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FACULDADE DE MEDICINA DENTÁRIA
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A SYSTEMATIC REVIEW

Dissertação apresentada à Universidade Católica Portuguesa
para obtenção do grau de Mestre em Medicina Dentária

Por:
Sara Alexandre Ferreira

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QUOTE

“The future belongs to those who believe in the beauty of their dreams.”

Eleanor Roosevelt

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Dedico esta dissertação de Mestrado à minha família e amigos, que sempre me apoiaram.
À minha Mãe, por sempre acreditar e me incentivar, pela compressão, amor e carinho em todos os momentos.
Ao meu pai, pelo grande exemplo, proteção e amor incondicional. Pelo apoio e por me proporcionar esta oportunidade.
À minha irmã e melhor amiga, por todos as brincadeiras e momentos passados.
Aos três um grande obrigada por serem o meu porto seguro. Sem vocês nada seria possível.
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ABSTRACT

Background: Dental implantology has advanced significantly since the introduction of osseointegrated implants, providing patients with esthetic and functional benefits that can greatly improve their quality of life. However, despite high success rates, failures can occur. While uncommon, implant fractures can have serious consequences for patients and implant removal is often necessary. Thus, a better understanding of this complication is needed in order to provide the best possible care for patients.

Aim: The aim of this study is to review the available literature related to the implant fracture risk factors and its reported incidence.

Materials and methods: A protocol based on the PRISMA guideline was used in this systematic review. An extensive research was conducted in the electronic databases PUBMED and COCHRANE, which included controlled clinical-trials and RCT´s (*Randomized Controlled Trials*) from the last 15 years.

Results: The initial research led to 457 articles (PUBMED and COCHRANE), combined with the results of the hand search, there were a total of 624 articles. After screening, full-text assessment and application of inclusion/exclusion criteria 12 articles were selected. This review found a fracture incidence between 0% and 2% on a follow-up period of 1 - 235 months.

Conclusions: Implant fractures are rare, however with severe complications. Factors such as implant location, material, design, diameter, length and prosthesis have been proposed as risk factors.

Clinical significance: Identifying risk factors related to dental implant fracture can help prevent it and it´s correspondent adverse effects.

Keywords: Dental implant, Complications, Periprosthetic fracture, Survival

RESUMO

Contexto: A implantologia dentária avançou significativamente desde a introdução dos implantes osseointegrados, proporcionando aos pacientes benefícios estéticos e funcionais que podem melhorar a sua qualidade de vida. No entanto, apesar das altas taxas de sucesso, podem ocorrer falhas. Embora incomuns, as fraturas de implantes podem ter sérias consequências para os pacientes e a remoção é muitas vezes necessária. Assim, é necessária uma melhor compreensão desta complicação para fornecer o melhor cuidado possível aos pacientes.

Objetivo: O objetivo deste estudo é rever a literatura disponível relacionada aos fatores de risco da fratura de implantes e respetiva incidência.

Materiais e métodos: O protocolo utilizado nesta revisão sistemático é baseado nas diretrizes PRISMA. Foi realizada uma pesquisa extensa nas bases de dados eletrónicas PUBMED e COCHRANE, que incluíram ensaios clínicos controlados e RCT's (*Ensaios Clínicos Randomizados*) dos últimos 15 anos.

Resultados: A pesquisa inicial resultou em 457 artigos (PUBMED e COCHRANE) que, em conjunto com os títulos encontrados manualmente deu um total de 624 publicações. Após a revisão do título e resumo, avaliação do texto completo e aplicação dos critérios de inclusão/exclusão 12 artigos foram selecionados. Esta revisão encontrou uma incidência de fratura entre 0 e 2% num período de seguimento de 1 a 235 meses.

Conclusões: As fraturas de implantes são raras, porém com complicações bastante graves. Fatores como a localização do implante, material, desenho, diâmetro, comprimento e tipo de prótese sobre o implante foram propostos como fatores de risco.

Significado clínico: Identificar os fatores de risco relacionados à fratura de implantes dentários pode ajudar a preveni-la e aos seus efeitos adversos.

Palavras-chave: Implante dentário, Complicações, Fratura Peri-protética, Sobrevivência

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LIST OF ABBREVIATIONS

TiO2: Titanium oxide

CPTi: Commercially pure Titanium

mm: millimeters

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PICO: Population, Intervention, Comparison, Outcome

RoB2: The Cochrane Risk of Bias 2

ROBINS-I: The Cochrane Risk of Bias in Non-randomized Studies of Interventions

RCT: Randomized Controlled Trial

NR: Not reported

NI: No information

I. INTRODUCTION

1. Introduction

Dental implants date back over 2 millennia in history, (1) with advancements in research and technology making them the standard of care for tooth replacement. (2)

At first, only a small number of specialists were trained in performing surgical procedures and restorations related to implants, however, as the treatment became more reliable and the advantages of the therapy became apparent over time, the demand of more acknowledgement escalated. (3)

The main indication of rehabilitating the stomatognathic system with implant-supported prosthesis was to restore the function of this system. (3,4) Currently the use of implants in modern dentistry has greatly expanded treatment possibilities in challenging cases where functional restoration was previously restricted or insufficient. (5) Innovations such as the incorporation of biocompatible materials, diverse thread geometries and implant shapes, etched-surfaces, surgical techniques, along with cutting-edge technologies, have enabled this progress. (3,6,7)

Osseointegrated dental implants are increasingly favored for aesthetic restorative dental treatments of partially or fully edentulous patients, restoring both esthetic and function. (7) Furthermore, it can be added that it has the power to restore the quality of life of edentulous patients. (8)

1.1 Osseointegration and primary stability

One of the most significant breakthroughs was achieved by Per-Ingvar Branemark by introducing the phenomenon that is known as “osseointegration”. (3) This term is defined as ‘‘a process in which a clinically asymptomatic rigid fixation of alloplastic material is achieved and maintained in bone during functional loading’’. (9) It is essentially a foreign body response, encompassing the healing of bone around the implant. (10,11)

The process of osseointegration is intricately linked to implant's surface characteristics and design. (7)

A dental implant to be considered successful has to osseointegrate, and a crucial factor for that to happen is the presence of significant primary stability during the insertion and subsequent loading of the implant, leading to an expected secondary stability. (6)

Even slight movements of the implant, lacking primary stability, can have a detrimental impact on osseointegration and bone remodeling, leading to the formation of fibrous tissues and subsequent bone resorption at the implant-bone interface. (7) Therefore, primary stability is necessary for biological integration and a strong indicator of the treatment's effectiveness. (6)

1.2 Dental implants

A dental implant is an object or material that is inserted or grafted into the bone or other tissue, such as an alloplastic substance. This is done for various purposes, including therapeutic, diagnostic, prosthetic, or experimental reasons. (1) In a standard dental implant, there is an implant body specifically designed to be surgically inserted into the bone. (7) The most frequently type used is the root-form implants which are supplemented by an abutment and a prothesis, as illustrated in Figure 1. (8)

The implant itself, also referred to as fixture, is a cylindrical metal post that is surgically placed into the osseous portion of the jaw, resembling the shape of a tooth root. An abutment can be connected to the fixture using an abutment screw, elevating it above the mucosal surface. (8) This structure is supposed to support and/or retain the prothesis, (7) which is either cemented to the implant or attached with a prosthetic screw. (8)

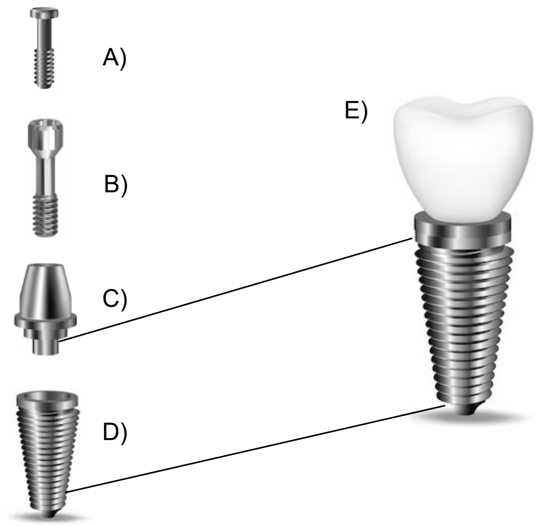

Figure 1. Implant-crown complex components: (A) Prosthetic screw, (B) Abutment screw, (C) Abutment, (D) Fixture, (E) Prosthesis

