Fifth Year Bachelor Degree in Dentistry

Prosthodontic Strategies to Prevent Peri-Implantitis: A Literature Review

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Abstract

Peri-implantitis remains a leading cause of implant failure, and is mainly caused by a combination of biological and mechanical factors. While systemic and surgical factors are well documented, the prosthetic phase offers a critical and modifiable opportunity for prevention. This literature review presents and evaluates multiple prosthodontic strategies that aim at minimizing peri-implantitis risk. This work focuses on key areas such as optimal abutment geometry, implant abutment interface design, retention methods, occlusal load control, material selection, material surface treatment, and prosthesis cleansability. The review highlights the vital role of establishing prosthetic planning that minimizes biological and mechanical complications, improves long-term stability, and improves clinical outcomes. Clinical recommendations are proposed to guide clinicians with prosthetic decisions that are biologically driven and evidence based. The prosthetic phase is not only a key aspect for esthetic and function, but also an essential determinant in peri-implant health and implant long-term success.

uic barcelona

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1. Introduction

Archaeological discoveries revealed that attempting the replacement of missing teeth dates back to thousands of years. Evidence suggests that early civilizations used materials such as shells and animal teeth. (1) As of today, with the advance of technologies we rely on newer and more sophisticated materials like titanium that is used for dental implants. Dental implants are an innovation that became increasingly popular, especially in the last twenty years, with with the use of implants rising from 0.07 percent in 1999–2000 to 5.07 percent in 2015–2016. (2) This growth reflects advancements in technology and an increasing preference for implants, as a treatment option. (2) Dental implant have become indispensable and key solutions for worldwide aging populations. As life expectancy increases, the need for long-term and durable dental solutions increases as well. (3) Implants have success rates of 90–95 percent over a five year period giving patients lasting reliability and improved functionality. (4) Despite their high success rates and popularity, their success is threatened by a multi-etiological condition called peri-implantitis.

Complications such as inflammation and peri-implant disease can impact implants longevity and eventually lead to their failures. (4)Biological complications such as peri-implantitis can pose significant challenges in implantology due to its infectious nature and the risk it poses to the long-term stability of implants. It is crucial to manage peri-implantitis in order to maintain the health and proper function of implants. This highlights the importance of preventing peri implant diseases for achieving implant survival and success.

1.1 Prevalence of Peri-Implantitis

The high prevalence of peri-implantitis and its negative impact on the prognostic of implant rehabilitation, makes it a highly relevant topic in modern dentistry. The reported prevalence for peri-implantitis varies widely among studies due to inconsistencies in how they're diagnosed and between follow-up periods. In a recent meta-analysis study, the prevalence of peri-implantitis was reported to be 20% at the patient level and 11.5% at the implant level. (4) Studies show that peri-implant mucositis impacts about 43% of patients, with an estimated actual range likely lying between 32% and 54%. (5) On the other hand the prevalence of peri-implantitis can range from 14% to 30%. (5) These discrepancies reveal the importance and need for standardized diagnostic criteria to ensure consistency in research and clinical application. In addition, its high incidence and clinical impact represent a significant concern for public health and this highlights the importance of establishing effective prevention strategies.

1.2 Preventive Strategies: A Key to Long-Term Implant Success

Peri-implantitis is a concern for the lifespan and effectiveness of implants as it can cause progressive bone loss and lead to implant failure due to pockets forming around the implant site if left untreated, which makes it more prone to failures. Each additional millimeter of bone loss increases the risk for implants to fail by 65%, this highlights the need for incorporating early prevention strategies. (5) Traditional methods for disease treatment usually focus on managing existing disease, however, current evidence shows the importance of proactive risk reduction through prevention. In other words, recent research highlights the importance of preventing peri-implantitis instead of treating well-established peri-implantitis. (5) This also includes preventing peri-implant mucositis, which is a precursor to peri-implantitis, and is especially crucial for stopping the disease progression. (5) This shows the importance of preventive and maintenance care as an essential component in maintaining healthy implants.

