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Risk Factors for Early Dental Implant Failure and Corresponding Clinical Management Strategies: A Systematic Review

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ABSTRACT

Early dental implant failure (EIF) is a multifactorial phenomenon. This systematic review aims to identify the key risk factors for EIF and to propose evidence-based clinical management strategies. The results indicate that patient-related factors (e.g., diabetes, smoking) are associated with a 2- to 3-fold increase in the risk of early failure. Local anatomical factors (such as placement in the anterior maxilla or the use of short implants) may lead to variations in failure rates ranging from 18% to 40%. Surgical procedural errors (e.g., bone temperature exceeding 47°C during osteotomy) can raise the failure risk by approximately 50%, whereas prophylactic antibiotic use may reduce it by about 60%. Based on current evidence, we propose a comprehensive four-dimensional preventive framework, which includes:(1) strict patient selection criteria (e.g., requiring HbA1c <7% and smoking cessation for at least 4 weeks preoperatively); (2) precise anatomical evaluation (e.g., utilizing cone-beam computed tomography for bone density analysis); (3) standardized surgical protocols (including limiting the number of implants placed per session and carefully controlling bone temperature during osteotomy); and (4) individualized healing protocols (prioritizing submerged healing for high-risk cases). Clinical evidence suggests that the implementation of this comprehensive management strategy can achieve an early implant survival rate exceeding 97%, thereby laying a solid foundation for long-term restorative success. This study provides clinicians with a systematic decision-making framework to reduce early implant failure rates, emphasizing the necessity of thorough preoperative assessment and enhanced diagnostic skills for improving implant outcomes.

Keywords: Early implant failure; Risk factors; Diabetes mellitus; Osteoporosis

INTRODUCTION

Since Brånemark introduced the theory of osseointegration in the 1970s, implant restoration has become one of the primary treatment modalities for partial and complete edentulism [1]. However, during the early healing period following implant placement, the implant-bone interface may fail to achieve optimal osseous integration due to various interfering factors, potentially leading to a failure of osseointegration and implant loss. Early Implant Failure (EIF) is defined as failure occurring before the implant is subjected to functional loading (i.e., during the bone healing period).

Currently, the precise pathophysiological mechanisms underlying failed osseointegration in EIF have not been fully elucidated [2], and a consensus on its definitive risk factors has yet to be established. Reported incidence rates of EIF vary considerably, ranging from approximately 0.76% to 7.47%, with a relatively rapid progression; approximately30% of early failures occur within the first month after placement [3,4].

In the context of increasing global demand for dental implants, a deeper understanding of EIF risk factors and enhanced pre-operative risk assessment are crucial. Therefore, conducting a comprehensive pre-operative patient evaluation and formulating an individualized implant treatment plan are paramount. This article aims to provide a systematic review of the factors influencing early implant failure.

Patient-Related Factors

Systemic Factors

Sex and Age

Current evidence regarding the association between sex and implant failure risk remains inconsistent. Some studies suggest that female patients may be more susceptible to early failure, potentially related to estrogen level fluctuations affecting bone metabolism [5]. However, other studies have found no significant correlation between sex and implant failure rates [6]. Overall, the factor of sex likely requires comprehensive evaluation in conjunction with other variables (e.g., hormonal status, bone quality) and should not be used as a definitive, standalone risk indicator.

Similarly, evidence regarding the impact of age on early implant failure is divergent. Some studies have reported that younger patients might exhibit a higher early failure rate, potentially due to premature loading or differences in bone metabolism activity shortly after implantation[6], suggesting that appropriately extending the healing period could help improve initial survival rates. On the other hand, older patients often present with multiple systemic conditions or physiological bone loss, which may also increase implantation risks [7]. Nevertheless, studies have shown that for patients over 65 years old, implant success rates can remain high (e.g., 95.39%) provided systemic conditions are strictly managed and implant selection is optimized [8]. Currently, high-quality research directly comparing early implant survival rates between young and elderly patients is relatively scarce. However, it is generally accepted that age itself is not a significant independent factor affecting the success of osseointegration. Therefore, advanced age should not be considered an absolute contraindication for implant therapy. However, given the potentially more complex systemic health status of elderly patients, a more thorough medical evaluation and risk management are essential during the pre-operative phase. Therefore, while age should be considered in the overall risk assessment, it is not a contraindication to implant therapy per se.

