Risk Factors Influencing Long-Term Survival of Dental Implants: A Systematic Review

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ABSTRACT

Background:
Dental implants are advanced and widely regarded as a predictable treatment modality for the replacement of missing teeth. However, long-term survival is influenced by multiple biological, behavioral, and technical factors. This systematic review aimed to evaluate the risk factors affecting long-term implant survival.

Methods:
A comprehensive literature search was performed across PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library for studies published between January 2013 and April 2024. Human clinical studies assessing implant survival ≥1 year post-loading and reporting associated risk factors were included. Study selection followed PRISMA 2020 guidelines. Risk of bias was assessed using Cochrane RoB 2 and ROBINS-I tools.

Results:
A total of 38 studies were included in the qualitative synthesis. Implant survival rates ranged from 85% to 98% across studies. Major risk factors identified included smoking, history of periodontitis, poor oral hygiene, and uncontrolled diabetes mellitus.

Additional contributors included inadequate bone quality, need for bone augmentation, implant design factors, and prosthetic complications such as occlusal overload and prosthetic misfit. Survival was significantly reduced in patients presenting with multiple concurrent risk factors.

Conclusion:
Long-term implant survival is multifactorial and requires comprehensive risk assessment, meticulous surgical and prosthetic planning, and strict maintenance protocols. Identification and modification of risk factors are essential for improving clinical outcomes.

Keywords: Dental implants, implant survival, risk factors, peri-implantitis, smoking, systematic review

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INTRODUCTION

Dental implants have revolutionized restorative dentistry since their pioneering development by Per-Ingvar Brånemark in the 1970s[1]. The introduction of osseointegration—the direct structural and functional connection between living bone and an implant surface—established a biological mechanism for predictable, long-term tooth replacement[1,2]. Over the past five decades, implant therapy has evolved from experimental treatment to routine clinical practice, with millions of implants placed globally each year[3].

Despite remarkable advances in implant design, surface modifications, and surgical techniques, implant therapy remains subject to both early and late failure[4,5]. Early implant failures, defined as loss before functional loading or abutment connection, result from inability to achieve osseointegration, typically occurring within three to six months of placement[4]. Conversely, late implant failures occur after establishment of osseointegration, following abutment connection, or after prosthetic loading, and may result from loss of established osseointegration or functional failure of the implant structure[5].

Historical data from North American general dental practices reveal that despite success rates approaching 93-95% in academic research settings, real-world survival rates are substantially lower[6]. A landmark study from the United States analyzing 922 implants through the Practitioners Engaged in Applied Research and Learning (PEARL) network demonstrated a survival rate of 93.0% (95% CI: 91.4-94.7) when implant loss from the oral cavity was the sole failure criterion[7]. However, when excessive bone loss was included as a criterion for failure, the survival rate dropped significantly to 81.3% (95% CI: 78.8-83.8)[7,8]. This substantial discrepancy (11.7 percentage points) underscores the importance of evaluating both complete implant loss and progressive bone loss as markers of implant failure[8].

Concerns persist regarding whether success rates reported in controlled academic settings are achievable in broader patient populations with diverse risk profiles[6]. Long-term survival data consistently experiences patient attrition, with individuals lost to follow-up before final assessment. Studies demonstrating >20% loss to follow-up carry increased risk of bias, particularly if attrition correlates with implant failure outcomes[10,11]. Common reasons for loss to follow-up include patient relocation (8%), death (25%), poor health (8%), and technical issues (9%), with approximately 50% remaining uncategorized[7].

The identified divergence between ideal and real-world implant outcomes has prompted systematic investigation of modifiable and non-modifiable risk factors affecting long-term survival. Understanding these factors enables clinicians to improve patient selection, optimize treatment planning, enhance surgical execution, and implement evidence-based prevention strategies[9,10].

MATERIALS AND METHODS

This systematic review was conducted in accordance with the PRISMA 2020 guidelines. The research question was formulated using the PICO framework, where the population comprised patients receiving dental implants, the intervention involved exposure to patient-related, implant-related, and procedural risk factors, the comparison included individuals without such risk factors, and the outcome assessed was long-term implant survival and failure.

