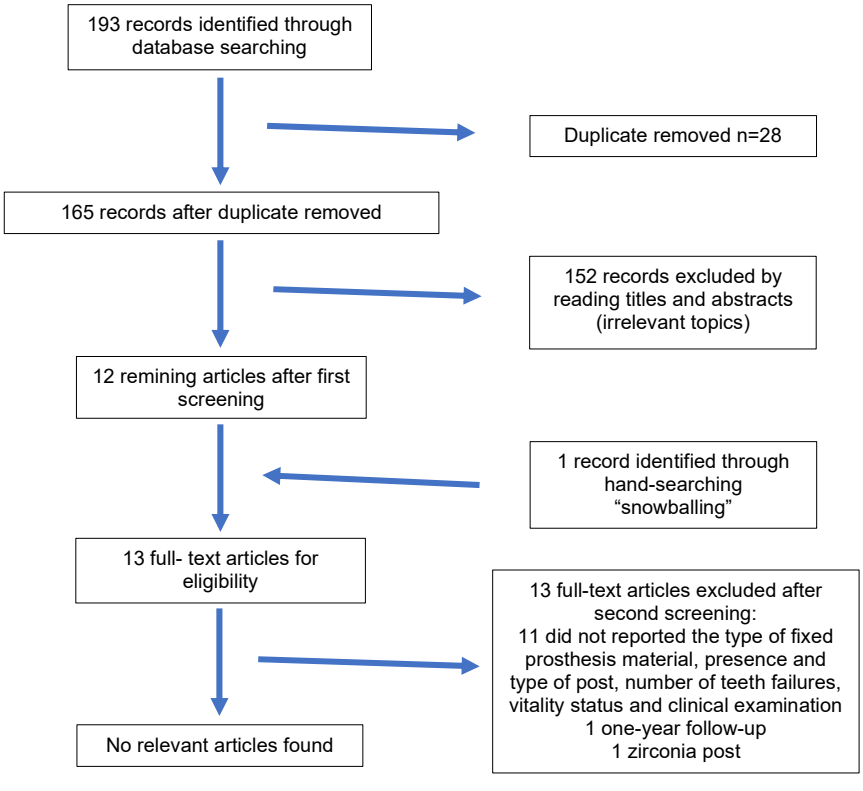

Fig. 2. Complementary search.

Full-coverage tooth-supported SCs

Table 1 shows the estimated 5-year survival and annual failure rates for SCs in respect to crown material, presence, and type of post. Sixteen studies included full coverage SCs with a total of 1,600 vital and 2,345 non-vital teeth (800 with fiber post, 1,254 with cast metal post, and 291 non-vital teeth without post).[2, 30, 33, 42, 59, 78-88]

Table 1. All-ceramic and metal–ceramic SCs and FDPs.

Type of material of SCs and FDPs, prsence and type of post	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
Metal–ceramic SCs, vital teeth		
Sub-group summary estimate (95% CI)	0.72 (0.24, 1.19) SE 0.24	97.5 (96.8, 98.3) SE 0.40
Metal–ceramic and all-ceramic SCs, vital teeth		
Global summary estimate (95% CI)	0.56 (0.24, 0.88) SE 0.16	97.8 (97.1, 98.5) SE 0.36
Metal–ceramic SCs, non-vital teeth (no post)		
Summary estimate (95% CI)	2.80 (1.96, 3.64) SE 0.43	95.7 (93.7, 97.7) SE 1.02
Metal–ceramic SCs, non-vital teeth (fiber post)		
Sub-group summary estimate (95% CI)	1.36 (1.18, 1.55) SE 0.09	95.01 (93.4, 96.6) SE 0.84
All-ceramic SCs, non-vital teeth (fiber post)		
Sub-group summary estimate (95% CI)	0.76 (0.59, 0.93) SE 0.09	99.1 (97.7, 100.4) SE 0.68
Metal–ceramic and all-ceramic SCs, non-vital teeth (fiber post)		
Global summary estimate (95% CI)	1.08 (0.97, 1.19) SE 0.06	97.5 (96.4, 98.5) SE 0.53
Metal–ceramic SCs, non-vital teeth (cast metal post)		
Summary estimate (95% CI)	1.95 (1.09, 2.80) SE 0.44	94.5 (93.3, 95.8) SE 0.64
Metal–ceramic FDPs, vital		
Sub-group summary estimate (95% CI)	0.61 (0.31, 0.90) SE 0.15	96.9 (95.5, 98.4) SE 0.74
Metal–ceramic FDPs, non-vital teeth (cast metal post)		
Sub-group summary estimate (95% CI)	1.15 (0.14, 2.16) SE 0.51	94.3 (89.3, 99.3) SE 2.55

SCs–Single crowns; FDPs–Fixed dental prostheses.

Comparisons of the 5-year survival estimates between groups of SCs are shown in Table 2. Cases restored with prefabricated metal post and composite or amalgam core were excluded, due to different properties and behavior such as,

e.g., stress distribution, which could affect clinical outcome compared to cast metal or fiber posts.[89, 90]

Table 2. Comparison of the 5-year survival estimates between two groups of SCs (group 1 has a higher survival rate than group 2).

Group 1	Group 2	p value
Vital metal–ceramic	Non-vital fiber post metal–ceramic	0.007
Vital metal–ceramic	Non-vital cast metal post metal–ceramic	<0.001
Non-vital fiber post (all)	Non-vital cast metal post metal–ceramic	<0.001
Non-vital fiber post all-ceramic	Non-vital fiber post metal–ceramic	<0.001
Non-vital fiber post all-ceramic	Non-vital cast metal post metal–ceramic	<0.001
Non-vital fiber post all-ceramic	Non-vital no post metal–ceramic	0.006
Vital (all)	Non-vital fiber post (all)	0.568
Vital (all)	Non-vital no post (all)	0.051
Vital metal–ceramic	Non-vital no post metal–ceramic	0.094
Vital metal–ceramic	Non-vital no post metal–ceramic	0.102
Non-vital no post (all)	Non-vital fiber post metal–ceramic	0.599
Non-vital no post metal–ceramic	Non-vital cast metal post metal–ceramic	0.328
Non-vital fiber post (all)	Non-vital no post metal–ceramic	0.127
Non-vital fiber post all-ceramic	Non-vital no post metal–ceramic	0.006
Non-vital fiber post all-ceramic	Vital metal–ceramic	0.051

SCs–Single crowns; All–(metal–ceramic and all-ceramic SCs).

The highest 5-year survival rate was observed for all-ceramic and metal–ceramic SCs on vital teeth 97.8% (95% CI [97.1–98.5%]) and all-ceramic SCs on non-vital teeth with fiber post, 99.1% (95% CI [97.7–100.4%]). A statistically significant higher estimated 5-year survival rate was observed for metal–ceramic SCs on vital teeth 97.5% (95% CI [96.8–98.3%]), compared to metal–ceramic SCs retained by cast metal 94.5% (95% CI [93.3–95.8%]; p <0.001) and fiber posts 95.1% (95% CI [93.4–96.6%]; p <0.007), respectively.

All-ceramic SCs with fiber posts 99.1% (95% CI [97.7–100.4%]) had a statistically significant higher estimated 5-year survival rate compared to metal–ceramic SCs of the same group 95.1% (95% CI [93.4–96.6%]; p < 0.001) and metal–ceramic SCs on non-vital teeth without posts 95.7% (95% CI [93.7–97.7%]; p <0.006), respectively.

SCs (including all-ceramic and metal–ceramic) with fiber post 97.5% (95% CI [96.4– 98.5%]) had a statistically significantly higher estimated 5-year survival

rate) than metal–ceramic SCs retained by cast metal post 94.5% (95% CI [93.3–95.8 %]; $p < 0.001$).

The highest estimated annual failure rates (per 100 SC years) were 2.80 (95% CI [1.96-3.64]) and 1.95 (95% CI [1.09–2.80]) for SCs retained by non-vital teeth without post and on cast metal post, respectively. Lowest estimated annual failure rates were observed in SCs (metal–ceramic and all-ceramic) on vital teeth at 0.56 (95% CI [0.24-0.88]), and metal–ceramic SCs on vital teeth, at 0.72 (95% CI 0.24–1.19]), followed by all-ceramic SCs with fiber post, at 0.76 (95% CI [0.59–0.93]).

Full-coverage tooth-supported FDPs

There were 946 FDPs retained by vital abutments[2, 32, 59] and 387 FDPs retained by non-vital abutments,[2, 32, 83] with at least one non-vital abutment for each FDP, 25 FDPs retained by non-vital abutment with fiber post[83] (each prosthesis has only one fiber post), 354 FDPs with cast metal post,[2, 32] and 8 FDPs without post.[32]

One study for each group of metal–ceramic FDPs supported by non-vital abutment/s with fiber and without post was included in the present review. Therefore, sub-group survival and failure analyses were only performed for FDPs supported by vital abutments and non-vital abutment/s with cast metal posts (Table 1)

The estimated 5-year survival rate was higher for metal–ceramic FDPs supported by vital abutments 96.9% (95% CI [95.5–98.4%]) compared to FDPs on non-vital abutment/s with cast metal post 94.3% (95% CI [89.3–99.3%]; p =0.1971), but the difference was not statistically significant. A higher estimated annual failure rate was reported for FDPs supported by non-vital abutment/s with cast metal post 1.15 (95% CI [0.14, 2.16]) compared to vital group 0.83 (95% CI [0.39, 1.28]).

Studies II, III, IV (retrospective clinical studies)

Extracted data (Patients and tooth-supported FDPs and SCs)

A total of 1493 prostheses (443 FDPs and 1050 SCs) were executed by dental students, general practitioners, or specialists at a prosthodontic and general adult dental care department during the period between 1981 and 2018, and had complete information as per outcomes (Figure 3).

Excluded FDPs and SCs

Data on 112 FDPs and 13 SCs were excluded from the analyses because they did not fulfil the inclusion criteria:

Excluded FDPs (Study II):

- Thirty-two FDPs larger than 7 units;
- Eleven FDPs had 2 units;
- Sixty-six FDPs with cantilever;
- Three FDPs were not followed up for a minimum of 6 months.

Excluded SCs (Study IV):

- Thirteen SCs had a minimum follow-up time of less than 6 months.

Included FDPs and SCs

Included FDPs (Study II):

A total of 331 (3–7 units) FDPs were finally included in the study, supported by 827 abutment teeth, of which 66.7% were vital and 33.3% were non-vital.
These FDPs were installed in 229 patients, 96 men and 133 women, who had a mean age of 59 years (59.3 ± 12.8 SD, min–max 20.9–89.5) and 56 years (56.8 ± 12.9 SD min-max 29.5– 86.1), respectively. The 331 FDPs were followed up for a mean of 132.1 ± 80.4 months, SD (min-max, 6.4–472.1). Most patients attended follow-up during the first year, but not all continued regular annual follow-up.

Included FDPs (Study III):

The cohort group consisted of 331 non-cantilevered FDPs with 3–7 prosthetic units followed up for a minimum of 6 months, of which 102 were installed in "probable" bruxers. The matching according to the tolerance set for the four aforementioned factors was possible for 62 of these 102 FDPs in bruxers, which were matched to 62 FDPs in non-bruxers.

Included SCs (Study IV):

The final sample consisted of 1037 SCs, 47.5% of which were supported by vital abutments, and 52.5% by nonvital abutments.
These SCs were installed in 401 patients, 195 men and 206 women, who had a mean age of 56.8 years (± 12.9 SD, min–max 21.0 – 86.6) and 57.7 years (± 12.5

SD, min–max 28.1–85.6), respectively. The 1037 SCs were followed for a mean of 134.8 ± 80.2 months, SD (min–max, 6.0–360.7). A majority of patients attended regular follow-up visits during the first year but not all continued after the first year.

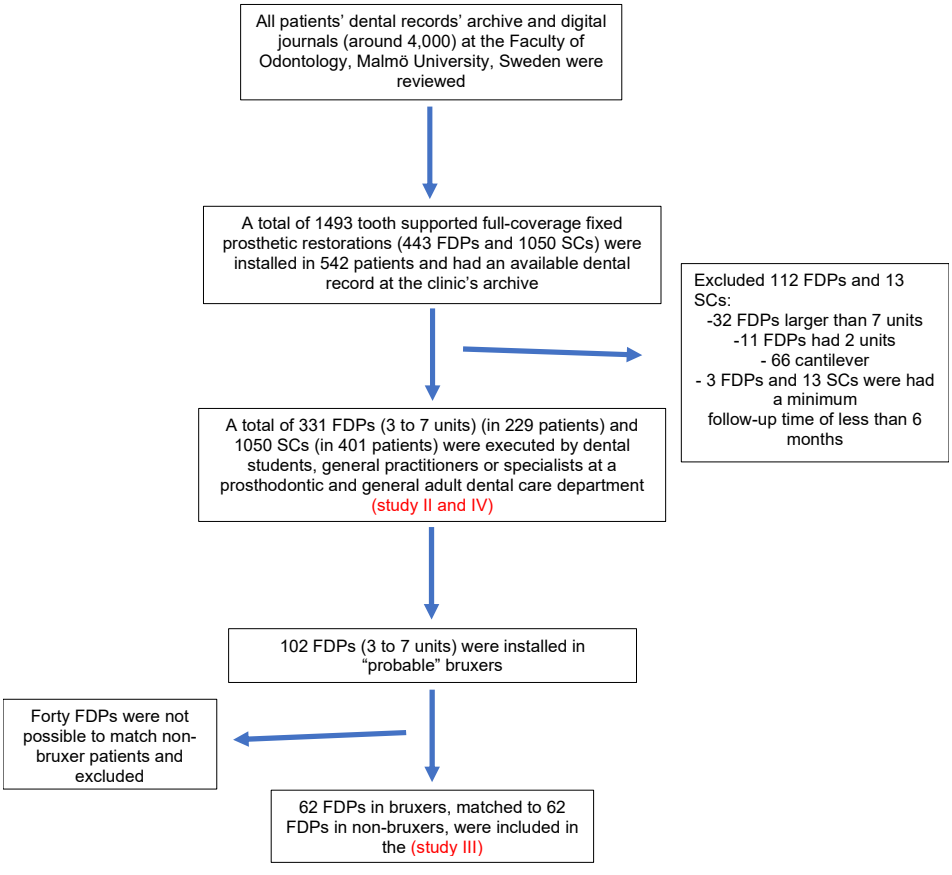

Fig. 3 Flowchart of the included subjects/tooth-supported fixed prosthetic restorations (FDPs, SCs).

Data description

Studies II and IV (FDPs and SCs)

Table 3 presents the descriptive characteristics of the FDPs and SCs included in Studies II and IV, with number of failed FDPs and SCs and follow-up time, according to the different factors analyzed.

Table 3. Descriptive data of the FDSs and SCs included in Studies II and IV, with follow-up time between the different factors. The statistical unit is the FDP and SC, not the patient.

Factors	Number of FDPs (%) / failed (%)	Number of SCs (%) / failed (%)	Follow-up (months) Mean ± SD (min–max) (FDPs)	Follow-up (months) Mean ± SD (min–max) (SCs)
Sex				
Male	137 (41.4) / 40 (29.1)	506 (48.8) /114 (22.5	133.0 ± 79.0 (6.4–351.4)	129.0 ± 83.0 (6.2–360.7)
Female	194 (58.6) / 50 (25.7)	531 (51.2) / 116 (21.8)	131.4 ± 81.6 (6.9–472.1)	140.3 ± 77.1 (6.0–355.4)
Age				
<50 years	NA	309 (29.8) / 86 (27.8)	NA	159.2 ± 79.6 (6.2–333.6)
≥50 years	NA	728 (70.2) / 144 (19.7)	NA	124.4 ± 78.3 (6.0–360.7)
Jaw				
Maxilla	201 (60.7) / 48 (23.8)	605 (58.3) / 150 (24.7)	135.2 ± 80.9 (6.4–472.1)	128.9 ± 80.4 (6.0–355.4)
Mandible	130 (39.3) / 42 (32.3)	432 (41.7) / 80 (18.5)	127.3 ± 79.7 (6.9–323.4)	143.1 ± 79.3 (6.9–360.7)
FDP and SC region				
Anterior	47 (14.2) / 9 (19.1)	282 (27.2) / 70 (24.8)	122.8 ± 85.7 (12.3–317.3)	115.4 ± 74.1 (6.0–335.1)
Posterior	154 (46.5) / 54 (35.0)	755 (72.8) / 160 (21.1)	136.1 ± 78.4 (6.4–351.4)	142.0 ± 81.3 (6.2–360.7)
Anterior/ posterior	129 (39.0) / 27 (20.9)	NA	131.0 ± 81.3 (7.7–472.1)	NA
Cross-arch	1 (0.3) / 0 (0)	NA	89.2	NA
Prosthetic units				
3	158 (47.7) / 37 (23.4)	NA	126.4 ± 80.9 (6.4–351.4)	NA
4	89 (26.9) / 30 (33.7)	NA	141.9 ± 78.1 (9.5–472.5)	NA
5	46 (13.9) / 15 (32.6)	NA	129.4 ± 79.9 (12.3–378.1)	NA
6	27 (8.2) / 6 (22.2)	NA	153.5 ± 92.5 (21.6–317.3)	NA
7	11 (3.3) / 2 (18.1)	NA	93.4 ± 40.0 (22.2–157.1)	NA
Number of abutments				
2	215 (65.0) / 56 (26.0)	NA	126.8 ± 79.3 (6.4–351.8)	NA
3	84 (25.4) / 28 (33.3)	NA	149.6 ± 78.2 (14.4–149.6)	NA

4	19 (5.7) / 6 (31.5)	NA	131.5 ± 99.6 (22.2–378.5)	NA
5	10 (3.0) / 0 (0)	NA	110.6 ± 81.8 (23.3–288.3)	NA
6	2 (0.6) / 0 (0)	NA	82.0 ± 35.1 (57.2– 06.9)	NA
7	1 (0.3) / 0 (0)	NA	115.8	NA
Tooth type for SC				
Incisor	NA	217 (20.9) / 56 (25.8)	NA	117.6 ± 73.6 (6.0–335.1)
Canine	NA	65 (6.3) / 14 (21.5)	NA	108.0 ± 75.8 (9.2–298.9)
Premolar	NA	391 (37.7) / 83 (21.2)	NA	138.6 ± 81.5 (6.8–360.7)
Molar	NA	364 (35.1) / 77 (21.1)	NA	145.8 ± 80.9 (6.2–316.0)
Abutments				
(All) [a] abutments vital	147 (44.4) / 32 (21.7)	493 (47.5) / 81 (16.4)	128.6 ± 82.7 (9.5–351.4)	136.6 ± 79.7 (6.2–360.7)
Vital and non-vital abutments	152 (45.9) / 53 (34.8)	NA	131.7 ± 72.5 (6.4–288.3)	NA
(All) abutments non-vital	32 (9.7) /5 (15.6)	544 (52.5) / 149 (27.3)	149.7 ± 102.9 (29.4–472.1)	132.8 ± 80.8 (6.0–132.8)
Position non-vital abutment [b]				
Mesial	48 (26.1) / 19 (39.5)	NA	139.2 ± 68.4 (6.4–260.7)	NA
Distal	78 (42.4) / 24 (30.7)	NA	136.5 ± 74.8 (6.9–288.3)	NA
Mesial and distal	39 (21.2) / 7 (17.9)	NA	144.6 ± 99.7 (28.2–472.1)	NA
Middle	19 (10.3) / 8 (42.1)	NA	122.2 ± 71.4 (14.4–257.1)	NA
Post and core				
Presence	NA	472 (86.9) / 131 (27.7)	NA	140.0 ± 80.2 (6.2–360.7)
Mesial	48 (15.4) /18 (37.5)	NA	141.6 ± 82.0 (6.4–458.1)	NA
Distal	57 (18.3) / 19 (33.3)	NA	140.1 ± 76.1 (7.7–288.3)	NA
Mesial and distal	21 (6.8) / 1 (4.7)	NA	129.9 ± 108.8 (28.2–72.1)	NA
Middle	23 (7.4) / 9 (39.1)	NA	133.7 ± 72.4 (14.4–257.1)	NA
No post and core	162 (52.1) / 35 (21.6)	71 (13.1) / 18 (25.3)	126.1 ± 74.7 (10.7–340.5)	112.1 ± 71.7 (7.0–290.5)
Material				
Full metallic, gold [c]	5 (1.5) / 0 (0)	68 (6.5) / 14	155.7 ± 136.0 (9.5–351.4)	143.1 ± 81.9 (8.4–143.1)

Metal acrylic	6 (1.8) / 4 (66.6)	NA	233.0 ± 88.9 (76.6–323.4)	NA
Metal ceramic	311 (94.0) / 84 (27.0)	NA	131.4 ± 77.6 (6.4–472.1)	NA
'Metal ceramic, unknow metal' [d]	5 / 1 (20.0)	NA	67.2 ± 45.0 (12.7–126.7)	NA
Titanium ceramic	16 / 1 (6.2)	NA	88.0 ± 48.7 (22.7–174.4)	NA
High-noble gold ceramic	226 / 64 (28.3)	678 (65.4) / 171 (25.2)	156.1 ± 74.0 (6.4–472.1)	158.1 ± 72.6 (7.3–360.7)
Full ceramic	9 (2.7) / 2 (22.2)	169 (16.3) / 26 (15.3)	75.8 ± 87.9 (6.9–291.7)	81.5 ± 65.4 (6.3–234.8)
Bruxism				
No	229 (69.2) / 58 (25.3)	696 (67.1) / 141	136.7 ± 81.1 (6.4–472.1)	141.9 ± 77.4 (6.0–360.7)
Yes	102 (30.8) / 32 (31.3)	341 (32.9) / 89	121.6 ± 78.1 (9.5–351.4)	120.3 ± 83.9 (8.5–333.6)
Treatment provider				
Dental student	NA	836 (80.6) / 197 (23.5)	NA	140.0 ± 77.3 (6.0–303.1)
General or specialist dentist	NA	201 (19.4) / 33 (16.4)	NA	113.1 ± 88.2 (7.6–360.7)
Smoking [e]				
No	80 (24.2) / 20 (25.0)	283 (50.6) / 61 (21.5)	144.9 ± 96.3 (5.3–472.1)	135.5 ± 78.3 (6.8–316.0)
Yes	70 (21.2) / 23 (32.9)	191 (34.2) / 50 (26.1)	105.7 ± 71.3 (6.4–255.3)	123.0 ± 82.9 (6.2–329.5)
Ex-smoker	17 (5.1) / 4 (23.5)	85 (15.2) / 17 (20)	98.3 ± 74.1 (10.7–278.0)	145.6 ± 80.2 (11.3–298.9)
FDP and SC [f] occluding to [g]				
Nothing	5 (1.5) / 2 (40.0)	NA	148.3 ± 81.2 (14.4–219.2)	NA
Natural teeth	177 (53.5) /48 (27.1)	591 (59.8) / 131 (22.1)	137.4 ± 74.4 (7.7–351.4)	138.3 ± 79.4 (6.0–355.4)
Fixed prosthesis	141 (42.6) / 40 (28.3)	398 (40.2) / 99 (24.8)	122.3 ± 86.1 (6.4–472.1)	127.8 ± 80.2 (6.2–360.7)
Removable partial denture	8 (2.4) / 0 (0)	NA	178.1 ± 90.6 (57.2–275.4)	NA

FDPs–fixed dental prostheses; SD–standard deviation; NA–Not available; [a] All FDPs abutments either vitals or non-vitals; [b] The FDPs did not add up to the total number of FDPs in the study, as 147 FDPs were supported only by vital abutments; [c] All SC were made of full gold; [d] The types of metal framework were unknown; [e] For the cases in which information on smoking habits was available; [f] Few cases were not considered here: SCs opposed removable partial denture (n =26), and not occluding to anything (n =22); [g] At the time of FDP and SC delivery. The status of the opposing arch could have changed at subsequent follow-up.

Study III (FDPs in matched groups of bruxers and non-bruxers)

Table 4 provides the descriptive characteristics of the matched groups. As expected from the matching process, the groups did not significantly differ regarding the number of FDPs, the number of FDPs installed in patients of different sexes, the number of FDPs with the respective number of prosthetic units, the mean age of the patients on the day of prosthesis delivery, or follow-up time. The number of prostheses in smokers did not differ between the two groups.

