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Original Article

Determinants of Dental Implant Prognosis: A Systematic Review of Key Influencing Factors

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ABSTRACT

Since the introduction of dental implants by Brånemark in the 1970s, they have become a widely accepted solution for replacing missing teeth from the 1970s. However, despite their success, studies show that the failure rate of dental implants can vary from 1% to 19%. These failures are classified based on the timing of the abutment connection—early failures occur before functional loading, while late failures occur after occlusal loading or following the removal of the provisional restoration in cases of immediate implant loading. Several factors contribute to bone loss around implants, categorized into systemic, social, and local influences. Among the local factors, variables such as the implant body, implant dimensions, occlusal loading, and biological properties play important roles. Structural aspects, including the type of implant-abutment connection (external hex, internal hex, conical) and the micro gap size, are also associated with bone resorption. Key determinants of marginal bone loss include smoking habits, abutment height, and bone substratum, whereas mismatching distances show minimal effect. Notably, abutment height is crucial in preserving peri-implant bone in the initial stages. Furthermore, time efficiency in digital workflows for implant-supported crowns varies depending on the choice of material. These insights provide essential knowledge to increase the longevity and success of dental implant treatments.

Keywords: Systematic review, Dental implants, Factors, Success rate.

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Introduction

Since their introduction by Brånemark, dental implants have emerged as a widely used approach for restoring missing teeth [1]. Despite their effectiveness, this treatment is not without limitations, as previous studies have reported failure rates ranging from 1% to 19% [2, 3]. Implant failures are categorized as late or early, depending on the timing of the abutment connection. Early failures occur before functional loading is applied, whereas late failures happen after occlusal loading has been introduced [4]. The inability to achieve osseointegration defines early failures, while late failures result from either insufficient osseointegration or a failure in function [5]. While early failures are primarily biological, late failures may involve both mechanical and biological complications. Peri-implantitis, characterized by soft and hard tissue loss, is a common biological consequence. On the other hand, improper implant loading design can lead to mechanical complications, such as fractures in the implant body, screw, or superstructure [4]. Poor osseointegration may cause implant instability, leading to micromovement and subsequent bone loss.

The fact is well established that every dental implant undergoes bone loss over time, which occurs in 2 phases. The extent of early bone loss depends on implant exposure duration and the nature of the prosthetic connection. Several factors influence marginal bone loss, including implant parameters such as diameter, connection type, surface modifications, and overloading, along with prosthesis-related aspects like retention methods and the number of prosthetic components [5].

Bone loss around implants is influenced by three primary categories of factors: systemic, social, and local. Local factors include the implant body, occlusal stress, biological characteristics, and implant dimensions. Structural elements affecting bone loss encompass the type of implant-abutment connection (external hex, internal hex, conical, and their variations) and the size of the micro gap between the implant and abutment. Additionally, implant design—whether one-piece, two-piece, or multi-part—along with variations in shape, length, diameter, stiffness, and surface treatments such as etching, oxidizing, sandblasting, and laser patterning, all play a significant role in the process [6]. The application of occlusal loading to implant-supported prostheses can contribute to peri-implantitis and eventual implant failure. Implant diameter primarily influences cortical peri-implant regions, which are susceptible to overloading, regardless of bone-implant contact length. However, both implant diameter and length can impact bone loss surrounding the implant [7].

While previous studies have identified peri-implantitis and implant overloading as significant contributors to late failure [8], there remains limited knowledge regarding other factors that influence the long-term stability of implant osseointegration. Research on risk factors associated with late dental implant failure has been scarce, with only one analysis in the past decade specifically addressing this issue. In contrast, most investigations have primarily focused on early implant failure [9]. Reported factors of risk for late failure include peri-implantitis, prosthesis overloading, and improper prosthesis fit [8]. However, due to the lack of detailed methodology and comprehensive reporting on selected studies, the review in question likely was more of an author's commentary rather than a systematic analysis [10, 11].

Following the PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines, the objective of this study is to conduct a systematic review of literature from the past decade to identify potential factors influencing the prognosis of dental implants.