1.3 Implant materials

The study and selection of the implant biomaterials plays a crucial role in understanding how materials interact with the body and maintain mechanical integrity. (7) Emerging implant technologies that manufacture ceramic implants are currently under development. (12) Zirconia, known for its highly aesthetic white opaque color, demonstrates numerous advantageous physical and mechanical properties, including favorable fracture and corrosion resistance, low thermal conductivity, and high flexural strength. Additionally, the material offers minimal plaque adhesion, excellent tissue integration and biocompatibility. (12,13)
Metallic biomaterials are often chosen for their ability to withstand heavy loads and regular movement, being the titanium one of the most endorsed. (14) Titanium can easily experience a reaction with oxygen promoting the formation of a titanium oxide (TiO_2) layer in its surface, conferring the material resistance to corrosion. Additionally, it has characteristics such as a low density and toughness ratio, slight elasticity modulus, adequate wear behavior and biocompatibility that makes titanium the ideal and most common material for the production of dental implants. (14,15) Commercially pure Titanium (CPTi) is available in four grades (Grade I to Grade IV) based on their purity and the

amount of processing oxygen, differing in strength, corrosion resistance and ductility. (15,16)
However, pure titanium is not flawless, and therefore, titanium alloys are used. By selectively adding alloying elements to titanium, a wide variety of mechanical and physical properties can be achieved. Some alloying elements and their corresponding effects include: (16,17)

- α-stabilizers (Aluminum, Oxygen, Carbon, Nitrogen): tend to stabilize the alpha phase in a hexagonal geometry up to a temperature of 882.5ºC;
- ß-stabilizers (Cobalt, Nickel, Iron, Vanadium): stabilize the beta phase by reducing the temperature of 1688ºC;
- Certain elements (Zirconium, Tin) maintain a neutral behavior.

Ti-6Al-4V, also known as Grade V Titanium, is a α-ß combination alloy composed of 6% aluminum and 4% vanadium. This changes the way the metal interacts with cells, resulting in enhanced mechanical properties and biocompatibility. (15,16)

1.4 Complications/Failures

Despite the high success rates reported, it is important to acknowledge that failures can occur. (18) These can be divided, chronologically, into early failures, which typically arises prior to the prosthetic phase of treatment and functional loading, representing a failure to achieve osseointegration (19,20), and late failures. Late failures occur after the prosthetic phase (21) involving an implant that has already achieved osseointegration (19), but nevertheless failed to maintain it. Approximately 50% of implant losses typically occur during the later stages, with a majority happening within the first year after loading. These losses are primarily attributed to a decrease in bone support. (7)

Such failures may further be classified as biological or mechanical. (20)

1.4.1 Biologic complications

Biologic complications, such as peri-implantitis, typically involve the loss of both soft and hard tissue around the implant, which can occur as a result of an infection. (7,20) Patients may exhibit symptoms such as redness, swelling, suppuration, increased probing depth, mobility, muffled sound at percussion and painful inflammation of the tissue (peri implant mucosa) surrounding the implant, radiographically, this complication can be identified as peri-implant radiolucency. (9,18,22) This kind of tissue changes frequently take place due to poor oral hygiene, the improper usage of abutments and healing caps, the existence of empty spaces beneath the superstructure, and the absence of attached mucosa. (23) All these factors can provoke the accumulation of pathogens leading to an imbalance in the body's immune system response and consequently, the development of an infection. (22) Once the biological barrier is breached, it may result in microbial contamination and rapid deterioration of the tissues surrounding the implant. (2)

1.4.2 Mechanical complications

Mechanical issues tend to arise later and more frequently when compared to biological complications. Their impact is significantly greater due to the intricate treatment procedures involved. (7) The application of forces caused by normal or abnormal contact between natural teeth can lead to either a physiological adjustment of the attachment tissues or, if the host's adaptive capacity is exceeded, it may result in occlusal trauma. (24) Since there's a lack of micromovement and no periodontal ligament, the majority of force distribution is focused on the highest point of the ridge, resulting in mechanical complications whether related to the implant, its components or the prosthetic structure. (5,7,24) In addition, the periodontal mechanoreceptors whose function is to regulate occlusal forces through the central nervous system and feedback, are absent around an implant. (18)

Inadequate implant angulation or placement, unsatisfactory posterior support and/or surrounding bone, or the presence of implant/prothesis stress from parafunctional habits (i.e. bruxism) are all factors that contribute to biomechanics overload. (2,22) It should be noted that, usually, these complications are of a time-dependent nature leading to mechanical failures. (7)

These complications may encompass the loosening or fracturing of the prosthetic and abutment screws, along with implant fractures. (25)

1.5 Implant fracture

Based on most literature sources, the occurrence rate of dental implant fractures is minimal in the range of 0,2% to 5%. (1,4,7,19,21,23–27) Despite the low incidence, implant fractures result in a variety of invasive and intricate procedures with uncertain predictability (4) posing a challenging situation not just for patients, but also for clinicians. (25)

Potential reasons for dental implant fractures have been proposed. These include factors such as: (2,4,19,21,22,25,28)

- Flaws in the design and/or manufacture of the implant;
- Inadequate fit of the prosthetic structure;
- Excessive biomechanical or physiological load;
- Parafunctional habits (significant occlusal loading);
- Implant location;
- Implant width (higher risk for implants with <4mm);
- Metal fatigue/galvanic behavior;
- Bone resorption (by reducing the quantity of bone that supports the implant);
- Lack of prosthetic support implants;
- Prosthetic screws loosening or undergoing torsion;
- Probing depth >5mm;
- Crown-implant ratio >1.

For the onset and spread of an initial crack, a series of conditions are often present. Bone resorption and subsequent reduction in the amount of surrounding bone places an unnecessary strain on the implant, thereby causing an increase in stress levels, this being the perfect location for a crack to occur. (18) In certain cases, this can be detected radiographically as a radiolucent line is visible passing through the dense implant before a fracture is actually seen. (22)

Within the scope of the diagnosis, if a patient exhibits more than three factors listed above, the risk of fracture has been reported to be high. (21)

Figure 2. Vertical complete fracture of dental implant. Courtesy of Prof. Dr. Bruno Leitão de Almeida

The clinical management of fractured implants poses a challenge hence, complete removal of the implant is usually the treatment of choice. However, Balshi (29) proposes three methods for the management of this event:

“1. Removal of the fractured implant, replacement of the implant, and refabrication of the prosthesis;

2. Modification of the existing prosthesis leaving the fractured portion of the implant in place;

3. Modification of the fractured implant and refabrication of a portion of the prosthesis.”

Dental implant fracture is a severe and complex complication that receives scant discussion of the scientific community. A diversity of mechanisms and factors can be related to this phenomenon and manifestation signs are of various nature.

OBJECTIVES

The aims of this literature review are to report the known risk factors that can lead to dental implant fractures and their reported incidence, addressing the PICO (*Population, Intervention, Comparison and Outcome*) question: "What are the risk factors for an endosseous dental implant to fracture and what is the incidence of this complication?"

II. MATERIALS AND METHODS

2. Materials and Methods

2.1 Study and recording protocol:

Type of study: Systematic review

The protocol used in this review was based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist. (30)

2.2 PICO question:

Through the PICO (*Population, Intervention, Comparison and Outcome*) strategy it was possible to define the clinical question as well as the information needed to address it.

POPULATION: Patients that have been submitted to dental implant placement

INTERVENTION: Occurrence of fracture

COMPARISON: Dental implant does not fracture

OUTCOME: The influence of different risk factors on fracture incidence and the prevalence of this complication

FOCUS QUESTION: What are the risk factors for an endosseous dental implant to fracture and what is the incidence of this complication?

2.3 Eligibility criteria:

The inclusion/exclusion criteria defined for this study were as follows:

INCLUSION

- Human clinical studies
- Prospective and retrospective observational studies
- Outcome of dental implant fracture
- Full-text article

- Follow-up longer than 1 year
- Titanium implants

EXCLUSION

- Animal studies
- “In vitro” studies
- Case reports
- Case series

2.4 Source of information and search strategy:

In October of 2023 an electronic search was conducted in PubMed and Cochrane Databases to find published literature in the last 15 years regarding longitudinal studies that evaluated the occurrence of fracture of dental implants. In order to generate a comprehensive collection of relevant studies, additional studies were accessed by hand and citation search.

The design and setup of the search strategy were performed by two investigators who, independently, conducted the searches based on the predefined MeSH (*Medical Subject Headings*) terms.