Table 4. Descriptive characteristics of the matched groups and comparison of prosthesis failure rates between bruxers and non-bruxers.

	Bruxers	**Non-Bruxers**	***P* Value**
FDP (N)	62	62	
Sex (number of FDP)	Woman (44) Man (18)	Woman (44) Man (18)	
Prosthetic units (number of FDP)	3 (40), 4 (16), 5 (4), 6 (2)	3 (40), 4 (16), 5 (4), 6 (2)	
Patients' age [a] (years), Mean±sd (min-max)	57.8 ± 11.7 (31.9-81.5)	58.3 ± 11.1 (37.7-84.3)	0.729 [b]
Follow-up (months), Mean±sd (min-max)	110.1 ± 66.6 (15.3-262.1)	106.5 ± 66.7 (6.0-259.3)	0.767 [c]
Smoking (number of FDP) [d] **no** **current + former smokers**	 20 15	 13 17	0.743 [e]
FDP failure, n (%)	20 (32.3)	16 (25.8)	0.001 [e]
Sex, n/total (%)			
Woman	12/44 (27.3)	10/44 (22.7)	0.002 [e]
Man	8/18 (44.4)	6/18 (33.3)	0.503 [e]
Smoking, n/total (%) [d]			
No	5/20 (25.0)	4/13 (30.8)	0.019 [e]
Current + former smokers	6/15 (40.0)	7/17 (41.2)	0.804 [e]
Prosthesis location, n/total (%)			
Maxilla	12/37 (32.4)	6/39 (15.4)	0.002 [e]
Mandible	8/25 (32.0)	10/23 (43.5)	0.383 [e]
Area of placement n/total (%)			
Anterior			0.219 [e]
Posterior	3/8 (37.5)	1/8 (12.5)	0.035 [e]
Anterior/posterior	15/38 (39.5)	10/31 (32.3)	0.064 [e]
Abutments, n/total (%)	2/16 (12.5)	5/23 (21.7)	
All abutments vital			0.001 [e]
Vital and non-vital abutments	6/31 (19.4)	6/41 (14.6)	0.541 [e]

All abutments non-vital	13/27 (48.1)	10/20 (50.0)	0.250 [e]
FDPs with post and core in non-Vital abutments, n/total (%) [f]	1/4 (25.0)	0/1 (0)	
No			0.727 [e]
Yes	3/12 (25.0)	6/11 (54.5)	0.332 [e]
Position non-vital abutment, n/total (%)	11/19 (57.9)	4/10 (40.0)	
Mesial			0.267 [e]
Distal	9/14 (64.3)	2/6 (33.3)	0.453 [e]
Mesial and distal	2/10 (20.0)	7/12 (58.3)	1.000 [e]
Middle	2/5 (40.0)	0/2 (0)	1.000 [e]
Material, n/total (%) [g]	1/2 (50.0)	1/1 (100)	
Gold ceramic			0.040 [e]
CoCr ceramic	16/38 (42.1)	7/38 (18.4)	0.180 [e]
Treatment provider, n/total (%)	4/16 (25.0)	8/18 (44.4)	
Dental student			0.001 [e]
General or specialist dentist	15/45 (33.3)	10/51 (19.6)	1.000 [e]
	5/17 (29.4)	6/11 (54.5)	
FDPs with at least one complication (n)	27	22	0.111 [e]
Complications (n)			
Technical:			<0.001 [e]
Major chipping	3	0	
Loss of retention	8	6	
Prosthesis replacement	7	3	
Tooth fracture	2	1	
Biological:			<0.001 [e]
Loss of tooth vitality	7	8	
Recurrent caries	12	7	
Periapical destruction	2	1	
Technical/biological			<0.001 [e]
Tooth loss	8	5	

FDP–fixed dental prosthesis; [a] On the day of prosthesis delivery; [b] Wilcoxon signed-rank test

[c] Paired-samples *t*-test; [d] Information not available for all patients; [e] McNemar's test; [f] Only for the prostheses that had at least one non-vital abutment tooth; [g] Analysis done only for the most prevalent materials used.

Survival rates

Study II (FDPs)

The cumulative survival rates (CSRs) after 5 and 10 years were 90.1% and 77.6%, respectively. After 15 and 20 years of functioning, the CSR for 94 and 36 FDPs was 67.9% and 52.1%, respectively.

Study IV (SCs)

The CSRs for all SCs were 89.9% and 80.9% after 5 and 10 years, respectively. After 15 and 20 years of function, the CSRs for the remaining SCs were 70.5% and 61.8%, respectively.

Failures

Study II (FDPs)

Ninety FDPs were considered failures (Table 5). Failure was more prevalent in the first year after delivery. Abutment failure occurred in 86 out of the 827 abutments in 54 patients, after a mean follow-up of 119.5 ± 79.4 months ± SD (min–max, 6.4–377.0). The most common reasons for FDP failures were loss of one or more abutment teeth, loss of FDP retention, and abutment tooth fracture.

Study IV (SCs)

Two hundred and thirty SCs were considered failures (Table 5). Failures occurred in 149 patients, after a mean follow-up time of 114.5 ± 70.4 months ± SD (min–max, 7.3–293.6). Loss of retention, tooth loss, and tooth fracture were the most common reasons for SC failures.

Table 5. Reasons for FDPs and SCs failures.

Failure	FDP / SC (frequency)	FDP / SC (percentage %)
Loss of retention	25 / 61	27.8 / 26.5
loss of one or more abutment/s teeth	28 / 31	31.1 / 13.5
Tooth fracture	9 / 29	10.0 / 12.6
Loss of tooth vitality	7 / 7	7.8 / 3.0
Replace old FDP and SC by new one due to change situation	7 / 25	7.8 / 10.9
Periapical destruction	4 /17	4.4 / 7.4
Framework fracture	3 /4	3.0 / 1.7
Recurrent caries	2 / 20	2.2 / 8.7
Major chipping	2 / 8	2.2 / 3.5
Mobility	1 / 8	1.1 / 3.5
Esthetic dysfunction	1 / 6	1.1 / 2.6
Allergy	1 / 0	1.1 / 0.0
Excessive bone loss	0 / 11	0.0 / 4.8
Tooth loss unknown reason	0 / 2	0.0 / 0.9
Poor fitting	0 / 1	0.0 / 0.4
Total	90 / 230	100 / 100

FDPs–fixed dental prostheses; SCs–Single crowns.

Study III (FDPs in matched groups of bruxers and non-bruxers)

FDPs in bruxers presented a significantly higher failure rate (p <0.001) in comparison to non-bruxers (32.3% vs. 25.8%, respectively). Failure rates were higher in women, in the maxilla, in the posterior region of the jaw, when all abutment teeth of the prosthesis were vital, for prostheses fabricated with high-noble gold-based metal–ceramic (Au-MC), and when the treatment was conducted by dental students. Loss of retention and tooth loss were the main reasons for FDP failures in both bruxers and non-bruxers (Table 6). For non-smokers, the FDP failure rate was higher in non-bruxers in comparison to bruxers (Table 4).

Table 6. The reasons for FDPs failures in bruxers and non-bruxers.

Reasons for FDPs failures	Bruxers		Non-bruxers	
	Frequency	Percentage %	Frequency	Percentage %
Loss of retention	5	25.0	4	25.0
Tooth loss	5	25.0	4	25.0
Tooth fracture (root or crown)	2	10.0	1	6.3
Major chipping	2	10.0	0	0
Periapical destruction (Radiolucency)	2	10.0	1	6.3
Replace old construction by new one due to change situation	2	10.0	1	6.3
Loss of tooth vitality	1	5.0	2	12.5
Mobility	1	5.0	0	0
Esthetic dysfunction	0	0	1	6.3
Allergy	0	0	1	6.3
Total	20	100.0	16	100.0

FDPs–Fixed dental prostheses.

Study II (FDPs)

Cobalt–chromium-based metal–ceramic (CoCr-MC) FDPs had a significantly higher HR (HR 5.361 95% CI 2.901, 9.907; p <0.001) than high-noble gold-based metal–ceramic (Au-MC) FDPs (Table 7).

Table 7. Comparison between failed and non-failed FDPs according to the most prevalent material used, and hazard ratio estimated from univariate Cox proportional hazard model.

Material	Failed prosthesis (n)	Non-failed prosthesis (n)	Hazard ratio (95% CI)	p value
Gold ceramic	64	162	1	
CoCr ceramic	18	46	5.361 (2.901, 9.907)	<0.001

FDPs–fixed dental prosthesis; 95% CI–95% confidence interval.

Multivariate Cox proportional hazard models

Study II (FDPs)

Smoking was statistically significant in the multivariate model in relation to non-smokers (HR 2.309; 95% CI 1.187, 4.493; p =0.014) (Table 8).

Table 8. Multivariate Cox proportional hazard model for FDP failure.

Factor	Hazard ratio (95% CI)	*p* value
Jaw		
Maxilla	1	
Mandible	1.297 (0.654, 2.570)	0.457
Abutments		
All abutments vital	1	
Vital and non-vital abutments	1.321 (0.466, 3.744)	0.601
All abutments non-vital	0.439 (0.077, 2.509)	0.355
Post and core location		
Mesial	1	
Distal	0.689 (0.239, 1.987)	0.490
Mesial and distal	0.231 (0.028, 1.891)	0.172
Middle	0.449 (0.086, 2.333)	0.341
No post and core	0.690 (0.189, 2.516)	0.574
Bruxism		
No	1	
Yes	1.280 (0.669, 2.451)	0.456
Smoking [a]		
No	1	
Yes	2.309 (1.187, 4.493)	0.014
Ex-smoker	1.266 (0.402, 3.985)	0.687

FDPs–fixed dental prosthesis 95% CI–95% confidence interval.

[a] Only one non-smoker made use of snuff (no failure), which was not considered here.

Study IV (SCs)

Multicollinearity was observed between the factors "crown region" and "tooth type." Therefore, the factor "tooth type", which was moderately associated with crown failure in the univariate model, was excluded from the multivariate model. The estimated HR indicated that the following factors were influential for SC survival: SCs in posterior teeth had a lower HR than in anterior teeth, SCs in vital teeth showed a lower HR than in non-vital teeth, and SCs in bruxers showed a higher HR than those in non-bruxers (Table 9).

Table 9. Multivariate Cox proportional hazard models for SC failure.

Factor	Hazard ratio (95% CI)	*p* value
Jaw		
Maxilla	1	
Mandible	0.77 (0.58, 1.03)	0.073
Crown region		
Anterior	1	
Posterior	0.73 (0.55, 0.99)	0.04
Tooth vitality		
Non-vital	1	
Vital	0.64 (0.49, 0.84)	0.001
Bruxism		
No	1	
Yes	1.52 (1.17, 1.98)	0.002

95% CI–95% confidence interval.

Biological and technical complications for FDPs and SCs

Studies II and IV

Loss of retention and recurrent caries were the most common complications for both FDPs (at abutment level) and SCs.

Study III (FDPs in matched groups of bruxers and non-bruxers)

Technical and biological complications were significantly more prevalent ($p < 0.001$) in bruxers than in non-bruxers (complication level), although not when only the number of prostheses with at least one complication (prosthesis level) was compared between groups (Table 4).

Cross-tabulation

Study III (FDPs in matched groups of bruxers and non-bruxers)

Cross-tabulation was performed with three variables (bruxism, smoking, and treatment provider) in order to verify whether there was a possible association regarding treatment provider to the higher prosthesis failure rate in nonsmokers among non-bruxers than among bruxers. Crosstabulation showed that all prosthetic treatments for nonsmoker and non-bruxer patients were conducted by dental students, whereas all types of treatment provider were represented in the other groups.

Study IV (SCs)

A crosstabulation was performed for two variables (presence of post and core and area of crown placement) in order to explore the reason for the higher HR in anterior than in posterior teeth. The analysis showed that 89.9% of non-vital anterior teeth had post and core.

DISCUSSION

Based on the results of the present systematic review and retrospective studies, the general null hypothesis was partially rejected, as some general and local factors showed an influence on the survival rates of full-coverage tooth-supported FDPs and SCs.

The null hypothesis of the systematic review (Study I), was partly rejected, as the results suggest that the survival rate of full-coverage SCs is influenced by tooth vitality. For FDPs, the null hypothesis was accepted, as there were no significant differences in survival rate of FDPs regarding any of the investigated factors.

Based on the results of the retrospective studies on FDPs (Studies II and III), the survival rates of FDPs retained solely by vital and non-vital abutments or a combination of both are not influenced by factors such as sex, length of the FDP, number of abutments, position of the non-vital abutment, presence and location of post and core, area of placement, location of the FDPs in relation to the jaws, abutment vitality, and bruxism. Instead, smoking and type of FDP material were factors that had a significant influence on the survival of FDPs (Study II). The null hypothesis was rejected for the matched groups of bruxers and non-bruxers (Study III), as a higher failure rate was observed among FDPs in bruxers compared to FDPs in the matched group of non-bruxers. The same was observed for the prevalence of technical and biological complications.

Based on the results of the retrospective study on SCs (Study IV), survival rates of SCs are influenced by the area of crown placement, tooth vitality, and bruxism. Patient's age and sex, presence of post and core, location of the crowns in relation to the jaws, type of tooth, type of crown material, status of the opposing arch (crown occluding to), treatment provider, and smoking habits showed no impact on the survival of SCs.

Survival rates of FDPs and SCs

Our retrospective study on FDPs (Study II) found a similar CSR after 10 years as a recent retrospective study that reported the CSR to be 78.9%.[91] However, after 15 years the present CSR of FDPs was higher than the previous study, which reported the CSR to be 61.6%.[91] Another retrospective study reported the 10-year survival rate of FDPs to be 74.4%, which is also lower than the present study.[51] The included FDPs in that study had a mean number of 7.3 units (range between 5–12 units) and 4.7 abutments.[51] The extensive length of the FDPs and the higher number of abutments compared to our retrospective study could have negatively influenced the results.[51, 62, 63, 92] The number of abutments has been shown to affect the mean life-span of FDPs with higher mean life-span for FDPs with two abutments compared to FDPs with three or more abutments.[93] A higher number of abutments for FDPs may force clinicians to over-prepare the abutments to establish the path of insertion, which could reduce retention and resistance form and lead to loss of retention[40, 93] which has been a common complication in FDPs.[51] Furthermore, overpreparation could jeopardize tooth vitality and increase the possibility of pulp necrosis.[94] With multi-retainer FDPs, there may also be difficulties to achieve a proper marginal fit,[95] and difficulty cleaning between the abutments, which could increase the risk of caries.[93]

On the other hand, the CSR in Study II was lower than that in some previous retrospective studies[55, 96] and reviews.[27, 28] The differences could be caused by different factors, one such factor could be treatment provider. The treatments in our study were performed in a dental school setting, by several treatment providers with different clinical experiences, whereas the treatment in a previous study was performed by two experienced clinicians at a private clinic.[55] The varying degrees of clinical experience for treatment providers in our study could have negatively influenced treatment outcomes. However, our study may be more representative, as the results obtained at a specialist clinic may perhaps not be expected to be obtained by general practitioners[97] although students' treatment is always supervised by experienced staff.

For SCs in Study IV, the CSR after 5 and 10 years of function was lower than reported in previous reviews[11, 26] and in a retrospective study.[98] Studies with even longer follow-up[2, 30] also report a higher survival rate of SCs compared to the present study. In one of the aforementioned studies, all treatment was performed by one prosthodontic specialist in a private prosthodontic clinic.[30] This is in contrast to the present study, where treatment was performed by general practitioners and dental students, as well as by a specialist which could have negatively influenced the treatment outcome. Additionally, patients seeking treatment at specialist private clinics are perhaps not representative of a general population of dental patients, which might also influence results.

A previous systematic review[28] and long-term retrospective study[40] reported higher long-term survival rates of FDPs after 5,10, and 20 years than those in Study II. In the review, all included prospective and retrospective cohort studies provided regular clinical follow-up examinations for all patients,[28] as did a long-term retrospective study which included regular maintenance follow-up visits every 6 months for all patients.[40] This is in contrast to our studies where few patients attended regular follow-ups in the first year. This could be another explanation for the lower survival rates compared to other studies, as regular follow-up is an important factor in achieving a high long-term prognosis for FDPs and SCs.[2, 99, 100] Regular recall and follow-up visits, including oral hygiene instruction and interventions, can minimize the incidence of caries and periodontal disease in the abutments of the prostheses and surrounding structures, and improve survival.[101]

Common complications and failures for FDPs and SCs

The main complications and failures identified were tooth loss, recurrent caries, tooth fracture, loss of retention, and loss of tooth vitality. The precise primary causative factors for any of these events cannot be confirmed by the present retrospective studies, as they are based on patient records and clinical examinations were not performed. But there are some factors of possible influence that should be discussed.

Tooth loss was one of the main reasons for FDP and SC failures in all three retrospective studies. Tooth loss occurred mainly as a consequence of extensive alveolar bone loss, tooth mobility, extensive caries, and tooth fracture. Periodontal diseases such as gingivitis and periodontitis were prevalent among the included patients in the present retrospective studies. Tooth loss is an effect of this disease if not treated successfully.[102] Another reason is recurrent caries. Caries could occur in the root surface adjacent to the margin of the FDPs and SCs [31] and may progress and make the tooth unsuitable to function as a retainer for FDP or SC and therefore lead to tooth extraction or loss. The progression of the aforementioned processes may take time to occur. This was emphasized in a previous study, where incidence of tooth loss increased with time since prosthesis placement.[103] Tooth fracture was also a common reason for FDP and SC failures, which also lead to tooth extraction and loss. The incidence of tooth fracture could relate to factors such as a significant loss of tooth structure,[104, 105] presence of post[39, 106, 107] and combination to excessive load by bruxers and non-parallel occlusal forces for anterior teeth.[44]

Loss of retention was the most common complication for FDPs and SCs in Studies II and IV. Additionally, loss of retention was the most common reason for FDP and SC failure in Studies III and IV, and the second most common reason for FDP failure in Study II. This finding is in agreement with other studies, where loss of retention has been reported to be among the most common complications for FDPs and SCs.[108, 109] Loss of retention could occur between prosthesis and abutment, or between post and core and abutment tooth.[31] This complication is related to several factors, such as insufficient clinical tooth substance, improper preparation and underextended or open margins.[31, 51, 58, 110, 111] Insufficient amount of retentive tooth substance and over taper abutment preparation reduce resistance to dislocating forces which could increase the risk of loss of retention.[40, 51, 58] Furthermore, underextended and open margins can lead to cement dissolution and subsequent loss of retention.[31] Thus, good marginal fit is one of the key clinical factors for the longevity of protheses.[112]

The longevity of FDP and SCs is closely related to the marginal seal between abutment and prostheses.[110, 113] This process is dependent on the fracture resistance of the luting cement, filling the irregularity between the fitting surface of prosthesis and abutment.[31, 110] The choice of cement, and proper handling of cement, also affects the risk of loss of retention. In Study IV, all-ceramic SCs cemented with resin cement revealed better clinical performance compared to SCs luted with other cements, such as zinc phosphate. This has been observed in other studies.[114-116] Zinc phosphate cement shows limited tensile strength and limited resistance to dissolution, which could increase the possibility of retention loss.[114] Resin cement, on the other hand, provides a chemical bond in addition to the mechanical and micro-mechanical bonds of other cements,[117] and also has an excellent ability to minimize marginal discrepancy and leakage.[118] Nevertheless, adhesive cement cannot compensate for the lack of resistance and retention form of the abutment and improper prosthesis margin to prevent the loss of retention.[110]

In Study II, failures were more prevalent during the first years of prosthesis delivery. The sampled studies did not analyze which type of failure occurred at different times; i.e., whether a specific failure occurred in the first years or later during follow-up. Speculatively, however, loss of retention could be a major reason for the early failures, as loss of retention has been recorded as the most prevalent complication occurring within the first years after cementation of a prosthesis.[103]

Recurrent caries was the most prevalent biological complication for FDPs and SCs in Studies II, II and IV. Recurrent marginal caries could be a consequence of ill-fitting margin or could follow the loss of prosthesis retention.[31] Karlsson found a significantly higher incidence of marginal caries in open margin and poor

adaptation FDPs, compared to FDPs with no open and underextended margins.[99] It is difficult to precisely predict which one occurred first: the process could start with loss of retention followed by caries, or the opposite could occur if there is an open margin.[31] The ill-fitting FDP and SC margin and uncovered prepared rough tooth structure can easily retain plaque and increase the occurrence of marginal caries.[99, 100] As a clinical examination was not performed in the present studies, the precise primary cause of the recurrent caries could not be ascertained.

Loss of tooth vitality was reported as one of the main biological complications and reason of failures for FDPs and SCs. Overpreparation of the teeth and inefficient water coolant may induce pulpal irritation and lead to pulp necrosis.[94] Thus, maintaining the proper thickness of the dentin structure and providing an adequate cooling system during tooth preparation are crucial to preserving the vitality of dental pulp.[119]

Factors influencing the survival of FDPs and SCs

Local factors

Tooth vitality showed an expected positive influence of the survival of SCs in the present systematic review and retrospective studies (I, IV). These findings are in agreement with a previous study, in which a higher failure rate was observed for SCs on non-vital teeth compared to SCs on vital teeth.[120]

Surrounding periodontal mechanoreceptors around natural teeth have extremely sensitive tactile sensors that help to control biting and chewing behaviors and provide information about tooth load.[121] Mechanosensitive afferent nerve fibers are located among collagen fibers of the periodontal ligament.[122] The majority of these afferent nerve fibers exist around the apical third of the root.[122] The mechanism of action of these mechanoreceptors is that, during tooth loading signals are transmitted from periodontal mechanoreceptor sensors to the surrounding socket bone to the brain through afferent nerve fibers.[121]

Both vital and non-vital teeth have these periodontal mechanoreceptors. However, non-vital teeth lack interdental receptors in the pulp tissue which protect the tooth from overloading force.[123] The lack of these receptors in the non-vital teeth tends to increase the threshold for maximum biting force compared to vital teeth,[123, 124] and thereby contributes to increased risk of tooth damage and fracture.[123] Furthermore, a significant loss of non-vital tooth structure during endodontic and restorative treatments may reduce fracture resistance[125, 126] and increase vulnerability to catastrophic tooth fracture.[104, 105]

Abutment vitality, however, showed no significant influence on the survival of FDPs in Study II. These results were unexpected and in contrast to an earlier study reporting a higher failure rate of non-vital abutments of FDPs compared to vital abutments.[34] Possible explanations for the different results could be due to two factors: the area of placement and choice of material. Almost half of the FDPs with vital abutments were placed in the posterior region, compared with one-third of the FDPs with non-vital abutments. Anterior teeth are subjected to lower masticatory forces than posterior teeth.[43] Thus, the anterior area of placement could have reduced the risk of complications in the non-vital group in the present study, although the area of placement alone did not show any significant influence on the survival of FDPs. De Becker et al. reported similar findings, with 85% and 63.6% survival rates for anterior and posterior/overlap (canine to premolars or molars) FDPs, respectively.[40] In Study III, a higher failure rate of FDPs with vital abutments is also unexpected finding and could be related to the status of the dentition and opposing arch, which may have an influence on the magnitude of the bite force among bruxers and could thus affect the prognosis of FDPs with vital abutments.[64, 68] Status of dentition and opposing arch are hypothetical influencing factors, as these two factors were not possible to evaluate. The status of the opposing arch could have changed from baseline to subsequent follow-ups without mention in patients' records, and it is thus difficult to judge whether a complication happened when the FDP was opposed by natural dentition or when the opposing arch had received fixed or removable prosthesis. Therefore, these two factors can only be mentioned as potential contributing factors.

