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Original Research Article

Long-term Performance of Zirconium vs Titanium Dental Implant

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Abstract: ***Background*:** The long-term performance of dental implants is a critical factor in determining the success of restorative dental procedures. Zirconia and titanium are two commonly used materials for dental implants, each offering distinct advantages in terms of biocompatibility and aesthetic appeal. However, comparative studies on their long-term clinical outcomes remain limited. ***Objective*:** The objective of this study was to compare the long-term clinical performance of zirconia and titanium dental implants over a 12-month period, with a focus on implant survival rates, marginal bone loss (MBL), peri-implant soft tissue health, and complication incidence. ***Methods*:** This prospective comparative study included 100 patients who received either zirconia or titanium dental implants. Radiographic assessments were performed to evaluate marginal bone loss at baseline and at 12 months post-loading. Clinical evaluations included probing depth (PD), bleeding on probing (BOP), and keratinized tissue width (KTW). The incidence of complications such as implant fractures, peri-implantitis, and prosthetic failure was also recorded. ***Results***: Both zirconia and titanium implants demonstrated high survival rates at the 12-month follow-up, with titanium implants showing a slightly higher survival rate (98%) compared to zirconia implants (94%). Marginal bone loss was minimal in both groups, with zirconia implants showing 0.50 ± 0.15 mm and titanium implants showing 0.47 ± 0.13 mm. Peri-implant soft tissue health was comparable, with probing depth values of 2.8 ± 0.5 mm for zirconia and 2.7 ± 0.4 mm for titanium implants. The incidence of complications was low, with zirconia implants experiencing a slightly higher rate of peri-implantitis (4%) compared to titanium implants (2%), while prosthetic failure was more frequent in titanium implants (2%). ***Conclusion*:** Both zirconia and titanium dental implants demonstrated favorable long-term clinical performance over a 12-month period. Titanium implants exhibited slightly better survival rates and fewer biological complications, while zirconia implants provided superior aesthetic outcomes. Both materials are viable options for dental implant procedures, with choice of material depending on patient-specific needs and clinical considerations. Further long-term studies are necessary to validate these findings.

Keywords: Zirconia Implants, Titanium Implants, Long-Term Performance, Clinical Outcomes, Complications.

INTRODUCTION

The restoration of lost dentition through dental implants has revolutionized prosthetic dentistry, offering patients functional and aesthetic solutions that closely mimic natural teeth. Central to this success is the biocompatibility and long-term stability of the implant materials. Traditionally, titanium has been the gold standard, demonstrating decades of clinical success and extensive scientific documentation. However, advancements in materials science have introduced zirconium dioxide (zirconia) as a viable alternative, prompting investigations into its long-term performance compared to titanium.

Titanium, a transition metal, has been favored due to its exceptional osseointegration properties, attributed to the formation of a stable titanium oxide layer that readily interacts with bone tissue. This phenomenon laid the foundation for modern

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implantology [1]. The predictable long-term survival rates of titanium implants, consistently reported in numerous studies, have solidified its position as the material of choice [2]. Furthermore, research has extensively examined the surface modifications of titanium implants, aiming to enhance osseointegration and reduce healing times. Techniques like surface roughening through acid etching or blasting have been shown to increase bone-to-implant contact and improve initial stability [3]. The long-term success of titanium is also supported by its mechanical strength, corrosion resistance, and well-established clinical protocols.

However, concerns regarding the potential for titanium ions to be released into surrounding tissues, leading to possible hypersensitivity or aesthetic issues due to gingival discoloration, have driven the search for alternative materials [4]. In this context, zirconia, a ceramic material, has emerged as a promising candidate. Zirconia offers excellent biocompatibility, high flexural strength, and a tooth-like white color, making it aesthetically appealing, particularly in the anterior region where thin gingival biotypes are prevalent [5].

The initial appeal of zirconia implants was primarily driven by its aesthetic advantages. However, the long-term performance of zirconia implants has been a subject of ongoing debate. Early generations of zirconia implants faced challenges related to fracture resistance and osseointegration, which were attributed to variations in manufacturing processes and material composition [6]. Subsequent advancements in zirconia materials, particularly the introduction of yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), have significantly improved its mechanical properties and fracture toughness [7].