PubMed: Dental implant [Mesh] AND Fracture [Mesh] OR Survival

Cochrane: Dental implant [Mesh] AND Fracture [Mesh] OR Survival

2.5 Study selection:

The screening process was initially focused on title and abstract selection. Following the initial sweep, full-text were read, analyzed and those who were not considered eligible were excluded.

2.6 Data extraction:

Microsoft Excel (version 1905) spreadsheets were used to summarize the extracted information. The following data was collected: nº of patients, age, gender, follow-up, nº of implants installed, implant length and width, implant material, shape and connection, nº of implants fractured, type of fracture and location of the fracture.

2.7 Quality assessment:

Risk of bias in the included longitudinal studies was assessed using *The Cochrane Collaborations Risk of Bias tool*. For randomized studies, the specific tool utilized was *The Cochrane Risk of Bias Tool for Randomized Controlled Trials (RoB 2)*. (31) In addition, for retrospective studies, *The Risk of Bias in non-randomized studies of interventions (ROBINS-I)* tool was employed. (32)

2.8 Statistical analysis:

A descriptive analysis of the registered outcomes of the sample was performed using mean values when possible.
Confounding variables and lack of comparable/reported data in the selected screened papers, did not met the requirements for meta-analysis.

III. RESULTS

3. Results

3.1 Study selection:

The initial search led to 457 articles (solely in PubMed and none in Cochrane) that, in conjunction with the manually found titles yielded a total of 624 publications. The removal of duplicates occurred prior to the screening process (n=19). After title and abstract reviewing of each study, 316 were selected, however 61 of them were not accessible for download. Out of the 255 full-text articles accessed, only 12 studies (33–44) were ultimately included in this review, the remaining articles were disregarded as they failed to meet the inclusion criteria. The following were the main reasons for the exclusion: 1: studies did not explain the reason of the implant failure/unsuccess; 2: articles were cases reports or systematic reviews; 3: the follow-up of the studies was less than 1 year; 4: the publication date did not fit in the time interval established for the research; 5: the material of the dental implants included in the studies was not titanium; 6. articles involved animal/in vitro studies.

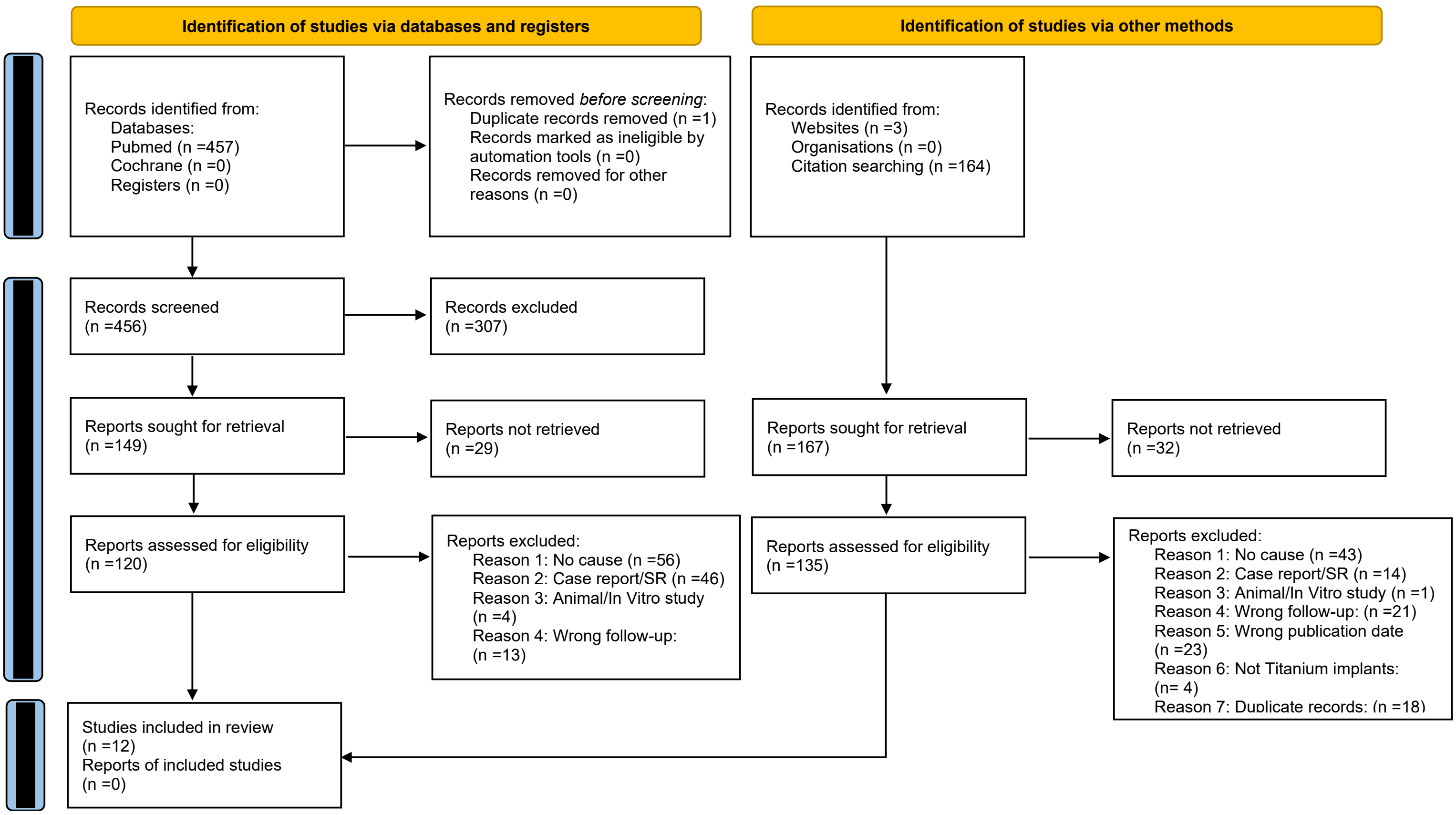

Figure 3. PRISMA *(Preferred Reporting Items for Systematic Reviews and Meta-Analyses)* flow diagram for study selection process

3.2 Data extraction and outcome variables:

The data extraction process focused on key aspects of the study, population, and dental implants engaged in the studies. Any discrepancies were resolved through discussion and collaboration between the two investigators involved in writing this review. All the collected data were recorded in predetermined tables. The following information was collected and arranged into tables:

- Core data: author, year of publication, study design;
- Population demographics: nº of patients, age mean and range (if described), gender;
- Dental implant-related information: time range and/or mean of follow-up, nº of dental implants, location of the implants in the jaw, implant material, shape, length and width;
- Main outcome: nº of fractured implants, type and location of the fracture (if reported).

3.3 Study characteristics:

Out of the selected studies, 1 was conducted prospectively, 9 were conducted retrospectively and 2 were RCT´s (Randomized Controlled Trials). The characteristics of the included studies are summarized, in chronological order, in Tables 1 and 2.

Table 1. Demographic information

Author	Year	Study Design	Nº of Patients	Mean Age (Range in years)	Gender
Gargallo Albiol et Al	2008	Retrospective study	19 *	56.9 (45 - 81) *	* Male: 15 (79%) Female: 4 (21%)
Grant et Al	2009	Retrospective study	124	56 (18 - 80)	Male: 35 (28.2%) Female: 89 (71.8%)
Manor et Al	2009	Retrospective study	194	51 ± 13 (20 - 83)	Male: 98 (50.5%) Female: 96 (49.5%)
Eccellente et Al	2011	Prospective study	45	60 (43 - 76)	Male: 27 (60%) Female: 18 (40%)
Schneider et Al	2012	Retrospective study	70	50.7 (19.8 - 76.6)	Male: 27 (37%) Female: 43 (63%)
Antoun et Al	2012	Rertospective study	44	70 (51 - 94)	Male 12 (27.3%) Female: 32 (72.7%)
Ormianer et Al	2012	Retrospective study	46	50.54 (18 - 75)	Male: 19 (41.3%) Female: 27 (58.7%)
Muller et Al	2015	RCT	47	72 ± 8 (54 - 92)	Male: 24 (51.1%) Female: 23 (48.9%)
Tabrizi et Al	2017	Rertospective study	37 *	53.18 ± 9.8 *	* Male: 27 (73%) Female: 10 (27%)
R Chrcanovic et Al	2017	Retrospective study	2670	NR	NR
			98	54.2 ± 15.7	Male: 47 (48%) Female: 51 (52%)
R Chrcanovic et Al	2018	Rertospective study	2670	NR	NR
Lago et Al	2018	RCT	100	50.5 (25 - 70)	Male: 54 (54%) Female: 46 (46%)