Presence of post showed a negative impact on the survival of SCs. The survival analysis in the review (Study I) suggested a higher estimated survival rate of metal–ceramic SCs on vital teeth compared to metal–ceramic SCs on non-vital teeth with post. These findings are in agreement with previous studies, in which a lower survival rate was reported for SCs on non-vital teeth with post compared to SCs on vital and non-vital teeth without post.[33] The presence of a post on non-vital tooth could increase the stress on the root surface and subsequently increase their susceptibility to fracture.[39, 106, 107] In an *in vitro* study, fractography analysis of fractured non-vital teeth was performed to evaluate the fracture pattern of the dentin.[107] High tensile unfavorable stress distribution was observed on the root surface of a non-vital tooth with parallel smooth sided stainless steel post, as a result of high stiffness of the metallic post which lead to root fracture.[107] Predominant microcracks started at the inner surface of the remaining dentine wall adjacent to the endodontic post, which progressed toward the outer surface of the root and led to fracture.[107, 127, 128] The same pattern of fracture was observed with cast metal post and core.[128] To overcome the risk of root fracture, fiber posts have been introduced later as an alternative to metal posts.[129] The

modulus of elasticity of fiber posts are similar to the dentine, which reduces stress on the root surface and therefore reduces the risk of root fracture.[87, 130] Nevertheless, another mode of failure has been demonstrated, such as post debonding and fracture.[131, 132]

The negative influence of the presence of posts was observed in the anterior SCs that presented with a high number of posts compared to posterior SCs. Therefore, anterior SCs had a higher HR in relation to posterior ones. A limited amount of remaining tooth structure in the non-vital anterior teeth compared to the posterior teeth could increase the incidence of loss of retention for post and core and lead to crown failure.[44] Loss of SC retention has been reported to occur 2.66 times more frequently in the anterior than in posterior teeth.[98] Preserving dentine structure and creating a ferrule of 1.5–2 mm during post preparation is crucial to increasing fracture resistance, reducing the risk of catastrophic tooth fracture, and reducing the risk of post debonding.[107, 127, 129, 133-136] The lack of sufficient coronal tooth structure and ferrule cannot be compensated for by any type of post; neither prefabricated titanium nor prefabricated fiber posts.[137] Tooth fracture and post debonding has been demonstrated in teeth with absence or limited coronal tooth structure and ferrule and restored with cast metal and fiber posts and covered by SCs.[129] In that situation, the type of post type did not influence the clinical performance of SCs.[129] Clinical examination was not performed in the present studies however, which precludes any assessment of the presence or absence of appropriate ferrules in the included cases.

On the other hand, a contradictory finding was observed. The presence of a post showed no significant influence on the survival of FDPs in Study I. The survival rate of metal–ceramic FDPs on vital abutments did not differ significantly from metal–ceramic FDPs supported by non-vital abutment/s with cast metal post. This result is in contrast to a recent retrospective study, where more failures were revealed in FDPs retained by non-vital abutment with post compared to FDPs on vital teeth.[51] Non-vital teeth can withstand high forces without discomfort or pain, which could increase the risk of overload and may lead to teeth fracture.[49, 138] The absence of significant differences could be due to the limited number of cases and studies in each group of FDPs, which could make the results unreliable to a drawing a valid conclusion.

The type of prosthetic material showed an influence on the survival of FDPs and SCs. Au-MC FDPs showed a significantly lower risk of failure compared to CoCr-MC FDPs. The results may be influenced by the long-standing tradition of using high-noble gold-based alloys in Sweden, where the national reimbursement system made gold alloys affordable and the predominant material for all fixed dental restorations for decades. This is noticeable in the skewed distribution of materials used, where metal–ceramic FDPs were more common compared to all-

ceramic restorations up until the last 5 to 10 years. Speculatively, the predominant use of high-noble gold-based alloys could have led to a high skill level for dentists and dental technicians, which reduced the risk of material-related complications. The positive influence of Au-MC FDPs material was also observed in FDPs with non-vital abutments. The majority of FDPs retained by solely non-vital abutments were made of high-noble Au-MC which have a lower HR in relation to CoCr-MC FDPs material that could have reduced the risk of complications and failures for the non-vital group.

Loss of retention and caries were common reasons for failure. These factors could be related to a risk of ill-fitting margins, which may have been more common among CoCr-MC FDPs because of the high stiffness and low ductility of this material, which makes it more challenging to shape during manufacturing processes, compared to high-noble gold alloy.[48, 139] In a previous *in vitro* study, CoCr frameworks of 3-unit FDPs were fabricated by three methods: conventional casting, milling and selective laser melting (SLM).[140] Most of the CoCr frameworks showed an underextended margin during examination.[140] A second factor is veneering ceramic defects, which occurred more often in CoCr-MC FDPs compared to Au-MC.[141] A recent retrospective study supported these findings, as they found a significantly higher occurrence of ceramic chipping in CoCr-MC FDPs compared to Au-MC ones.[51] The bond strength of porcelain to Au-MC-based restorations is significantly higher compared to bonding to non-precious alloys such as CoCr-MC based restorations, affecting the tendency for adhesive veneering ceramic fracture.[142]

For SCs, significant influence of the type of SC material was observed on the estimated survival rates of non-vital teeth with fiber post. All-ceramic SCs with fiber post showed significantly higher 5-year survival rate than metal–ceramic SCs with fiber post. However, contradicting findings have been reported where all-ceramic and metal–ceramic SCs with fiber post were reported to present similar survival rate after 5 and 8 years of function.[78, 86] In those studies, both crown materials were evaluated in the same studies and under equal circumstances.[78, 86] In the present systematic review, the difference of the estimated survival between metal–ceramic and all-ceramic SCs with fiber post could be related to the heterogenicity of the clinical variables among included studies. The amount of the remaining tooth structure, presence and amount of ferrule, status of the dentation, opposing arch, treatment provider, setting and type of cement were not standardized and matched among patients in both groups.[30, 42, 78-81, 83, 85-88] Differences regarding these factors could have influenced material choice in each individual clinical case. Moreover, the low number of all-ceramic SCs compared to the metal–ceramic group could have influenced the results. Due to the small sample size in each group of SCs, other influential clinical variables, such as amount of the remaining tooth structure, presence, and amount of ferrule

could not be properly analyzed. Separating the material into subgroups would, however, make the sample size in each group even smaller. Therefore, no strong conclusions can be drawn for this particular group.

In contrast to the findings of the present systematic review, the type of crown material had no significant influence on the survival of the SCs in Study IV. The results are in agreement with a previous review, where most types of all-ceramic SCs showed similar survival rates to those reported for metal–ceramic ones.[11] The type of material may influence the outcome of SCs less than in FDPs, due to the difference in biomechanics between SCs and FDPs, as SCs are less complicated in their design, having no connector and splinting areas.[59] Furthermore, the fabrication process of FDPs is more complicated for dental technicians compared to SCs, which could increase the manufacturing flaws of frameworks and veneer materials of FDPs.

The factor 'area of placement' did not show any significant influence on the survival of FDPs but it was hypothetically suggested that the lack of influence of the factor 'tooth vitality' on the survival of FDPs in Study II could be due to area of placement and type of FDP materials. Almost half of FDPs with vital abutments were placed in the posterior region, compared to one-third of the FDPs with non-vital abutments. Anterior teeth are subjected to lower masticatory forces compared to posterior teeth.[43] Thus, the anterior area of placement could reduce the risk of the complications in the non-vital group in the present study, even though the area of placement alone did not show any significant influence on the survival of FDPs. FDPs made of Au-MC had a higher failure rate in bruxers. Possible explanations for these results could be the area of placement. Most of FDPs made of Au-MC were delivered in the posterior region of the bruxer patients, which is subjected to higher masticatory force compared to anterior regions.[43, 67, 106, 143] A contradictory finding was shown for SCs, as anterior SCs had a higher HR in relation to posterior ones. This may be surprising, considering the generally lower loads expected in the anterior area compared to the posterior area.[43, 67] The reason behind this could be related to the high number of presences of post and core in the anterior teeth, which could increase the risk of anterior SCs failure. Similar findings were observed previously, where anterior teeth with post and core showed a higher risk of failure than posterior teeth with post and core.[44] The occlusal load of anterior teeth is often not parallel to the long axis of the tooth, which results in an unfavorable load distribution,[44, 144] which might increase the micromotion of the crown and post, and subsequently increase stress on the root surface, leading to tooth fracture, which was one of the most common reasons for SC failures in Study IV.[39, 106]

Bruxism has commonly been considered a detrimental factor for dental restorations, tooth structure, and periodontal support.[145] In Study III, loss of

retention and tooth loss occurred more commonly in bruxers compared to non-bruxers and in Study IV, an increased incidence of loss of retention and tooth loss was observed in patients with bruxism, which was the most common complication and the main reason for SC failures. These findings are in agreement with previous studies, where loss of retention has been reported to occur more frequently in bruxers.[48, 59] Excessive overload could induce micromotion of the framework, and may cause loss of retention.[48] Furthermore, loss of retention could relate to the minimum resistance and retention form of worn dentition, which could be expected in bruxers.[58] Hypothetically, the unconscious overloading forces in bruxers could increase the active tissue destruction of the inflamed periodontal tissues in patients with periodontal disease, which could increase the risk of bone resorption and tooth loss.[102] Furthermore, premature occlusal contact and imbalance occlusion of FDPs and SCs could increase the detrimental vertical and horizontal forces on the abutments and subsequently accelerate the process of pathological changes and tooth loss;[102] especially in patients with periodontal disease[146, 147] and bruxism.[58] Major porcelain chipping occurred only in the bruxer group. Porcelain chipping has been reported previously as one of the main technical complications in bruxers.[48, 59] The excessive loading by bruxers could increase susceptibility to porcelain chipping, initiated with roughness of the porcelain veneer at the occlusal surface as a result of wear, with subsequent cracks propagating until chipping occurs.[58, 148] Fabricating FDPs with only metal at the occlusal surface might help to improve the treatment prognosis and eliminate the occlusal chipping complication.[149]

General factors

Smoking significantly influenced the occurrence of FDP failure. The association between smoking and tooth loss is highly probable,[150] and smokers have been found to show a two-fold higher risk of tooth loss than non-smokers.[151] The incidence and progression of periodontitis are increased by smoking, and periodontal disease is associated with tooth loss.[69] On the other hand, smoking showed no impact on the survival of SCs. The incidence of periodontitis and tooth loss could be more prevalent in FDPs than SCs due to the difficulty in cleaning between the abutments of FDPs, and periodontal breakdown has been reported to happen more often in FDPs than SCs.[32] However, periodontal status and diagnosis were not matched among included patients in the present retrospective studies. Further studies are needed to investigate the direct association between abutment vitality and smoking.

Patient´s age and sex had no significant influence on the survival of SCs. The magnitude of the biting force is higher in men than in women and decreases significantly after 50 years of age.[66] It could thus be hypothesized that failure

and complications would be more common among male patients and patients under the age of 50.[65-67, 152] However, number of teeth has been reported as the most important factor affecting the magnitude of the biting force, rather than patient´s age and sex.[66] This factor was not controlled for among included patients and could have influenced the results.

Methodology

Systematic review

The systematic review is considered one of the best evidence-based methods to answer focused research questions.[153, 154] The search process and data synthesis may be challenging, but a systematic review has several advantages.[153] It can provide a broad overview of the main subject, give a proper summary for the results of the main topic, and guide the researchers in identifying knowledge gaps.[154, 155] For these reasons, a systematic review is an appropriate inclusion in a doctoral thesis.

The synthesis of a systematic review should be performed by at least two reviewers who work independently, and preferably involve more than one electronic database.[154, 155] Included studies should be assessed by quality assessment tools to assess the risk of bias and identify low-quality studies. The Newcastle–Ottawa Scale (NOS) calculates the risk of bias on the basis of three domains: selection of study groups, comparability of groups, and determination of outcomes.[74] NOS has been recommend for observational cohort and case-control studies, and was used in the present review.[73, 156]

Limitations of the present systematic review (Study I)

Different types of study design fulfilled the inclusion criteria and were included in the present systematic review, resulting in a high level of heterogenicity. Most of the data were from non-randomized retrospective and prospective studies. Almost half of the included studies were retrospective cohort studies, which have a high risk of bias and low level of evidence compared to well-designed RCTs and prospective studies.[157, 158] The lack of controlled clinical variables, the small samples size for each group, and the differences in clinical evaluation parameters are other limitations. Research outcomes should preferably be extracted from solid evidence, such as meta-analyses.[159] Meta-analysis can assess the presence of publication bias and analyze inconsistencies in the results of included studies.[155, 160] However, the number of studies making comparisons of different groups was very low, and therefore pairwise meta-analyses were not recommended.

Retrospective study

A retrospective cohort study is used to study the incidence and causes of an outcome, and helps to estimate the prognosis of the evaluated treatment, as it can provide information about risks and complications.[91, 161] The methodology is also appropriate to identify possible associations between an exposure and an outcome.[161]

The strength of the present record-based retrospective studies is that data collection was performed in as much detail as possible, considering several clinical variables for each subject. Furthermore, presence of only one investigator in the process of data collection and insertion into a software (SPSS) could be a strength, since lack of calibration between multiple investigators could negatively affect the outcomes.

Limitations of the present retrospective studies (II, III, IV)

There are limitations to record-based retrospective studies. The clinical procedures were not standardized as they could have been in a prospective study, and all the professionals involved in the treatment of these patients were not calibrated. Moreover, some data may not have been completely recorded in the patient's journals at each follow-up appointment. These factors may reduce the quality and reliability of retrospective studies.[92]

One of the limitations of Study II was the low number of included FDPs considering the extensive period of 1981 to 2018 and taking into account all different treatment providers; dental students, general practitioners, and specialists. As cantilever FDPs represent very specific challenges from the perspective of abutment tooth vitality aspects,[138, 162] these were excluded. It was also decided to exclude longer FDPs (more than 7 units), as 3–7-unit FDPs may be more representative of regular prosthetic treatment than longer or full-arch FDPs. These factors, together with all the aforementioned exclusion criteria, contributed to lowering the number of included FDPs in Study II.

In Study III, the lower sample size of subgroups and a potential risk of misclassification and/or under- or overdiagnosis of bruxism could also be considered limitations. Self-reporting questionnaires and a clinical examination, in combination with a polysomnography recording (PSG), are used for 'definite' diagnosis of sleep bruxism.[56] Electromyography recording (ECG) of the masseter muscles is also one of the methods for grading 'definite' awake bruxism. However, the PSG and ECG diagnostic options are not commonly used in the clinic, due to their high cost and limited availability.[56, 163] Instead, self-report questionnaires and clinical examinations are commonly used for both clinical and research purposes, and they are suitable and practical to be applied to a large population.[56, 164, 165] However, they are still not good enough for identifying

bruxer patients.[166] Therefore, clinical diagnosis of bruxism is complicated, and there is a risk that the present group of patients could be either under- or over-diagnosed.[57, 167]

The absence of a standardized system for classification and diagnosis of periodontal diseases in the dental school precluded the involvement of periodontal status as a local clinical factor in the present retrospective studies, which is considered as one of the limitations. Moreover, presence of variations among patients in attending regular maintenance follow-up visits could affect treatment prognosis and could be considered a limitation.

Generalizability

The retrospective studies emanated from a teaching institution, where treatment providers as well as patients may differ from general dental practice. Treatment was performed by several treatment providers with different levels of clinical experience, including general practitioners, specialists, and dental students. The patients that were not treated by students and specialists are probably representative of general dental practice. Patients seeking treatment at a low-cost student clinic could differ from general dental practice, e.g., by having lower socio-economic status, which may be associated with poorer general and oral health,[168] and patients seeking specialist treatment may represent cases with more complex treatment needs. The potential influence of this was not analyzed, but these factors may limit the generalizability of the results. Nevertheless, record-based retrospective studies based on cases treated at general public dental clinics such as dental school clinics involve several clinical variables, and treatment providers may be considered more representative of everyday clinical practice than studies conducted by specialists at private clinics under highly specific conditions, as the results obtained by specialists may perhaps not be expected to be obtained by general practitioners.[97]

Ethical considerations

The data used to support the findings of the retrospective studies (II, III, and IV) were obtained from records of patients treated at the Faculty of Odontology, at Malmö University. The data was processed in accordance with the General Data Protection Regulation (EU) 2016/679 and the ethical vetting (Dnr 2018/856), in order to protect patient privacy. The decoding lists linking patient names and numbers were stored by the principal investigator, who was the only person with access to the lists. No information in any of the studies can be traced back to an individual patient. These lists will be destroyed after completion of the studies.

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Clinical significance

To be able to reliably predict clinical outcomes, as many general and local factors as possible should be taken into consideration by the treatment provider. The present retrospective studies are based on multiple-factor analysis, including several local and general factors. Within the limitations of the studies, the results provide an improved understanding of the relationships between these factors, and as to which of the evaluated factors are significantly related to the clinical outcomes of tooth-supported FDPs and SCs. Recognizing these impact factors during treatment planning may reduce the risk of complications and failure.

Future perspectives

Further studies are needed. Such studies should involve several general and local variables. A randomized controlled clinical trial design could help to provide better management of the included factors for precise and accurate estimation of the association, strength, and influence of different clinical factors on the survival of FDPs and SCs.

CONCLUSIONS

Within the limitation of the systematic review, it was concluded that:

- Tooth vitality contributes positively to the survival of SCs, although it was not possible to analyze the possible influence of remaining coronal tooth structure from the results of the review.
- The presence of uncontrolled confounding variables included in studies in the systematic review could increase the risk of bias. Therefore, the present results should be interpreted with caution.

Within in the limitations of the retrospective studies it can be concluded that:

- Bruxism and smoking are suggested to contribute to FDP failure, irrespective of abutment vitality.
- Type of prosthetic material contributed to FDP failure, as Au-MC FDPs showed a significantly lower risk of failure compared to CoCr-MC FDPs material.
- The absence of influence of abutment vitality on the survival of FDPs could be due to other factors, such as area of placement, type of FDPs material, status of the dentition, opposing arch, and bruxism. Therefore, the positive or negative influence of some clinical factors on the survival of FDPs and SCs seems to be affected by other general and local factors, to a certain extent.
- Anterior placement, non-vital abutments, and bruxism are factors increasing the failure rate of SCs.
- Presence of multiple negative influencing factors in one case may increase their detrimental effect and could worsen the prognosis of FDPs and SCs.

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I

THE LONGEVITY OF FIXED PROSTHETIC RESTORATIONS ON VITAL AND NON-VITAL TEETH : A SYSTEMATIC REVIEW.

ABSTRACT

Purpose: To evaluate the survival rate of full coverage fixed prosthetic restorations, fixed dental prostheses and single crowns (FDPs, SCs), taking into consideration the potential influence of tooth-vitality, presence and type of post, and type of prosthetic restoration material.

Materials and methods: PubMed, Web of Science and ScienceDirect electronic databases search as well as hand search were conducted in September 2020 to identify clinical human studies on full coverage FDPs and SCs supported by vital and/or non-vital abutments and/or a combination of both, with a minimum observation period of 24 months.

Results: Out of 2052 and 61 studies identified through database and hand searching respectively, 17 studies fulfilled the inclusion criteria and were included in the analysis of the present systematic review. Included studies scored six points and more according to Newcastle-Ottawa Scale (NOS). The highest estimated 5-year survival rate was observed for metal-ceramic and all-ceramic SCs on vital teeth 97.8% (95% CI [97.1– 98.5]) and all ceramic SCs on non-vital teeth with fiber post 99.1% (95% CI [97.7– 100.4]). Metal-ceramic SCs on vital teeth 97.5% (95% CI [96.8– 98.3%]) showed a statistically significant higher estimated 5-year survival rate compared to metal-ceramic SCs with cast metal post 94.5% (95% CI [93.3– 95.8%], $P < 0.001$) and fiber post 95.1% (95% CI [93.4– 96.6%], $P < 0.007$). All-ceramic SCs with fiber post 99.1% (95% CI [97.7– 100.4]) had a statistically significant higher estimated 5-year survival rate

compared to metal-ceramic SCs on non-vital teeth with fiber post 95.1% (95% CI [93.4–96.6%], P < 0.001) and without post 95.7% (95% CI [93.7– 97.7%], P < 0.006), respectively. SCs (All-ceramic and metal-ceramic) with fiber post 97.5% (95% CI [96.4– 98.5%]) had a statistically significantly higher estimated 5-year survival rate than SCs made of metal-ceramic and retained by cast metal post 94.5% (95% CI [93.3– 95.8%], $P < 0.001$). For FDPs, the 5-year survival rate was higher for metal-ceramic FDPs on vital abutments 96.9% (95% CI [95.5–98.4]) compared to FDPs retained by non-vital abutment/s/ with metal cast post 94.3% (95% CI [89.3– 99.3], $P = 0.1971$). The difference was not statistically significant. The results are limited by few numbers of studies and presence of uncontrolled cofounding clinical variables.

Conclusions: Tooth vitality is suggested to contribute positively to the survival of SCs.

KEYWORDS: tooth-supported prosthesis; tooth vitality; post and core; survival and failure rates; single crown and fixed dental prosthesis; systematic review.

INTRODUCTION

The Incidence and prevalence of teeth loss have been reduced in the last years[1] due to better dental health care including regular follow-up prophylaxis visits.[2] Nevertheless, tooth damage and loss due to caries, trauma and periodontal disease still occurs and that may affect masticatory function, person´s appearance, and impaired quality of life.[3] When that happens, tooth-supported fixed prosthetic restoration, with either fixed dental prosthesis (FDP) or single crown (SC), is a reliable treatment option which has been used for decades to restore oral function and esthetics.[4, 5] Complications do however occur.[6, 7] To improve the predictability of treatment, the factors that may influence the long-term survival of tooth-supported fixed prosthetic restorations should be investigated. One such major factor is tooth vitality.[8] Using non-vital teeth as retainers for fixed prosthetic restorations is challenging.[9, 10] A tooth may need both endodontic and restorative treatments after losing the vitality due to caries or trauma, which could result in a significant loss of tooth structure and may subsequently increase the vulnerability of catastrophic tooth fracture.[11, 12]

The clinical performance of endodontically treated teeth might also be influenced by the presence of post and core.[13] Some older literature recommended providing all non-vital teeth with post and core as an essential procedure before prosthetic treatment.[14] However, more recent research suggests that a post-and-core should be used for retentive purposes only.[15, 16] Post and core should be avoided if sufficient retention can be achieved from existing tooth substance, as its presence

has been associated with increased risk of root fracture due to increased stress in the root surface.[15, 17]

The type of prosthetic restoration could also affect the prognosis of endodontically treated teeth.[18] Extraction of endodontically treated teeth has been suggested to occur more often in FDP abutments than in SC abutments.[19] This finding is in agreement with a previous study where the survival rates of

post and core abutments of posterior FDPs were lower than posterior SC abutments with post and core due to the larger loading force on FDPs abutments, which could negatively affect the survival.[20]

The longevity of fixed prosthetic restorations might also be influenced by the framework material.[7, 21] Complications have occurred in prosthetic restorations (FDPs, SCs) made of metal-ceramic as well as all-ceramic materials, but porcelain chipping and loss of retention have been found to be more prevalent in veneered all-ceramic FDPs and SCs.[6, 7] Moreover, the risk of catastrophic failure such as complete framework fracture has been reported only for all-ceramic FDPs and SCs.[7, 22.]

The clinical performance of non-vital teeth as retainers for fixed prosthetic restorations is debated and the number of high-quality studies reporting on this aspect is limited. Predictions about clinical outcomes of non-vital abutments should be based on best available evidence such as systematic reviews.[4] The present systematic review aimed to evaluate and compare the survival and failure rates of full coverage fixed prosthetic restorations (FDPs, SCs) on tooth abutments with different vitality conditions, taking into consideration the potential influence of three main factors: tooth-vitality, presence and type of post, and type of prosthetic restoration material. The null hypothesis for the present systematic review was that there would be no difference in survival and failure rates of fixed prosthetic restorations (FDPs, SCs) retained by vital and non-vital abutments irrespective of the presence and type of post and type of prosthetic restoration material.

MATERIALS AND METHODS:

This systematic review followed the PRISMA statement guidelines[23] and was registered at the International Prospective Register of Systematic Reviews (PROSPERO).[24]

The focused questions were:

Is there a difference regarding survival of fixed prosthetic restorations (FDPs, SCs) on vital and non-vital abutments?