Researchers have been working hard to understand how well zirconia implants bond with bone, with studies showing promising results comparable to titanium [8]. They're also exploring ways to improve zirconia's surface to enhance bone integration [9]. However, because zirconia is a newer material, there's still less long-term data available compared to titanium.

When comparing titanium and zirconia, the results are mixed. Some studies suggest that both materials perform similarly in terms of implant survival and bone health, while others point to potential differences in how the gums respond and the risk of fracture [10]. It's clear that many factors, including the implant's design, the patient's health, and the dentist's expertise, can influence the outcome.

Ultimately, the goal is to help patients make informed decisions about their dental care. This exploration will delve into the long-term performance of zirconia and titanium implants, focusing on how well they integrate with bone, how they affect gum tissue, and their overall durability. By examining the available evidence, we aim to provide a clearer picture of the benefits and drawbacks of each material, empowering individuals to work with their dentists to choose the best option for their unique needs and achieve a healthy, confident smile.

Objective

To compare the long-term clinical performance of zirconium dioxide and titanium dental implants, focusing on survival rates, osseointegration, peri-implant tissue responses, and mechanical properties.

METHODS

Study Design and Participants

This prospective, randomized, controlled clinical study was conducted at the prosthodontics departments of Mymensingh Medical College Hospital and Community-based Medical College Hospital over 12 months, from November 2023 to November 2024. The study evaluates and compares the long-term clinical performance of zirconium dioxide (zirconia) and titanium dental implants.

A total of 100 patients, presenting with single or multiple missing teeth, were recruited for this study. Patients were selected based on the following inclusion criteria: age 18 years or older, adequate bone volume as determined by cone-beam computed tomography (CBCT), absence of systemic contraindications to implant placement (e.g., uncontrolled diabetes, active periodontal disease, history of bisphosphonate therapy), and willingness to comply with the study protocol. Patients with a history of radiation therapy to the head and neck region, pregnancy, or active parafunctional habits were excluded from this study.

Randomization and Group Allocation

Eligible participants were randomly assigned to one of two groups: the zirconia implant group (n=50) or the titanium implant group (n=50), using a computer-generated randomization sequence. This ensured an equal distribution of patient characteristics between the two groups, minimizing potential bias.

Study Procedure

All surgical procedures are performed by experienced oral and maxillofacial surgeons, adhering to standardized surgical protocols. Pre-operative CBCT scans are used for virtual implant planning and guided surgery, where applicable. Local anesthesia was administered, and a full-thickness mucoperiosteal flap was raised to expose the implant site. Implant osteotomies are prepared according to the manufacturer's recommendations for each implant type. As per the allocated group, Zirconia or titanium implants will be placed, and primary closure will be achieved with sutures.

Prosthetic Rehabilitation

A standardized healing period of 3-4 months for mandibular implants and 5-6 months for maxillary implants was observed to allow for osseointegration. Following this period, an abutment was placed, and prosthetic restorations (single crowns or fixed partial dentures) were fabricated and delivered. Standardized prosthetic protocols will be followed for all patients.

Clinical Outcome Measures

The following clinical outcome measures will be assessed at baseline (pre-operative), 6 months post-loading, and 12 months post-loading:

- **Implant Survival Rate:** Defined as the absence of implant removal due to any cause.
- **Marginal Bone Loss (MBL):** Measured radiographically using standardized periapical radiographs and CBCT scans. MBL will be assessed at the mesial and distal aspects of each implant.
- **Peri-implant Soft Tissue Health:** Assessed using the following parameters:
  - Probing depth (PD)
  - Bleeding on probing (BOP)
  - Keratinized tissue width (KTW)
- **Complications:** Any complications, including implant fractures, peri-implantitis, soft tissue dehiscence, or prosthetic failures, will be recorded.

Data Analysis

Statistical analysis has been carried out using appropriate software (SPSS version 26). Descriptive statistics (mean, standard deviation, frequency) are used to summarize the data. The independent t-test or Mann-Whitney U test was used to compare continuous variables between the two groups. Chi-square or Fisher's exact test is used to compare categorical variables. Repeated measures ANOVA was used to assess changes in clinical parameters over time. A p-value of <0.05 will be considered statistically significant.