* Information related to fractured implants only
NR: Not Reported

Table 2. Implant information

Author	Year	Follow-Up Range (Mean)	Nº of Implants	Implant Location (Maxilla/Mandible)	Implant Location (Anterior/Posterior)	Implant Material	Shape	Length	Width	Nº of Fractured Implants
Gargallo Albiol et Al	2008	NR	1500	NR	* Anterior: 4 Posterior: 17	* Ti Grade IV: 16 Ti Grade V: 5	* Tapered: 19 Straigth: 2	10 - 15 mm *	* 3.75 mm: 20 4 mm: 1	21
Grant et Al	2009	25 months	335	Mandible	Posterior	NR	NR	8 mm	3.5 mm: 42 4.3 mm: 212 5 mm: 75 6 mm: 6	1
Manor et Al	2009	72 months	294	NR	NR	NR	NR	NR	NR	6
Eccellente et Al	2011	12 - 54 months (26.7)	180	Maxilla	Anterior: 97 Posterior: 83	Ti Grade II	Tapered	9.5 mm: 3 11 mm: 84 14 mm: 92 17 mm: 1	3.5 mm: 153 4.5 mm: 27	1
Schneider et Al	2012	56.76 - 140.4 months (74.4)	100	NR	Posterior	Ti Grade IV	Tapered: 76 Straigth: 24	11.5 mm (mean)	3.75 - 4.1 mm: 66 4.8 - 5 mm: 34	0
Antoun et Al	2012	3 - 56 months (17.6)	205	Maxilla: 79 Mandible: 125	NR	Ti Grade IV	Straigth	10 mm: 3 11.5 mm: 13 13 mm: 86 15 mm: 103	3.35 mm: 2 3.75 mm: 15 4 mm: 185 5 mm: 3	1
Ormianer et Al	2012	103 - 126.5 months (120.25)	173	NR	Anterior: 63 Posterior: 110	Ti Grade V	Tapered	10mm: 24 13mm: 125 16mm: 24	3.7mm: 129 4.7mm: 44	0
Muller et Al	2015	60 months	89	Mandible	NR	Ti Grade IV: 44 TiZr: 45	Tapered	8, 10, 12 and 14 mm	3.3 mm	0
Tabrizi et Al	2017	120 months	18.700	* Maxilla: 12 Mandible: 25	* Anterior: 2 Posterior: 35	NR	* Tapered: 23 Cylindrical: 14	* 10.86 ± 0.34 mm (mean)	* 3.86 ± 1.34 mm (mean)	37
R Chrcanovic et Al	2017	1 - 235 months	10.096	NR	NR	NR	Cylindrical or tapered	NR	NR	40
		1 - 235 months	175	Maxilla: 129 Mandible: 46	Anterior: 109 Posterior: 66	NR	Cylindrical or tapered	11 ± 1.9 mm (mean)	3.78 ± 0.23 mm (mean)	2
R Chrcanovic et Al	2018	39.9 ± 19.6 months	10.099	Maxilla: 5776 Mandible: 4323	Anterior: 6092 Posterior: 4007	Ti Grade I: 5748 Ti Grade III-IV: 4351	Tapered: 357 Cylindrical: 9640	12.7 ± 1.85 mm (mean)	3.70 ± 0.33 mm (mean)	44
Lago et Al	2018	60 months	202	Maxilla: 93 Mandible: 109	Posterior	Ti Grade IV: 100 Roxolid: 102	Straigth	8 mm: 39 10 mm: 100 12 mm: 63	3.3 mm: 16 4.1 mm: 112 4.8 mm: 74	0

* Information related to fractured implants only
NR: Not Reported

The total number of patients evaluated in the 12 studies was 6 066. Some of the included papers failed to provide information about gender and age in relation to the whole studied population. As a result, 433 women and 385 men, aged 18 – 94 years, were documented. The follow-up was between 1 and 235 months. Overall, 41 973 implants were installed, 151 were lost by fracture, depicting an incidence range of 0% to 2%. Characteristics of the fractured dental implants are showed in Table 3.

Table 3. Fractured implant information

Author	Year	Nº of Fractured Implants	Implant Location (Maxilla/Mandible)	Implant Location (Anterior/Posterior)	Implant Material	Shape	Length	Width	Type of restauration	Implant Platform
Gargallo Albiol et Al	2008	21	NR	Anterior: 4 Posterior: 17	Ti Grade IV: 16 Ti Grade V: 5	Tapered: 19 Straigth: 2	10 - 15 mm	3.75 mm: 20 4 mm: 1	Splinted partial: 19 Full: 2	Internal hex: 3 External hex: 16 Internal octagon: 2
Grant et Al	2009	1	Mandible	Posterior	NR	NR	8 mm	NR	Single	NR
Manor et Al	2009	6	NR	NR	NR	NR	NR	NR	NR	NR
Eccellente et Al	2011	1	Maxilla	Anterior	Ti Grade II	Tapered	17 mm	NR	NR	Internal hex
Antoun et Al	2012	1	Mandible	Posterior	Ti Grade IV	Straigth	13 mm	4 mm	Full	External hex
Tabrizi et Al	2017	37	Maxilla: 12 Mandible: 25	Anterior: 2 Posterior: 35	NR	Tapered: 23 Cylindrical: 14	10.86 ± 0.34 mm (mean)	3.86 ± 1.34 mm (mean)	Single: 22 Splinted partial: 15	Internal hex: 6 Conical: 31
R Chrcanovic et Al	2017	40	NR	NR	NR	NR	NR	NR	NR	NR
		2	NR	NR	NR	NR	11 ± 1.9 mm (mean)	3.78 ± 0.23 mm (mean)	NR	NR
R Chrcanovic et Al	2018	44	Maxilla: 27 Mandible: 17	Anterior: 25 Posterior: 19	Ti Grade I: 30 Ti Grade III-IV: 14	Cylindrical	NR	3 - 3.5 mm: 14 3.7 - 4.1 mm: 30	Single: 6 Splinted partial: 13 Full: 25	Internal hex: 30 External hex: 1 Conical: 7 Internal octagon: 6

Only two studies revealed the location of the fracture (*Grant et al, 2009; R. Chrcanovic et al, 2018*), being outlined fractures solely in the platform and body of the implant. *R. Charcanovic et al (2018)* found transversal fractures along the bodies of approximately 93% of all fractured implants. (Table 4)

Table 4. Location and type of the fracture

Author	Year	Nº of Fractured Implants	Type of Fracture	Location of the Fracture
Grant et Al	2009	1	NR	Platform
R Chrcanovic et Al	2018	44	Transversal: 41	Platform: 3 Implant body (threaded area): 41
Total		45	Transversal: 41	Platform: 4 Implant body (threaded area): 41

The data presented in Table 5 offers a comprehensive overview of the occurrence of implant fractures, shedding light on the success rates and implant longevity.

Table 5. Fracture incidence

Author	Year	Fracture incidence
Gargallo Albiol et Al	2008	1.4%
Grant et Al	2009	0.3%
Manor et Al	2009	2%
Eccellente et Al	2011	0.6%
Schneider et Al	2012	0%
Antoun et Al	2012	0.5%
Ormianer et Al	2012	0%
Muller et Al	2015	0%
Tabrizi et Al	2017	0.2%
R Chrcanovic et Al	2017	0.4%
R Chrcanovic et Al	2018	0.4%
Lago et Al	2018	0%

3.3.1 Implant sites

Implant location was classified according to the jaw (Maxilla/Mandible) and position (Anterior/Posterior). With regard to implantation in the jaws, 1 article studied 335 implants placed in the mandible *(Grant et al, 2009)*, in another study implants were placed in the mandibular arch (n=89) *(Muller et al, 2015)*, while in a separate study, implants were inserted in the maxillary arch *(Eccellent et al, 2011)*. *Antoun et al, 2012* related 79 implants placed in the maxillary arch and 126 implants in the mandibular arch.

Position area of the implants was exclusively identified in two papers *(Ormianer et al, 2012; Schneider et al, 2012)*. Manor et al, 2009 did not provided that information and the rest identified location with regard to both jaw and position *(R. Chrcanovic et al, 2017; R. Chrcanovic et al, 2018).* Only two of the studies revealed location of fractured implants *(Gargallo Albiol et al, 2008; Tabrizi et al, 2017)*.