Does the presence of post have any influence on the survival of fixed prosthetic restorations (FDPs, SCs) on non-vital abutments?

Does the type of post have any influence on the survival of fixed prosthetic restorations (FDPs, SCs) on non-vital abutments?

Does the type of restoration material have any influence on the survival of fixed prosthetic restorations (FDPs, SCs) on vital and non-vital abutments?

The P.I.C.O.S Model format was used to frame the focused question of the present systematic review.[25]

1. Participants

Patients who received full coverage fixed prosthetic restorations (FDPs, SCs) retained by vital, non-vital, non-vital with post and core as well as combinations of these three types of abutments.

2. Interventions

Prosthetic rehabilitation with full-coverage tooth-supported fixed restorations (FDPs, SCs) with different abutment vitality condition (vital. non-vital), with/or without post and core, different types of post (cast metal post, prefabricated fiber post), and different types of prosthetic material (metal–ceramic, all-ceramic) with a minimum observational period of 24 months.

3. Comparison

Studies comparing survival rate of FDPs and/or SCs on vital, non-vital, non-vital abutments with post and core, or a combination of these three, different types of post (cast metal post, prefabricated fiber post), and type of prosthetic material (metal-ceramic or all-ceramic).

4. Outcomes

Success or survival and/or failure/complications of the abutment and/or prosthetic restorations (FDPs, SCs).

5. Study design

Clinical human studies, either randomized or not, such as randomized controlled clinical trials (RCT), controlled clinical trials (CCT), prospective or retrospective cohort clinical studies, case control and case series studies of full coverage FDPs and SCs retained by vital and/or non-vital abutments and/or a combination of both.

Search strategies

Search strategies

An electronic search was undertaken in September 2020 in PubMed, Web of Science, and ScienceDirect databases. The following terms were used in the search strategy.

Subject: (prosthesis)

AND

Adjective: ("endodontically treated teeth" OR "vital teeth")

Two authors (MH, BC) independently conducted the search in each database. Publications were selected based on the inclusion and exclusion criteria, first by reading the titles and abstracts. The full publications were obtained for the potentially relevant studies appearing to fulfil the inclusion criteria. Full-text literatures were screened, and requiring data were extracted and added in a table for more detailed evaluation and analysis. Reasons of exclusion were also recorded in the table. “Snowballing” was performed for all references listed in the included studies in search for additional eligible studies. Discussion between the two authors was undertaken to resolve any disagreement regarding inclusion or exclusion of studies.

Definitions

Survival was defined as the prosthesis remaining in situ and in function, even though complications might have occurred. A prosthesis that had been removed or replaced was considered a failed prosthesis.

Inclusion criteria

Eligibility criteria included clinical human studies such as RCTs, CCTs, prospective or retrospective cohort clinical studies, case control and case series studies of full coverage FDPs and SCs retained by vital and/or non-vital abutments and/or a combination of both, with a minimum observation period of 24 months. The included studies should report the success or survival rate and/or failure/complications of the abutment and/or fixed prosthetic restorations (FDPs, SCs), abutment vitality condition, presence of post, type of post (cast, prefabricated fiber), and type of prosthesis material (metal-ceramic, all-ceramic), and clinical examination should be provided for all included patients.

Exclusion criteria

Non-clinical, case report, pilot, animal, in vitro, and clinical studies not clearly reporting success or survival and/or failure/complications of the abutment and/or prosthetic restorations, abutment vitality condition, presence and type of post and prosthesis material were excluded.

Quality Assessment

For cohort and case-control studies, the Newcastle-Ottawa Scale was used (Figure 1 and 2).[26, 27] The NOS risk assessment tool calculates the risk of bias on the basis of three domains: selection of study groups, comparability of groups, and determination of outcomes.[28] A maximum of nine stars/points can be given to the highest quality studies; four stars for selection, two points for comparability as maximum, and three points for outcomes.[28] Studies scored with six points or more were considered high-quality.

Data extraction

The following data were extracted: year of publication, study design, number of patients, gender, age, follow-up, type of fixed prosthetic restoration (FDP, SC), vitality condition of the abutments (vital/non-vital, and non-vital with post and core), type of post, type of prosthetic material, and success/survival and failure of the abutment and/or fixed prosthetic restoration.

Statistical analysis

Prosthesis survival and failure were the dichotomous outcomes measures evaluated. The statistical units for the outcomes were FDPs and SCs. Non clearly stated outcomes were not used for analysis.

For each study, event rates for the prostheses were calculated by dividing the total number of events by the total SC exposure time in years. The five-year survival proportions were calculated via the relationship between event rate and survival function S, S(T) = exp (−T*event rate), by assuming constant event rates. The 95% confidence intervals for the survival proportions were calculated using the 95% confidence limits of the event rates. A meta-analysis for each group was conducted using proportions with inverse-variance weights. The value of 0.5 are added to zero frequencies. Groups were then compared using a z-test. Data were statistically analyzed using the SPSS software version 28 (IBM, Chicago, IL, USA). The degree of statistical significance was considered $p < 0.05$.

RESULTS

Literature Search

The process of selection is summarized in Figure 3. The electronic search strategy in the databases resulted in 2,052 studies (1,003 in PubMed, 500 in Web of Science, 549 in ScienceDirect). Manual hand-searching identified 61 studies. After discarding duplicates, screening on title and abstract level, and assessing the eligibility of full-text studies, 40 potentially relevant studies qualified for full-text analysis. In the last step, 23 articles were excluded (Table S1) resulting in 17 articles finally included in the review.

Description of the studies

Out of the 17 included studies, 4 were RCTs,[29, 30, 31, 32] 1 CCT,[33] 4 prospective,[34, 35, 36, 37] and 8 retrospective studies.[8, 10, 38, 39, 40, 41, 42, 43] The number of included SCs and FDPs was 3,945 and 1,333, respectively, retained by vital and/or non-vital abutments and/or a combination of both. Sixteen studies included full coverage SCs with a total of 1,600 vital and 2,345 non-vital teeth (800 with fiber post, 1,254 with cast metal post, and 291 non-vital teeth without post).[8, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43]

Data of SCs and FDPs from one study were excluded[10] due to overlap with another study[10, 43] and using prefabricated metal post and amalgam core for FDPs. Four studies included both SCs and FDPs.[8, 10, 35, 37] Altogether, there were 946 FDPs retained by vital abutments[8, 10, 37] and 387 FDPs retained by non-vital abutments,[8, 10, 35] with at least one non-vital abutment for each FDP, 25 FDPs retained by non-vital abutment with fiber post[35] (each prosthesis has only one fiber post), 354 FDPs with cast metal post,[8, 10] and 8 FDPs without post.[10]

Sixteen studies included a total of 2,465 patients. One study did not report the number of included patients.[8] The majority of the publications (n = 16) included metal-ceramic SCs[8, 29, 30, 31, 32, 33, 35, 36, 37, 38, 39, 40, 41, 42, 43] and/or FDPs.[8, 10, 35, 37] Four of them also evaluated all-ceramic SCs[29, 32, 38, 39] and one study only included all-ceramic SCs.[34]

The clinical outcomes of posts on root canal treated teeth restored with SCs were evaluated in 10 studies[8, 30, 32, 33, 35, 36, 38, 39, 40, 41] and in two studies that investigated FDPs.[8, 35] Eight studies assessed the longevity and clinical performance of SCs[29, 31, 32, 34, 37, 42, 43] and/or FDPs[10, 37] retained by vital and/or non-vital abutments, or combination of both. Two studies used the United States Public Dental Health criteria[34] and a modified version (USPHS)[29] to evaluate the clinical performance of SCs. Another study evaluated SCs using FDI World Dental Federation criteria involving esthetic, functional and biological properties.[31]

Quality assessment

According to the NOS assessment tool, all included studies scored six points or more, being considered of high-quality (Table 1).

Estimated survival rates of SCs

Studies were classified according to type of fixed prosthetic restoration (SC, FDP), type of prosthesis material (metal-ceramic, all-ceramic), abutment vitality condition (vital, non-vital) and presence and type of post (no-post, fiber, metal cast post) (Tables 2, 3, 4, ,5 and 6). Comparisons of the 5-year survival estimates between groups of SCs are shown in Table 7. Cases restored with prefabricated metal post and composite or amalgam core were excluded due to different properties and behavior such as e.g., stress distribution, which could affect the clinical outcome compared to cast metal or fiber posts.[44, 45]

The highest estimated 5-year survival rate was observed for metal-ceramic and all-ceramic SCs on vital teeth 97.8% (95% CI [97.1– 98.5]) and all ceramic SCs on non-vital teeth with fiber post 99.1% (95% CI [97.7– 100.4]). A statistically significant higher estimated 5-year survival rate was observed for metal-ceramic SCs on vital teeth 97.5% (95% CI [96.8– 98.3%]) compared to metal-ceramic SCs retained by cast metal 94.5% (95% CI [93.3– 95.8%], $P < 0.001$) and fiber posts 95.1% (95% CI [93.4– 96.6%], $P < 0.007$), respectively. All-ceramic SCs with fiber post had a statistically significant higher estimated 5-year survival rate 99.1% (95% CI [97.7– 100.4%]) compared to metal-ceramic SCs of the same group 95.1% (95% CI 93.4– 96.6%], $P < 0.001$) and metal-ceramic SCs on non-vital teeth without post 95.7% (95% CI [93.7– 97.7%], $P < 0.006$), respectively. SCs (including all-ceramic and metal-ceramic) with fiber post 97.5% (95% CI [96.4– 98.5%]) had a statistically significantly higher estimated 5-year survival rate than metal-ceramic SCs retained by cast metal post 94.5% (95% CI [93.3– 95.8%], $P < 0.001$).

Estimated failure rates of SCs

The highest estimated annual failure rates (per 100 SC years) were 2.80 (95% CI [1.96– 3.64]) and 1.95 (95% CI [1.09– 2.80]) for SCs retained by non-vital teeth without post and on cast metal post, respectively. Lower estimated annual failure rates were observed in metal-ceramic and all-ceramic SCs on vital teeth with 0.56 (95% CI [0.24– 0.88]), followed by all-ceramic SCs with fiber post with 0.76 (95% CI [0.14– 0.33]).

Estimated survival and failure rates of FDPs

One study for each group of metal-ceramic FDPs supported by non-vital abutment/s with fiber and without post was included in the present review. Therefore, sub-group survival and failure analyses was only performed for FDPs supported by vital abutments and non-vital abutment/s with cast metal post. The estimated 5-year survival rate was higher for metal-ceramic FDPs supported by vital abutments (96.9%; 95% CI [95.5–98.4]) compared to FDPs on non-vital abutment/s with metal cast post (94.3%; 95% CI [89.3–99.3], $P = 0.1971$), but the difference was not statistically significant. A higher estimated annual failure rate was reported for FDPs supported by non-vital abutment/s with cast metal post 1.15 (95% CI [0.14, 2.16]) compared to vital group 0.83 (95% CI [0.39, 1.28]).

DISCUSSION

Based on the results of the present systematic review, the null hypothesis was partly rejected. It is suggested that the survival rate of full-coverage SCs is influenced by tooth vitality.

The survival analysis showed a higher estimated survival rate of metal-ceramic SCs on vital teeth compared to metal-ceramic SCs on non-vital teeth with post. These findings are in agreement with previous studies, in which a higher survival rate of metal-ceramic SCs on vital teeth compared to metal-ceramic SCs on non-vital teeth with/without post was observed.[42, 46] Loss of tooth structure by chemical and mechanical debridement of the root canal system combined with restorative procedures may reduce the biomechanical properties and fracture resistance and increase the susceptibility of tooth fracture.[11, 12, 47] Additionally, interdental receptors which protect the tooth from overloading force[48] are lost in non-vital teeth which tends to increase the threshold for the maximum biting force[48, 49] and thereby contribute to increased risk of tooth damage and fracture.[48] Similar findings were noted for FDPs, where the survival rate of metal-ceramic FDPs on vital abutments was higher compared to metal-ceramic FDPs supported by non-vital abutment/s with cast metal post, although the difference was not significant. The absence of significant differences could relate to the low number of included studies in both FDP groups.

The highest failure rate was observed in SCs on non-vital teeth with post compared to SCs on vital and non-vital teeth without post.[42] Presence of a post could increase the stress on the root surface and subsequently increase the susceptibility to fracture.[15, 17, 50] In an in vitro study, fractography analysis of fractured non-vital teeth was performed to evaluate the fracture pattern of the dentin.[50] High tensile unfavorable stress distribution was observed on the root

surface of non-vital tooth with parallel smooth sided stainless steel post, as a result of high stiffness of the metallic post which lead to root fracture.[50] Predominant microcracks started at the inner surface of the remaining dentine wall adjacent to the endodontic post, which progressed toward the outer surface of the root and lead to fracture.[50, 51, 52] The same pattern of fracture was observed with cast metal post and core.[52] Preserving dentine structure during post preparation is a key factor for retaining the tooth toughness and fracture resistance.[50, 51] Moreover, presence of ferrule in the non-vital teeth with post showed a significant improvement of load resistance.[53, 54, 55]

On the other hand, the presence of post has shown a significant positive effect on the failure rate of SCs in extensively destructed teeth.[56] In previous RCTs, the failure rates of SCs supported by non-vital teeth with minor coronal tooth substance have been reduced when using a fiber post compared to teeth with no interradicular retention post.[30, 32] The same was observed in the present review, where SCs with fiber post showed a significantly higher estimated 5-year survival compared to no-post group irrespective of the type of SC material. Loss of SC retention of the non-vital teeth without post and with minimal remaining tooth structure has been reported as one of the most common failures.[30] The amount of remaining coronal tooth structure is a crucial factor for the survival of SCs on non-vital teeth with/without post.[30, 36] When a non-vital tooth exhibited a minor coronal substance loss, the positive influence of endodontic post on the survival of SC was not observed.[32, 56] However, a post should only be used for retentive purposes if the retention from preserving coronal tooth structure is not possible to achieve.[15]

In the present study, SCs with fiber post showed significantly higher estimated 5-year survival compared to SCs with cast metal post. The same finding was observed in a previous retrospective study.[40] Metal-ceramic SCs with fiber post showed a significantly better performance than metal-ceramic SCs with cast metal post.[40] The modulus of elasticity of fiber posts are close to that of root dentine, which reduces the stress on the root surface and therefore decreases the susceptibility of root fracture.[40] Furthermore, using resin cement with fiber post has an ability to provide bonding and minimize the leakage between fiber post and root canal dentin, which subsequently increases the post retention.[40] The influence of the presence and type of post could be attributed to the amount of preserved coronal tooth structure. This factor seems to be a major factor for the survival of SC on non-vital teeth with or without post.[30, 36] However, the amount of remaining tooth structure for the included cases could not be evaluated.

Prefabricated metal post and direct composite or amalgam core were excluded from the present review due to the fact that during loading, the unfavorable stress distribution[44, 45, 57] could increase the susceptibility of non-vital tooth fracture

when passive prefabricated metal post is used as a core retainer for SC.[44, 57] During vertical and oblique loading, the high stress was unevenly concentrated at apical[57] and coronal regions of the root, respectively.[45] Further, premature failure of the passive prefabricated metal post was observed as a result of high stress that occurred at one portion of the post compared to other portions.[57]

In the present review, significant influence of the type of crown material was observed in the estimated survival rates of non-vital teeth with fiber post. All-ceramic SCs with fiber post showed significantly higher 5-year survival estimate than metal-ceramic SCs with fiber post. This is in contrast to previous studies where all-ceramic and metal-ceramic SCs with fiber post were reported to present similar survival rate after 5 and 8 years of functions.[29, 39] In those studies, both crown materials were evaluated in the same studies and under equal circumstances.[29, 39] In the present systematic review, the difference of the estimated survival between metal-ceramic and all-ceramic SCs with fiber post could be related to the heterogenicity of the clinical variables among included studies. The amount of the remaining tooth structure, presence and amount of ferrule, status of the dentation, opposing arch, treatment provider, setting and type of cement were not standardized and matched among patients in both groups.[29, 30, 31, 32, 33, 35, 38, 39, 40, 41, 43] Moreover, the low number of all-ceramic SCs compared to metal-ceramic group could have had an influence on the results. Due to the small sample size in each group of SCs, other influential clinical variables such as amount of the remining tooth structure, presence, and amount of ferrule could not be properly analyzed. Separating the material into subgroups would make the sample size in each group even smaller. No analysis estimate was performed for the group of all-ceramic SCs on non-vital teeth without post as there were not enough studies with a considerable sample size included.[32] Therefore, no strong conclusion can be drawn for this particular group.

The majority of data of the present systematic review was based on non-randomized studies such as retrospective and prospective studies. Further well-designed RCTs should be done to improve the validity of the outcomes. The lack of controlled clinical variables, the small samples size for each group, the presence of non-RCTs, and the differences of clinical evaluation parameters are limitations of the present systematic review. Research outcomes should preferably be extracted from solid evidence such as meta-analysis.[4] Meta-analysis can assess the presence of publication bias and analyze the inconsistency in results of included studies.[58, 59] The number of studies making comparisons of different groups was very low, therefore pairwise meta-analyses were not recommended.

Different types of study design fulfilled the inclusion criteria and were included in the present systematic review, resulting in a high level of heterogenicity.

Almost half of the included studies were retrospective cohort studies, which have a high risk of bias and low level of evidence compared to well-designed RCTs and PS.[60, 61] The varying degree of clinical experience including specialists or general practitioners and dental students differed among included studies. All included studies however, scored six or more points on NOS risk assessment tool. The NOS risk assessment tool is recommended to use when nonrandomized studies such as cohort and case-control were included in the systematic review and its use could have improved the validity of the outcomes.[28]

CONCLUSIONS

Within the limitations of the present review, preserved tooth vitality is suggested to contribute positively to SC survival, although it was not possible to analyze the possible influence of remaining coronal tooth structure on the results. The present results should be interpreted with caution as presence of uncontrolled confounding variables among included studies could increase the risk of bias.

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TABLES

Table 1. Quality assessment of the studies by the Newcastle-Ottawa scale.

Study	Published	Selection				Comparability		Outcome			Total (9/9)
		Representati-veness of the exposed cohort	Selection of external control	Ascertai-nment of exposure	Outcome of interest not present at start	Comparability of cohorts		Assessm-ent of outcome	Follow-up long enough	Adequa-cy of follow-up	
						Main factor	Additio-nal factor				
Amaral	2015	★	★	★	0	★	★	★	★	★	8/9
Bitter	2009	★	★	★	0	★	★	★	★	★	8/9
Creugers	2005	★	★	★	0	★	0	★	★	0	6/9
De Backer	2007	★	★	★	0	★	0	★	★	★	7/9
Ferrari	2012	★	★	★	★	★	★	★	★	★	9/9
Ferrari	2000	★	★	★	0	★	0	★	★	★	7/9
Glazer	2000	★	★	★	★	★	★	★	★	★	9/9
Guldener	2017	★	★	★	★	★	★	★	★	★	9/9
Mannocci	2002	★	★	★	0	★	0	★	★	★	7/9
Monaco	2017	★	★	★	★	★	★	★	★	★	9/9
Piovesan	2007	★	★	★	0	★	0	★	★	★	7/9
Reitemeier	2013	★	★	★	0	★	★	★	★	★	8/9
Schmidlin	2010	★	★	★	0	★	0	★	★	★	7/9
Skupien	2016	★	★	★	0	★	0	★	★	★	7/9
Toksavul	2007	★	★	★	0	★	0	★	★	★	7/9
Walton	2013	★	★	★	★	★	0	★	★	★	8/9
Walton	2009	★	★	★	0	★	0	★	★	★	7/9

Table 2. All-ceramic and Metal-ceramic SCs, vital teeth.

Study	Published	Study design	Patients (n)	Follow-up (range)	Failure/total	Total exposure time (years)	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
All-ceramic crowns								
Toksavul 34	2007	PS	21	Mean 58 mo (12-60)	0/77	371.9	0	100
Metal-ceramic crowns								
Backer 8	2007	RS	NM	Mean 11.4 y	18/87	991.8	1.81	91.0
Reitemeier 37	2013	PS	81	Maximum 12.1 y	9/190	2090	0.43	97.9
Schmidlin 42	2010	RS	64	Mean11.8 y (0.8–26.4)	1/56	660.8	0.15	99.3
Walton 43	2013	RS	670	up to 25 y	59/1190	10948	0.54	97.3
Sub-group summary estimate (95% CI)							0.72 (0.24, 1.19) SE 0.24	97.5 (96.8, 98.3) SE 0.40
Global summary estimate (95% CI)							0.56 (0.24, 0.88) SE 0.16	97.8 (97.1, 98.5) SE 0.36

SCs – Single crowns; NM – not mentioned; RS – retrospective study; PS – prospective study.
mo – months;
y – years

Table 3. All-ceramic and metal-ceramic SCs, non-vital teeth (no post).

Study	Published	Study design	Patients (n)	Follow-up (range)	Failure/total	Total exposure time (years)	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
All-ceramic crowns								
Bitter [32]	2009	RCT	75	32.4 mo (13.7)	0/6	16.2	0	100
Metal-ceramic crowns								
Creugers [36]	2005	PS	249	5 y	2/42	210	0.95	95.3
Bitter [32]	2009	RCT	76	Mean 32.4 mo (13.7)	6/35	94.5	6.35	68.3
Ferrari [30]	2012	RCT	304	6 y	62/107	642	9.65	51.8
Guldener [41]	2017	RS	85	8.8 y (5.1–15.3)	1/5	44	2.27	88.7
Schmidlin [42]	2010	RS	64	Mean11.8 y (0.8–26.4)	3/34	401.2	0.74	96.3
Walton [43]	2013	RS	670	Up to 25 y	1/62	570.4	0.18	99.1
Summary estimate (95% CI)							2.80 (1.96, 3.64) SE 0.43	95.7 (93.7, 97.7) SE 1.02

NM – not mentioned; RS – retrospective study; PS – prospective study;
mo – months;
y – years

Table 4. All-ceramic and metal-ceramic SCs, non-vital teeth (fiber post).

Study	published	Study design	Patients (n)	Follow-up (range)	Failure/ total	Total exposure time (years)	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
All-ceramic crowns								
Amaral [38]	2015	RS	75	3 y (36-41 mo)	0/96	288	0	100
Bitter [32]	2009	RCT	76	32.4 mo (13.7)	1/8	21.6	4.63	76.9
Monaco [29]	2017	RCT	72	6-mo,1-,2-,3-,5-y	1/45	225	0.44	97.8
Piovesan [39]	2007	RS	60	97 mo	3/39	292.5	1.03	94.9
Toksavul [34]	2007	PS	21	Mean 58 mo (12-60)	0/1	4.83	0	100
Sub-group summary estimate (95% CI)							0.76 (0.59, 0.93) SE 0.09	99.1 (97.7, 100.4) SE 0.68
Metal-ceramic crowns								
Amaral [38]	2015	RS	75	3 y (36-41 mo)	0/43	129	0	100
Bitter [32]	2009	RCT	76	32.4 mo (13.7)	2/40	108	1.85	90.8
Ferrari [40]	2000	RS	195	1-,2-,4-y	2/97	388	0.52	97.4
Ferrari [30]	2012	RCT	304	6 y	66/209	1254	5.50	72.5
Glazer [35]	2000	PS	42	6.7- 45.4 mo	3/27	62.1	4.83	75.9
Guldener [41]	2017	RS	85	8.8 y (5.1–15.3)	2/41	360.8	0.55	97.3
Mannocci [33]	2002	CCT	117	1-,2-,3- y	3/57	171	1.75	91.3
Monaco [29]	2017	RCT	72	6-mo,1-,2-,3-,5-y	1/40	200	0.50	97.5
Piovesan [39]	2007	RS	60	97 mo	2/29	217.5	0.92	95.4
Skupien [31]	2016	RCT	47	Mean 2.5 y (13–59 mo)	1/27	67.5	1.48	92.6
Walton [43]	2013	RS	670	Up to 25 y	0/1	9.2	0	100
Sub-group summary estimate (95% CI)							1.36 (1.18, 1.55) SE 0.09	95.01 (93.4, 96.6) SE 0.84
Global summary estimate (95% CI)							1.08 (0.97, 1.19) SE 0.06	97.5 (96.4, 98.5) SE 0.53

SC – single-crown | SE – standard error | RS – retrospective study; PS – prospective study; CCT – controlled clinical trial; RCT – randomized clinical trial; G1.mo – months; | y – years

Table 5. Metal-ceramic SCs, non-vital teeth (cast metal post).