Osteoporosis and Diabetes Mellitus

The impact of systemic diseases on implant osseointegration primarily involves potential interference with local wound healing and a reduction in the bone's repair and remodeling capacity. Well-established risk factors for implantation include a history of head and neck radiation therapy, poorly controlled diabetes mellitus, bleeding and coagulation disorders, and long-term regular use of bisphosphonates. It is noteworthy that these risk factors have not fundamentally changed over the past few decades, nor have their associated risk levels significantly decreased despite advancements in implant design and surface technology.

Osteoporosis (OP) is a systemic metabolic bone disease characterized by reduced bone mass and deterioration of bone microarchitecture, clinically prevalent in postmenopausal women aged 50-75. The influence of OP on implant therapy manifests mainly in two aspects: On one hand, decreased bone density may directly affect the primary stability achieved at the time of implant placement [9,10]. On the other hand, bisphosphonates, commonly used to treat OP, are associated with an increased risk of medication-related osteonecrosis of the jaw (MRONJ), indicating that implant surgery in these patients requires particular caution [11]. Other studies have suggested a potential association between the duration of oral bisphosphonate therapy and the risk of implant failure [12]. The 2022 American Association of Oral and Maxillofacial Surgeons (AAOMS) expert consensus notes that the overall risk for patients on oral bisphosphonates is considered low but necessitates individualized assessment [13]. There is currently no unified clinical standard regarding whether to discontinue bisphosphonates prior to implant surgery, and decision-making requires a careful risk-benefit analysis.

In addition to osteoporosis, diabetes mellitus (DM)is another common metabolic disorder that significantly impacts implant treatment through multiple mechanisms related to chronic hyperglycemia: (1) Metabolic effects: Persistent hyperglycemia can inhibit osteoblast activity and promote osteoclast activity, thereby compromising osseointegration capacity [14]. (2) Infection risk: Hyperglycemia-induced immune dysfunction and microangiopathy significantly increase the patient's susceptibility to post-operative infections [15]. Key clinical management strategies include: Strict glycemic control (HbA1c <7%) as a fundamental prerequisite [16]; the routine recommendation of prophylactic antibiotics (e.g., 2g amoxicillin orally 1 hour pre-operatively) [17-19]; and consideration of an intensified antibiotic regimen (e.g., combined pre- and post-operative administration) for high-risk patients (e.g., immunocompromised, those undergoing extensive bone grafting) [20]. Studies confirm that prophylactic antibiotic use can reduce the risk of early failure by 2- to 3-fold [21], though the specific protocol should be stratified according to individual patient risk.

Local Factors

Periodontitis

A significant association exists between periodontitis and early implant failure, primarily mediated through three mechanisms. First, the influence of bacterial biofilm: periodontitis-specific pathogens in the patient's oral cavity may colonize the surface of newly placed implants via direct contact or hematogenous spread, interfering with the osseointegration process. A meta-analysis indicated that patients with periodontitis have an approximately 69% higher implant failure rate compared to those with periodontal health [22]. Second, the chronic inflammatory state induced by periodontitis persistently activates osteoclasts and may simultaneously inhibit osteogenic differentiation. This immune microenvironment, unfavorable for bone healing, can delay peri-implant bone regeneration, clinically manifesting as a higher rate of early implant mobility. Particularly for patients with aggressive periodontitis, the risk of implant failure is significantly elevated, potentially stemming from the trans-tooth-implant transmission of periodontal pathogens [23]. Finally, severe periodontitis is often accompanied by substantial alveolar bone loss and soft tissue defects. This not only compromises the primary stability of the implant but also easily creates a biological environment detrimental to the long-term survival of the implant. Prospective studies have confirmed that patients with uncontrolled periodontitis exhibit 2.3 times greater marginal bone loss around implants compared to the healthy group [22]. Research has also demonstrated that the microbial composition associated with peri-implantitis is highly similar to the microbial profile of periodontitis around natural teeth [24, 25]. Therefore, comprehensive periodontal therapy and the establishment of a long-term, stable plaque control regime are imperative prerequisites before planning implant treatment for patients with periodontitis.