Table 6. Fracture incidence in the maxilla and mandible according to the studies that identified the jaw of installed and fractured implants

Study	Jaw (Maxilla/Mandible)	Implants installed	Implants fractured
Grant et Al 2009	Maxilla	0	0
	Mandible	335	1
Eccellente et Al 2011	Maxilla	180	1
	Mandible	0	0
Antoun et Al 2012	Maxilla	79	0
	Mandible	125	1
Muller et Al 2015	Maxilla	0	0
	Mandible	89	0
R Chrcanovic et Al 2018	Maxilla	5 776	27
	Mandible	4 323	17
Lago et Al 2018	Maxilla	93	0
	Mandible	109	0
Total	Maxilla	6 128	28 (0.5%)
	Mandible	4 981	19 (0.4%)

Six studies addressed the comparison of Anterior/Posterior placement regions and the occurrence of fractures (Table 7). (34,36,37,39,43,44)

Table 7. Fracture incidence according to the studies that identified the regions of installed and fractured implants

Study	Region (Anterior/Posterior)	Implants installed	Implants fractured
Grant et Al 2009	Anterior	0	0
	Posterior	335	1
Eccellente et Al 2011	Anterior	97	1
	Posterior	83	0
Schneider et Al 2012	Anterior	0	0
	Posterior	100	0
Ormianer et Al 2012	Anterior	63	0
	Posterior	110	0
R Chrcanovic et Al 2018	Anterior	6 092	25
	Posterior	4 007	19
Lago et Al 2018	Anterior	0	0
	Posterior	202	0
Total	Anterior	6 252	26 (0.4%)
	Posterior	4 837	20 (0.4%)

3.3.2 Parafunctional habits

Two studies report on parafunctional habits (*R. Chrcanovic et al, 2017; R. Chrcanovic et al, 2018*) and 110 patients presented bruxism. In one retrospective study, 16 fractured implants out of the 446 installed occurred in patients with bruxism (*R. Chrcanovic et al, 2018*). In the study of *R. Chrcanovic et al, 2017*, 12 patients with a sum of 27 implants were found to have bruxism. Out of this patients, 4 experienced failure of 8 implants, however the specific cause (fracture or other) wasn't specified.

Table 8. Fractures in patients with bruxism

Author	Year	Nº of Patients	Nº of Patients with bruxism	Nº of Implants	Nº of Fractured Implants
R Chrcanovic et Al	2017	2 670	12	27	NR
R Chrcanovic et Al	2018	2 670	98	446	16
Total		5 340	110	473	16

NR: Not Reported

3.3.3 Periodontal status

Uncontrolled periodontal disease was present in 29 patients of a retrospective study that did not report any fractures (*Ormianer et al, 2012*). No other studies made reference to the periodontal status of individuals.

3.3.4 Implant material

The different types of titanium implants and related fractures are presented in Table 9, with the majority of implants being Grade I Titanium (n=5748) and, to a lesser extent, Titanium-zirconium (n=147).

Table 9. Fracture incidence according to the studies that identified the biomaterial of installed and fractured implants

Study	Implant material	Implants installed	Implants fractured
Eccellent et Al 2011	Titanium-zirconium (TiZr)/ Roxolid	0	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	180	1
	Grade III-IV Titanium (Ti Grade III-IV)	0	0
	Grade V Titanium (Ti Grade V)	0	0
Schneider et Al 2012	Titanium-zirconium (TiZr)/ Roxolid	0	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	100	0
	Grade V Titanium (Ti Grade V)	0	0
Antoun et Al 2012	Titanium-zirconium (TiZr)/ Roxolid	0	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	205	1
	Grade V Titanium (Ti Grade V)	0	0
Ormianer et Al 2012	Titanium-zirconium (TiZr)/ Roxolid	0	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	0	0
	Grade V Titanium (Ti Grade V)	173	0
Muller et Al 2015	Titanium-zirconium (TiZr)/ Roxolid	45	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	44	0
	Grade V Titanium (Ti Grade V)	0	0
R Chrcanovic et Al 2018	Titanium-zirconium (TiZr)/ Roxolid	0	0
	Grade I Titanium (Ti Grade I)	5 748	30
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	4 351	14
	Grade V Titanium (Ti Grade V)	0	0
Lago et Al 2018	Titanium-zirconium (TiZr)/ Roxolid	102	0
	Grade I Titanium (Ti Grade I)	0	0
	Grade II Titanium (Ti Grade II)	0	0
	Grade III-IV Titanium (Ti Grade III-IV)	100	0
	Grade V Titanium (Ti Grade V)	0	0
Total	Titanium-zirconium (TiZr)/ Roxolid	147	0
	Grade I Titanium (Ti Grade I)	5 748	30 (0.5%)
	Grade II Titanium (Ti Grade II)	180	1 (0.6%)
	Grade III-IV Titanium (Ti Grade III-IV)	4 800	15 (0.3%)
	Grade V Titanium (Ti Grade V)	173	0

3.3.5 Implant design

3.3.5.1 Shape

Table 10. Fracture incidence according to the studies that identified the shape of installed and fractured implants

Study	Shape	Implants installed	Implants fractured
Eccellent et Al 2011	Tapered	180	1
	Straigth	0	0
	Cylindrical	0	0
Schneider et Al 2012	Tapered	76	0
	Straigth	24	0
	Cylindrical	0	0
Antoun et Al 2012	Tapered	0	0
	Straigth	205	1
	Cylindrical	0	0
Ormianer et Al 2012	Tapered	173	0
	Straigth	0	0
	Cylindrical	0	0
Muller et Al 2015	Tapered	89	0
	Straigth	0	0
	Cylindrical	0	0
R Chrcanovic et Al 2018 *	Tapered	357	0
	Straigth	0	0
	Cylindrical	9 640	44
Lago et Al 2018	Tapered	0	0
	Straigth	202	0
	Cylindrical	0	0
Total	Tapered	875	1 (0.1%)
	Straigth	431	1 (0.2%)
	Cylindrical	9 640	44 (0.5%)

* The information regarding the implant shape is unknown for various implants

With regard to the shape of implants installed: 875 were tapered, 431 were straight and 9 640 had a cylindrical body shape.

3.3.5.2 Platform

The implant platform was reported in all except five studies, (33–35,41,42) as demonstrated in Table 11 below. A large number of fractures were observed in implants featuring internal hexagon platforms (n=31).

Table 11. Fracture incidence according to the studies that identified the platform of installed and fractured implants

Study	Implant platform	Implants installed	Implants fractured
Eccellent et Al 2011	Internal hex	180	1
	External hex	0	0
	Conical	0	0
	Internal octagon	0	0
Schneider et Al 2012	Internal hex	0	0
	External hex	76	0
	Conical	0	0
	Internal octagon	24	0
Antoun et Al 2012	Internal hex	0	0
	External hex	205	1
	Conical	0	0
	Internal octagon	0	0
Ormianer et Al 2012	Internal hex	173	0
	External hex	0	0
	Conical	0	0
	Internal octagon	0	0
Muller et Al 2015	Internal hex	89	0
	External hex	0	0
	Conical	0	0
	Internal octagon	0	0
R Chrcanovic et Al 2018 *	Internal hex	6 328	30
	External hex	2 783	1
	Conical	601	7
	Internal octagon	285	6
Lago et Al 2018	Internal hex	102	0
	External hex	0	0
	Conical	0	0
	Internal octagon	100	0
Total	Internal hex	6 872	31 (0.1%)
	External hex	3 064	2 (0.1%)
	Conical	601	7 (1.2%)
	Internal octagon	409	6 (1.5%)

* The information regarding the implant platform is unknown for various implants

3.3.6 Length and diameter/width

In Tables 12 and 13 is quantified the number of fractures for different lengths and diameters of implants, measured in five longitudinal studies. (34,36,38,39,44)

Table 12. Fracture incidence according to the studies that identifies the length of installed and fractured implants