Study	Published	Study design	Patients (n)	Follow-up (range)	Failure/total	Total exposure time (years)	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
Backer [8]	2007	RS	NM	Mean 11.4 y	71/699	7968.6	0.89	95.6
Creugers [36]	2005	PS	249	5 y	7/127	635	1.10	94.5
Ferrari [40]	2000	RS	195	1-,2-,4-y	14/98	392	3.57	82.2
Schmidlin [42]	2010	RS	64	Mean11.8 y (0.8–26.4)	13/39	460.2	2.82	85.9
Walton [43]	2013	RS	670	Up to 25 y	38/291	2677.2	1.42	92.9
Summary estimate (95% CI)							1.95 (1.09, 2.80) SE 0.44	94.5 (93.3, 95.8) SE 0.64

SCs – Single crowns; RS – retrospective study; PS – prospective study; RCT – randomized clinical trial; G1.
mo – months;
y – years

Table 6. Metal-ceramic FDPs, non-vital teeth (fiber post, no-post, cast metal post).

Study	Published	Study design	Patients (n)	Follow-up (range)	Failure/total [a]	Total exposure time (years)	Estimated annual failure rate (per 100 SC years)	Estimated survival after 5 years (in %)
Metal-ceramic FDPs, vital								
Walton [10]	2009	RS	225	10 y	13/461	3088.7	0.42	97.9
Backer [8]	2007	RS	NM	Mean 11.4 y	23/209	2382.6	0.97	95.2
Reitemeier [37]	2013	PS	110	Maximum 11.1 y	14/276	3036	0.46	97.7
Sub-group summary estimate (95% CI)							0.61 (0.31, 0.90) SE 0.15	96.9 (95.5, 98.4) SE 0.74
Metal-ceramic FDPs, non-vital (no-post)								
Walton [10]	2009	RS	225	10 y	0/8	53.6	0	100
Metal-ceramic FDPs, non-vital teeth (fiber post)								
Glazer [35]	2000	PS	42	6.7-45.4 mo	1/25	57.5	1.74	91.3
Metal-ceramic FDPs, non-vital teeth (cast metal post)								
Walton [10]	2009	RS	225	10 y	12/107	716.9	1.67	91.7
Backer [8]	2007	RS	NM	Mean 11.4 y	18/247	2815.8	0.64	96.8
Sub-group summary estimate (95% CI)							1.15 (0.14, 2.16) SE 0.51	94.3 (89.3, 99.3) SE 2.55
Global summary estimate (95% CI)							0.83 (0.39, 1.28) SE 0.23	95.8 (93.6, 98.0) SE 1.14

FDPs – Fixed dental prostheses; NM – not mentioned; PS – prospective study; RS – retrospective study
$p = 0.1971$ (between non-vital cast metal post and vital
a Number of FDPs abutments
mo – months;
y – years

Table 7. Comparison of the 5-year survival estimates between two groups of SCs (group 1 has higher survival rate than group 2).

Group 1	Group 2	p value
Vital metal-ceramic	Non-vital fiber post metal-ceramic	0.007
Vital metal-ceramic	Non-vital cast metal post metal-ceramic (all)	< 0.001
Non-vital fiber post (all)	Non-vital cast metal post metal-ceramic (all)	< 0.001
Non-vital fiber post all-ceramic	Non-vital fiber post metal-ceramic	< 0.001
Non-vital fiber post all-ceramic	Non-vital cast metal post metal-ceramic (all)	< 0.001
Non-vital fiber post all-ceramic	Non-vital no post metal-ceramic	0.006
Vital (all)	Non-vital fiber post (all)	0.568
Vital metal-ceramic	Non-vital no post metal-ceramic	0.094
Vital metal-ceramic	Non-vital no post metal-ceramic	0.102
Non-vital no post (all)	Non-vital fiber post metal-ceramic	0.599
Non-vital no post metal-ceramic	Non-vital cast metal post metal-ceramic (all)	0.328
Non-vital fiber post (all)	Non-vital no post metal-ceramic	0.127
Non-vital fiber post all-ceramic	Non-vital no post metal-ceramic	0.006
Non-vital fiber post all-ceramic	Vital metal-ceramic	0.051

SCs – Single crowns

NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE
COHORT STUDIES

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability

Selection

1) Representativeness of the exposed cohort
   a) truly representative of the average _____ (describe) in the community ✸
   b) somewhat representative of the average _____ in the community ✸
   c) selected group of users eg nurses, volunteers
   d) no description of the derivation of the cohort

2) Selection of the non exposed cohort
   a) drawn from the same community as the exposed cohort ✸
   b) drawn from a different source
   c) no description of the derivation of the non exposed cohort

3) Ascertainment of exposure
   a) secure record (eg surgical records) ✸
   b) structured interview ✸
   c) written self report
   d) no description

4) Demonstration that outcome of interest was not present at start of study
   a) yes ✸
   b) no

Comparability

1) Comparability of cohorts on the basis of the design or analysis
   a) study controls for _____ (select the most important factor) ✸
   b) study controls for any additional factor ✸ (This criteria could be modified to indicate specific control for a second important factor.)

Outcome

1) Assessment of outcome
   a) independent blind assessment ✸
   b) record linkage ✸
   c) self report
   d) no description

2) Was follow-up long enough for outcomes to occur
   a) yes (select an adequate follow up period for outcome of interest) ✸
   b) no

3) Adequacy of follow up of cohorts
   a) complete follow up - all subjects accounted for ✸
   b) subjects lost to follow up unlikely to introduce bias - small number lost - > ____ % (select an adequate %) follow up, or description provided of those lost) ✸
   c) follow up rate < ____% (select an adequate %) and no description of those lost
   d) no statement

Fig.1 Risk of bias assessment tool (cohort studies).

NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE
CASE CONTROL STUDIES

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Exposure categories. A maximum of two stars can be given for Comparability.

Selection

1) Is the case definition adequate?
   a) yes, with independent validation ✸
   b) yes, eg record linkage or based on self reports
   c) no description

2) Representativeness of the cases
   a) consecutive or obviously representative series of cases ✸
   b) potential for selection biases or not stated

3) Selection of Controls
   a) community controls ✸
   b) hospital controls
   c) no description

4) Definition of Controls
   a) no history of disease (endpoint) ✸
   b) no description of source

Comparability

1) Comparability of cases and controls on the basis of the design or analysis
   a) study controls for _____ (Select the most important factor.) ✸
   b) study controls for any additional factor ✸ (This criteria could be modified to indicate specific control for a second important factor.)

Exposure

1) Ascertainment of exposure
   a) secure record (eg surgical records) ✸
   b) structured interview where blind to case/control status ✸
   c) interview not blinded to case/control status
   d) written self report or medical record only
   e) no description

2) Same method of ascertainment for cases and controls
   a) yes ✸
   b) no

3) Non-Response rate
   a) same rate for both groups ✸
   b) non respondents described
   c) rate different and no designation

Fig.2 Risk of bias assessment tool (case control studies).

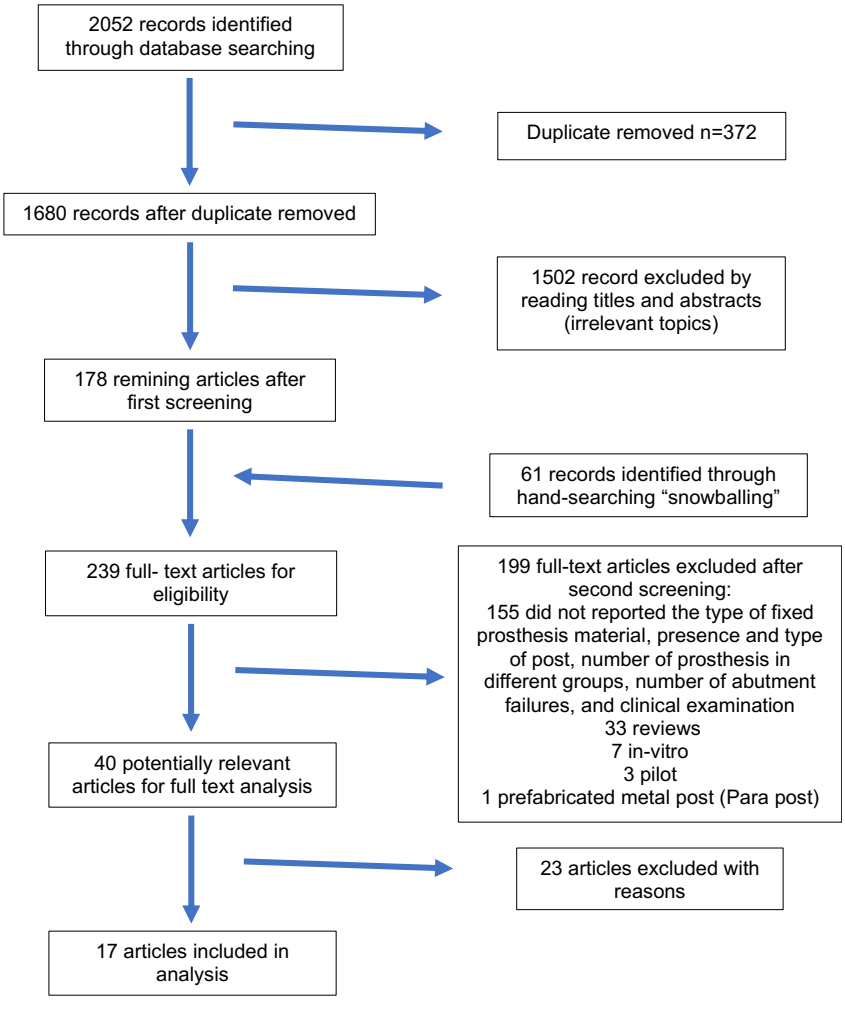

Fig.3 Study screening process.

SUPPLEMENTARY TABLE.

Table S1. Reasons of excluded studies at final screening

Authors	Published	Reasons of exclusion
Bateli	2014	Number of different types of prostheses (FDPs fixed dental prosthesis, CC ceramic crown, MCC metal-ceramic crown, CMC casted metal crown) were not reported.
Cagidiaco	2008	Shorter follow-up of included study (Ferrari 2012).
Cantner	2019	Number of fiber glass posts for non-vital teeth was not reported.
De Backer	2008	Overlapping with the patients reported in Backer 2007. This publication is from one year later, but it has far less patients/prostheses than De Backer 2007. Yet, the follow-up of both is the same.
De Backer-1	2006	(FDPs) Overlapping with the patients reported in De Backer 2007.
De Backer-2	2006	(SCs) Overlapping with the patients reported in De Backer 2007.
Ferrari	2007	Possible overlapping with patients reported in Cagidiaco 2008.
Fokkinga	2007	Number of failures for different types of posts of non-vital teeth was not reported Number and types of construction materials of SCs were not reported.
Mancebo	2010	Number of metal-ceramic and all ceramic SCs with respect to the presence and absence of ferrule was not reported. Number of failures for each group was not reported.
Mehta	2008	Number of crowns fabricated with different materials was not reported.
Olley	2018	The survival and success crowns were not identified in the result.
Örtorp	2009	Number of failures of SCs with different vitality conditions was not reported.
Palmqvisl	1993	Presence and type of post of non-vital teeth were not reported. Presence of post in different fixed prostheses (FDPs and SCs) was not reported. Number of failures for each group was not reported.
Parisi	2015	Types of construction materials for SCs and FDPs weren't reported.
Phang	2020	Number of failures for each group of FDPs was not reported.
Reitemeier	2006	No adequate information and low-quality assessment.
Salvi	2007	Types and number of posts for different fixed prostheses (FDPs, and SCs) were not reported. Number of failures for each group was not reported.

Taskonak	2006	Number of failures for SCs and FDPs with different vitality conditions was not reported.
Toman	2015	Number of failures for non-vital teeth was not reported.
Valea	2017	Prefabricated metal (Para) post.
Walton	1999	Shorter follow-up of Walton 2013.
Walton	1997	Overlapping of SCs with Walton 2009 and Walton 2013.
Zicari	2011	The definition of survival is differed than our systematic review (crown or post could change and consider a survival crown because the tooth is not extracted).

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Original article

Long-term retrospective clinical study of tooth-supported fixed partial dentures: A multifactorial analysis

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Abstract

Purpose: To assess the influence of several factors on the survival of tooth-supported fixed partial dentures (FPDs) with vital and non-vital abutments.

Materials and methods: The present retrospective cohort study was based on the records of patients treated with 3-to-7-unit tooth-supported FPDs with a minimum follow-up time of 6 months after prosthesis delivery. Cumulative survival rate (CSR) was calculated over the maximum follow-up period. Cox regression models were used to evaluate the association between the clinical covariates and prosthesis failure.

Results: A total of 331 FPDs in 229 patients were included. The CSRs were 90.1% and 77.6% after 5 and 10 years and 67.9% and 52.1% after 15 and 20 years, respectively. Tooth-supported FPD failure was more prevalent within the first years of prosthesis delivery. Loss of one or more abutment teeth and loss of prosthesis retention were the main reasons for failure. Smoking and type of prosthesis material significantly influenced the survival of FPDs. Abutment vitality, position of the non-vital abutment, or prosthesis length did not show any significant influence on the occurrence of prosthesis failure.

Conclusion: Smoking and the type of prosthesis material are suggested to contribute to an increased rate of FPD failure irrespective of abutment vitality.

Keywords: Survival rate, Prosthesis failure, Smoking, Post and Core, Prosthesis material

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1. Introduction

Tooth loss may occur because of caries, periodontal disease, or trauma. Missing teeth can be replaced with different treatment options, fixed or removable, to restore oral function and aesthetics. Tooth-supported fixed partial dentures (FPDs) are among the most reliable treatment options that have been successfully used for decades[1].

Choosing a tooth as an abutment for FPD is an important decision for clinicians. Controversy exists among dentists, especially when the abutment is endodontically treated as the fracture resistance of teeth may be reduced when tooth structure is removed as a result of the endodontic treatment[2,3]. It has been suggested that the dentin of endodontically treated teeth becomes more brittle than that of vital dentin[4]. However, this hypothesis was challenged in a more recent study in which endodontically treated teeth and vital teeth of the same individuals were compared [5], and no difference in brittleness was observed[5,6]. However, mechanical receptors in the dental pulp that can participate to protect the tooth from overloading force are lost when the tooth is endodontically treated, which may contribute to increased risk of tooth damage and fracture[7,8]. Therefore, endodontic treatment may compromise the tooth as an abutment.

Both anterior and posterior teeth can be used as abutments. The magnitude of occlusal force increases from the anterior teeth toward the molars[9]. The ability of teeth to withstand occlusal force and successfully function as abutments may differ depending on the area of placement, which could influence the survival of FPDs.

The long-term survival and success rates of metal-ceramic FPDs have been reported to be 78% and 71%, respectively, after an 18-year period of function[10]. The survival of FPDs supported by non-vital abutments may be affected by factors such as the presence of posts and cores. De Becker et al. reported a mean survival rate of 66.2% for all FPDs after 20 years[11]. The failure rates differed significantly between vital and non-vital abutments with post and core, with significantly more failures occurring in the latter group[11]. Another factor that may influence the long-term survival of FPDs is the length of the prosthesis (number of units). Näpänkangas et al. found a significantly lower survival rate for long FPDs (5-11 units) compared to short ones (3-4 units) after a mean flow-up period of 7.5 years[12]. From a technical perspective, good marginal fit is one of the key clinical factors for the longevity of FPDs[13]. The FPD material might affect marginal fit and influence prosthesis survival in other manners[14].

Despite the presence of long-term studies on the survival of

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FPDs retained by vital and non-vital abutments, data on complications covering combined variables such as length of FPD (number of units), position of the non-vital abutment (mesial or distal), presence or absence of post and core, area of placement (anterior and posterior), type of prosthesis material, smoking, bruxism, and status of the opposing arch (natural dentition, fixed, or removable denture) are limited. Specifically, information comparing FPD survival based on the status of the abutments, namely vital, non-vital, and non-vital, with post and core, as well as combinations of these three types of abutments. Therefore, this retrospective clinical study aimed to evaluate and compare the survival rates of FPDs retained by vital and non-vital teeth, considering all the mentioned variables.

2. Materials and Methods

2.1. Study design

All patients' dental record archives and digital journals (around 4,000) at the Faculty of Odontology, Malmö University, Sweden, were reviewed by one investigator (MH) to identify patients rehabilitated with tooth-supported FPDs. The study protocol was approved by the Regional Ethical Committee of Lund, Sweden (Dnr 4,3-2018/422; Dnr 2018/856). This observational study followed the STROBE guidelines[15].

2.2. Definitions

Survival was defined as the prosthesis remaining *in situ* with the occurrence of any complications while still functioning. Prostheses removed or replaced were considered failed prostheses. Chipping was defined as the loss of veneer substance with or without metal exposure, classified as minor (managed chair-side) or major (sent to the dental lab for reparation). An abutment was considered a failure if it exhibited extensive alveolar bone loss and/or excessive tooth mobility, extensive caries, or any other complication that would make the abutment unsuitable to function as a retainer for FPD and therefore lead to abutment loss. The criteria for the diagnosis of "possible" and "probable" sleep or awake bruxism were used. A "possible" sleep or awake bruxism should be based on self-report using questionnaires and/or the anamnestic part of a clinical examination. "Probable" bruxism should be based on self-report together with clinical examination[16]. The information on the self-report and clinical examination was verified from annotations in the dental records of each eligible patient. Patients were thus classified as "probable" bruxers if such findings were identified.

2.3. Inclusion and exclusion criteria

The inclusion criteria consisted of patients treated with full-coverage tooth-supported FPDs (limited to three to seven prosthetic units) at the aforementioned faculty, who had an available dental record in the clinic's archive, a minimum follow-up time of 6 months after delivery of the prosthetic work, and attended the clinic for follow-up in the last 10 years. The exclusion criteria were FPDs smaller or larger than 3 to 7 units, resin-bonded and cantilever FPDs, single crowns, and cases with lack of information or reported unknown outcomes.

2.4. Data collection

The patients' data were collected and entered directly into a database in an SPSS file (SPSS software, version 27, SPSS Inc., Chicago, USA) by one investigator (MH). The following data were collected: patient age and sex, type of prosthesis material, number of prosthetic units, position of the non-vital abutment, situation of the opposing arch (natural dentition, fixed or removable denture), presence of post and core, type of post and core, area of placement (anterior, posterior, anterior and posterior, and cross-arch FPDs), location of the prostheses in relation to the jaws (maxilla and mandible), smoking habits, bruxism, and complication/s after delivery of the definitive prosthetic restoration, including the date of occurrence. The types of materials used in the FPDs were registered according to the dental laboratory order, and technical and biological complications were evaluated radiographically and through patient records. Biological complications included caries, loss of tooth vitality, periapical infection, mobility, and abutment loss. Technical complications included tooth fracture, loss of retention, framework fracture, and minor or major veneer chipping.

2.5. Statistical analysis

The mean, standard deviation (SD), and percentage were calculated for several variables. The interval survival rate (ISR) of the FPDs was calculated using the information on the period of failure, and the cumulative survival rate (CSR) was calculated over the maximum period of follow-up reported in a life-table survival analysis. Univariate and multivariate Cox regression analyses were used to evaluate the association between the clinical covariates and prosthesis failure. Hazard ratios (HR) and 95% confidence intervals (95% CI) were estimated using Cox proportional hazards models. To verify multicollinearity, a correlation matrix of all predictor variables with a significant odds ratio (p value cut-off point of 0.1) identified in the univariate models was scanned to determine whether there were some high correlations among the predictors. Collinearity statistics obtaining the variance inflation factor (VIF) and tolerance statistics were also performed to detect more subtle forms of multicollinearity. In the final multivariable Cox regression model, all variables that were moderately associated ($p < 0.10$) with prosthesis failure were included. For this prosthesis-level analysis, the clustering of multiple prostheses within each patient was accounted for in the Cox models using the methods outlined by Lee et al. (1992) and Lin (1994)[17,18]. Data were statistically analyzed using SPSS software. Cox models were performed using the Stata software version 15 (StataCorp LLC, College Station, TX, USA). The command *mestreg* was used for the Cox models to consider repeated events. The degree of statistical significance was set at $p < 0.05$.

3. Results

A total of 443 FPDs were executed by dental students, general practitioners, or specialists at prosthodontic and general adult dental care departments between 1981 and 2018 and had complete outcome information. The data of 112 FPDs were excluded from the analyses because they did not fulfil the inclusion criteria: 32 FPDs larger than 7 units, 11 prostheses had 2 units, 66 FPDs with cantilever, and 3 FPDs had a minimum follow-up time of less than 6 months.

A total of 331 (3–7 units) FPDs were finally included in the study, supported by 827 abutment teeth, of which 66.7% were vital and 33.3% were non-vital. These prostheses were installed in 229 patients, 96 men and 133 women, who had a mean age of 59 years (59.3 ± 12.8 SD, min-max 20.9 - 89.5) and 56 years (56.8 ± 12.9 SD min-max 29.5 - 86.1), respectively, on the day of prosthesis delivery. Most patients regularly attended follow-up during the first year, but not all

continued regular annual follow-up. The 331 FPDs were followed up for a mean of 132.1 ± 80.4 months, SD (min-max, 6.4 - 472.1).

Table 1 presents descriptive data for the FPDs included in this study. Non-vital abutments are often located at the distal extremity of FPDs. **Table 2** shows the results of the life-table analysis. The CSRs after 5 and 10 years were 90.1% and 77.6%, respectively. After 15 and 20 years of functioning, the CSR for 94 and 36 FPDs was 67.9% and 52.1%, respectively. **Table 3** shows the results of the univariate Cox proportional hazard models. The location of the FPDs in relation to the jaws, vitality of the abutments, use and location of post and core, bruxism, and smoking were moderately associated with FPD failure; only smoking remained statistically significant in the multivariate model (HR,2.309; 95% CI, 1.187, 4.493; $p = 0.014$) (**Table 4**).

Separated univariate models were used to analyze some variables, as these variables were not applied to all the cases included in the study and therefore could not be included in the omnibus broad regression model. For these separated models, FPDs with mesial and distal non-vital abutments resulted in a significantly lower HR (HR:0.348; 95% CI: 0.138, 0.878; $p = 0.025$) in relation to FPDs with mesial non-vital abutments. Cobalt-chromium-based metal-ceramic (CoCr-MC) FPDs had a significantly higher HR (HR:5.361 95% CI 2.901, 9.907; $p < 0.001$) than high-noble gold-based metal-ceramic (Au-MC) FPDs (**Table 5**).

A univariate Cox regression combining the factors bruxism and abutment vitality showed that FPDs with vital/non-vital abutments in bruxer patients had a statistically significantly higher HR than FPDs with only vital abutments delivered in non-bruxer patients (**Table 6**).

A total of 90 FPDs were considered as failures. Failure was more prevalent immediately following the first year of delivery. Abutment failure occurred in 86 out of the 827 abutments in 54 patients, after a mean follow-up of 119.5 ± 79.4 months ± SD (min-max, 6.4 - 377.0). The reasons for FPDs failure were as follows: loss of one or more abutment teeth (n = 28), loss of prosthesis retention (n = 25), abutment tooth fracture (n = 9), replacement of the old prosthesis with a new prosthesis (n = 7), loss of tooth vitality (n = 7), periapical destruction (n = 4), prosthesis framework fracture (n = 3), recurrent caries (n = 2), major chipping (n =2), esthetic dysfunction (n = 1), prosthesis mobility (n = 1), and allergy (n = 1). **Table 7** shows biological and technical complications at the abutment level.

Cross tabulations of the data concerning the vitality condition of each abutment, the position of nonvital abutment versus area of placement, type of metal framework, history of bruxism, and prosthesis failure were performed (**Tables S1, S2, and S3**).