A comprehensive literature search was carried out using PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library. Studies published between January 2013 and April 2024 were considered. The search strategy incorporated a combination of keywords, including "dental implants," "implant survival," "implant failure," "risk factors," "periodontitis," "smoking," "diabetes mellitus," and "bone augmentation," which were combined using Boolean operators such as AND and OR.

Eligibility Criteria

Studies were included if they met the following criteria:

- Clinical studies conducted in human subjects, including randomized controlled trials, cohort studies, and retrospective or prospective investigations
- Studies reporting implant survival outcomes with a minimum follow-up period of one year after functional loading
- Studies evaluating one or more risk factors influencing implant survival

Studies were excluded if they:

- Were in vitro or animal-based investigations
- Were case reports, case series, reviews, or letters
- Were not published in English
- Involved specialized implant systems such as zygomatic implants
- Did not provide sufficient data for analysis

Study selection was performed independently by two reviewers at the level of titles, abstracts, and full texts. Any discrepancies were resolved through discussion, and where necessary, consultation with a third reviewer.

Data Collection and Analysis

Relevant data were extracted using a standardized approach. The collected information included study design, sample size, duration of follow-up, implant survival rates, identified risk factors, and reported effect measures such as odds ratios or hazard ratios.

Assessment of Methodological Quality

The quality of included studies was evaluated using established tools. Randomized controlled trials were

assessed using the Cochrane Risk of Bias 2 (RoB 2) tool, while non-randomized studies were evaluated using the ROBINS-I tool.
Given the variability in study designs, follow-up durations, and outcome measures, a quantitative meta-analysis was not considered appropriate. Therefore, the findings were synthesized qualitatively.
Ethical approval was not required, as this study was based exclusively on previously published data.

RESULTS:

Study Selection

The initial database search yielded a total of 375 records (PubMed = 42, Embase = 300, Scopus = 23, Cochrane Library = 10), as detailed in Table/Fig 2. After removing duplicates, the remaining studies were screened based on titles and abstracts. Full-text evaluation was then carried out for the shortlisted articles. Following this process, 38 studies fulfilled the inclusion criteria and were incorporated into the qualitative synthesis (Table/Fig 1).
Study Characteristics
The selected studies were primarily retrospective and prospective in design, with a smaller number of randomized controlled trials. The duration of follow-up varied considerably across studies, ranging from 2 to 36 years. Most studies assessed outcomes such as implant survival, marginal bone changes, and the occurrence of biological or mechanical complications. Detailed characteristics of the included studies are presented in Table/Fig 3.

Risk Factors Identified

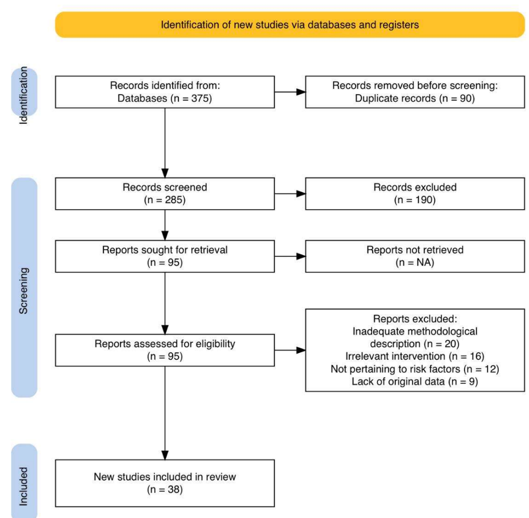
The factors associated with implant survival were broadly grouped into patient-related, implant-related, surgical, and prosthetic categories.Patient-related variables such as smoking, previous history of periodontitis, inadequate oral hygiene, and absence of regular maintenance care were consistently associated with poorer outcomes.
From a surgical and implant perspective, reduced bone quality—particularly in the posterior maxilla—and the need for bone augmentation procedures were linked to comparatively lower survival rates. In addition, implants with shorter length or reduced primary stability demonstrated a higher tendency for failure in certain studies.
Prosthetic considerations also played an important role. Factors such as occlusal overload, cantilever extensions, and inaccuracies in prosthetic fit were found to contribute to both mechanical complications and biological deterioration. A summary of the major risk factors influencing implant survival is presented in Table/Fig 4.