Implant Site and Bone Density

The relationship between the implant site and the early failure rate demonstrates distinct anatomical variations. Multiple studies indicate that the early failure rate of implants in the maxillary anterior region is typically higher than in other sites [26]. The maxillary posterior region also carries a relatively high failure risk due to anatomical characteristics such as thinner cortical bone, relatively porous trabecular bone, and the frequent need for complex procedures like sinus floor elevation [27]. Findings regarding the mandible are inconsistent: some studies suggest a higher failure rate in the mandibular anterior region, potentially due to overly dense bone affecting blood supply, whereas others report that the overall failure rate in the mandible may be comparable to or slightly different from the maxilla[6]. Of particular importance is that abnormal bone density (such as Lekholm and Zarb class 1 dense bone and class 4 porous bone) can increase the risk of failure by compromising primary stability [28]. These findings highlight the critical need for thorough pre-operative radiographic assessment (e.g., using CBCT), focusing on key indicators like bone density classification and cortical bone thickness. Surgical protocols should be adjusted according to regional anatomical characteristics-for instance, considering bone condensation techniques in the maxillary posterior region or modifying osteotomy protocols in the dense mandibular anterior area-to optimize primary implant stability and thereby reduce the risk of early failure.

Status of Adjacent Teeth

The early success of an implant is closely related to the periodontal and periapical health of adjacent teeth. Clinical studies show that the prognosis is directly influenced by the condition of neighbouring teeth: the risk of early implant failure increases significantly when the distance between the implant and an adjacent tooth is less than the recommended safe distance of 2 mm, or if the adjacent tooth has uncontrolled active periodontitis or periapical pathosis [29]. The primary reasons include: 1) Periodontal pathogens from the adjacent tooth may spread via biofilm, inducing inflammation in the peri-implant tissues; 2) Inflammatory mediators from a periapical lesion can interfere with the osseointegration process in the adjacent area; 3) An insufficient inter implant distance can violate the biological width, compromising soft tissue health. It is noteworthy that although the failure rate for implants adjacent to natural teeth (7.2%) is slightly higher than in edentulous spans (5.8%), this difference may not reach statistical significance [29]. To mitigate risks, it is essential to: 1) Ensure the periodontal health of adjacent teeth, or confirm that endodontic treatment is sound and stable after an adequate observation period; 2) Meticulously maintain a minimum safety distance of 2 mm between the implant and the adjacent tooth during planning; 3) Complete systematic periodontal therapy and establish a stable periodontal condition for adjacent teeth with pre-existing issues before implant placement. These measures are crucial for preventing early implant failure associated with the status of adjacent teeth.

Habitual and Behavioral Factors

Patient lifestyle habits significantly impact early implant survival rates. Multiple studies consistently identify smoking as a key risk factor for early implant failure, with smokers facing up to a 6-fold increased risk of EIF compared to non-smokers [30]. The primary mechanisms likely involve nicotine-induced vasoconstriction, reduced local blood supply, and inhibition of osteoblast activity, all of which severely impede the osseointegration process. Furthermore, chronic excessive alcohol consumption has also been demonstrated to interfere with normal healing and increase the risk of early failure. Patients' post-operative oral hygiene maintenance is equally critical; studies show that failure to adhere to effective oral cleaning significantly increases the incidence of peri-implantitis. Therefore, comprehensive patient education and behavioral interventions are strongly recommended during the pre-operative phase. These include strongly advising smoking cessation for at least 4 weeks prior to surgery, controlling alcohol intake, and establishing and practicing good oral hygiene habits. These measures have been proven to significantly reduce the incidence of EIF [31].

Surgery-Related Factors

Surgical Procedure

Surgical technique is a critical determinant of early implant osseointegration success, with several core aspects requiring meticulous control. The first critical aspect is temperature management. Due to the thermal sensitivity of bone tissue, experimental studies have shown that sustained bone temperatures exceeding 47°C for one minute can lead to necrosis, while temperatures above 60°C for one minute may cause irreversible osteocyte damage [32]. Consequently, effective cooling measures are mandatory during surgery, such as using sharp drills, employing an intermittent pecking motion drilling technique, and utilizing copious, continuous irrigation with sterile saline [33].

Another key factor is operative time control. Research indicates a positive correlation between surgical duration and failure rate, with infection risk increasing by 1.8 times for every additional 30 minutes of surgery time [34]. Finally, the number of implants placed is significant; placing multiple implants (≥4) in a single session is linked to a 2.3-fold increase in the early failure rate [35-37]. It is therefore advisable to limit single-session surgery to a maximum of 3 implant sites. For complex cases, a staged approach is recommended. Utilizing sequential drilling in high-density bone and establishing standardized protocols are suggested standardized protocol measures that can reduce the early failure rate by up to 40% [33]. It must be emphasized that the surgeon must strike a balance between operative efficiency and precision, avoiding any compromise of the implant's primary stability in the pursuit of speed.