4. Discussion

The results of the present study suggest that the survival rates of FPDs retained solely by vital and non-vital abutments or a combination of both are not influenced by factors such as abutment vitality, position of the non-vital abutment, and length of the FPD. Instead, smoking and type of prosthesis material were factors that had a significant influence on the survival of FPDs.

In this study, the CSR after 10 and 15 years was higher than that in a recent retrospective study that reported the CSR of FPDs as 70.4% and 53.4% after 10 and 15 years, respectively[19]. However, the CSR was lower than that in other retrospective studies[20,21] and reviews[1,22]. Svanborg et al. observed a 92.8% 5-year survival rate for metal-ceramic FPDs[20]. The treatment was performed by two experienced clinicians at a private clinic, which differs from the present study in which the treatment was performed by several different operators with varying experience, which could have influenced the results. Despite the limitations of a retrospective study, data representing reality preferably involve several categories of treatment providers with varying degrees of experience.

Pjetursson et al. estimated a 5-year survival rate of 93.8% for tooth-supported FPDs and 89.2% in 10 years[22]. Prospective and retrospective cohort studies included regular clinical follow-up examinations for all patients[22]. In the present study, there were limitations regarding follow-up, as few patients attended regular annual follow-ups in the first year. This could be another explanation for the lower survival rates compared to other studies, as regular follow-up is an important factor in achieving a high long-term prognosis for FPDs[23]. The longevity of tooth-supported FPDs depends on the management of risk factors such as caries and periodontitis[24]. In this study, caries was the most prevalent biological complication. If left untreated, caries may progress and lead to loss of retention or even loss of abutment, which are common reasons for failure of FPDs in the present study.

Regular recall and follow-up visits, including oral hygiene instruction and interventions, can minimize the incidence of caries and periodontal disease in FPDs abutments and surrounding structures, and improve survival[24]. A previous long-term retrospective study, which included regular maintenance follow-up visits every 6 months for all patients, reported higher long-term survival rates than those in the present study[11].

Abutment vitality had no significant influence on the survival of FPDs. This finding is in contrast to an earlier study reporting a 77.4% survival rate for all FPDs supported by vital abutments, but only 56.7% for FPDs with at least one non-vital abutment[25]. At the abutment level, the failure rate was significantly higher for non-vital abutments than for vital abutments[25]. Excessive removal of the dentin structure by mechanical and chemical debridement of the root canal system may compromise tooth structure and reduce fracture resistance[3,26]. Furthermore, the increased brittleness of the dentin structure of non-vital abutments may increase the risk of tooth fracture[4]. Possible explanations for the different results observed in the present study could be due to two factors: the area of placement and choice of material. Almost half of the FPDs with vital abutments were placed in the posterior region compared with one-third of the FPDs with non-vital abutments. Anterior teeth are subjected to lower masticatory forces than posterior teeth[9]. Thus, the anterior area of placement could reduce the risk of complications in the non-vital group in the present study, although the area of placement alone did not show any significant influence on the survival of FPDs. De Becker et al. reported similar findings, with 85% and 63.6% survival rates for anterior and posterior/overlap (canine to premolars or molars) FPDs, respectively[11].

Au-MC FPDs showed a significantly lower risk of failure than CoCr FPDs. The results may be influenced by the long-standing tradition of using high-noble gold-based alloys in Sweden and the national reimbursement system that made gold alloys affordable and the predominant material for all fixed dental restorations for decades. This is visible in the skewed distribution of materials used, where metal-ceramic FPDs were more common than all-ceramic restorations up

Table 1. Descriptive data of the FPDs included in the study, with follow-up time between the different factors. The statistical unit is the prosthesis, not the patient.

Group	Number of FPDs (%)	Number of failed FPDs (%)	Follow-up (months) Mean ± SD (min - max)
Sex			
Male	137 (41.4)	40 (29.1)	133.0 ± 79.0 (6.4 - 351.4)
Female	194 (58.6)	50 (25.7)	131.4 ± 81.6 (6.9 - 472.1)
Jaw			
Maxilla	201 (60.7)	48 (23.8)	135.2 ± 80.9 (6.4 - 472.1)
Mandible	130 (39.3)	42 (32.3)	127.3 ± 79.7 (6.9 - 323.4)
Prosthesis region			
Anterior	47 (14.2)	9 (19.1)	122.8 ± 85.7 (12.3 – 317.3)
Posterior	154 (46.5)	54 (35.0)	136.1 ± 78.4 (6.4 – 351.4)
Anterior/posterior	129 (39.0)	27 (20.9)	131.0 ± 81.3 (7.7 – 472.1)
Cross-arch	1 (0.3)	0 (0)	89.2
Prosthetic units			
3	158 (47.7)	37 (23.4)	126.4 ± 80.9 (6.4 – 351.4)
4	89 (26.9)	30 (33.7)	141.9 ± 78.1 (9.5 – 472.5)
5	46 (13.9)	15 (32.6)	129.4 ± 79.9 (12.3 – 378.1)
6	27 (8.2)	6 (22.2)	153.5 ± 92.5 (21.6 – 317.3)
7	11 (3.3)	2 (18.1)	93.4 ± 40.0 (22.2 – 157.1)
Number of abutments			
2	215 (65.0)	56 (26.0)	126.8 ± 79.3 (6.4 – 351.8)
3	84 (25.4)	28 (33.3)	149.6 ± 78.2 (14.4 – 149.6)
4	19 (5.7)	6 (31.5)	131.5 ± 99.6 (22.2 – 378.5)
5	10 (3.0)	0 (0)	110.6 ± 81.8 (23.3 – 288.3)
6	2 (0.6)	0 (0)	82.0 ± 35.1 (57.2 – 106.9)
7	1 (0.3)	0 (0)	115.8
Abutments			
All abutments vital	147 (44.4)	32 (21.7)	128.6 ± 82.7 (9.5 – 351.4)
Vital and non-vital abutments	152 (45.9)	53 (34.8)	131.7 ± 72.5 (6.4 – 288.3)
All abutments non-vital	32 (9.7)	5 (15.6)	149.7 ± 102.9 (29.4 – 472.1)
Position non-vital abutment [a]			
Mesial	48 (26.1)	19 (39.5)	139.2 ± 68.4 (6.4 – 260.7)
Distal	78 (42.4)	24 (30.7)	136.5 ± 74.8 (6.9 – 288.3)
Mesial and distal	39 (21.2)	7 (17.9)	144.6 ± 99.7 (28.2 – 472.1)
Middle	19 (10.3)	8 (42.1)	122.2 ± 71.4 (14.4 – 257.1)
Post and core			
Mesial	48 (15.4)	18 (37.5)	141.6 ± 82.0 (6.4 – 458.1)
Distal	57 (18.3)	19 (33.3)	140.1 ± 76.1 (7.7 – 288.3)
Mesial and distal	21 (6.8)	1 (4.7)	129.9 ± 108.8 (28.2 – 472.1)
Middle	23 (7.4)	9 (39.1)	133.7 ± 72.4 (14.4 – 257.1)
No post and core	162 (52.1)	35 (21.6)	126.1 ± 74.7 (10.7 – 340.5)
Material			
Full metallic	5 (1.5)	0 (0)	155.7 ± 136.0 (9.5 – 351.4)
Metal acrylic	6 (1.8)	4 (66.6)	233.0 ± 88.9 (76.6 – 323.4)
Metal ceramic	311 (94.0)	84 (27.0)	131.4 ± 77.6 (6.4 – 472.1)
'Metal ceramic, unknow metal' [b]	5	1 (20.0)	67.2 ± 45.0 (12.7 – 126.7)
Titanium ceramic	16	1 (6.2)	88.0 ± 48.7 (22.7 – 174.4)
Cobalt-chromium ceramic	64	18 (28.1)	60.1 ± 34.1 (10.7 – 128.5)
High-noble gold ceramic	226	64 (28.3)	156.1 ± 74.0 (6.4 – 472.1)
Full ceramic	9 (2.7)	2 (22.2)	75.8 ± 87.9 (6.9 – 291.7)
Bruxism			
No	229 (69.2)	58 (25.3)	136.7 ± 81.1 (6.4 – 472.1)
Yes	102 (30.8)	32 (31.3)	121.6 ± 78.1 (9.5 – 351.4)
Prosthesis occluding to [c]			
Nothing	5 (1.5)	2 (40.0)	148.3 ± 81.2 (14.4 – 219.2)
Natural teeth	177 (53.5)	48 (27.1)	137.4 ± 74.4 (7.7 – 351.4)
Fixed prosthesis	141 (42.6)	40 (28.3)	122.3 ± 86.1 (6.4 – 472.1)
Removable partial denture	8 (2.4)	0 (0)	178.1 ± 90.6 (57.2 – 275.4)

FPDs - fixed partial dentures
SD - standard deviation
[a] The FPDs did not add up to the total number of FPDs in the study, as 147 FPDs were supported only by vital abutments.
[b] The types of metal framework were unknown.
[c] At the time of prosthesis delivery. The status of the opposing arch could have changed at subsequent follow-up.

Table 2. Life-table survival analysis showing the cumulative survival rate of the FPDs.

Interval start time (years)	Number entering interval	Number withdrawing during interval	Number exposed to risk	Prosthesis failures	Survival rate within each interval – ISR (%)	Cumulative proportion surviving at end of interval – CSR (%)	Standard error (%)
0	331	3	329.5	2	99.4	99.4	0.4
1	326	10	321	5	98.4	97.8	0.8
2	311	15	303.5	6	98.0	95.9	1.1
3	290	13	283.5	2	99.3	95.2	1.2
4	275	11	269.5	4	98.5	93.8	1.4
5	260	9	255.5	10	96.1	90.1	1.7
6	241	16	233	7	97.0	87.4	2.0
7	218	11	212.5	4	98.1	85.8	2.1
8	203	11	197.5	2	99.0	84.9	2.2
9	190	13	183.5	7	96.2	81.7	2.4
10	170	17	161.5	8	95.0	77.6	2.7
11	145	5	142.5	4	97.2	75.5	2.8
12	136	15	128.5	4	96.9	73.1	3.0
13	117	11	111.5	1	99.1	72.5	3.0
14	105	9	100.5	2	98.0	71.0	3.1
15	94	7	90.5	4	95.6	67.9	3.3
16	83	12	77	5	93.5	63.5	3.7
17	66	9	61.5	2	96.7	61.4	3.8
18	55	8	51	2	96.1	59.0	4.0
19	45	8	41	1	97.6	57.6	4.2
20	36	9	31.5	3	90.5	52.1	4.8
21	24	7	20.5	2	90.2	47.0	5.5
22	15	2	14	1	92.9	43.6	6.1
23	12	2	11	0	100	43.6	6.1
24	10	3	8.5	0	100	43.6	6.1
25	7	0	7	0	100	43.6	6.1
26	7	2	6	1	83.3	36.4	8.4
27	4	0	4	0	100	36.4	8.4
28	4	1	3.5	0	100	36.4	8.4
29	3	1	2.5	0	100	36.4	8.4
30	2	0	2	0	100	36.4	8.4
31	2	0	2	1	50.0	18.2	13.5
32	1	0	1	0	100	18.2	13.5
33	1	0	1	0	100	18.2	13.5
34	1	0	1	0	100	18.2	13.5
35	1	0	1	0	100	18.2	13.5
36	1	0	1	0	100	18.2	13.5
37	1	0	1	0	100	18.2	13.5
38	1	0	1	0	100	18.2	13.5
39	1	1	0.5	0	100	18.2	13.5

FPDs - fixed partial dentures
ISR - interval survival rate, CSR - cumulative survival rate

until the last 5 to 10 years, also reflecting the long-term follow-up. The predominant use of high noble gold-based alloys could have led to a high skill level for dentists and dental technicians, which reduced the risk of material-related complications. The majority of FPDs retained solely by non-vital abutments were made of a high-noble Au-MC material, which could also reduce the risk of failures in the non-vital group. The CoCr-MC FPDs showed a significantly higher HR than the highly noble Au-MC FPDs. Loss of retention and caries were the most common complications of FPDs. These factors could be related to the ill-fitting margin, which may have been more common among CoCr-MC FPDs. In a previous in vitro study, CoCr frameworks of 3-unit FPDs were fabricated using three methods: conventional casting, milling, and selective laser melting (SLM)[27]. Most of the CoCr frameworks showed an under-extended margin during examination[27]. The uncovered prepared rough tooth structure can easily retain plaque and increase the occurrence of marginal caries[23].

Table 3. Univariate Cox proportional hazard models for FPD failure.

Factor	Hazard ratio (95% CI)	*p* value
Sex		
Male	1	
Female	0.893 (0.588, 1.356)	0.595
Jaw		
Maxilla	1	
Mandible	1.447 (0.954, 2.195)	0.082
Prosthesis region [a]		
Anterior	1	
Posterior	1.672 (0.824, 3.389)	0.154
Anterior/posterior	1.026 (0.480, 2.193)	0.947
Prosthetic units		
3	1	
4	1.283 (0.791, 2.080)	0.313
5	1.358 (0.742, 2.487)	0.321
6	0.687 (0.289, 1.635)	0.397
7	1.342 (0.321, 5.622)	0.687
Number of abutments [b]		
2	1	
3	1.059 (0.672, 1.671)	0.804
4	1.029 (0.435, 2.432)	0.949
Abutments		
All abutments vital	1	
Vital and non-vital abutments	1.666 (1.066, 2.605)	0.025
All abutments non-vital	0.494 (0.174, 1.397)	0.183
Post and core location		
Mesial	1	
Distal	0.908 (0.473, 1.745)	0.772
Mesial and distal	0.137 (0.018, 1.034)	0.054
Middle	1.192 (0.531, 2.676)	0.670
No post and core	0.681 (0.382, 1.214)	0.193
Bruxism		
No	1	
Yes	1.448 (0.939, 2.234)	0.094
Smoking [c]		
No	1	
Yes	2.041 (1.107, 3.762)	0.022
Ex-smoker	1.259 (0.427, 3.714)	0.676

FPD - fixed partial denture
95% CI - 95% confidence interval
[a] There was only one cross-arch FPD (no failure), which was not considered here.
[b] There was a very small number of FPDs with five or more abutments; these were not considered here.
[c] Only one non-smoker made use of snuff, which was not considered here.

Table 4. Multivariate Cox proportional hazard model for FPD failure.

Factor	Hazard ratio (95% CI)	*p* value
Jaw		
Maxilla	1	
Mandible	1.297 (0.654, 2.570)	0.457
Abutments		
All abutments vital	1	
Vital and non-vital abutments	1.321 (0.466, 3.744)	0.601
All abutments non-vital	0.439 (0.077, 2.509)	0.355
Post and core location		
Mesial	1	
Distal	0.689 (0.239, 1.987)	0.490
Mesial and distal	0.231 (0.028, 1.891)	0.172
Middle	0.449 (0.086, 2.333)	0.341
No post and core	0.690 (0.189, 2.516)	0.574
Bruxism		
No	1	
Yes	1.280 (0.669, 2.451)	0.456
Smoking [a]		
No	1	
Yes	2.309 (1.187, 4.493)	0.014
Ex-smoker	1.266 (0.402, 3.985)	0.687

FPD - fixed partial denture
95% CI - 95% confidence interval
[a] Only one non-smoker made use of snuff (no failure), which was not considered here

Table 5. Comparison between failed and non-failed FPDs according to the most prevalent material used, and hazard ratio estimated from univariate Cox proportional hazard model.

Material	Failed prosthesis (n)	Non-failed prosthesis (n)	Hazard ratio (95% CI)	*p* value
Gold ceramic	64	162	1	
CoCr ceramic	18	46	5.361 (2.901, 9.907)	<0.001

FPDs - fixed partial dentures
95% CI - 95% confidence interval

Table 6. Univariate Cox proportional hazard model for FPD failure, for when the factors bruxism and abutment vitality were combined.

Group	Hazard ratio (95% CI)	*p* value
Non-bruxer + all abutments vital	1	
Non-bruxer + vital/non-vital	1.760 (0.988, 3.134)	0.055
Non-bruxer + all abutments non-vital	0.651 (0.190, 2.232)	0.495
Bruxer + all abutments vital	1.781 (0.888, 3.572)	0.104
Bruxer + vital/non-vital	2.647 (1.332, 5.259)	0.005
Bruxer + all abutments non-vital	0.487 (0.065, 3.665)	0.485

FPD - fixed partial denture
95% CI - 95% confidence interval

An underextended margin can also lead to cement dissolution and subsequent loss of retention[28] which was a common complication in the present study. A second factor is the veneering ceramic defects that occur more often in CoCr-MC FPDs than in Au-MC[29]. A recent retrospective study supported these findings and found a significantly higher occurrence of ceramic chipping in CoCr-MC FPDs than in Au-MC FPDs[30]. The bond strength of porcelain to Au-MC-based restorations is significantly higher than that of bonding to non-precious alloys, such as CoCr-MC-based restorations, which affects the tendency for adhesive veneering ceramic fracture[31].

Loss of retention and porcelain chipping have also been suggested to be more prevalent in patients diagnosed with bruxism[32]. While bruxism showed no significant influence on prosthesis failure in the present study, great caution should be taken regarding the material selection and restoration design due to the unfavorable loading in those patients[32].

Table 7. Biological and technical complications at abutment level.

Complications	Frequency	Percentage %
Loss of retention	102	12.3
Caries	71	8.6
Abutment loss	68	8.2
Loss of vitality	58	7.0
Bone loss	24	2.9
Mobility	19	2.3
Periapical destruction	16	1.9
Chipping	12	1.5
Framework fracture	11	1.3
Tooth Fracture	11	1.3

Smoking significantly influences the occurrence of prosthesis failure. Smoking has a detrimental effect on the periodontium because it affects the microbiota composition and immune system and reduces the capacity of periodontium healing. The incidence and progression of periodontitis are increased by smoking, and periodontal disease is associated with tooth loss[33]. Current smokers have been found to show a two-fold higher risk of tooth loss than non-smokers[34]. The association between smoking and tooth loss is highly probable[35]. However, further studies are needed to investigate the direct association between abutment vitality and smoking.

FPDs with mesial non-vital abutments showed a significantly higher risk of failure. As almost one-third of FPDs with mesial non-vital abutment were found in patients with probable bruxism, the higher risk could be related to the bruxism habit rather than the position of the non-vital abutment itself. Unfavorable loading in bruxer patients could increase the risk of technical complications and prosthesis failure[32]. Opposing arch factors could not be evaluated in the present study. Since the status of the opposing arch could have changed at subsequent follow-ups, it is difficult to judge when the technical complication had occurred, if it happened when the FPD was opposed by natural dentition or when the opposing arch received a fixed or removable prosthesis.

There are limitations to retrospective studies that are based on patient records. The clinical procedures were not standardized, as in a prospective study, and all professionals involved in the treatment of these patients were not calibrated. Moreover, some data may not have been completely recorded in the patients' journals at each follow-up appointment, which is connected to the retrospective nature of the present study. This may limit the generalizability of the results. However, retrospective studies involving several variables may be considered more representative of everyday clinical practice than studies conducted by specialists under highly specific conditions.

All general and local factors should be considered by treatment providers. Recognizing these factors during treatment planning may reduce the risk of complications and failures.

5. Conclusion

Within the limitations of this study, the following conclusions are suggested:

- Based on multivariate analysis, smoking contributes to FPD failure irrespective of abutment vitality.

- The type of prosthesis material contributed to FPD failure irrespective of abutment vitality, as observed in a separate univariate analysis, taking into consideration only the two most prevalent FPD materials.

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Conflict of interest

The authors deny any conflicts of interest with regard to this study.

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III

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Research Article

Retrospective Study Comparing Clinical Outcomes of Fixed Dental Prostheses in Matched Groups of Bruxer and Nonbruxer Patients

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Background. Tooth-supported fixed dental prosthesis (FDP) is one of the most reliable treatment options to replace missing teeth. The longevity of the treatment could, however, be affected by several general and local factors, especially bruxism. *Objective*. To investigate the influence of bruxism on the long-term survival of tooth-supported FDPs in bruxers compared to a matched group of nonbruxers, taking several clinical variables into account. *Materials and Methods*. The present retrospective cohort study was based on records of patients treated with 3–7-unit tooth-supported FDPs with a minimum follow-up time of 6 months after prosthesis delivery. The criteria for the diagnosis of "possible" and "probable" sleep or awake bruxism were used. A matched group of nonbruxers was selected on the basis of similarities in four factors, patients' gender and age, number of prosthetic units of the FDPs, and follow-up time. The paired-samples *t*-test or Wilcoxon signed rank test were used to compared mean values between the two groups. Contingency tables of categorical data were analyzed by McNemar's test. *Results*. The cohort group consisted of 62 noncantilevered FDPs in each group, followed up for a mean of 110.1 and 106.5 months (bruxers and nonbruxers, respectively). Tooth-supported FDPs in bruxers presented significantly higher failure rate than in nonbruxers (32.3% vs. 25.8%, respectively; $p = 0.001$). Loss of retention and tooth loss were the main reasons for failures in both groups. For nonsmokers, the FDP failure rate was higher in nonbruxers. Technical and biological complications were significantly more prevalent in bruxers compared to nonbruxers. *Conclusions*. Bruxism is suggested to increase technical and biological complications and FDP failure.

1. Background

Tooth-supported fixed dental prostheses (FDPs) are used to replace missing tooth substance and missing teeth in partially edentulous patients [1] to restore oral function and aesthetics [2]. FDPs have generally shown high survival rates [2–7], but complications occur, and one of the main suggested factors to affect survival and complication rates is bruxism [8–11].

Bruxism is defined as a repetitive jaw-muscle activity represented by clenching and grinding of the teeth and/or by bracing or thrusting of the mandible during wakefulness and sleep [12]. The etiology of bruxism is not fully clear [13]. Several factors have been reported as risk factors for bruxism including young age, female gender, tobacco usage, alcohol drinking, caffeine consumption, stress, anxiety, obstructive sleep apnea, genetic, and certain medications [14–16].

The prevalence of bruxism has been estimated at around 10% of the population, but some studies suggest a prevalence of up to a third of the population [13, 17]. The wide variations in prevalence and the lack of accurate estimation among studies is due to different methods applied to diagnose bruxism and different selected samples [14, 17]. Since the estimated number of people with bruxism is considerable, it is important to study the influence of bruxism on the survival of FDPs.

Technical complications such as loss of retention and material fracture have been reported to occur more

frequently in bruxers compared to nonbruxers [10, 14]. The risk of metal-ceramic defect of FDPs has been reported to be 2.5 times higher in bruxers compared to nonbruxers [11].

Several studies have reported a possible association between bruxism and technical complications of FDPs, but, as far as we know, there is still limited evidence concerning the survival of FDPs when subjected to multiple factors in a clinical setting and few studies compare matched groups of bruxer and nonbruxer patients [8, 10, 11]. Investigating the outcomes under the influence of many clinical independent variables, better represent a real-life situation. Recognizing conditions that place the patient at high risk of failure will allow the clinician to make an appropriate decision and refine the treatment plan to optimize the treatment outcome.

The aim of the present retrospective study was to evaluate and compare the failure rates and technical and biological complications of FDPs in a group of patients presenting bruxism in comparison with a matched group of nonbruxers with respect to several clinical variables. The null hypothesis was that there is no influence of bruxism on the survival of tooth-supported FDPs.

2. Materials and Methods

2.1. Study Design. This retrospective study included patients rehabilitated with tooth-supported FDPs at the Faculty of Odontology, Malmö University, Sweden, during the period between 1981 and 2018. The prosthetic treatments were executed by dental students, general practitioners, or specialists at a prosthodontic and general adult dental care department. The study protocol was approved by the Regional Ethical Committee in Lund, Sweden (Dnr 4,3-2018/422; Dnr 2018/856). This observational study followed the STROBE guidelines [18].

2.2. Definitions. Success was defined as a prosthesis that had remained unchanged (no complication or intervention) over the observation period. Survival was defined as the prosthesis remaining in situ with the occurrence of any complication while still in function. A prosthesis removed or replaced was considered a failed prosthesis. Chipping was defined as loss of veneer substance with or without metal exposure, being classified as minor (managed chair-side) or major (sent to the dental lab for reparation). An abutment was considered as a failure if exhibiting extensive alveolar bone loss and/or excessive tooth mobility, extensive caries, or any other complication that would make the abutment unsuitable to function as a retainer for FDP and lead to abutment loss.