Overall Survival Trends

Across the included studies, implant survival rates were generally high, ranging from approximately 85% to 98%. However, a noticeable decline in survival was observed in patients who presented with multiple coexisting risk factors, indicating a cumulative effect on implant prognosis.

Risk of Bias

The overall quality of the included studies was assessed as moderate. This was mainly due to the predominance of retrospective study designs and the limited control of confounding variables. Despite these limitations, similar patterns across multiple studies support the influence of modifiable risk factors on long-term implant survival.



Table/Fig 1: PRISMA flow diagram showing study selection process.

Database	Search strategy	No. of articles
MEDLINE(PUBMED)	Dental Implants"[MeSH Terms] OR "dental implant*"[Title/Abstract] OR "implant survival"[Title/Abstract] OR "implant failure"[Title/Abstract]) AND ("Risk Factors"[MeSH Terms] OR "risk factor*"[Title/Abstract] OR "smoking"[MeSH Terms] OR "periodontitis"[MeSH	42

	Terms] OR "bone augmentation"[Title/Abstract] OR "diabetes mellitus"[MeSH Terms] OR "bisphosphonates"[MeSH Terms]) AND ("Survival Rate"[MeSH Terms] OR "long-term outcome*"[Title/Abstract]	
EMBASE	('dental implant'/exp OR 'oral implant' OR 'endosseous implant' OR 'implant survival' OR 'implant failure') AND ('risk factor'/exp OR 'smoking'/exp OR 'periodontitis'/exp OR 'bone augmentation' OR 'guided bone regeneration' OR 'diabetes mellitus'/exp OR 'bisphosphonate'/exp) AND ('long term outcome' OR 'survival rate'/exp OR 'late implant failure')	300
SCOPUS	(TITLE-ABS-KEY ("dental implant*") OR TITLE-ABS-KEY ("implant survival") OR TITLE-ABS-KEY ("implant failure")) AND (TITLE-ABS-KEY ("risk factor*") OR TITLE-ABS-KEY (smoking) OR TITLE-ABS-KEY (periodontitis) OR TITLE-ABS-KEY (diabetes) OR TITLE-ABS-KEY ("bone augmentation") OR TITLE-ABS-KEY ("guided bone regeneration")) AND (TITLE-ABS-KEY ("long-term outcome*") OR TITLE-ABS-KEY ("survival rate*"))	23
COCHRANE LIBRARY	("dental implant*"):ti,ab,kw OR ("implant survival"):ti,ab,kw OR ("implant failure"):ti,ab,kw AND ("risk factor*"):ti,ab,kw OR (smoking):ti,ab,kw OR (periodontitis):ti,ab,kw OR ("bone augmentation"):ti,ab,kw OR ("guided bone regeneration"):ti,ab,kw OR (diabetes):ti,ab,kw OR (bisphosphonate*):ti,ab,kw AND ("long-term outcome*"):ti,ab,kw OR ("late failure"):ti,ab,kw OR ("survival rate*"):ti,ab,kw	10

Table/Fig 2: Search strategy across electronic databases.

REF.NO	Author	Population (P)	Intervention (I)	Comparison (C)	Outcome (O)	Risk Factors for Failure/Complications
11	Sailer et al.	Patients with multi-unit FDPs	Zirconia-ceramic or monolithic zirconia	Metal-ceramic FDPs	98.7% survival (metal-ceramic) vs. 93% (zirconia)	Zirconia has a significantly higher risk of framework fracture
12	Nam, D. H. et al.	Patients receiving 490 implants	Implants with micro-threads at the neck	Internal- vs. External-connection	97.9% 10-year Cumulative Survival Rate (CSR)	2-stage surgery significantly improves success (P=0.046)