Materials and Methods

A systematic review of the literature published between the years 2000 and 2023 was conducted using the Medline, PubMed, and ScienceDirect databases. The search process involved the use of specific keywords, including implants, prognosis, and systematic review. To ensure a structured selection of relevant studies, the PRISMA flowchart was utilized to outline the screening and inclusion process (**Figure 1**). Studies included in this review were required to be published in English within the specified time frame and to be either case-control or randomized-controlled trials. Only in vivo research conducted on human subjects was considered for analysis.

Certain types of studies were excluded from the review to maintain the focus on primary research. Systematic reviews, expert opinions, meta-analyses, and narrative reviews were not considered. Survey-based research was also excluded, along with studies that fell outside the designated publication period or were published in languages other than English. Additionally, in vitro studies were not included in the analysis.

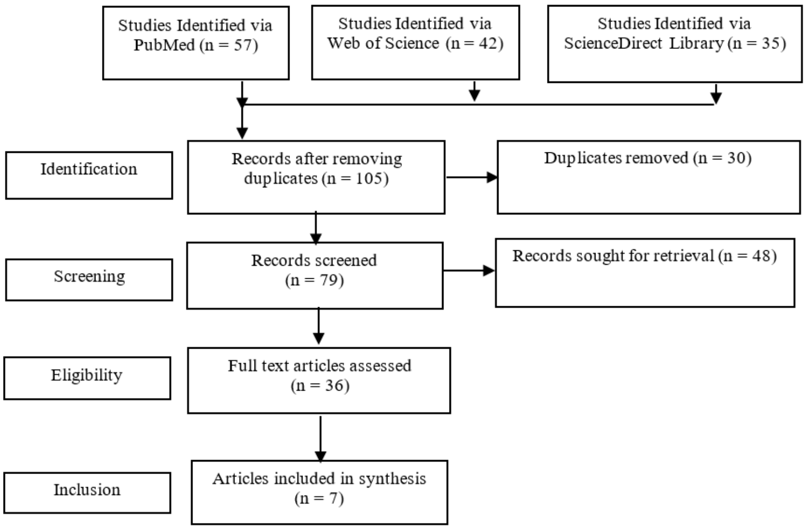

Figure 1. PRISMA flow diagram

Risk of Bias Assessment

The quality of the selected studies was assessed using the Cochrane risk of bias assessment technique. This method evaluates potential sources of bias in research, ensuring a more reliable analysis of the included studies. The findings from this assessment are summarized in **Table 1**.

Table 1. Summary of Cochrane risk of bias assessment

Study	**Selection bias (control selection and baseline similarity)**	**Randomization bias**	**Allocation concealment bias**	**Blinding bias (performance)**	**Selective reporting bias**	**Outcome assessor blinding bias**	**Confounding bias consideration**
Blanco *et al.* [7]	-	+	+	+	+	+	+
Galindo-Moreno *et al.* [8]	+	+	+	+	+	+	-
Tan *et al.* [9]	+	+	+	+	+	+	+
Jokstad and Shokati [10]	+	+	+	+	+	+	+
Schmidt *et al.* [12]	+	+	+	+	-	+	+
Cappare *et al.* [13]	+	+	+	+	+	+	+
Joda and Brägger [14]	-	+	+	+	+	+	+

Results and Discussion

Table 2. Summary of the studies with their findings

Study	Research aim	Sample size	Key variables examined	Primary conclusions
Blanco *et al.* [7]	Effect of abutment height on marginal bone loss	108 patients, 228 implants	Abutment height, smoking habits, bone quality, follow-up period, implant diameter	Short abutments, smoking, and bone quality influence marginal bone loss in both the short- and medium-term. Greater mismatch does not decrease bone loss.
Galindo-Moreno *et al.* [8]	Influence of abutment height on interproximal bone loss	22 patients, 44 implants	Abutment height	Short abutments contribute to greater interproximal bone loss after six months.
Tan *et al.* [9]	Tissue-level implant healing with different neck configurations	18 patients, 2 implants per patient	Neck design	Implants with a 1.8 mm turned neck experience less crestal bone loss after one year compared to those with a 2.8 mm turned neck.
Jokstad and Shokati [10]	Relationship between implant-prosthetic mismatch and complications	30 patients with implant-supported fixed dental prostheses	Prosthetic mismatch	The type of metal alloy used in frameworks does not significantly impact adverse events.