The criteria for the diagnosis of "possible" and "probable" sleep or awake bruxism were used. A "possible" sleep or awake bruxism should be based on self-report using questionnaires and/or the anamnestic part of a clinical examination. "Probable" bruxism should be based on self-report together with clinical examination [12]. The information from the self-report and clinical examination was verified from annotations on the dental records of each eligible patient.

2.3. Inclusion and Exclusion Criteria. The inclusion criteria consisted of patients treated with tooth-supported FDPs (limited to 3–7 prosthetic units) at the aforementioned faculty, who had an available dental record at the clinic's archive, and a minimum follow-up time of 6 months after delivery of the prosthetic work. The exclusion criteria consisted of cases with lack of information regarding the outcome measures in the dental records, FDPs smaller or larger than 3–7 units, single crowns, and cantilever bridges.

2.4. Data Collection. The patients' data were collected and inserted directly into a database in a SPSS file (SPSS software, version 27, SPSS Inc., Chicago, USA) by one investigator. The following data were collected: patient's age at the day of prosthesis delivery, sex, abutment vitality, type of prosthesis material, number of prosthetic units, position of the nonvital abutment(s), presence of post and core, area of placement (anterior, posterior, and anterior/posterior), location of the prostheses in relation to the jaws (maxilla, mandible), smoking habits, bruxism, and complications after delivery of the definitive prosthetic restoration including the date when they occurred. Types of materials used in FDPs were registered according to the dental lab order. Technical and biological complications were evaluated radiographically and through the patients' records. Biological complications included caries, loss of tooth vitality, periapical infection, mobility, and abutment loss. Technical complications included tooth fracture, loss of retention, framework fracture, and minor and major veneer chipping.

2.5. Formation of a Matched Group. From the group of patients not presenting bruxism, a control group was included with the same number of patients as in the study group. The matching was performed in SPSS (version 27 software, IBM Inc., Chicago, IL, USA). The matches were selected on the basis of similarities in four factors, namely, patients' gender (equal matching), age of the patients at the day of prosthesis delivery (tolerance of 10 years of difference), number of prosthetic units of the FDPs (equal matching), and follow-up time (tolerance of 18 months of difference).

2.6. Statistical Analysis. The mean, standard deviation (SD), and percentage were calculated for several variables. The Kolmogorov–Smirnov test was performed to evaluate the normal distribution of the variables, and Levene's test evaluated homoscedasticity. The performed tests for the comparison of mean values between the two groups were the paired-samples t-test or Wilcoxon signed rank test, depending on the normality, and McNemar's test was used in the analysis of contingency tables of categorical data. The degree of statistical significance was considered $p < 0.05$. All data were statistically analyzed using SPSS. There was only one prosthesis per patient. Therefore, there was no clustering effect.

3. Results

The cohort group consisted of 331 noncantilevered FDPs with 3–7 prosthetic units followed up for a minimum of 6 months, of which 102 were installed in "possible" or "probable" bruxers. The matching according to the tolerance set for the four aforementioned factors was possible for 62 of these 102 FDPs in bruxers, which were matched to 62 FDPs in nonbruxers.

Table 1 provides the descriptive characteristics of the matched groups. As expected from the matching process, the groups did not significantly differ with regard to number of FDPs, the number of FDPs installed in patients of different sexes, the number of FDPs with the respective number of prosthetic units, the mean age of the patients at the day of prosthesis delivery, and the follow-up time. The number of prostheses in smokers did not differ between the two groups.

FDPs in bruxers presented significantly higher failure rates of 32.3% ($p < 0.001$) in comparison to nonbruxers 25.8%. Failure rates were higher in women, in the maxilla, in the posterior region of the jaws, when all abutment teeth of the prosthesis were vital, for prostheses fabricated with gold-based metal-ceramic (Au-MC), and when the treatment was conducted by dental students. Loss of retention and tooth loss were the main reasons for FDPs failures in bruxers and nonbruxers (Table 2). For nonsmokers, the FDP failure rate was higher in nonbruxers in comparison to bruxers (Table 1).

Technical and biological complications were significantly more prevalent ($p < 0.001$) in bruxers than in nonbruxers (complication level), although not when only the number of prostheses with at least one complication (prosthesis level) was compared between the groups (Table 1).

Cross-tabulation was performed with three variables (bruxism, smoking, and treatment provider) in order to verify whether there was a possible association with treatment provider to the higher prosthesis failure rate in nonsmokers among nonbruxers than among bruxers. Cross-tabulation showed that all prosthetic treatments for nonsmoker and nonbruxer patients were conducted by dental students, whereas all types of treatment provider were represented in the other groups (Table 3).

4. Discussion

In the present study, a higher failure rate was observed among FDPs in bruxers compared to FDPs in the matched group of nonbruxers. The same was observed for the prevalence of technical and biological complications. The influence of bruxism on the survival of FDPs was also suggested by previous studies, with a high prevalence of technical complications [10, 11].

Loss of retention and tooth loss were the main reasons for FDPs failures in both groups. Both complications occurred more commonly in bruxers compared to nonbruxers. The findings are in agreement with previous studies where loss of retention has been reported to occur more frequently in bruxers [10, 11]. Excessive overload could induce micromotion of the framework and may cause loss of retention [10]. This event is dependent on the fracture resistance of the luting cement filling the irregularity between fitting surface of FDP and abutment [9]. Loss of retention could also occur between FDP and abutment or between post and core and abutment tooth [9]. Furthermore, loss of retention could relate to the minimum resistance and retention form of the worn dentition in bruxers [14]. Subgingival preparation to increase the amount of tooth structure and create space for the FDP materials may be required [14]. Abutment tooth loss could also be a consequence of the excessive loading force by bruxers. In periodontitis patients, overloading force could enhance periodontal breakdown and negatively influence the alveolar bone density and create a bony defect which leads to pathological tooth mobility and may cause tooth loss [19–21].

In the present matched groups, major porcelain chipping occurred only in bruxers. Porcelain chipping was also reported as one of the main technical complications in bruxers [10, 11]. The excessive loading by bruxers could increase the susceptibility of porcelain chipping, initiated with roughness of the porcelain veneer at the occlusal surface which would propagate until chipping occurs [14, 22]. Fabricating FDPs with only metal at the occlusal surface might help to improve the treatment prognosis and eliminate the occlusal chipping complication [23]. The risk of porcelain chipping for the posterior FDPs could be higher compared to the anterior ones, since the posterior teeth are subjected to higher masticatory forces [24–26].

Recurrent caries was the most common complication in bruxers. Recurrent marginal caries could be a consequence of loss of retention of FDPs [9]. It is difficult to precisely predict which one occurred first: the process could start with loss of retention followed by caries or the opposite way if there is an open margin [9]. However, as a clinical examination was not performed, the precise primary cause cannot be ascertained. Marginal discrepancies, as open and under extended margins, are also among the factors that may have an influence on loss of retention and recurrent caries [27]. The uncovered prepared rough tooth structure can easily retain the plaque and increase the susceptibility of marginal caries [27]. Karlsson found a significantly higher incidence of marginal caries in open margin and poor adaptation FDPs compared to FDPs with no open and underextended margins [27]. Regular follow-up involving FDPs and surrounding structure is an important factor to achieving the long-term prognosis [27].

Loss of tooth vitality was observed to be one of the main biological complications for both groups. Mechanical trauma during tooth preparation with the insufficient cooling system and little remaining dentin thickness may increase the risk of pulpal irritation and lead to pulp necrosis [28, 29]. Detailed investigation for the loss of tooth vitality was not possible due to the record-based retrospective design of the study.

A higher failure among vital abutments is an unexpected finding as it is generally a risk reducing factor compared to nonvital abutments. In a previous study, lower survival rates

Table 1: Descriptive characteristics of the matched groups and comparison of the prosthesis failure rates between bruxers and nonbruxers.

	Bruxers	Nonbruxers	P value
FDP (N)	62	62	
Sex (number of FDP)	Woman (44) Man (18)	Woman (44) Man (18)	
Prosthetic units (number of FDP)	3 (40), 4 (16), 5 (4), 6 (2)	3 (40), 4 (16), 5 (4), 6 (2)	
Patients' age[†] (years), mean ± SD (min-max)	57.8 ± 11.7 (31.9–81.5)	58.3 ± 11.1 (37.7–84.3)	0.729[††]
Follow-up (months), mean ± SD (min-max)	110.1 ± 66.6 (15.3–262.1)	106.5 ± 66.7 (6.0–259.3)	0.767[‡‡]
Smoking (number of FDP)[‡]			0.743[§§]
No	20	13	
Current + former smokers	15	17	
FDP failure, N (%)	20 (32.3)	16 (25.8)	0.001[§§]
Sex, N/total (%)			
Woman	12/44 (27.3)	10/44 (22.7)	0.002[§§]
Man	8/18 (44.4)	6/18 (33.3)	0.503[§§]
Smoking, N/total (%)[‡]			
No	5/20 (25.0)	4/13 (30.8)	0.019[§§]
Current + former smokers	6/15 (40.0)	7/17 (41.2)	0.804[§§]
Prosthesis location, N/total (%)			
Maxilla	12/37 (32.4)	6/39 (15.4)	0.002[§§]
Mandible	8/25 (32.0)	10/23 (43.5)	0.383[§§]
Area of placement, N/total (%)			
Anterior	3/8 (37.5)	1/8 (12.5)	0.219[§§]
Posterior	15/38 (39.5)	10/31 (32.3)	0.035[§§]
Anterior/posterior	2/16 (12.5)	5/23 (21.7)	0.064[§§]
Abutments, N/total (%)			
All abutments vital	6/31 (19.4)	6/41 (14.6)	0.001[§§]
Vital and nonvital abutments	13/27 (48.1)	10/20 (50.0)	0.541[§§]
All abutments nonvital	1/4 (25.0)	0/1 (0)	0.250[§§]
FDPs with post and core in nonvital abutments, N/total (%)[§]			
No	3/12 (25.0)	6/11 (54.5)	0.727[§§]
Yes	11/19 (57.9)	4/10 (40.0)	0.332[§§]
Position nonvital abutment, N/total (%)			
Mesial	9/14 (64.3)	2/6 (33.3)	0.267[§§]
Distal	2/10 (20.0)	7/12 (58.3)	0.453[§§]
Mesial and distal	2/5 (40.0)	0/2 (0)	1.000[§§]
Middle	1/2 (50.0)	1/1 (100)	1.000[§§]
Material, N/total (%)[¶]			
Gold ceramic	16/38 (42.1)	7/38 (18.4)	0.040[§§]
CoCr ceramic	4/16 (25.0)	8/18 (44.4)	0.180[§§]
Treatment provider, N/total (%)			
Dental student	15/45 (33.3)	10/51 (19.6)	0.001[§§]
General or specialist dentist	5/17 (29.4)	6/11 (54.5)	1.000[§§]
FDPs with at least one complication (N)	27	22	0.111[§§]
Complications (N)			
Technical			<0.001[§§]
Major chipping	3	0	
Loss of retention	8	6	
Prosthesis replacement	7	3	
Tooth fracture	2	1	
Biological			<0.001[§§]
Loss of tooth vitality	7	8	
Recurrent caries	12	7	
Periapical destruction	2	1	
Technical/biological			<0.001[§§]
Tooth loss	8	5	

FDP, fixed dental prosthesis. [†]On the day of prosthesis delivery. [‡]Information not available for all patients. [§]Only for the prostheses that had at least one nonvital abutment tooth. [¶]Analysis done only for the most prevalent materials used. [††]Wilcoxon signed rank test. [‡‡]Paired-samples t-test. [§§]McNemar's test.

were reported for FDPs with at least one nonvital abutment compared to FDPs supported by vital ones [30]. Excessive removal of the dentin structure by mechanical and chemical debridement of the root canal system may compromise the tooth structure and reduced the fracture resistance [31, 32]. Furthermore, increasing the brittleness of the dentin structure

Table 2: The reasons for FDPs failures in bruxers and nonbruxers.

Reasons for FDPs failures	Bruxers		Nonbruxers	
	Frequency	Percentage	Frequency	Percentage
Loss of retention	5	25.0	4	25.0
Tooth loss	5	25.0	4	25.0
Tooth fracture (root or crown)	2	10.0	1	6.3
Major chipping	2	10.0	0	0
Periapical destruction (radiolucency)	2	10.0	1	6.3
Replace old construction by new one due to change situation	2	10.0	1	6.3
Loss of tooth vitality	1	5.0	2	12.5
Mobility	1	5.0	0	0
Esthetic dysfunction	0	0	1	6.3
Allergy	0	0	1	6.3
Total	20	100.0	16	100.0

FDPs, fixed dental prostheses.

Table 3: Cross-tabulation of smoking, history of bruxism, and treatment provider factors to verify a possible association of treatment provider to the higher prosthesis failure rate in nonsmokers among nonbruxers.

Treatment provider			History of bruxism		Total
			No	Yes	
Dental student	Smoking	No	13	12	25
		Yes	9	7	16
		Quit smoking	2	5	7
	Total		24	24	48
General practitioner or specialist	Smoking	No	0	8	8
		Yes	6	2	8
		Quit smoking	0	1	1
	Total		6	11	17
Total	Smoking	No	13	20	33
		Yes	15	9	24
		Quit smoking	2	6	8
	Total		30	35	65

of the nonvital abutments may increase the incidence of the tooth fracture [29]. A possible reason for the higher failure rate of FDPs with vital abutments in bruxers could be due to status of the dentition and opposing arch which may have an influence on the magnitude of the bite force among bruxers and could thus affect the prognosis of FDPs [33, 34]. Any influence of the status of the opposing teeth could, however, not be evaluated in the present study. The status of the opposing arch could have changed from baseline to subsequent follow-ups without mention in patients' records, and it is thus difficult to judge whether a complication happened when FDP was opposed by natural dentition or when the opposing arch received fixed or removable prosthesis.

FDPs made of Au-MC material had a higher failure rate in bruxers. Possible explanations for these results could be the area of placement factor. Most of FDPs made of Au-MC material were delivered in the posterior region of the bruxer patients which is subjected to higher masticatory force compared to anterior region [24–26, 35].

There was a higher failure rate of FDPs for bruxers in the maxilla and in women in comparison to nonbruxers. Some factors were not matched between groups, e.g., treatment provider, status of the dentition, and opposing arch. These factors could have had an influence on the results. Treatment results obtained by dental students are not expected to be equal to the treatment results obtained by general practitioners and specialists [36]. The failure rates of FDPs for nonsmoker patients were higher in nonbruxers compared to bruxers. The reason could relate to the treatment provider factor, as all prosthetic treatments for nonsmoker and nonbruxer patients were conducted by dental students only.

There are limitations with record-based retrospective studies. The clinical procedures were not standardized as it could be in a prospective study, and the professionals involved in the treatment of these patients were not calibrated. Moreover, some data may not have been completely recorded in the patients' journals at each follow-up appointment, which is connected to retrospective nature of the present study. The lower sample size of subgroups could also be considered as one of the limitations of the present study. Clinical diagnosis of bruxism is difficult, so the present group of patients could be either under or overdiagnosed [8, 37]. Misclassification and underdiagnosis of bruxism could affect the treatment prognosis. Self-reporting questionnaire combined with clinical examination could be a practical and an appropriate way for the diagnosis of bruxism [12, 38]. Furthermore, well-designed randomized clinical trials (RCTs) studies are needed to assess the risk of bruxism on the survival of FDPs.

Nevertheless, identifying bruxer patients before prosthetic treatment might help the clinician highlight risks during planning and execution in order to reduce technical and biological complications and improve treatment outcome [11].

5. Conclusion

Within the limitations of this retrospective study, bruxism is suggested to contribute to FDP failure due to an increased prevalence of technical and biological complications.

Data Availability

The data used to support the findings of this study are obtained from patients treated at the XXXXXX, and cannot be shared, in accordance with the General Data Protection Regulation (EU) 2016/679 and are restricted by the Regional Ethical Committee in Lund, Sweden (Dnr 4,3-2018/422; Dnr 2018/856), in order to protect patient privacy.

Conflicts of Interest

The authors declare no conflicts of interest.

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ORIGINAL ARTICLE

Retrospective clinical study of tooth-supported single crowns: A multifactor analysis

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Abstract

The purpose of the study was to investigate the influence of multiple factors on the survival of tooth-supported single crowns and assess the biological and technical complications. This retrospective study included patients rehabilitated with single crowns with a minimum follow-up time of 6 months after delivery. The cumulative survival rate was calculated over the maximum period of follow-up time and reported in a life-table survival analysis. Univariate and multivariate Cox regression was used to evaluate the associations between clinical covariates and crown failure. The included cohort group consisted of 1037 single crowns delivered in 401 patients and followed for a mean of 134.8 ± 80.2 months. Cumulative survival rate was 89.9% and 80.9% after 5 and 10 years and 70.5% and 61.8% after 15 and 20 years, respectively. The main reasons for single crown failure were loss of retention, tooth loss, and fracture. Anterior placement, non-vital abutments, and bruxism significantly influenced the survival of single crowns. The survival of single crowns was not influenced by patient's age and sex, location of the crowns in relation to the jaws, type of tooth, presence of post and core, and type of crown material, treatment providers, or smoking. Anterior placement, non-vital abutments, and bruxism are factors suggested to increase the risk of single crown failure and the prevalence of technical and biological complications.

KEYWORDS
post and core, single crown, survival rate, technical and biological complications, tooth vitality

INTRODUCTION

Missing coronal tooth structure due to caries and/or trauma can be restored by dental restorations [1]. The amount of remaining tooth structure is the main factor determining the type of coronal restoration, that is, whether to use full or partial coverage restorations, and also influences the type of material to be used, for example, amalgam, composite, glass ionomer, ceramic, or metal [2]. Short- and long-term clinical performance of tooth-supported single crowns have been reported by several studies. The estimated survival rates at short- to medium-term follow-up, up to 5 years, have been reported to range between 93.3%–96.6% [3, 4] and 85.4% after a period of 25 years of function [5]. Failures do occur and it is important to investigate the cause of failures in order to improve the prognosis.

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Single crowns are subjected to several clinical circumstances which could influence the survival and complication rates. One such variable is tooth vitality. Interdental receptors in the dental pulp have a protective role against harmful overloading force and this could be reduced or lost in non-vital teeth [6]. Furthermore, loss of tooth structure following endodontic and subsequent restorative treatments could weaken the tooth and increase susceptibility of fracture [7, 8]. When the remaining coronal tooth structure is insufficient to retain a restoration, a post is needed [1, 9]. Presence of a post could increase the stress on the root surface and subsequently increase the risk of tooth fracture [10, 11]. Another variable that could affect the survival of single crowns is the magnitude of biting force which is affected by several factors such as patient's age, sex, tooth location, status of the dentition, opposing arch, and bruxism [11–18].

Single crowns may be fabricated from several materials such as metals, metal-ceramics, or all-ceramics. The type of restorative material may affect the clinical outcome of single crowns [19]. Metal and zirconia frameworks are generally covered by a porcelain veneer [5, 20]. Porcelain chipping has been reported as one of the most frequent technical complications for veneered single crowns [3]. To overcome the problem of chipping, all-ceramic single crowns can be made without a veneer. However, these restorations have sometimes showed a risk of complete fracture [21]. Many studies have compared the survival of different types of single crown materials [3] but few have included type of material among other clinical variables in multifactorial analyses.

Treatment plan and decision-making should rely on several general and local factors. Recognizing these factors during treatment planning may reduce the risk of complications and failures. Therefore, the aim of the present retrospective study was to investigate the survival rates and technical and biological complications of tooth-supported single crowns with respect to several aforementioned variables.

MATERIAL AND METHODS

Study design

The dental records archive and the digital journals of all patients (a total number of approximately 4000 records) at the Faculty of Odontology, Malmö University, Sweden were reviewed by one investigator (MH) to identify patients rehabilitated with tooth-supported full coverage single crowns. The study protocol was approved by the Regional Ethical Committee in Lund, Sweden (Dnr 4,3-2018/422; Dnr 2018/856) and followed the STROBE guidelines [22].

Definitions

Survival was defined as the prosthesis remaining in situ and in function, even though complications might have occurred. A prosthesis that had been removed or replaced was considered a failed prosthesis. Chipping was defined as loss of veneer substance with or without metal exposure, being classified as minor (managed chair-side) or major (sent to the dental lab for reparation). A tooth was considered as a failure if exhibiting extensive alveolar bone loss and/or excessive tooth mobility, extensive caries, or any other complication that would make the tooth unsuitable to remain as retainer for single crown and therefore lead to tooth loss. Crowns on incisors and canines were classified as anterior crowns, while crowns on premolars and molars were classified as posterior crowns.

All patients included in the present study had undergone clinical examination including an anamnestic part and self-report questionnaire to identify bruxism. In the present study, a distinction between "possible" and "probable" sleep or awake bruxism was made. A recording of "possible" sleep or awake bruxism was based on self-report using questionnaires and/or the anamnestic part of a clinical examination. A recording of "probable" bruxism was based on self-report together with clinical examination [23]. The information on the self-report and clinical examination was verified from annotations in the dental records of each eligible patient. Patients were thus classified as "probable" bruxers if such findings were identified.

Inclusion and exclusion criteria

All patients treated with full coverage tooth-supported single crowns at the aforementioned faculty who had a minimum follow-up time of 6 months after delivery of the prosthetic work and an available dental record at the clinic's archive were included. The exclusion criteria consisted of conventional full-coverage fixed dental prostheses, resin-bonded and cantilever fixed dental prostheses, partial-coverage crowns, and cases with lack of information regarding the outcome measures.

Data collection

The patient data were collected and entered directly into a database in a SPSS file (SPSS version 27; SPSS) by one investigator (MH). The following data were collected: patient's age and sex, location of the crowns in relation to the jaws (maxilla, mandible), area of crown placement (anterior, posterior), type of tooth (incisor, canine, premolar, molar), tooth vitality, presence of post and core, type of crown material, type of

cement, situation of the opposing arch (natural dentition, fixed or removable denture), treatment provider (dental student, general or specialist dentist), smoking habits, bruxism, and complications after delivery of the single crowns including the date when they occurred. Information on types of materials used in the single crowns were obtained from the dental lab order. Technical and biological complications were evaluated radiographically and through the patients' records. Biological complications included caries, loss of tooth vitality, periapical infection, mobility, and tooth loss. Technical complications included tooth fracture, loss of retention, framework fracture, and minor and major porcelain chipping.

Statistical analysis

The data were described using mean values, standard deviations (SD), and percentages. The interval survival rate of the single crowns was calculated using the information of the period of failure, and the cumulative survival rate was calculated over the maximal period of follow-up reported, in a life-table survival analysis.

Univariate and multivariate Cox regression was used to evaluate the associations between clinical covariates and crown failure. Hazard ratio (HR) and 95% confidence intervals (95% CI) were estimated from Cox proportional hazard models. In order to verify multicollinearity, a correlation matrix of all the predictor variables with a significant odds ratio (p value cut-off point of 0.1) identified in the univariate models was examined, to see whether there were some high correlations among the predictors. Collinearity statistics obtaining variance inflation factor (VIF) and tolerance statistic were also performed to detect more subtle forms of multicollinearity. For the final multivariable Cox regression model, all variables that were univariably moderately associated ($p < 0.10$) with single crown failure were included. For this crown-level analysis, clustering of multiple single crowns within each patient was accounted for in the Cox models using the methods outlined by Lee et al. [24] and Lin [25]. Data were statistically analyzed using the SPSS software. Cox models were performed using the Stata software version 15 (StataCorp). The command *mestreg* was used for the Cox models, in order to take into account clustering of observations in patients. The statistical significance level was set at $p < 0.05$.

RESULTS

A total of 1050 single crowns were executed by dental students, general practitioners, or specialists at a prosthodontic and general adult dental care department during the period between 1981 and 2018 and had complete information on outcomes. The data of 13 single crowns were excluded from the analyses as they had a minimum follow-up time of less than 6 months (Figure 1).