13	Stadlinger et al.	Patients on antiresorptive drugs (ARDs)	Dental implant placement	ARD users vs. Non-users	Implants are valid; risk of MRONJ exists	High-dose bisphosphonates; Poor oral hygiene; Smoking
14	Compton, S. M.	Adults aged 60+	1,256 implants placed	Success rates across age groups	92.9% survival rate	Smoking ($P < 0.05$)
15	Lim, J. et al.	426 patients (1,298 implants)	TS III SA implants (Osstem)	Mandible vs. Maxilla	98.3% 11-year survival rate	Male sex (higher risk); Maxilla (lower survival than mandible)
16	Chatzopoulos	10,842 patients (Big Data)	General implant placement	Smokers vs. Non-smokers	98.2% overall survival	Smoking; History of Periodontitis; Marijuana use
17	Akkurt, S.	324 patients (1,130 implants)	RBM hybrid surface implants	Standard vs. Narrow diameter	94.4% 60-month survival	Smoking; Narrow-diameter implants (<3.7 mm)
18	Yum, L. et al.	782 implants (SNUDH)	Implants in patients with Diabetes	DM patients vs. Healthy	Mean MBL: 1.85 mm (DM) vs. 1.59 mm (Healthy)	Diabetes Mellitus (DM); Large implant size
19	Blume, O. et al.	113 patients (270 implants)	NobelActive implants	10-year follow-up	91.1% survival; 75.9% success	Plaque/Poor hygiene (affects "success" more than survival)
20	Condezo, A.	169 head/neck cancer patients	Implants in irradiated bone	HBOT vs. No HBOT	92.9% 7.4-year survival	Irradiation dose >50Gy; Mandible location
21	Wang, Y. et al.	Patients with full-arch restorations	All-on-4 screw-retained	Titanium vs. Zirconia	92.5% success for Zirconia-Ceramic (ZC)	Smoking (OR 5.54); Mechanical complications
22	Aldahlawi, S.	Diabetic patients	Dental implant placement	High vs. Low HbA1c	Higher failure in poorly controlled DM	HbA1c levels (Poor glycemic control)
23	Li, Z. et al.	Patients with periodontitis	Dental implant placement	Periodontitis (PD) vs. Healthy	97.23% survival (PD) vs. 100% (Healthy)	Chronic Periodontitis; High IL-6 and TNF-α levels
24	Hu, K. et al.	551 implants (211 patients)	Long-term (10-year) follow-up	Maintenance vs. No Maintenance	10-year survival: 92.6%	Smoking (HR 3.7); Poor oral hygiene (HR 1.5)
25	Muelas-Jimenez	52 patients	Immediate vs. Delayed loading	1-week follow-up vs. 1-year	High stability (ISQ) reached early	Low primary stability at insertion
26	Baek, W.	65 elderly patients (90 implants)	Implants in 65–89 year olds	Age 65-69 vs. 70-74	95.39% 5-year survival	Frailty; Systemic disease in 70-74 age group

27	Liao, C.	Solid Organ Transplant (SOT) recipients	Dental implant placement	SOT vs. Non-SOT	Slightly higher MBL in SOT	Immunosuppressive drugs (potential risk, though survival is high)
28	Ahlgren et al.	58 patients (T-I-H technique)	Implants in root-reduced bone	Men vs. Women	High survival; HR 2.46 for certain factors	Anatomical constraints; Male sex (HR 2.46)
29	Ofec, R. et al.	4,247 implants (retrospective)	Long-term follow-up (up to 10 years)	Smokers vs. Non-smokers	98.9% survival	Smoking (Cigarettes)
30	Mao, W. H.	Short implant candidates	6 mm vs. 10 mm implants	Anterior vs. Posterior	Good long-term clinical effect	Poor bone quality; Surgical technical errors
31	Villarinho, E.	46 patients (posterior region)	6-mm short implants	High vs. Low Crown-to-Implant (C/I) ratio	High success despite high C/I	High C/I ratio (potential risk for bone loss)
32	Kinsel & Liss	Edentulous patients	Implants for overdentures	Maxilla vs. Mandible	95%+ survival	Smoking; Poor bone quality in Maxilla
33	French et al.	2,000+ implants (10 years)	General implant practice	Smoker vs. Non-smoker	98.1% survival	Smoking; History of Periodontitis
34	Jemt & Lekholm	Maxillary edentulous patients	Implants for fixed prostheses	15-year follow-up	90% survival	Poor bone quality (Type IV); Smoking
35	Buser et al.	Healthy patients	SLA-surface implants	10-year follow-up	98.8% survival	None (High success in healthy subjects)
36	Pjetursson et al.	Systematic Review	Single crowns vs. FDPs	10-year meta-analysis	94.6% (SC) vs. 92.8% (FDP)	Smoking; History of Periodontitis
37	Moy et al.	4,680 implants	Success across ages/sex	Male vs. Female	High survival	Diabetes; Smoking; Post-menopausal women (no HRT)
38	Maló et al.	Edentulous patients	All-on-4 protocol	Immediate loading	95%+ 10-year survival	Smoking; Parafunction (Bruxism)
39	Zitzmann et al.	Patients with bone loss	GBR (Guided Bone Regen)	GBR vs. No GBR	95% 15-year survival	Smoking; Improper hygiene maintenance
40	Salvi et al.	Periodontal patients	Dental implants	High vs. Low risk profiles	Increased peri-implantitis risk	History of Periodontitis; Poor compliance
41	Chen, W. Y.	Maxillary sinus lifting	Lateral MSFA	RBH ≥3 mm vs. <3 mm	94.5% CSR	RBH < 3 mm; Smoking; Male sex
42	Windael et al.	Edentulous mandible	Immediate loading (fluoride-mod)	10-year follow-up	100% survival	Early bone loss (first 2 years)
43	Zhang, X.	Full-arch restoration	Immediate full-arch restoration	Angled vs. Straight abutments	98% survival	Smoking; 30° angled abutments; Age