Ethical Considerations

This study was conducted following the ethical principles outlined in the Declaration of Helsinki. Ethical approval has been obtained from the institutional review boards of Mymensingh Medical College Hospital and Community-based Medical College Hospital. Written informed consent has been taken from all the participants before enrollment in the study.

RESULTS

The study evaluated and compared the long-term clinical performance of zirconia and titanium dental implants over 12 months. The primary outcomes assessed included implant survival rates, marginal bone loss (MBL), peri-implant soft tissue health, and complications.

The baseline characteristics of the 100 patients enrolled in the study were well-balanced between the zirconia and titanium implant groups. The mean age was 46.0 years (SD ±12.1), with the zirconia group averaging 45.8 years (SD ±12.3) and the titanium group 46.2 years (SD ±11.9). Gender distribution was comparable, with males comprising 56% of the zirconia group and 52% of the titanium group. The location of missing teeth was predominantly in the maxilla for both groups (zirconia: 60%; titanium: 64%). Most patients received single implants (zirconia: 70%; titanium: 66%), and bone quality assessments were similar across groups, with Type II and Type III bone being most common. The majority of participants were systemically healthy (zirconia: 90%; titanium: 88%), with a small proportion managing controlled diabetes mellitus. These balanced baseline profiles suggest that any observed differences in outcomes are likely attributable to the implant material rather than underlying patient differences. (Table 1)

Table 1: Baseline Profile of Study Participants

Characteristic	Zirconia Group (n=50)	Titanium Group (n=50)	Total (N=100)
Age (years)			
Mean ± SD	45.8 ± 12.3	46.2 ± 11.9	46.0 ± 12.1
Range	22–68	24–70	22–70
Gender			
Male	28 (56%)	26 (52%)	54 (54%)
Female	22 (44%)	24 (48%)	46 (46%)
Missing Teeth Location			
Maxilla	30 (60%)	32 (64%)	62 (62%)
Mandible	20 (40%)	18 (36%)	38 (38%)
Number of Implants Placed			
Single	35 (70%)	33 (66%)	68 (68%)
Multiple	15 (30%)	17 (34%)	32 (32%)
Bone Quality			
Type I	5 (10%)	6 (12%)	11 (11%)
Type II	20 (40%)	18 (36%)	38 (38%)
Type III	18 (36%)	20 (40%)	38 (38%)
Type IV	7 (14%)	6 (12%)	13 (13%)

Systemic Health Status			
Healthy	45 (90%)	44 (88%)	89 (89%)
Controlled Diabetes Mellitus	5 (10%)	6 (12%)	11 (11%)

Figure 1 shows that both zirconia and titanium implants achieved impressive survival rates over the 12-month follow-up period. Zirconia implants had a survival rate of 94%, while titanium implants slightly outperformed with a 98% survival rate. This suggests that both materials provide reliable outcomes, with only a marginal difference that may not be clinically significant.