Schmidt *et al*. [12]	Comparison of intraoral scanners and conventional impression techniques	5 patients	Intraoral scanners vs. traditional impressions	Modern intraoral scanning systems with updated software show improved accuracy for short-span impressions, while traditional impressions maintain greater consistency over longer spans.
Cappare *et al*. [13]	Efficiency of monolithic lithium disilicate with titanium base vs. porcelain-fused-to-zirconia for implant crowns	20 participants	Crown material and production workflow	Monolithic lithium disilicate crowns combined with a titanium base in a digital workflow provide better time efficiency than porcelain-fused-to-zirconia crowns.
Joda and Brägger [14]	Treatment outcomes for monolithic lithium disilicate single-unit restorations	44 patients, 50 implant-supported lithium disilicate crowns	Monolithic lithium disilicate restorations	Two clinical appointments are sufficient for successful treatment. Lithium disilicate restorations demonstrate a 100% survival rate with no reported complications over two years.

Blanco *et al*.'s study [7] aimed to evaluate marginal bone loss (MBL) by comparing different mismatching distances in implants and analyzing how prosthetic abutment height influences MBL across these distances. This retrospective study included 108 patients with a total of 228 implants, of which 180 had a diameter of 4.5 mm and 48 had a diameter of 5.0 mm. Various patient factors were recorded, including smoking habits, gender, age, bone substratum, history of periodontitis, and prosthetic characteristics. Radiographic assessments were conducted at 6 and 18 months post-loading to track MBL progression. According to a mixed linear analysis of mesial and distal MBL values, several factors significantly impacted bone loss, including smoking, bone substratum, duration of follow-up, the interaction between abutment height and time, and implant diameter. After eighteen months, MBL was observed to be higher in implants with a 5.0 mm diameter compared to those with 4.5 mm, in grafted versus unmodified bone, and in shorter abutments compared to longer ones. These findings indicate that in the medium and short term, factors such as abutment height, smoking, and bone substratum play a crucial role in MBL, while increased mismatching would not appear to reduce bone loss (**Table 2**).

The randomized clinical trial by Galindo-Moreno *et al.* [8] investigated how different abutment heights (1 mm and 3 mm) in bone-level implants with a platform-switched design impact interproximal bone loss (IBL). The study involved 22 patients who received 44 implants, ranging from 6.5 to 10 mm in length and 3.5 to 4 mm in diameter, to replace at least 2 adjacent missing teeth. Each participant received one implant-supported bridge, with 2 implants per bridge. Patients were randomly assigned to receive abutments of either 1 mm or 3 mm in height, with each bridge containing abutments of only one height. Clinical and radiographic evaluations were performed at 3 and 6 months post-surgery. Analysis of IBL revealed that clinical variables and patient characteristics showed no significant correlations, except for smoking, which had a measurable impact. The study confirmed that abutment height plays a crucial role in preserving implant bone levels in the early healing stages. After six months, patients with shorter abutments exhibited greater interproximal bone loss compared to those with longer abutments.

Tan *et al.* [9] conducted a study to explore how different neck designs of tissue-level implants influence the remodeling of soft and hard tissues after at least one year of functional load. Eighteen patients, each with multiple missing teeth in the same sextant, received 2 implants per patient. One implant (the control group) had a turned neck measuring 2.8 mm, while the other (the experiment group) had a 1.8 mm turned neck. Both implants were placed transmucosally with a sink depth of approximately 1.8 mm. The study found that, after one year, 50% of the test implants had crestal bone levels 1-2 mm below the implant shoulder, compared to only 5.6% of the control implants. Implants with the 1.8 mm turned neck demonstrated less crestal bone resorption, preserving more bone around the implant than those with the 2.8 mm turned neck. Additionally, other factors, such as the vertical orientation and rough SLA surface of the implant, also influenced crestal bone levels after one year of use.