The significant prevalence of peri-implant diseases highlights the necessity of regular maintenance and oral hygiene practices.

1.3 Understanding and Addressing the Multifactorial Nature of Peri-Implantitis

Peri-implantitis is a multifactorial condition because it is influenced by a combination of factors such as; systemic, surgical, prosthetic, and maintenance related factors – all these factors can significantly compromise implant health and success. It is essential to understand and recognize these risk factors for developing effective strategies to prevent peri-implantitis. Due to its multifactorial nature, preventing peri-implantitis entirely is nearly impossible, however, it is possible to significantly reduce its development and severity. Minimizing the occurrence of peri-implantitis can be achieved by careful patient selection, meticulous surgical techniques, well-designed prosthetics along with strict maintenance protocols and educating patients on oral hygiene. Together these key elements form the foundations for preventing peri-implantitis.

1.4 The Strategic Role of the Prosthetic Phase

Despite the recent advances in surgery and materials, peri-implantitis continues to affect about one fourth of implants, which puts in question the limitations of the current preventive approaches. (5) While the implication of factors such as the surgical technique, patient maintenance, and systemic factors are well recognized, the prosthetic phase is critical and its influence often underestimated regarding the development and prevention of peri-implant disease.

What makes the prosthetic phase so important is that it includes factors that can be modified and controlled by clinicians, which reflects its direct influence on the implant environment. From the very beginning, when abutment connections are chosen and delivered to the final restoration, every decision regarding the selection of component, emergence profile, occlusal scheme and hygiene accessibility can have an impact on the colonization of bacteria, stability of soft tissue, and preservation of marginal bone. Unlike patient related risk factors such as smoking, diabetes or anatomical limitations such as thin biotypes, prosthetic decisions can be carefully planned and corrected, which makes them the most effective tools for clinicians to influence biological outcomes.

In addition, the prosthetic design is directly associated with the long-term maintainability of the restoration, which is crucial since the accumulation of biofilm is the first etiologic factor causing peri-implantitis. A prosthesis that is poorly designed can limit accessibility, daily hygiene, plaque retention, overload the implant or affect the mucosal seal. The combination of these mechanical and biological factors, can cause inflammation and lead to, or accelerate bone loss.

In other words, the prosthetic phase is not only the final step of an implant treatment, but it is a phase that is biologically influential and strategically modifiable that can determine the success or failure of the implant restoration in the long term. It is essential for clinicians to recognize the key role of the prosthetic phase, especially for clinicians that want to increase the standard of their work and move from reactively managing peri-implantitis to proactively preventing it. This thesis focuses on finding and presenting some of the most impactful prosthodontic strategies to support peri-implant tissue health.

2. Objectives

The main objective of this literature review is to find, present and evaluate prosthodontic strategies that contribute to the prevention of peri-implantitis, with the aim to offer evidence-based information and clinical recommendations that support the long-term success of implant therapy.

This review focuses on:

- Analyze how some of the factors from the prosthetic phase can help prevent or contribute to peri-implantitis
- Find key prosthetic data and information, including abutment selection, retention methods, component compatibility, surface treatments, occlusal design, and hygiene accessibility, which have an influence peri-implant tissue stability.
- Summarize the current scientific evidence and analyze their biological and mechanical association on peri-implant health.
- Propose practical and clinical recommendations that are evidence based and can be incorporated into daily practice to minimize peri-implantitis.

3. Materials and Methods

Study Design

This thesis uses a narrative review methodology, analyzes and integrates recent research correlated on peri-implantitis prevention and more particularly on the prosthetic level. By using a review model, this thesis allows to explore the multifactorial nature of peri-implantitis, which offers a comprehensive evaluation of the disease, by presenting different prosthetic contributing factors and preventative strategies.

Aim

The aim of this literature review is to find and analyze prosthodontic strategies that contribute to preventing peri-implantitis, and focus on the influence of abutment selection, retention methods, component compatibility, surface treatments, occlusal design, and hygiene accessibility, which have an influence peri-implant tissue stability. By analyzing current scientific evidence, this review aims to provide strategies that are clinically relevant and ultimately support the long-term success of implant-supported rehabilitations. This thesis was written using relevant studies, such as randomized controlled trials, systematic reviews, meta-analyses, cohort studies, and expert guidelines.