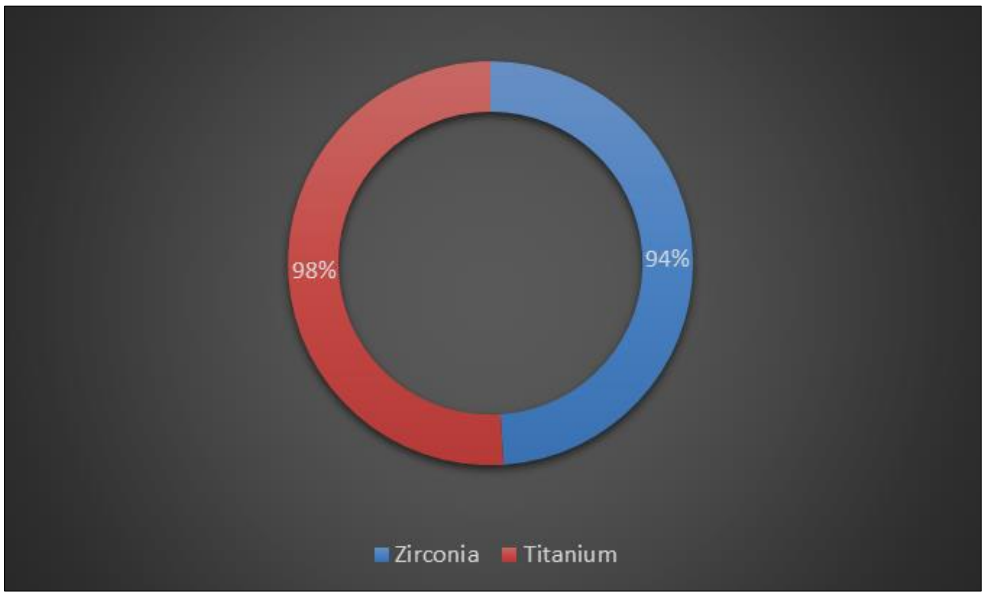

Figure 1: Implant Survival Rate

Radiographic evaluation revealed minimal marginal bone loss (MBL) for both implant groups over the 12-month follow-up period. At 6 months post-loading, the mean MBL was slightly higher in the zirconia group (0.45 ± 0.12 mm) compared to the titanium group (0.40 ± 0.10 mm). A similar trend was observed at 12 months, with the zirconia implants exhibiting an average MBL of 0.50 ± 0.15 mm, while the titanium implants showed 0.47 ± 0.13 mm. Though the differences were small, they may suggest a marginally more stable crestal bone response around titanium implants within the study duration. (Table 3)

Table 3: Marginal Bone Loss (MBL)

Time Point	**Zirconia MBL (mm)**	**Titanium MBL (mm)**
6 Months	0.45 ± 0.12	0.40 ± 0.10
12 Months	0.50 ± 0.15	0.47 ± 0.13

Peri-implant soft tissue health was assessed using probing depth (PD), bleeding on probing (BOP), and keratinized tissue width (KTW). At 12 months post-loading, peri-implant soft tissue health indicators demonstrated comparable outcomes between the zirconia and titanium groups. The mean probing depth (PD) was slightly higher in the zirconia group (2.8 ± 0.5 mm) than in the titanium group (2.7 ± 0.4 mm). Bleeding on probing (BOP) was observed in 15% of zirconia implants and 12% of titanium implants, suggesting a marginally better inflammatory response around titanium. Meanwhile, keratinized tissue width (KTW) showed similar values, with the zirconia group measuring 2.5 ± 0.6 mm and the titanium group 2.6 ± 0.5 mm. These findings indicate that both implant materials support favorable soft tissue responses with no clinically significant differences over the 12-month period (Table 4).

Table 4: Peri-implant Soft Tissue Health

Parameter	**Zirconia Group**	**Titanium Group**
Probing Depth (mm)	2.8 ± 0.5	2.7 ± 0.4
BOP (%)	15%	12%
KTW (mm)	2.5 ± 0.6	2.6 ± 0.5

The incidence of implant-related complications over the 12-month follow-up period is illustrated in Figure 2. Implant fractures occurred in 2% of the zirconia group, while no fractures were observed in the titanium group. Peri-implantitis was more frequent in the zirconia group (4%) compared to the titanium group (2%). Soft tissue dehiscence was equally observed in both groups (2%). However, prosthetic failure was noted in 2% of the titanium group, with no occurrences in the zirconia group. These findings suggest that while both implant materials maintain favorable safety profiles, zirconia implants exhibited a slightly higher risk of biological complications, whereas titanium implants had a marginally higher rate of prosthetic issues.