Jokstad and Shokati's [10] study examined the impact of implant-prosthetic mismatch on long-term biological and mechanical complications in patients with implant-supported fixed dental prostheses (FDPs) placed in the edentulous jaw. The study involved 30 patients who had received implant-supported prostheses in their edentulous mandibles before 2000. Each patient had between 4 and 6 implants placed to support an acrylic FDP, and three types of metal alloys

(Pd-Ag, Ag-Pd, and Au type IV) were used for the frameworks. Throughout the study, 14 patients experienced at least one complication, such as screw loosening, abutment failure, or prosthetic screw fractures. The analysis, using Fisher's exact test, showed that the frequency of complications did not differ significantly between the metal alloys used ($P > 0.05$).

In Schmidt *et al.*'s [12] clinical investigation, the accuracy of four modern intraoral scanners (IOS) equipped with the latest software versions was compared with traditional impressions (CVI). The study involved five patients, each of whom provided a traditional impression alongside digital scans using four IOS models: Trios3Pod, Trios3Cart, Trios4Pod, and Primescan. The scan data were analyzed using a three-dimensional measurement conventional model and tools. Statistically significant differences were assessed with a P-value < 0.05. The results indicated that the current IOS devices, featuring the latest software, showed reduced deviation for short-span distances when compared to traditional impressions. However, the traditional method showed less variation in larger span distances. This study highlights that modern IOS systems have improved the accuracy of patient transfer for full-arch scans, offering a more efficient alternative to conventional impression techniques.

Cappare *et al.*'s [13] randomized controlled trial aimed to compare the time efficiency of two materials for implant crowns in a digital workflow: porcelain fused to zirconium dioxide (ZrO_2) and monolithic lithium disilicate (LS2) with a titanium base. The study involved 20 patients who required single-tooth replacements at premolar and molar sites. All participants received screw-retained implant reconstructions on soft tissue-level implants. Implant positioning was recorded using intraoral optical scanning (IOS). Two clinical visits were sufficient to fit the crowns and perform the IOS. The results showed that the LS2 and titanium base crowns had a significantly shorter production time, with an average of 75.3 minutes, compared to 156.6 minutes for the ZrO_2 crowns, with a P-value of 0.0001.

In the study by Joda and Brägger [14], the goal was to assess a fully digital approach for monolithic lithium disilicate (LS2) single-unit restorations. This prospective clinical study included 44 patients, with 50 screw-retained monolithic LS2 crowns placed on prefabricated titanium abutments at premolar and molar sites. The crowns were digitally designed through intraoral optical scanning (IOS) and CAD/CAM processing. The "Functional Implant Prosthodontic Score" (FIPS) was used to evaluate outcomes after two years of loading. The study showed that all patients were treated in just two visits, with no adjustments needed for the crown seating. After two years, the survival rate of the LS2 restorations was 100%, with no complications. The FIPS scores ranged from 6 to 10, with an average of 7.7 ± 1.0.

A review of different studies on factors influencing the prognosis of dental implants highlights several key insights. It reveals that abutment height, smoking, and bone substratum are significant factors affecting marginal bone loss, while mismatching distances do not have a notable effect. Abutment height is particularly important in maintaining bone stability around the implant during the early stages. In terms of digital workflows for implant crowns, the time efficiency varies considerably depending on the materials used. These findings provide crucial guidance for optimizing the longevity and success of dental implant procedures.

Earlier studies have demonstrated the impact of scan routes on the accuracy of full-arch scans [15-19]. Lately, Passos et al. found that a more complex scanning approach can improve accuracy. However, it remains unclear how much knowledge practitioners need regarding various scanning paths or how to select the optimal path for a particular scanner. To enhance compatibility with the IOS system, a consistent scan route was maintained [20]. Only two studies have focused on full-arch impressions in patients using a reference [10, 21, 22], making it challenging to compare our findings with existing literature. Most studies have superimposed datasets of digital scans and models derived from traditional impressions using a best-fit approach [9, 23]. However, this method allows for a comparison of 2 digital data sources but does not address whether an individual's real conditions match the digital information. It remains uncertain whether compensation computations, like the best-fit approach, eliminate discrepancies between the datasets [21]. Previous research by O'Toole et al. examined various alignment techniques and recommended reference alignment to minimize measurement errors [24-26].