Databases used

The data and information were sourced from PubMed, the UIC Library, the National Institutes of Health.

Search Terms

The search terms used were related to the four section of this review:
"overcontoured crowns", "implant connection systems", "screw loosening and inflammation", "prosthetic design and peri-implantitis", "overcontoured crowns", "prosthetic design and peri-implantitis", "emergence profile and peri-implant health", "crown contour and peri-implantitis", "mucosal seal and prosthesis design", "platform switching and peri-implant bone loss", "cement-retained vs screw-retained implants", "implant spatial planning", "prosthesis contour and hygiene access", "fixed vs removable implant prosthesis", "implant prosthetic materials and inflammation", "surface roughness and peri-implantitis", "full-arch implant restoration design".

Inclusion Criteria

- Articles in English that have been published in the last 10-15 years for better relevance.
- Peer-reviewed publications, like RCTs, cohort studies, systematic reviews, meta-analyses, and expert opinions.

Exclusion Criteria

- Non-peer-reviewed articles, editorials, and content without primary and relevant data.
- Articles missing significant quantitative and qualitative information regarding peri-implantitis risk factors.

Article Selection Process

- Abstracts were reviewed to find studies focused on the prevention of peri-implantitis at the prosthetic level.
- Full-texts were analyzed to make sure the information met the inclusion / exclusion criterias.

Data Extraction and Analysis

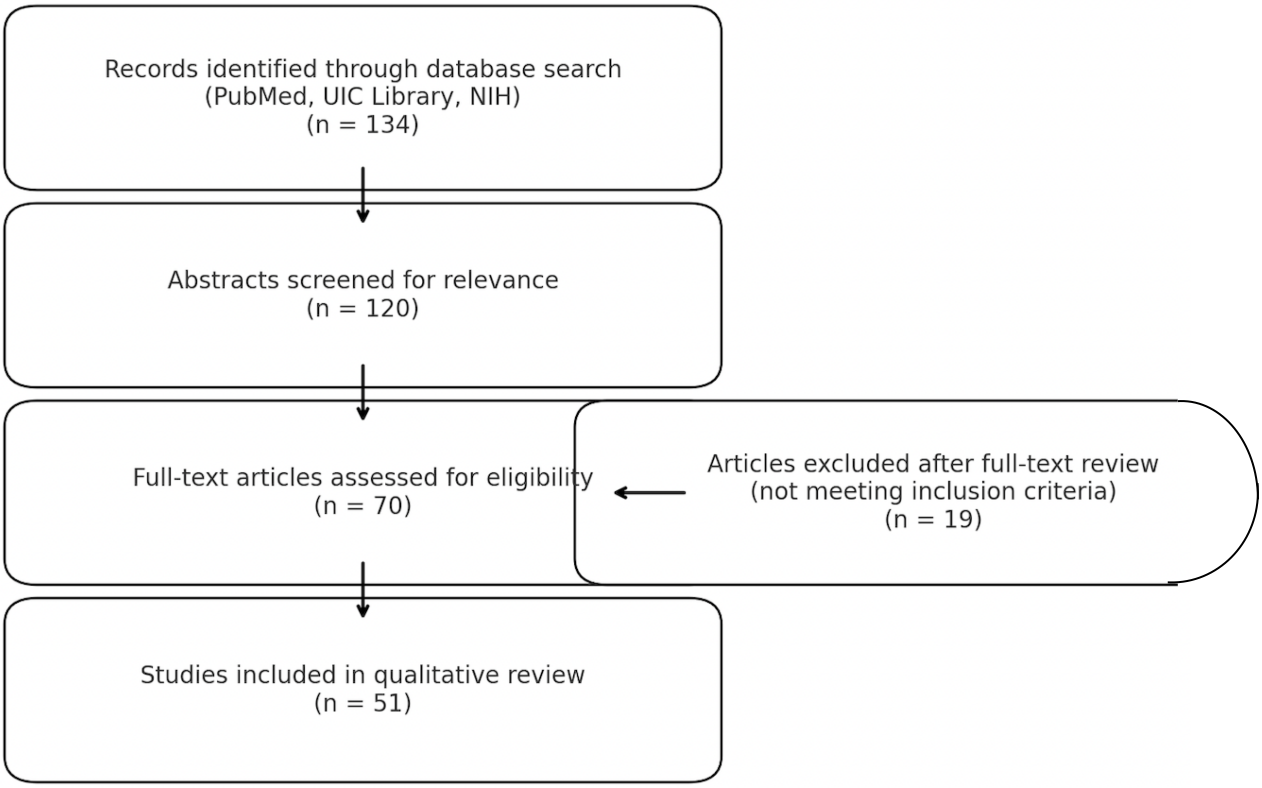
- Information relevant to the topic of "minimizing peri-implantitis" was used and separated into different sections about the most relevant prosthetic preventive information.