44	Chrcanovic	1,045 implants	20–36 year follow-up	Early vs. Late failure	87.8% 36-year survival	Irradiation; Bruxism; Failures peak in first 3 years
45	Ha, J. et al.	Grafted maxillary sinus	Lateral MSFA + implants	Various graft materials	96.04% 10-year survival	Pre-op RBH ≤ 5 mm
46	Hwang, I.	Patients requiring NDIs	3.0-mm Narrow Diameter (NDI)	5-year retrospective	90.6% survival	Advanced age (HR 1.17)
47	Grassi, R.	Dental implant patients	D-BioTECH (Personalized hygiene)	Concept study	Theoretical success	Improper hygiene management
48	Luo, J. et al.	Edentulous patients	Monolithic zirconia IFCDPs	Maxilla vs. Mandible	97.64% (imp), 82.35% (pros)	Mandible (High risk for framework fracture)

Table/Fig 3: Characteristics of included studies and associated risk factors.

Category	Risk Factor	Impact on Long-Term Survival / Success
Lifestyle	Smoking (Tobacco)	High Risk: Most consistent predictor of failure and marginal bone loss (MBL).
	Smoking (Marijuana)	Emerging Risk: Associated with increased risk of failure similar to tobacco
Systemic Health	Diabetes (Poorly Controlled)	High Risk: Elevated HbA1c levels correlate with higher failure and infection.
	History of Periodontitis	High Risk: Significant predictor of peri-implantitis and late-stage failure.
	Radiotherapy (>50 Gy)	Moderate-High Risk: Irradiated bone (head/neck cancer) shows reduced CSR.
	Antiresorptive Drugs	Specific Risk: Risk of MRONJ, though survival can be high with protocols.
Anatomy	Residual Bone Height <3-5mm	Critical Risk: Low initial bone in sinus lift cases significantly increases failure.
	Poor Bone Quality (Type IV)	Moderate Risk: Higher failure rates due to lack of primary stability.
	Mandibular Flexure	Mechanical Risk: Causes framework fractures in cross-arch zirconia bridges.

Prosthetic	Bruxism / Parafunction	High Risk: Leads to mechanical complications and late-stage implant loss.
	High Crown-to-Implant Ratio	Moderate Risk: Disproportionate length increases stress and marginal bone loss.
	Over-contoured Contours	Biological Risk: Bulky emergence profiles hinder hygiene and cause inflammation.
Implant Size	Narrow Diameter (<3.5mm)	Moderate Risk: Higher risk of fatigue fracture and reduced bone-to-implant contact.
	Short Implants (<8mm)	Moderate Risk: Sensitive to loading protocols and bone quality.

Table/Fig 4: Major risk factors influencing long-term implant survival.