Study	Length	Implants installed	Implants fractured
Grant et Al 2009	Short (≤8 mm)	335	1
	Regular (]8 mm, 13 mm])	0	0
	Long (>13 mm)	0	0
Eccellent et Al 2011	Short (≤8 mm)	0	0
	Regular (]8 mm, 13 mm])	87	0
	Long (>13 mm)	93	1
Antoun et Al 2012	Short (≤8 mm)	0	0
	Regular (]8 mm, 13 mm])	102	1
	Long (>13 mm)	103	0
Ormianer et Al 2012	Short (≤8 mm)	0	0
	Regular (]8 mm, 13 mm])	149	0
	Long (>13 mm)	24	0
Lago et Al 2018	Short (≤8 mm)	39	0
	Regular (]8 mm, 13 mm])	163	0
	Long (>13 mm)	0	0
Total	Short (≤8 mm)	374	1 (0.3%)
	Regular (]8 mm, 13 mm])	501	1 (0.2%)
	Long (>13 mm)	202	1 (0.5%)

Table 13. Fracture incidence according to the studies that identified the width of installed and fractured implants

Study	Width	Implants installed	Implants fractured
Schneider et Al 2012	Narrow (≤3.5 mm)	0	0
	Regular (]3.5 mm, 4.5 mm[)	66	0
	Wide (≥4.5 mm)	34	0
Antoun et Al 2012	Narrow (≤3.5 mm)	2	0
	Regular (]3.5 mm, 4.5 mm[)	200	1
	Wide (≥4.5 mm)	3	0
Ormianer et Al 2012	Narrow (≤3.5 mm)	0	0
	Regular (]3.5 mm, 4.5 mm[)	129	0
	Wide (≥4.5 mm)	44	0
Muller et Al 2015	Narrow (≤3.5 mm)	89	0
	Regular (]3.5 mm, 4.5 mm[)	0	0
	Wide (≥4.5 mm)	0	0
Lago et Al 2018	Narrow (≤3.5 mm)	16	0
	Regular (]3.5 mm, 4.5 mm[)	112	0
	Wide (≥4.5 mm)	74	0
Total	Narrow (≤3.5 mm)	107	0
	Regular (]3.5 mm, 4.5 mm[)	507	1 (0.2%)
	Wide (≥4.5 mm)	155	0

3.3.7 Implant prosthesis

The different types of restorations reported includes single crowns, full arch prosthesis, and splinted partial prosthesis.

Table 14 shows a correlation between higher implant fracture rates and an increasing number of teeth in the prosthesis.

Table 14. Fracture incidence according to the studies that identified the type of restauration of installed and fractured implants

Study	Type of restauration	Implants installed	Implants fractured
Grant et Al 2009	Single	75	1
	Splinted partial	255	0
	Full	5	0
Schneider et Al 2012	Single	100	0
	Splinted partial	0	0
	Full	0	0
Antoun et Al 2012	Single	0	0
	Splinted partial	0	0
	Full	205	1
Ormianer et Al 2012	Single	16	0
	Splinted partial	156	0
	Full	0	0
Muller et Al 2015	Single	0	0
	Splinted partial	0	0
	Full	89	0
R Chrcanovic et Al 2018 *	Single	1 683	6
	Splinted partial	2 971	13
	Full	5 348	25
Lago et Al 2018	Single	202	0
	Splinted partial	0	0
	Full	0	0
Total	Single	2 076	7 (0.3%)
	Splinted partial	3 382	13 (0.4%)
	Full	5 647	26 (0.5%)

* The information regarding the implant prosthesis is unknown for various implants

3.4 Results of the quality assessment

Table 15. Assessment of bias risk overall using *The Cochrane Risk of Bias 2 (RoB2)* tool

References	Randomization process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Eccellente et Al						
Muller et Al						
Lago et Al						

Table 16. Assessment of bias risk overall using *The Cochrane Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I)* tool

References	Bias due to confounding	Selection of participants	Classification of interventions	Deviations from the intended interventions	Missing data	Measurement of the outcome	Selection of the reported result	Overall
Gargallo Albiol et Al		NI			NI			
Grant et Al								
Manor et Al								
Schneider et Al								
Antoun et Al								
Ormianer et Al								
Tabrizi et Al								
R Chrcanovic et Al								
R Chrcanovic et Al								

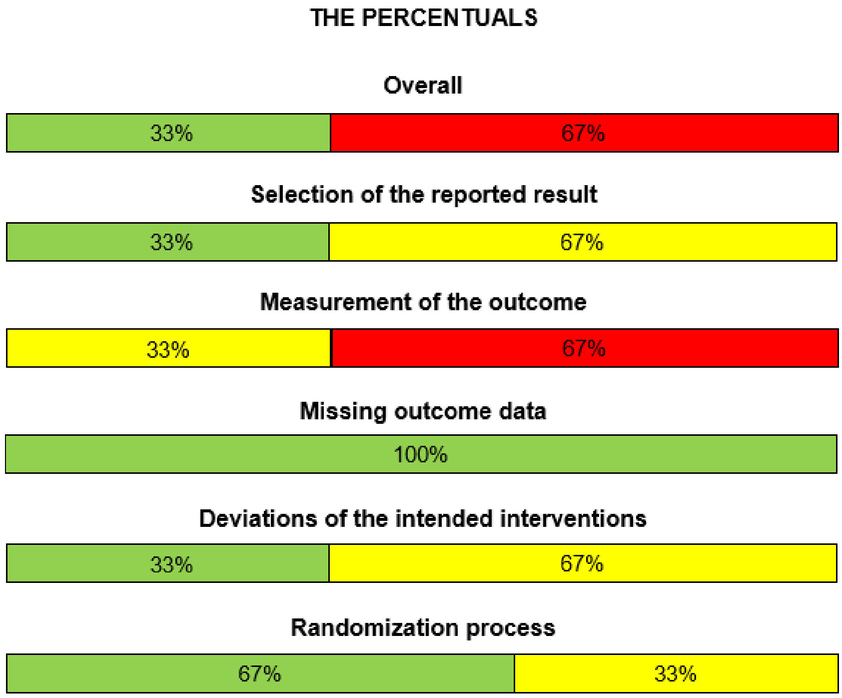

Figure 5. Percentual of assessment of bias risk overall using *The Cochrane Risk of Bias 2* (RoB2) tool

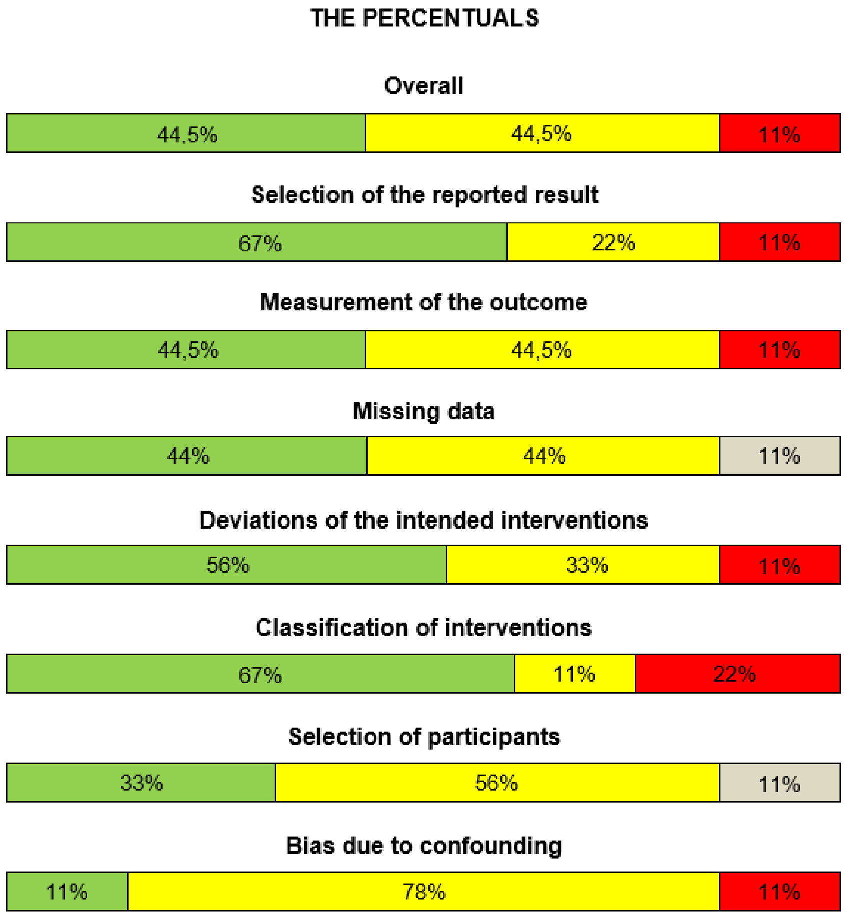

Figure 6. Percentual of assessment of bias risk overall using *The Cochrane Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I)* tool

IV. DISCUSSION

4. Discussion

The main goal of this systematic review was to collect and summarize information from published literature regarding implant fractures incidence and the factors that contribute to their occurrence. Literature reports an incidence rate ranging from 0.2% to 5%.