Limitations on Methods

- Variations in peri-implantitis and peri-mucositis diagnostic criteria:
- The absence of standardized definitions for peri-implantitis among studies made it more challenging to compare the different data and results gathered.
- There are limitations in finding long-term relevant data on universal prosthetic design guideline, maintenance protocols and strategies, and common errors and mistakes based studies.
- The research was solely focused in English and could exclude data that was published in other languages.

- Such a narrative review offers a comprehensive approach, however, it lacks the detailed and accurate data found in a systematic review design, which somewhat limits the quantitative data and conclusion in this review.

PRISMA Flow Diagram of Study Selection



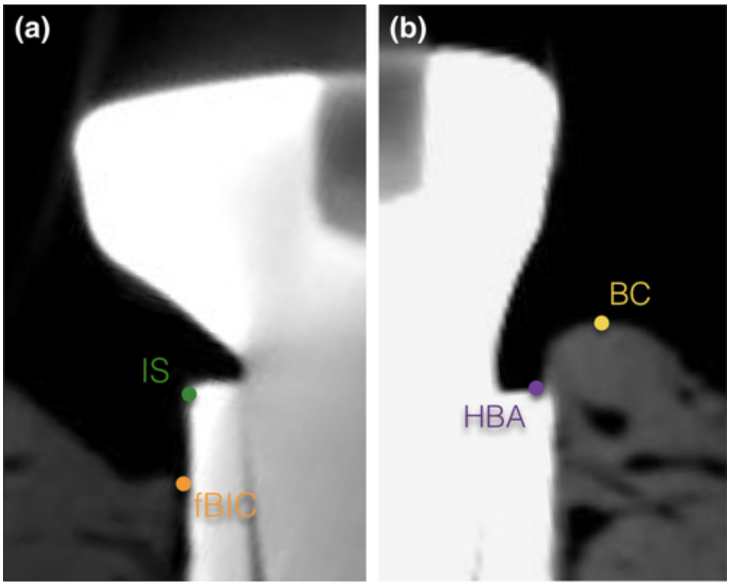
4. Results:

Implant Type	Marginal Bone Loss (MBL)	Notes	Author	Year	Study Design
Platform-Switched (PSW)	0.57 mm	Less MBL vs RP implants	Santigo J.	2016	Systematic Review & Meta-Analysis
Platform-Switched (PSW)	0.29 mm	Significant bone preservation over time	Chrcanovic B.	2015	Meta-Analysis
Platform-Switched (PSW)	–0.41 mm (vs RP)	Meta-analysis of 25 studies (1098 pts, 2310 implants) / Longer follow-up periods and larger implants mismatches showed less MBL	Santiago J.	2015/ 2016	Systematic Review (25 studies) & Meta-Analysis
Non-Platform-Switched (NPS)	0.98 mm	Higher bone loss compared to PSW	Chrcanovic B. / Santigo J.	2016	Systematic Review & Meta-Analysis
Platform-Switched (PSW)	Conflicting evidence	A systematic review of 15 clinical studies showed that 50% of them reported no significant difference compared to non-platform-switched (NPS) implants	Romanos GE.	2020	Systematic Review