Restoring edentulous or partially edentulous jaws with osseointegrated implants is a complex process for both patients and clinicians. Scientific progress has led to a consensus that less invasive treatments, such as combining axial and non-axial implants with rapid loading techniques, may be preferable over more invasive procedures like bone grafting. These alternatives help minimize complications, reduce costs, and improve patient acceptance [4, 27]. The limitations of bone quality can be addressed with these rehabilitation strategies, particularly in the maxillary and posterior regions. The benefits of this approach, including its minimal invasiveness, quicker functional and aesthetic outcomes [1], and shorter overall treatment times [5], align with patient expectations. In contrast, the traditional method of implant prosthetic rehabilitation once considered the gold standard, involves multiple manual phases, dental specialists, and impression materials prone to dimensional inconsistencies [6].

A literature review [7] highlighted that the primary factor influencing the fit of implant structures is the accuracy of the impression, which is affected by the type of impression material, the method used, implant angulation, and the number of implants. The long-term success of an implant-supported prosthesis relies heavily on achieving a precise fit [8]. Any errors in the framework fit can lead to biological complications and mechanical problems, such as screw loosening or breakage, which could ultimately affect the uniformity of the occlusal load [8, 9].

The results of this radiographic study challenge the hypothesis that larger horizontal mismatching distances would lead to reduced marginal bone loss (MBL). One notable finding was the implants with larger diameters (5.0 mm) exhibited greater MBL compared to those with smaller diameters (4.5 mm), particularly when the abutment height was 2 mm or more. When data from implants of both diameters were combined, it became clear that abutment height significantly influenced peri-implant MBL, with greater loss observed when the abutment height exceeded 2 mm, which aligns with other studies. Although some bone loss after the prosthesis is placed is expected due to biological width, recent studies suggest that bone loss greater than 0.45 mm six months post-loading is a clear indicator of ongoing bone resorption, regardless of its cause. This underscores the importance of clinicians taking all possible measures to minimize initial MBL [25, 28, 29].

Recent studies have shown that platform switching did not prevent marginal bone resorption in cases with thin mucosa. To address this, our analysis focused only on patients with at least 3 mm of mucosal thickness at the surgical site. Research suggests that implant-abutment contact plays a significant role in marginal bone changes [30-32]. The bacterial colonization of internal surfaces and the micro-gap in external abutment connection implants may contribute to the presence of pathogens in these areas. The formation of biological width leads to an expected infiltration of inflammatory cells and subsequent bone remodeling. However, implants with internal abutment connections, such as those used in this study, have been shown to effectively mitigate these issues [33, 34].

In this study, clinical and radiological outcomes did not show significant differences between the experiment and control sites due to the randomization of patients. This provided an ideal setting for assessing postoperative bone loss in the randomized controlled trial (RCT). The bone loss observed in the Straumann implants in this study was consistent with findings from other studies using the same implant system. Additionally, the clinical trial examining the impact of increased sink depth showed similar radiographic bone loss when compared to the control conditions in the current investigation [35, 36].

Many researchers have attempted to measure the gap between the abutments and framework to assess the impact of mismatches in clinical settings. Since evaluating the internal stress distribution within both the implants and superstructure is not feasible, this process is mainly driven by practical considerations. It has been proposed that vertical gaps as narrow as 100 micrometers can be effectively filled once the retaining screws are tightened. Standard techniques used to evaluate vertical gaps between the abutments and framework should more accurately capture the internal stress within the superstructure. A modern solution to this challenge involves using a 3D intra-oral scanner paired with a lab scanner and specialized software that computes the differences between virtual 3D models of the framework and abutments [37].

In the current study, the total misfit of the fixed dental prosthesis (FDP) on the supporting implants ranged from 95 to 232 micrometers. Despite an average follow-up period of 19 years, no correlation was found between the degree of marginal bone loss and the mismatch. It remains unclear how much static stress the non-passive superstructures might have exerted on the surrounding bone and implants. One possibility is that the artificial gold screws may have absorbed some of this stress [38].

Many studies have relied on superimposing datasets from digital scans and conventional impressions using a best-fit approach. While this setup allows for a comparison of the two data sources, it doesn't address whether the digital information aligns with the patient's actual condition. Furthermore, it is still uncertain whether using compensation techniques like the best-fit method resolves any discrepancies between the datasets [23]. In this study, digital impressions proved more accurate than traditional impressions for shorter distances in the posterior segments (D1_2 and D3_4), which aligns with the findings of Keul *et al.* [23].