DISCUSSION

The present review highlights that long-term survival of dental implants is not determined by a single factor, but rather by the combined influence of multiple biological, behavioral, and technical variables. Across the included studies, a consistent pattern emerges in which both patient-related and treatment-related factors contribute to implant prognosis.

Among prosthetic considerations, zirconia-based restorations have shown favorable esthetics but may be associated with an increased risk of mechanical complications, particularly framework fractures under high functional stress [11,21,48]. These complications appear to be more pronounced in anatomically demanding regions such as the mandible, where biomechanical forces are greater.

Systemic health plays a crucial role in implant success. Patients receiving antiresorptive medications may be at risk of complications such as medication-related osteonecrosis of the jaw, although careful case selection can help mitigate these risks [13]. Similarly, poorly controlled diabetes mellitus, especially elevated HbA1c levels, has been associated with impaired healing and increased marginal bone loss [18,22]. Exposure to radiotherapy, particularly at higher doses, further compromises bone quality and reduces implant survival rates [20,44].

Lifestyle-related factors continue to be among the most predictable determinants of implant outcomes. Smoking, in particular, has been consistently associated with reduced osseointegration and increased risk of peri-implant disease [16,29,33]. In addition, a history of periodontitis and inadequate maintenance protocols significantly increase the likelihood of biological complications over time [23,24,40].

Surgical and anatomical factors also contribute substantially to treatment outcomes. Reduced bone quality and limited residual bone height, especially in the posterior maxilla, present challenges for achieving primary stability and long-term success [41,45]. These findings reinforce the importance of appropriate case selection and the use of adjunctive procedures when necessary.

Demographic variables such as age and sex have shown variable associations with implant survival. While advanced age and male sex have been linked to increased risk in certain studies, these factors are often influenced by underlying systemic conditions and bone quality rather than acting as independent predictors [15,26,46].

From a biomechanical standpoint, prosthetic design plays a critical role in load distribution. Factors such as high crown-to-implant ratios, occlusal overload, and prosthetic misfit can lead to marginal bone loss and mechanical complications if not properly managed [30,31]. These findings highlight the importance of prosthetically driven implant planning.

The timing of implant failure is another important consideration. Early failures are generally associated with inadequate osseointegration, often due to surgical or biological factors, whereas late failures are more commonly linked to mechanical overload, parafunctional habits such as bruxism, or peri-implant disease [44]. In addition, technical variables such as low insertion torque, reduced implant dimensions, and suboptimal surgical protocols may further increase the risk of failure [17,30].

Overall, the evidence suggests that implant success depends on a comprehensive and individualized approach. Rather than focusing on isolated risk factors, clinicians should consider the cumulative effect of multiple variables and adopt strategies that address patient-specific risks, optimize surgical outcomes, and ensure long-term maintenance.

CONCLUSIONS:

In conclusion, the long-term survival of dental implants depends on a rigorous management of biological, lifestyle, and mechanical risk factors. Systemic stability—particularly glycemic control in diabetics and the management of medication or radiation effects—forms the essential foundation for osseointegration. This foundation is frequently undermined by habits like tobacco and a history of periodontal disease, which significantly drive inflammatory complications and late-stage bone loss. Beyond patient health, technical precision is paramount; specific anatomical constraints like low residual bone height require specialized surgical protocols, while prosthetic designs must account for material limitations and mechanical stresses, such as mandibular flexure in zirconia frameworks. Ultimately, ensuring implant longevity requires a personalized, risk-stratified approach that integrates precision engineering with consistent professional maintenance and strict patient compliance.

Limitations

The limitations of this review primarily stem from the significant heterogeneity in study designs and follow-up periods, which range from short-term 3-year assessments to long-term 36-year observations. Inconsistent definitions of "success" versus "survival" across the 39 studies make it difficult to standardize marginal bone loss thresholds or biological failure criteria. Additionally, the reliance on patient self-reporting for lifestyle factors like smoking and bruxism introduces potential reporting bias, while the rapid evolution of implant technology means older results may not fully reflect the performance of modern surface treatments and CAD/CAM materials.

Conflict of Interest

None declared.

Ethical Approval

Not applicable, as this study is a systematic review of previously published data.

Acknowledgment

None.

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