Abutment Shape	MBL (mm)	Buccal Margin Change	Soft Tissue Thickness	Mucosal Recession (%)	Author	Year	Study Design
Convex	-0.69 ± 0.48	-0.54 ± 0.93	Thinner	64.3%	Theofilos Koutouzis	2023	3-year RCT (28 patients)
Concave	-0.16 ± 0.22	-0.53 ± 0.87	Thicker	14.3%	Theofilos Koutouzis	2023	3-year RCT (28 patients)

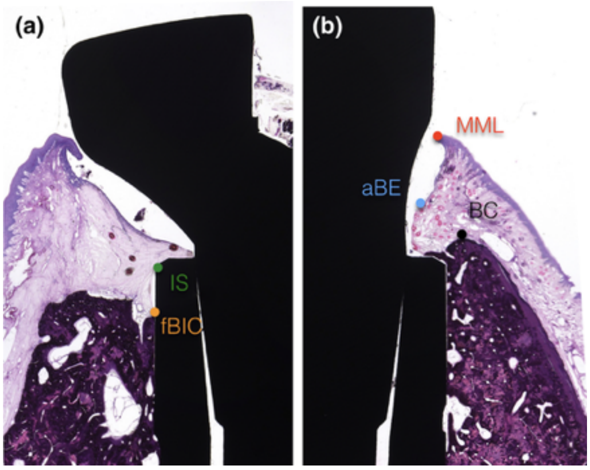
Emergence Angle Design

A recent study comparing wide emergence (WE) and narrow emergence (NE) healing abutment found that both designs led to similar dimensions regarding peri-implant biologic width, including epithelial and connective tissue attachment. (6) However, wide emergence abutments led to an apical shift of the marginal bone tip in relation to the implant shoulder. As represented in (figure 1), wide abutments demonstrated increased vertical bone remodeling and bone loss compared to narrow abutments. (6)



(Figure 1) The cross-sectional scan shows an implant and its surrounding bone and soft tissues. (Laleman I) (7)

The “wide” abutment (45°) creates more divergence above the implant, which consequently lead to increased bone remodeling in this zone. In contrast, a “narrow” abutment (15°) generally produces a more smooth contour, which helps to preserve bone closer to the implant platform. This microscopic image (figure 2), shows how soft tissues and bone integrate around an implant restored with wide and narrow abutments.



(Figure 2) Shows soft tissues and bone integration around an implant restored with wide and narrow abutments. (Galindo-Moreno P.) (8)