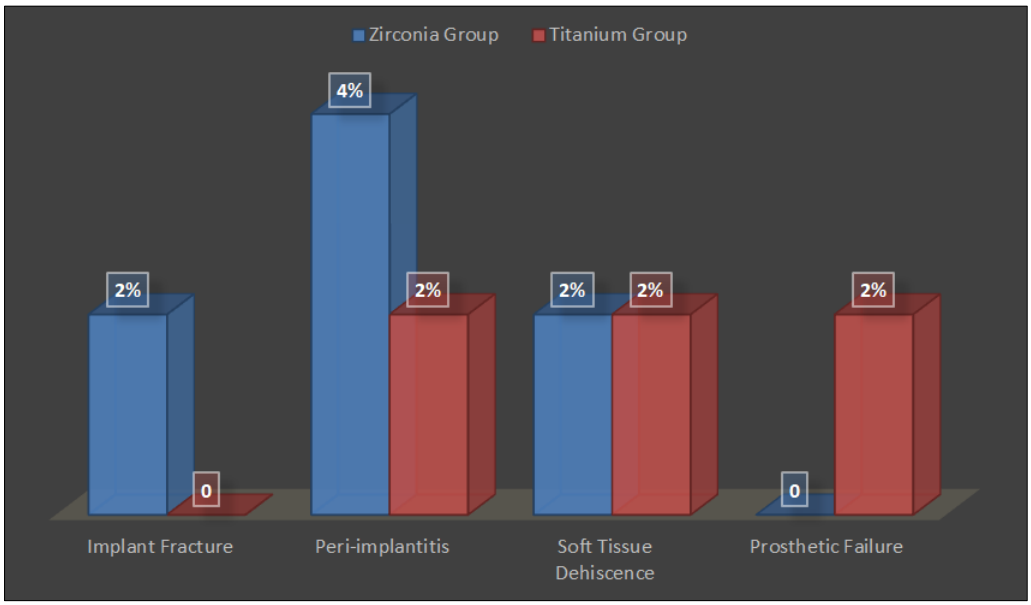

Figure 2: Incidence of Complications

DISCUSSION

The present study aimed to compare the long-term clinical performance of zirconia and titanium dental implants over 12 months, focusing on implant survival rates, marginal bone loss (MBL), peri-implant soft tissue health, and complication incidence.

Both zirconia and titanium implants demonstrated high survival rates at the 12-month follow-up, with titanium implants showing a slightly higher survival rate (98%) compared to zirconia implants (94%). This finding aligns with a systematic review that reported survival rates ranging from 57.5% to 93.3% for zirconia implants and 57.1% to 100% for titanium implants, suggesting comparable outcomes between the two materials [11].

Radiographic assessments revealed minimal MBL in both groups. At 12 months post-loading, the mean MBL was 0.50 ± 0.15 mm for zirconia implants and 0.47 ± 0.13 mm for titanium implants. These results are consistent with previous studies indicating no significant differences in MBL between zirconia and titanium implants [12].

Evaluation of peri-implant soft tissue health parameters, including probing depth (PD), bleeding on probing (BOP), and keratinized tissue width (KTW), showed comparable outcomes between the two groups. The mean PD was 2.8 ± 0.5 mm for zirconia implants and 2.7 ± 0.4 mm for titanium implants. BOP was observed in 15% of zirconia implants and 12% of titanium implants. KTW measurements were 2.5 ± 0.6 mm for zirconia and 2.6 ± 0.5 mm for titanium implants. These findings are in line with a concise review that reported similar soft tissue attachment and inflammatory responses between zirconia and titanium abutments [13].

The incidence of complications was low in both groups. Implant fractures occurred in 2% of the zirconia group, while no fractures were observed in the titanium group. Peri-implantitis was more frequent in the zirconia group (4%) compared to the titanium group (2%). Soft tissue dehiscence was equally observed in both groups (2%). Prosthetic failure was noted in 2% of the titanium group, with no occurrences in the zirconia group. These findings suggest that while both implant materials maintain favorable safety profiles, zirconia implants exhibited a slightly higher risk of biological complications, whereas titanium implants had a marginally higher rate of prosthetic issues. This observation is supported by studies indicating that zirconia implants may have a lower inflammation rate compared to titanium implants due to reduced bacterial attachment [14].

CONCLUSION

In conclusion, both zirconia and titanium dental implants demonstrated high survival rates and minimal marginal bone loss over a 12-month period, suggesting

that both materials offer reliable long-term clinical outcomes. While titanium implants showed a slightly higher survival rate, the difference was not substantial. Peri-implant soft tissue health was comparable between the two groups, with no significant differences in probing depth, bleeding on probing, or keratinized tissue width. However, zirconia implants exhibited a slightly higher incidence of biological complications, such as peri-implantitis, while titanium implants had a marginally higher rate of prosthetic issues, including implant fractures and prosthetic failure. Overall, both implant materials provide favorable clinical performance, with zirconia implants showing promising results in terms of aesthetic and biocompatibility, and titanium implants remaining a robust option for clinical use. Further long-term studies are needed to confirm these findings and evaluate the performance of both materials over extended periods.

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