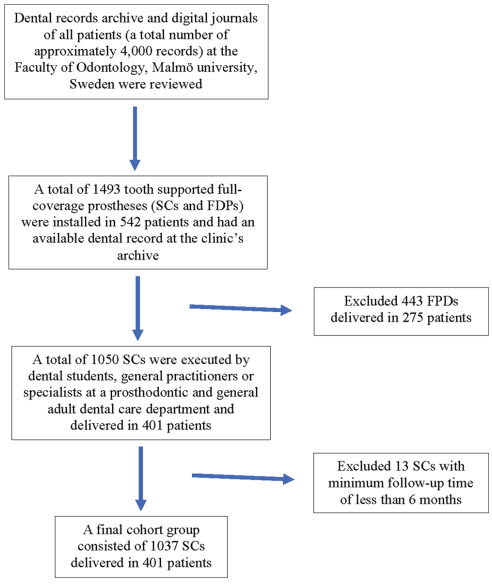

FIGURE 1 Flow-chart describing the selection of participants/crowns. SC, single crown; FDP, fixed dental prosthesis

The final sample consisted of 1037 single crowns, 47.5% of which were supported by vital abutments and 52.5% by non-vital abutments. These single crowns were installed in 401 patients, 195 men and 206 women, who had a mean age of 56.8 years (± 12.9 SD, min–max 21.0–86.6) and 57.7 years (± 12.5 SD, min–max 28.1–85.6), respectively, at the day of crown delivery. Most patients attended regular follow-up visits during the first year but not all continued regular annual follow-ups. The 1037 single crowns were followed for a mean of 134.8 ± 80.2 months, SD (min–max, 6.0–360.7).

Table 1 presents the descriptive characteristics of the single crowns included in the study, with number of failed crowns and follow-up time according to the different factors analyzed. Tables 2 and 3 show the different types of all-ceramic single crown materials and the veneering status, respectively. Veneered oxide ceramics, zirconia (27.8%) and alumina (24.9%), were the most common material used for all-ceramic single crowns. Partial veneering was used in most veneered zirconia single crowns. Table 4 presents the results for the life-table survival analysis. The cumulative survival rates for all single crowns were 89.9% and 80.9% after 5 and 10 years, respectively. After 15 and 20 years of function, the cumulative survival rates for 284 and 111 single crowns were 70.5% and 61.8%, respectively. A total of 230 single crowns

TABLE 1 Descriptive data of the single crowns included in the study, with follow-up time according to the different factors. The descriptive unit is the crown, not the patient

Factor	Number of single crowns (%)	Number of failed single crowns	Follow-up time (months) Mean ± SD (min–max)
Sex			
Male	506 (48.8)	114	129.0 ± 83.0 (6.2–360.7)
Female	531 (51.2)	116	140.3 ± 77.1 (6.0–355.4)
Age			
<50 years	309 (29.8)	86	159.2 ± 79.6 (6.2–333.6)
≥50 years	728 (70.2)	144	124.4 ± 78.3 (6.0–360.7)
Jaw			
Maxilla	605 (58.3)	150	128.9 ± 80.4 (6.0–355.4)
Mandible	432 (41.7)	80	143.1 ± 79.3 (6.9–360.7)
Crown region			
Anterior	282 (27.2)	70	115.4 ± 74.1 (6.0–335.1)
Posterior	755 (72.8)	160	142.0 ± 81.3 (6.2–360.7)
Tooth type			
Incisor	217 (20.9)	56	117.6 ± 73.6 (6.0–335.1)
Canine	65 (6.3)	14	108.0 ± 75.8 (9.2–298.9)
Premolar	391 (37.7)	83	138.6 ± 81.5 (6.8–360.7)
Molar	364 (35.1)	77	145.8 ± 80.9 (6.2–316.0)
Tooth vitality			
Non-vital	544 (52.5)	149	136.6 ± 79.7 (6.2–360.7)
Vital	493 (47.5)	81	132.8 ± 80.8 (6.0–132.8)
Post and core[a]			
No	71 (13.1)	18	112.1 ± 71.7 (7.0–290.5)
Yes	472 (86.9)	131	140.0 ± 80.2 (6.2–360.7)
Material			
All-ceramic	169 (16.3)	26	81.5 ± 65.4 (6.3–234.8)
High-noble gold ceramic	678 (65.4)	171	158.1 ± 72.6 (7.3–360.7)
Full gold	68 (6.5)	14	143.1 ± 81.9 (8.4–143.1)
CoCr ceramic	122 (11.8)	19	74.3 ± 72.3 (6.0–262.5)
Crown occluding to[b]			
Natural teeth	591 (59.8)	131	138.3 ± 79.4 (6.0–355.4)
Fixed prosthesis	398 (40.2)	99	127.8 ± 80.2 (6.2–360.7)
Treatment provider			
Dental student	836 (80.6)	197	140.0 ± 77.3 (6.0–303.1)
General or specialist dentist	201 (19.4)	33	113.1 ± 88.2 (7.6–360.7)
Bruxism			
No	696 (67.1)	141	141.9 ± 77.4 (6.0–360.7)
Yes	341 (32.9)	89	120.3 ± 83.9 (8.5–333.6)
Smoking[c]			
No	283 (50.6)	61	135.5 ± 78.3 (6.8–316.0)
Yes	191 (34.2)	50	123.0 ± 82.9 (6.2–329.5)
Ex-smoker	85 (15.2)	17	145.6 ± 80.2 (11.3–298.9)

Abbreviation: SD, standard deviation.

[a]Only for non-vital teeth.

[b]Few cases were not considered her: crowns opposed removable partial denture ($n = 26$), and not occluding to anything ($n = 22$).

[c]For the cases in which information on smoking habits was available.

TABLE 2 Types of all-ceramic materials used for the single crowns

Types of all-ceramic material	Frequency	(%)
Zirconia with porcelain veneer	47	27.8
Alumina with porcelain veneer	42	24.9
Lithium disilicate glass-ceramic (e.max)	29	17.2
Monolithic zirconia	23	13.6
Leucite-reinforced glass-ceramic (Empress)	21	12.4
Lithium disilicate glass-ceramic (Empress 2)	4	2.4
Feldspathic porcelain	3	1.8
Total	169	100.0

TABLE 3 Veneering status of all-ceramic single crowns

Type of ceramic material	Complete veneer	Partial veneer	Total
Zirconia	17	30	47
Alumina	42	0	42
Total	59	30	89

were considered failures (Table 4). Failures occurred in 149 patients, after a mean follow-up time of 114.5 ± 70.4 months ± SD (min–max, 7.3–293.6). Loss of retention, tooth loss, and tooth fracture were the most common reasons for single crown failures (Table 5).

Tables 6 and 7 present the results for the univariate and multivariate Cox proportional hazard models. Multicollinearity was observed between the factors "crown region" and "tooth type." Therefore, the factor "tooth type", which was moderately associated with crown failure in the univariate model, was excluded from the multivariate model. The estimated hazard ratio (HR) indicated that the following factors were influential for single crown survival: single crowns in posterior teeth had a lower HR than anterior teeth, crowns in vital teeth showed a lower HR than non-vital teeth, and crowns in bruxers showed a higher HR than in non-bruxers. Table 8 shows the biological and technical complications recorded for the single crowns. Loss of retention and recurrent caries were the most common complications. All-ceramic and cobalt-chromium based metal-ceramic single crowns cemented with resin cement showed a lower occurrence of loss of retention than other types of single crown materials and cements (Table 9).

A crosstabulation was performed for two variables (presence of post and core and area of crown placement) in order to explore the reason for the higher HR in anterior than in posterior teeth. The analysis showed that 89.9% of non-vital anterior teeth had post and core (Table 10).

DISCUSSION

Based on the results of the present study, the survival rates of single crowns are influenced by area of crown placement (anterior, posterior), tooth vitality, and bruxism. The cumulative survival rate of single crowns after 5 and 10 years of function were lower than reported by previous reviews and a retrospective study [3, 4, 26]. Reviews have reported the 5-year survival rates of metal-ceramic and all-ceramic single crowns to be between 90.7% and 96.6%, respectively [3, 4]. A retrospective study reported 10-year survival rate of anterior and posterior metal-ceramic single crowns to be 92.3% and 95.9%, respectively [26]. Studies with even longer follow-up, reported the survival rates of single crowns after 18 and 25 years of function to be between 74.9% and 85.4%, respectively [1, 5] which also were higher compared to the present study. In one of mentioned studies, all treatment was performed by one prosthodontic specialist in a private prosthodontic clinic [5]. This is in contrast to the present study, where treatment was performed in a dental school by several treatment providers with different clinical experience, including general practitioners and dental students as well as specialists. The varying degree of experience could have negatively influenced the treatment outcome. However, our study may be more representative as the results obtained at a specialist clinic may perhaps not be expected to be obtained by general practitioners [27]. Additionally, patients seeking treatment at specialists' private clinics are perhaps not representative of a general population of dental patients and this might also influence results. A factor with expected positive influence on the survival rate of single crowns is a regular follow-up [1]. Regular follow-up visits, including professional oral prophylaxis every 6 months, has been shown to have a positive influence on the prognosis of fixed prosthetic treatment [28]. This factor was however limited in the present study as few patients attended regular annual follow-up visits past the first year.

The area of crown placement showed a significant influence on the survival of single crowns. Anterior single crowns showed a higher HR in relation to posterior ones. This may be surprising considering the generally lower loads expected in the anterior area [14, 15]. However, the high frequency of post and core in the anterior teeth could be the reason behind the higher rate of failure in anterior teeth. It has been reported that anterior teeth with post and core showed a higher risk of failure than posterior teeth with post and core [29]. Furthermore, the occlusal load of anterior teeth is often not parallel to the long axis of the tooth which results in an unfavorable load distribution [29] that might increase the micromotion of the crown and post if present, which subsequently increases the stress on the root surface, leading to tooth fracture, which was one of the most common reasons for single crown failures in the present study [10, 11]. Generating an appropriate ferrule in the remaining tooth structure during post fabrication

TABLE 4 Life-table survival analysis showing the cumulative survival rate of the single crowns

Interval start time (years)	Number entering interval	Number withdrawing during interval	Number exposed to risk	Single crown failures	Survival rate within each interval (%)	Cumulative proportion surviving at end of interval (%)	Standard error (%)
0	1037	26	1024.0	10	99.0	99.0	0.3
1	1001	43	979.5	18	98.2	97.2	0.5
2	940	47	916.5	14	98.5	95.7	0.6
3	879	29	864.5	17	98.0	93.8	0.8
4	833	21	822.5	16	98.1	92.0	0.9
5	796	58	767.0	18	97.7	89.9	1.0
6	720	33	703.5	12	98.3	88.3	1.1
7	675	33	658.5	12	98.2	86.7	1.2
8	630	44	608.0	13	97.9	84.9	1.2
9	573	39	553.5	15	97.3	82.6	1.3
10	519	44	497.0	10	98.0	80.9	1.4
11	465	27	451.5	9	98.0	79.3	1.5
12	429	35	411.5	13	96.8	76.8	1.6
13	381	42	360.0	10	97.2	74.6	1.7
14	329	38	310.0	7	97.7	73.0	1.8
15	284	29	269.5	9	96.7	70.5	1.9
16	246	30	231.0	11	95.2	67.2	2.0
17	205	20	195.0	3	98.5	66.1	2.1
18	182	39	162.5	2	98.8	65.3	2.2
19	141	27	127.5	3	97.6	63.8	2.3
20	111	26	98.0	3	96.9	61.8	2.5
21	82	33	65.5	0	100	61.8	2.5
22	49	9	44.5	2	95.5	59.0	3.0
23	38	16	30.0	2	93.3	55.1	3.9
24	20	9	15.5	1	93.5	51.6	5.0
25	10	3	8.5	0	100	51.6	5.0
26	7	2	6.0	0	100	51.6	5.0
27	5	3	3.5	0	100	51.6	5.0
28	2	0	2.0	0	100	51.6	5.0
29	2	1	1.5	0	100	51.6	5.0
30	1	1	0.5	0	100	51.6	5.0

could increase the fracture resistance and reduce the risk of tooth fracture [30–32]. Clinical examination was not performed in the present study however, which precludes any assessment of the presence or not of an appropriate ferrule in the included cases. Moreover, a limited amount of remaining tooth structure in the non-vital anterior teeth compared to the posterior teeth could increase the incidence of loss of retention for post and core and lead to crown failure [29]. Loss of single crown retention has been reported to occur 2.66 times more frequently in the anterior than in posterior teeth [26]. While no explanations were offered for these findings [26], the result is in agreement with our findings.

Tooth vitality had a significant influence on the survival of single crowns in the present study. Dental pulp has interdental receptors which protect the tooth from overloading force [6]. These receptors are lost in non-vital teeth which tends to increase the threshold for the maximum biting force [6, 33] and thereby contribute to increased risk of tooth damage and fracture [6]. Additionally, loss of tooth structure during endodontic and restorative procedures may reduce the biomechanical properties and fracture resistance and increase the susceptibility to tooth fracture [7, 8, 34]. The result is in agreement with a previous study, where single crowns on non-vital teeth with/without post showed a high rate of failure

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TABLE 5 Reasons for the single crown failures

Failure	Frequency	(%)
Loss of retention	61	26.5
Tooth loss	31	13.5
Tooth fracture	29	12.6
Replace old crown by new one due to change situation	25	10.9
Recurrent caries	20	8.7
Periapical destruction	17	7.4
Excessive bone loss	11	4.8
Major chipping	8	3.5
Mobility	8	3.5
Loss of tooth vitality	7	3.0
Esthetic dysfunction	6	2.6
Framework fracture	4	1.7
Tooth loss unknown reason	2	0.9
Poor fitting	1	0.4
Total	230	100

compared to single crowns on vital teeth [35]. Higher failure rate of single crowns on non-vital teeth than on vital ones was also reported by another previous study [36]. In the present study, the majority of single crowns supported by non-vital teeth had post and core, which could also increase the risk of single crowns failures [10, 11]. single crowns on non-vital teeth with post and core have showed a higher failure rate compared to single crowns on non-vital teeth without post and core [35]. On the other hand, the result of the present study was in contrast to a previous paper, where the survival rates were not statistically significant different between single crowns on vital and non-vital teeth with post and core [1]. The latter lack of difference was mainly attributed to the fact that there was no additional removal of tooth substance for the root canals that received post and core [1].

In the present study, bruxism showed a significant influence on the occurrence of single crown failure. Bruxism has been defined as a repetitive jaw-muscle activity represented by clenching and grinding of the teeth and/or by bracing or thrusting of the mandible during wakefulness and sleep [23]. Diagnosis of bruxism based on diagnostic grading system of "possible," "probable," and "definite" sleep or awake bruxism has been suggested for both clinical and research situations [23]. Self-report questionnaire, a clinical examination, in combination with a polysomnographic recording are used for "definite" diagnosis of sleep bruxism [23]. Electromyography recording of the masseter muscles is also one of the methods for grading "definite" awake bruxism. However, the polysomnographic and electromyographic diagnostic options are not commonly used in the clinic due to high cost and limited availability [23, 37]. Instead, self-report

TABLE 6 Univariate Cox proportional hazard models for single crown failure

Factor	Hazard ratio (95% CI)	*p* value
Sex		
Male	1	
Female	0.88 (0.68, 1.14)	0.33
Age		
<50 years	1	
≥50 years	0.94 (0.72, 1.23)	0.65
Jaw		
Maxilla	1	
Mandible	0.67 (0.51, 0.88)	0.004
Crown region		
Anterior	1	
Posterior	0.66 (0.50, 0.88)	0.004
Tooth type		
Incisor	1	
Canine	0.94 (0.52, 1.69)	0.84
Premolar	0.66 (0.47, 0.93)	0.017
Molar	0.65 (0.46, 0.91)	0.013
Tooth vitality		
Non-vital	1	
Vital	0.61 (0.47, 0.80)	<0.001
Post and core[a]		
No	1	
Yes	0.82 (0.50, 1.35)	0.44
Material		
All-ceramic	1	
Gold ceramic	0.75 (0.49, 1.14)	0.17
Full gold	0.71 (0.37, 1.37)	0.31
CoCr ceramic	1.11 (0.61, 2.01)	0.73
Crown occluding to		
Natural teeth	1	
Fixed prosthesis	1.19 (0.91, 1.55)	0.21
Treatment provider		
Dental student	1	
General or specialist dentist	0.89 (0.61, 1.29)	0.53
Bruxism		
No	1	
Yes	1.55 (1.88, 2.02)	0.001
Smoking		
No	1	
Yes	1.37 (0.94, 1.99)	0.10
Ex-smoker	0.85 (0.50, 1.46)	0.56

Abbreviation: 95% CI, 95% confidence interval.

[a]Only for non-vital teeth.

TABLE 7 Multivariate Cox proportional hazard regression analysis of single crown failure

Factor	Hazard ratio (95% CI)	*p* value
Jaw		
Maxilla	1	
Mandible	0.77 (0.58, 1.03)	0.073
Crown region		
Anterior	1	
Posterior	0.73 (0.55, 0.99)	0.04
Tooth vitality		
Non-vital	1	
Vital	0.64 (0.49, 0.84)	0.001
Bruxism		
No	1	
Yes	1.52 (1.17, 1.98)	0.002

Abbreviation: 95% CI, 95% confidence interval.

TABLE 8 Biological and technical complications for single crowns

Complication	Frequency	(%)
Loss of retention	103	9.9
Recurrent caries	89	8.6
Tooth loss	75	7.2
Periapical destruction	61	5.9
Loss of vitality	48	4.6
Tooth fracture	29	2.8
Mobility	28	2.7
Bone loss	19	1.8
Chipping	19	1.8
Framework fracture	5	0.5

questionnaires are commonly used for both clinical and research purposes and can be applied for a large population [38]. In the present study, information from anamnesis, self-report questionnaire and clinical examination was used, and patients were thus classified as "probable" bruxers if such findings were identified.

Bruxism could increase the incidence of loss of retention which was the most common complication and the main reason for single crown failures in the present study. Loss of retention has been reported to occur more frequently in bruxers as there is often limited clinical crowns height as a result of tooth wear, combined with excessive occlusal forces [18]. Loss of retention was reported in a previous study as one of the most common complications for single crowns [39]. The longevity of single crowns is closely related to the marginal seal between abutment and crown [40]. Resin cement has an excellent ability to minimize the marginal discrepancy and leakage of all-ceramic single crowns [41]. In the present study, all-ceramic single crowns cemented with resin cement revealed better clinical performance compared to single crowns bonded with other cements such as zinc phosphate, as also observed in other studies [42–44]. The possible reason is the limited tensile strength of zinc phosphate cement which could increase the possibility of retention loss [42]. In addition to providing sealing, resin cements can form a chemical bond to ceramics after proper conditioning [45]. However, the groups are imbalanced as few metal-based crowns were cemented using resin cement.

Bruxism could also increase the risk of tooth loss. In the present study, tooth loss occurred as a consequence of extensive alveolar bone loss and/or excessive tooth mobility. In periodontally compromised patients, excessive overload by bruxism could enhance periodontal breakdown and negatively influence the alveolar bone density and create a bony defect which leads to pathological tooth mobility and tooth loss [46–48]. The risk of porcelain chipping of single crowns has been reported to be three times higher in bruxers compared to non-bruxers [49]. In the present study however, porcelain chipping was reported as one of the less frequent complications. The reason for this observation could be the high number of single crowns made of precious alloy as framework (high-noble gold-based ceramic). The bond strength of

TABLE 9 Occurrence of single crown loss of retention, according to the type of crown material and type of cement

	Types of cement				
Material	Zinc phosphate cement *n/N* (%)	Resin cement *n/N* (%)	Glass ionomer cement *n/N* (%)	Resin modified glass-ionomer cement *n/N* (%)	Total *n/N* (%)
All-ceramic	6/55 (10.9)	7/110 (6.4)	1/4 (25.0)	0/0 (0)	14/169 (8.3)
Gold ceramic	68/657 (10.4)	1/4 (25.0)	1/8 (12.5)	1/4 (25.0)	71/673 (10.5)
Gold	6/66 (9.1)	0/1 (0)	0/1 (0)	0/0 (0)	6/68 (8.8)
CoCr ceramic	11/116 (9.5)	0/6 (0)	0/0 (0)	0/0 (0)	11/122 (9.0)
Total	91/894 (10.2)	8/121 (6.6)	2/13 (15.4)	1/4 (25.0)	102/1032 (9.9)

TABLE 10 Tooth vitality, presence of post and core and area of crown placement

Tooth vitality	Anterior *n/N* (%)	Posterior *n/N* (%)	Total *n/N* (%)
Vital tooth	144/282 (51.1)	350/755 (46.4)	494/1037 (47.6)
Nonvital tooth without post and core	14/282 (4.9)	57/755 (7.5)	71/1037 (6.9)
Nonvital tooth with post and core	124/282 (44.0)	348/755 (46.1)	472/1037 (45.5)

porcelain to precious alloy is significantly higher compared to bonding to non-precious alloy frameworks which reduces the tendency for adhesive veneering ceramic fracture for the precious alloy single crowns [26, 50, 51]. This was also found in a previous paper where only 1.7% of single crowns made of precious alloy framework had porcelain chipping [26].

Recurrent caries was reported as the second most common complication in the present paper. Recurrent marginal caries could be a consequence of ill-fitting margin or could follow the loss of single crown retention [52]. Ill-fitting crown margins accumulate more plaque which could increase the incidence of the recurrent marginal caries [28, 53]. As a clinical examination was not performed in the present study, the precise primary cause of the recurrent caries could not be ascertained.

The types of crown material had no significant influence on the survival of the single crowns. These results are in agreement with a previous review where most types of all-ceramic single crowns showed similar survival rates to those reported for metal ceramic ones [3]. The type of material may influence the outcome of single crown less than in fixed dental prostheses due to the difference in biomechanics between single crowns and fixed dental prostheses as single crowns are less complicated in their design having no connector and splinting areas [49].

Patient's age and sex had no significant influence on the survival of single crowns. The magnitude of the biting force is higher in men than women [12–14, 54] and decreases significantly after 50 years of age [13]. However, number of teeth has been reported as the most important factor affecting the magnitude of the biting force rather than patient's age and sex [13]. This factor was not controlled among included patients and could have influenced the results.

The status of the opposing arch was included as a variable in the multifactor analysis. However, as the dentition may have changed at subsequent follow-ups, it is difficult to judge if complications occurred when the single crowns were opposed by natural dentition or fixed or removable prosthesis.

There are limitations with retrospective studies based on patient records. Treatment providers were not calibrated, and the clinical procedures were not standardized and controlled as it could be in a prospective study. Moreover, some data may not have been completely recorded in the patients journals at each follow-up appointment. The present study emanated from a teaching institution. The patients that were not treated by students and specialists are probably representative of general dental practice. While patients seeking treatment at a low-cost student clinic could have lower socio-economic status and poorer general and oral health, this was not analyzed. This may limit the generalizability of the results. Nevertheless, record-based retrospective studies involving several variables and treatment providers are valuable as they provide information about risks and complications which can help the practitioner in everyday treatment planning.

Within the limitations of this retrospective study, we conclude that anterior placement, non-vital abutments, and bruxism are factors increasing the rate of single crown failure.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson Larsson; **Methodology**: Mohammed Hawthan, Bruno Chrcanovic; **Software**: Mohammed Hawthan, Bruno Chrcanovic; **Validation:** Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Formal analysis**: Mohammed Hawthan, Bruno Chrcanovic; **Investigation**: Mohammed Hawthan, Bruno Chrcanovic; **Resources**: Christel Larsson; **Data curation**: Mohammed Hawthan; **Writing-original draft preparation**: Mohammed Hawthan; **Writing – review and editing**: Bruno Chrcanovic, Christel Larsson; **Visualization**:Mohammed Hawthan, Bruno Chrcanovic, Christel Larsson; **Supervision**: Bruno Chrcanovic, Christel Larsson; **Project administration**: Mohammed Hawthan; **Funding acquisition**: Mohammed Hawthan.

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