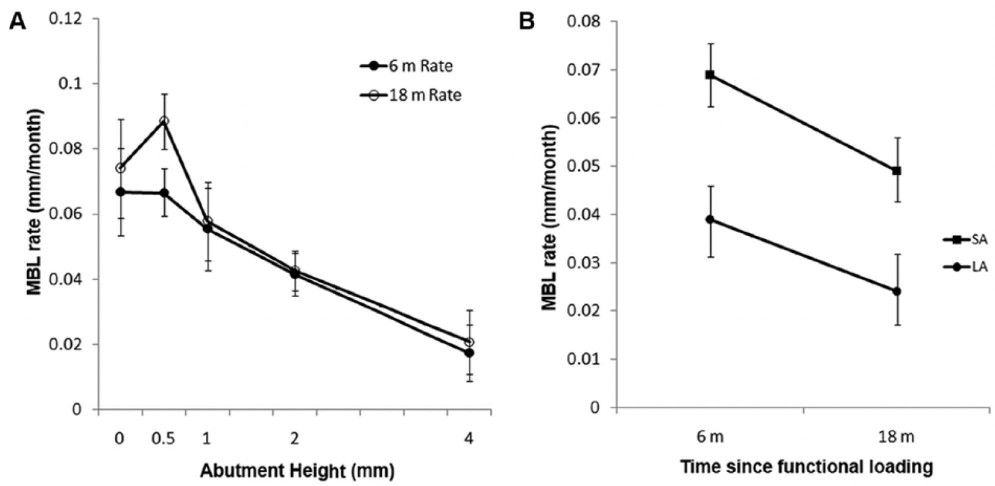
Transmucosal Profile Design

Convergent profiles appear to promote the formation of a thicker soft tissue band that can protect the adjacent bone. One study that used convergent tissue-level implant, reported minimal bone remodeling and favorable soft tissue thickness. (9) A meta-analysis has shown that these designs result in significant less marginal bone loss (MBL). For example, an analysis reported a mean difference of 0.772mm in favor of concave/convergent abutments. In addition, the analysis highlighted that those benefits were even more important when used with platform-switching implants. (10) Straight abutments are reliable but have shown slightly more marginal bone loss when compared to convergence or concave profiles(9) Divergent abutments have also been associated with higher bone resorption.

Abutment Height	MBL at 1 Year	Notes	Author	Year	Study Design
<2 mm	1.17 mm	More bone loss	Zhaozhao Chen DDS	2019	Systematic Review (131 patients)
2 mm	0.86–1.03 mm	Moderate bone preservation	Zhaozhao Chen DDS	2019	Systematic Review (131 patients)
3 mm	0.38–0.41 mm	Best performance	Zhaozhao Chen DDS	2019	Systematic Review (131 patients)

The Role of Abutment Height and Width

Bone loss shows that it is more pronounced in the first six months after loading, followed by a slower rate of change. (7) In the first 6 months, bone-level implants with long abutments (greater than 2mm) have demonstrated to significantly lower early marginal bone loss by preserving crestal bone during the "critical healing phase". (11) Additionally, it was demonstrated that combining longer abutment with subcrestal placement, enhances the supracrestal mucosal seal and consequently minimizes early bone remodeling. (12) Another strong finding compared bone covering implants shoulders in long and short abutments, and the results showed that the long abutment group had 46.9% bone cover compared to none in the short abutment group. (12)



In Figure 3 the relationship between abutment heigh (mm) and marginal bone loss (MBL) is represented. Higher abutments correlate with lower marginal bone loss.
(Chen Z.) (11)

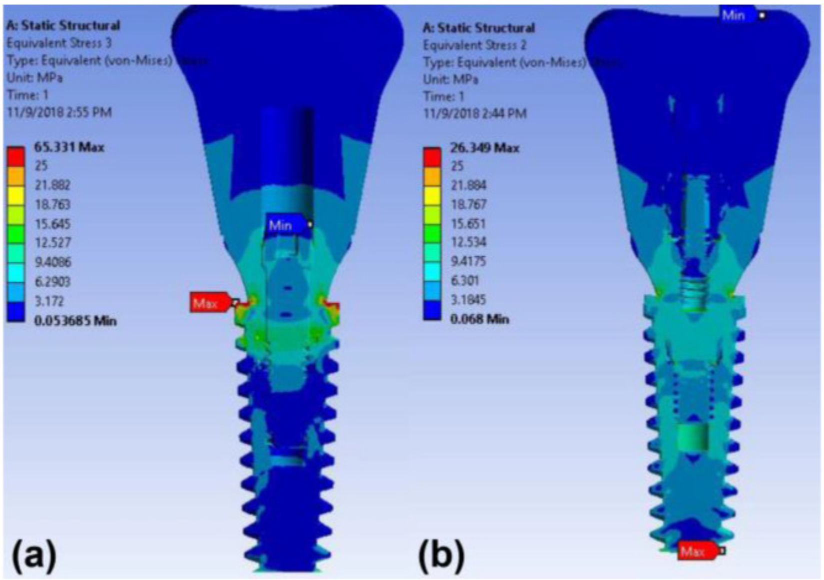
Parameter	One-Time Abutment	Repeated Disconnection	Author	Year	Study Design
IL-1β Levels	Lower	Higher	Filipe Moreira	2021	Double-Blind Study (53 Implants)
Bone Loss at 6 Months	0.14 ± 0.18 mm	0.23 ± 0.29 mm	Filipe Moreira	2021	Double-Blind Study (53 Implants)
Bone Loss at 12 Months	0.14 ± 0.21 mm	0.21 ± 0.27 mm	Filipe Moreira	2021	Double-Blind Study (53 Implants)
Soft Tissue Stability	Slightly improved	Slightly reduced	Filipe Moreira	2021	Double-Blind Study (53 Implants)
Implant Survival Rate (12 months)	100%	100%	Filipe Moreira	2021	Double-Blind Study (53 Implants)