Implant Selection

The choice of implant system and the design of implant specifications exert a certain influence on early success rates. Regarding implant systems, long-term clinical follow-up studies of mainstream brands (e.g., Dentium, ANKYLOS, Straumann) have shown favorable 10-year survival rates, consistently within the 93%-96% range, with no statistically significant differences in early survival rates among brands [38-40]. The impact of implant geometric parameters is more complex: 1) Diameter factor: A "dual-risk zone" phenomenon exists. Narrow-diameter implants (e.g., <3.75mm) may be associated with a higher early failure rate due to a relatively reduced bone-to-implant contact area, while overly wide diameters might cause bone damage from excessive osteotomy [41, 42]. 2) Length factor: A "critical value effect" is observed. Multiple studies indicate that shorter implants (particularly <10mm) carry a relatively increased risk of EIF [30]. One study noted that short implants (<10mm) could have a 5.8-fold increased EIF risk, with the risk rising by 16% for each 1mm decrease in length [43, 44]. This risk requires careful assessment, especially in cases with insufficient bone height (e.g., <7mm in the maxilla or <5.5mm in the mandible) [45]. These findings suggest clinicians should avoid extreme implant dimensions. For cases with specific anatomical limitations, priority should be given to improving bone conditions via bone augmentation procedures rather than relying excessively on implants with extreme dimensions to gain restorative space.

Choice of Healing Protocol

The selection of the healing protocol (submerged/closed healing vs. non-submerged/open healing) should be based on a comprehensive assessment of various patient factors. Current research indicates no fundamental difference in the final osseointegration outcome between the two protocols, although some studies suggest a slightly higher early failure risk with open healing, albeit the difference might be small (approximately 2%) [46,47]. Clinical decision-making can be guided by the following principles: For patients with favorable conditions-good oral hygiene (e.g., non-smoking, healthy adjacent teeth, no active periodontal disease), adequate local bone volume (sufficient width of attached gingiva), and ideal primary implant stability (insertion torque typically ≥20-35 N· cm)-the open healing protocol offers advantages such as avoiding a second-stage surgery and shortening the overall treatment time, with studies showing success rates can reach high levels (e.g., 98%)[48]. It reduces the number of appointments, avoids the discomfort of a second surgery, and shortens the prosthetic phase. However, for cases with risk factors (e.g., uncontrolled periodontitis, insufficient bone volume, suboptimal primary stability, smoking), the submerged (closed) healing protocol is generally recommended. This approach better isolates the implant from the oral environment, reducing the risk of early infection and providing a more protected milieu for osseointegration [49]. In specific circumstances, even with insertion torque <20 N·cm, successful outcomes with open healing can be achieved if coupled with strict plaque control and regular maintenance [48]. The key to success lies in a thorough pre-operative assessment of the patient's risk profile, enabling the formulation of an individualized healing protocol that optimizes the conditions for osseointegration.

CONCLUSION

In summary, the early survival rate of dental implants is the result of the combined effects of multiple factors, including patient-related factors, local anatomical conditions, surgical techniques, and post-operative management. This necessitates comprehensive and meticulous pre-operative assessment and precise intra-operative control by the clinician. The key influencing factors can be summarized into four core aspects: the patient's systemic health (e.g., glycemic control as measured by HbA1c, osteoporosis status), local oral conditions (bone density/quality, anatomical site), standardized surgical protocols (temperature control, insertion technique), and thorough post-operative management (infection prevention, choice of healing protocol). Based on current clinical evidence, establishing a systematic risk assessment framework is crucial. By focusing on controlling critical indicators (such as maintaining HbA1c <7%), strictly enforcing pre-operative smoking cessation, standardizing the rational use of prophylactic antibiotics, prudently selecting implant dimensions (avoiding extremes in diameter or length), and formulating individualized treatment plans for high-risk cases, the risk of early failure can be significantly reduced. This approach can elevate the early implant survival rate to a high level exceeding 97%. This requires clinicians not only to possess proficient surgical skills but also to demonstrate comprehensive risk assessment capabilities and a commitment to standardized, full-process management. Ultimately, clinical decision-making must be grounded in evidence-based medicine. The adoption of the proposed four-dimensional preventive framework, emphasizing patient selection, anatomical evaluation, surgical protocol, and healing management, provides a systematic approach to mitigate EIF risk and ensure successful long-term outcomes.

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