In this systematic review 12 studies, 6 010 patients and 41 973 implants were analyzed within a follow-up of approximately 50 months, exhibiting a fracture incidence rate of 0% to 2%, with 151 implants lost.

The research delved into studies that detailed instances of implant failures due to fracture of the implant body. Studies that showed a 100% success rate were also taken into account. Analyzed studies have shown a range between 0% and 2% in the occurrence of implant fractures, even though some studies have limited sample sizes and short follow-up periods which, for the most, happen to align with those having the fewest fractures or even none at all. (33–35,38,40,44)
In a 120-month follow-up with 18 700 implants, a fracture incidence of 0.2% was reported, with only 37 implants fractured. (41) On the other hand, *Manor et al* (35) evaluated 294 titanium implants and related a higher fracture rate of 2% over a period of 72 months.
Several factors that may increase the risk of implant fracture are described within the literature, such as: location, parafunctional habits, periodontal status, implant material, design, length, diameter and type of prosthesis.

4.1 Implant sites

Implant location, whether in the maxilla or mandible, and in the anterior or posterior regions, was found to influence implant fracture rates. The maxilla showed a higher rate of failures compared to the mandible (0.5% and 0.4% respectively), with 28 implant fractures documented in the maxilla and 19 in the mandible, alike to a study by *C. Goiato et al.* (26) This difference may be due to variables like bone density and quality, as the trabecular bone is less dense and the cortical bone is thinner, (20) as well as the biomechanical forces experienced by implants in different jaw locations. Additionally, while most fractured implants were located in the anterior area (n=26), the incidence was equal in both regions (0.4%). However, placing implants in posterior areas is reported to be a risk factor for implant failure. (20,33,39,41)

4.2 Parafunctional habits

A parafunction is characterized as an abnormal, non-physiological function (16) that can increase the risk of overload due to heightened load intensity, direction and extended duration and frequency caused by the habit. (26) Patients with habits such as bruxism or grinding are associated with mechanical and biological complications, being therefore, at a greater risk for fractures. (18,25)

In the study of *R. Chrcanovic et al* (41), an incidence rate of 3.6% for implant fracture was reported in patients with bruxism over a period of approximately 20 to 60 months. Similar correlations were found in studies reported by *A. Do et al*, *Sanivarapu et al* and *C. Gealh et al*. (17,18,25)

Hence, it is probable that these stresses could lead to the failure of an implant that is already integrated. As a result, it is crucial to manage parafunction both before and after the treatment to ensure a successful outcome.

4.3 Periodontal status

Periodontitis is a leading cause of tooth loss that often requires implant rehabilitation. (18) It affects a significant portion of the population and can be a predictor of peri-implantitis, leading to late implant failure. (7) Studies have shown a link between a history of periodontitis and inflammation at the implant site, potentially due to the transmission of periodontal pathogens. (18)

Unlike most revised literature, uncontrolled periodontal disease was found to not have influence on implant fracture in the retrospective study of *Ormianer et al*, (37) with an incidence rate of 0%. It was the only included paper that depicted the periodontal status of the participants, focusing solely on implant fracture and not addressing peri-implantitis.

Possible reasons for periodontitis not impacting the outcomes could include factors such as bone density, implant design and material composition. Titanium implants are known for their biocompatible and resistant to corrosion and degradation caused by periodontal disease. (14) Additionally, regular maintenance and care, such as dental check-ups, cleanings, and good oral hygiene practices, could help prevent periodontitis-related complications and reduce the risk of implant fracture. (18)

This highlights the complex interplay between periodontal health and implant success, underscoring the importance of comprehensive oral care in implant rehabilitation.

4.4 Implant material

Eccelente et al (36) reported that only 0.6% of 180 Grade II titanium implants experienced fractures over an average period of 26.7 months. *Antoun et al* (38) found a fracture rate of 0.5% among 205 Grade II-IV titanium implants. In *R. Chrcanovic's* study (43), involving 10 099 implants, an overall fracture rate of less than 0.5% was observed, with 30 Grade I titanium and 14 Grade III-IV titanium fractured implants. Additionally, four studies indicated a fracture incidence of zero. (37,39,40,44)

The information provided highlights the variety of materials used for dental implants and the discrepancy in the total number of implants across each parameter. Grade I Titanium is clearly the most commonly used material, closely followed by Grade III-IV Titanium. So, why is Grade I Titanium the preferred choice among professionals?

One possible explanation could be that Grade I Titanium is known for its biocompatibility, corrosion resistance and impact toughness making it a reliable choice for dental implants. It may also be more cost-effective than other grades of titanium or alternative materials. (17)

Nevertheless, it is noteworthy that Grade III-IV Titanium implants exhibited a lower risk of fracture compared to Grade I Titanium implants, with a 32.4%

reduction in probability, which is analogous to the findings of the study conducted by *R. Chrcanovic et al*. (43)

Factors that may skew our material with respect to fracture percentage is the lowest known strength of Grade I Titanium implants. (Table 17) (16)

The fact that four studies reported a fracture incidence of zero suggests that Grade IV Titanium is a particularly durable and reliable material for dental implants. This material has the highest oxygen content (0.4%), resulting in superior mechanical strength and elastic modulus. (Table 17) (15)

Overall, this information emphasizes the importance of carefully selecting the right material for dental implants and considering the specific needs and circumstances of each individual patient when choosing.

Further research and studies may be needed to explore the long-term effects and outcomes of different implant materials to better inform clinical decision-making.

Table 17. Properties of titanium alloys for dental implants, adapted from "Titanium alloys for dental implants: A review" by *W. Nicholson,* 2020, Prosthesis

Alloy	Elastic Modulus/GPa	Yield Strength/MPa	Density/g cm^{-3}
Ti Grade I	102	170	4.5
Ti Grade II	102	275	4.5
Ti Grade III	102	380	4.5
Ti Grade IV	104	483	4.5

4.5 Implant design

The goal of a well-designed implant is to securely anchor it into the bone, playing an important role in how the bone responds to the implant, as well as the occlusal forces. (5,7,27)

4.5.1 Shape

Stress distribution is influenced by the surface area, which, in turn, is determined by the implant shape. To achieve a primary stability, research studies have been conducted, leading to the conclusion that bone reacts uniquely to the various types of shapes. (5)
The data presented raises an important discussion regarding the shape of dental implants and their platform, highlighting their potential impact on fracture and failure risks. This indicates a possible correlation between implant shape and the likelihood of fracture.
Due to the tapered design of the implant, a reduced occurrence of fracture compared to straight or cylindrical shaped implants is noted. This can be attributed to variations in the quantity of each type of implants installed, considering that tapered implants account for only 8% of the total. Other factors that may influence the results include the location, follow-up, length, diameter, and so forth. *T. Steigenga et al*, also states that greater apical torque bone compression is experienced during the last turn of placement, enhancing the rigidity and stability of the tapered implant. (5)
The analysis by R. *Chrcanovic et al* (43) concluded that the majority of implant fractures occurred in cylindrical implants (n=44).

4.5.2 Platform

Anecdotal reports of internal hexagon failure resulting in fracture of the coronal part of the implant walls have been documented by *R. Chrcanovic et al* (n=3) (43). While internal hexagon implant platforms had the highest number of fractures (n=31), the literature review suggests that the fracture of an external connection may pose a comparable or potentially greater risk than internally hexed implants. (27) According to this study, conical shaped platforms and internal octagon configurations may experience earlier fractures, given their relatively higher incidence (1.2% and 1.5% respectively). This could be tied to the fact that, in these particular studies, these implants primarily supported either splinted partial or full-arch prostheses, which could have played a role as the etiological factor.