However, Ender *et al.* [21] found that the conventional impression (CVI) technique provided the highest accuracy, even for small distances. Although more accurate results were obtained for short spans, these findings are consistent with previous research, indicating greater accuracy for short-term spans. This could be due to an increase in matching or stitching errors over longer scan durations [38, 39]. For longer spans, including those covering the entire quadrant (D1_4), the CVI technique showed better precision and trueness, supporting earlier findings [3, 10]. The Trios 3 Pod and Primescan scanners used in this study exhibited greater overall deviations compared to laboratory results from Ender *et al.* [21] and Torres-Alemany *et al.* [40]. This difference could be attributed to the in vivo setting, varying evaluation methods (such as percentiles), and environmental factors like oral structures, saliva, and patient movement that may have impacted accuracy [39].

Time efficiency is a critical consideration in everyday clinical practice, with patients increasingly seeking high-quality care that is also convenient. This often translates to fewer visits and shorter treatment times. The primary focus of the economic comparison between two workflows for implant crown production—"monolithic LS2 with titanium base" and "porcelain fused to ZrO2"—was to assess time efficiency. The findings from this randomized controlled trial (RCT) favor the monolithic LS2 with titanium base method, as it significantly reduced the overall time required for both clinical and laboratory stages. This supports the hypothesis that using monolithic LS2 with a titanium base leads to a faster workflow compared to porcelain fused to ZrO2. Interestingly, there is a lack of prospective or retrospective studies in dental literature that analyze digital implant workflows with a focus on time efficiency, with only two studies assessing implant prosthetic procedures from this perspective [40].

The use of monolithic crowns attached to prefabricated abutments streamlines the treatment process for implant-supported single-unit restorations. The procedure begins with intraoral optical scanning (IOS) and proceeds digitally, eliminating the need for physical models. With the digital data in hand, the entire process becomes completely "digital." Standardized manufacturing ensures material-specific benefits, simplifying labor-intensive tasks in the laboratory. The quality of the prosthodontic treatment is heavily influenced by the specific digital protocols and technologies, including the IOS device and subsequent data processing. Both technicians and clinicians must be well-trained in the relevant software programs and applications. While the restoration's expansion is limited, the precision of IOS in single-unit restorations is well-established. However, there remains ongoing debate about which CAD/CAM material is optimal for monolithic implant restorations [40].

On the flip side, these materials must withstand significant loading forces, increasing the likelihood of wear on opposing teeth, particularly natural ones. Additionally, the aesthetic demands of monolithic implant restorations, especially in the aesthetic zone, must meet high standards, regardless of the materials available. Standardized protocols offer advantages in terms of workflow efficiency, predictability, and simplicity, but creating customized aesthetics using full digital techniques can be challenging. Early in vitro experiments on monolithic implant restorations have shown promising results. These laboratory studies demonstrated consistent stiffness and strength values for prefabricated titanium abutments combined with hybrid ceramics and LS2 superstructures. Notably, the strength of these materials exceeded the average occlusal force exerted by naturally dentate patients under quasistatic loading.

The functional implant prosthodontic score (FIPS) was used in this study to evaluate all clinically and radiographically significant aspects of fixed implant restoration in a straightforward manner. In these preliminary tests, neither the hybrid ceramics nor LS2 exhibited any signs of loosening at the bonding connection [41]. This innovative approach shows potential as an additional tool for evaluating patient satisfaction, identifying early treatment failures, and comparing follow-up results. A prosthodontist oversaw every phase of the surgical planning and follow-up in this study. Further clinical trials are necessary to reassess and, ideally, validate the use of FIPS. It would be valuable to conduct a trial examining the repeatability of FIPS across various specialized practitioners to better understand the benefits and limitations of this new scoring method [42, 43].

Conclusion

In conclusion, the height of the abutment plays a critical role in maintaining implant bone during the initial stages. The efficiency of digital workflows for implant crowns shows considerable variation depending on the materials used. These insights are crucial for enhancing the effectiveness and durability of dental implant treatments.

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