4.6 Length and diameter/width

The predictability and success of implants have been demonstrated to be influenced by factors such as the length and diameter of the fixture. (5,10,18,23)
In implantology, it is a fundamental principle that the implants used for rehabilitation should ideally have the greatest length achievable, as its increase provides better stability, resistance, healing and less mobility. (5,10)
The literature presents varying perspectives on survival rates related to implant length, as well as categorizing them as short, regular and long implants. The designation "short" for dental implants has been employed to refer to a range of 4 to 11 mm. (26) Some studies define "short" as implants with a length of 8 mm. (34) In a study by *Pardo-Zamora's et al*, implants measuring 7 and 8.5 mm were deemed as short, whereas implants with lengths equal to or greater than 10 mm were classified as standard/regular. (45)
Therefore, in this study, the following classifications were established: implants of 8 mm or less were categorized as short, those ranging from 8 to 13 mm fell under the regular category, and lengths exceeding 13 mm were classified as long.
Five studies provided data on the lengths of both installed and fractured implants. Thus, a total of 1 077 implants across three different lengths were analyzed. The most frequently used diameter fell within the range of]8 mm,13 mm] (categorized as regular), with 501 implants, one of which fractured. Short implants were less frequently installed (n=374), followed by 13mm implants or longer (n=202).
The data suggests that there is a tendency for implants of certain lengths to experience fractures, with long implants showing a slightly higher incidence (0.5%) compared to regular and shorter lengths (0.2% and 0.3% respectively). This contradicts the findings of *Pardo-Zamora et al,* who states that longer implants offer increased primary stability and more advantageous outcomes, as well as anecdotal reports of higher success rates with these implants. (45)
Three studies documented a solitary fracture, with occurrences observed in one short implant (8 mm), one regular implant (13 mm), and one long implant (17 mm), indicating similar fracture incidence rates of 0.3%, 0.5%, and 0.6% respectively. (34,36,38)

According to the findings of this systematic review, it seems that short implants can be reliable, with survival rates comparable to standard-length implants.

It can be inferred that implant diameter also plays a crucial role in implant survival. Wider diameter implants appear to yield superior outcomes compared to standard or narrower implants, which are more prone to fracture due to their lower resistance to fatigue. (10,19,28)
In the classification of dental implant diameters, the same thing as described above happens. For instance, *Muller et al* defined narrow implants as those with a diameter of 3.3 mm (40), while *R. Chrcanovic et al.* defined them as implants ranging 3 to 3.5 mm in diameter. R. *Chrcanovic et al.* also considered implants with a diameter of 3.7 to 4.1 mm to be categorized as "average size implants" and implants with a diameter of 4.2 to 5 mm as “wide”. (43)
Schneider et al. have already defined regular diameters as ranging from 3.75 to 4.1 mm and wide diameters as ranging from 4.8 to 5 mm. (37)
Although they exhibit varying ranges, overall, the values do not differ significantly. In this study, the following classifications were considered: implants of 3.5 mm or less were categorized as narrow, a range of 3.5 to 4.5 mm fell under the regular category, and diameters equal to or exceeding 4.5 mm were classified as wide.
During the assessment period ranging from 3 to 140.4 months, 107 narrow implants, 507 regular implants, and 155 wide implants were evaluated.
Within this systematic review, the greatest occurrence of fractures based on diameter was observed in 4 mm implants (0.2%), classified as regular diameter implants. *C. Gealh et al* and *Eckert et al* reported the highest prevalence of fractures in 3.75 mm implants, also falling within the category of regular diameter. (19,46)
Research has demonstrated that a decrease in implant diameter could diminish the osseointegration surface and jeopardize the mechanical integrity of the implant. Additionally, narrow diameter implants are at a higher risk of mechanical failure due to reduced fatigue resistance. (26) In another systematic review, *C. Goiato et al* supports this statement, reporting an increased number of fractures in narrow implants (3.25 mm). (26) However, there are no reported cases of narrow and wide implant fractures in our review. This is probably due to the fact

that the studies reporting the highest number of fractures do not specify the diameter of the implants. (42,43)
Overall, it can be concluded that among all implant lengths, fractures may be less common with certain widths.

4.7 Implant prosthesis

Implant-supported prostheses need to be able to withstand the specific load capacities of each patient. The choice between the types of restorations can impact the amount of stress placed on the implant, (7) which needs to be minimal and evenly dispersed in order to prevent mechanical complications. (18)
Effective prosthetic planning is essential for further reducing dental implant fracture rates (19), which is confirmed since the type of prosthesis and the number of teeth involved were also found to impact these.
Out of the 12 selected studies, only 7 provided information on the type of prothesis used in both installed and fractured implants. Within these 7 studies, 769 implants were analyzed across 3 different prosthesis configurations. The majority of patients were rehabilitated with a full prosthesis (51%), which also reported the highest number of fractures (n=26).
It is noteworthy that despite the differing study durations, a consistent pattern emerges in the data, indicating a progressive trend towards lower survival rates as the number of prosthetic teeth increases. This correlation was also noted by *J. Duyck et al* and *J. Charles et al.* (18,23) One possible explanation is that larger protheses may experience higher levels of stress and the distribution of forces could be more uneven. (5) Factors such as material and prosthetic design could also influence fracture rates, making this type of protheses might require additional attention and maintenance.
On top of that, most fractured implants supporting full prosthesis were installed in the mandibular arch, (38) contradicting the findings of *Verma et al,* that reported higher number of failures in prosthesis placed in the maxilla (n=86). (1)

4.8 Limitations of the study

While the findings of our study are promising, it is important to acknowledge that there are certain limitations that should be considered when interpreting the results. The design of the majority of studies, characterized by moderate to high risk of bias, undermines the reliability of the final results, therefore any extrapolations should be made with caution.

The primary sources of article bias are: bias due to confounding, selection of participants, classification of interventions and measurement of the outcome.

Despite addressing potential confounding factors, studies did not explicitly mention how these were identified or controlled in the analysis. This lack of clarity may introduce bias and impact the validity and reliability of the study findings regarding factors influencing implant fractures.

In terms of patient selection, most authors typically focus on healthy, non-smoking and non-bruxers individuals, that may not accurately reflect the population encountered by clinicians in their daily clinical activity.

The absence of control groups with which it is possible to make comparisons can also contribute to the weak scientific evidence of the studies, as most studies are retrospective and few are randomized controlled trials.

Regarding measurement of the outcome, most measurements relied on collecting retrospective data, with a notable absence of detailed information regarding the reliability, validity, blinding of assessors, and consistency in assessment methods.

In addition to that, some studies showed variations related to multiple parameters and others did not provide sufficient information, that deemed it to be difficult to systematically compare the reviews studies with each other. So, a descriptive yet structured and methodologically sound analysis was conducted.

Due to these grounds, it is essential to conduct additional clinical studies that thoroughly document all parameters assessed in this systematic review, specifically controlled and randomized trials. This will enhance the scientific evidence available for future systematic reviews on the subject and ultimately have a substantial influence on clinical practices.

4.9 Future perspectives

The dentist is important not only in identifying, but also in planning preventive and therapeutic strategies, in order to minimize complications and improve the longevity and functionality of dental implants and, consequently, enhance the quality of life of patients. Therefore, it is imperative that a greater understanding of these parameters is developed to reduce the risk of fracture and failure.

However further research and clinical studies are needed to understand these factors in more detail and develop strategies to reduce the incidence of implant fractures in clinical practice. It could focus on exploring patient-specific factors (age, gender and oral health habits), implant material, design, placement techniques and improved maintenance protocols.

V. CONCLUSION

5. Conclusion

- In the revised studies the fracture rate varies from 0% to 2%.

Within the limitations of this study, regarding our sample, it has been found that:

- When comparing the implant sites, more implants were lost in the maxilla. Implants placed in anterior positions had the highest rate of fracture.

- Patients with habits such as bruxism may have a greater risk for fractures.

- Grade I Titanium implants exhibited more fractures, followed by Grade II-IV and Grade II.

- The incidence of fracture was higher in cylindrical implants. Internally hexed implants also showed a higher rate of fractures.

- Incidence of fracture was comparable across the different implant lengths and implants with a width between 3.5mm and 4.5mm had higher rates of failure.

- Full-arch prosthesis resulted in a higher number of implant fractures compared to splinted partial or single crowns.

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VII. ATTACHEMENTS

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Cover
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page VII
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 9
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 10
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 14
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 15
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 15
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 15
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 16
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 21
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 21
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 16
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Page 16
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 14
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	-------
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 16
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 16
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	-------
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	-------
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Page 16
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	--------

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 20
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 20
Study characteristics	17	Cite each included study and present its characteristics.	Page 20
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 36
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Page 21
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 36
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Page 25
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	-------
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	-------
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Page 36
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	------
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 41
	23b	Discuss any limitations of the evidence included in the review.	Page 48
	23c	Discuss any limitations of the review processes used.	Page 49
	23d	Discuss implications of the results for practice, policy, and future research.	Page 49