Factor / Strategy	Impact / Findings	Author	Year
Incidence Rate in Single Crowns	8% to 45% incidence	Sunyoung Choi	2023
Effect of Screw Loosening	Microgaps enable bacterial infiltration; increased micromovements	Ebrahim F. Alsubaiy	2020-2023
Vulnerability of External Hex Implants	Flat design = poor rotational resistance	Ebrahim F. Alsubaiy	2020
Gold or Diamond-Like Coated Screws	Improved preload retention	Sunyoung Choi	2023
Screw Retightening After 10 Minutes	Reduces settling effects and improves stability	Sunyoung Choi	2023
Narrowing Occlusal Table in Posterior Zones	Lowers lateral forces	Sunyoung Choi	2023
Wider Diameter Implants	Reduces screw loosening risk	Sunyoung Choi	2023
Restoration Material (Metal-Ceramic vs. Acrylic)	Metal-ceramic has lower loosening than acrylic	Sunyoung Choi	2023
Use of Chlorhexidine During Reconnection	Improves stability and limits bacterial contamination	Sunyoung Choi	2023

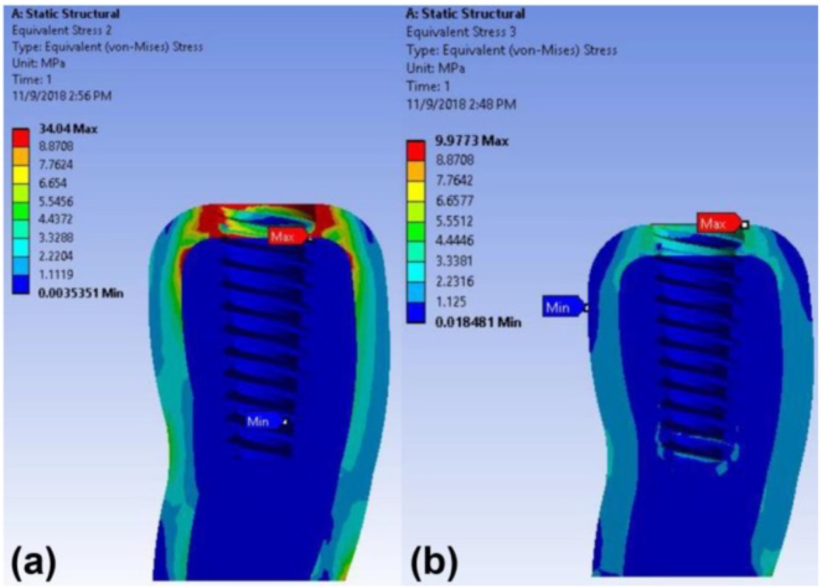
Parameter	Cement-Retained	Screw-Retained	Notes	Author	Year	Study Design
Implant Stress (Vertical Load)	65.3 MPa	26.3 MPa	↓ 59.7% with screw-retained	Jae-Hyun Lee	2021	Finite Element Analysis
Implant Stress (Oblique Load)	110.6 MPa	79.83 MPa	↓ 27.8% with screw-retained	Jae-Hyun Lee	2021	Finite Element Analysis
Bone Stress (Vertical Load)	34.04 MPa	9.97 MPa	↓ 70.7%	Jae-Hyun Lee	2021	Finite Element Analysis
Bone Stress (Oblique Load)	52.71 MPa	20.63 MPa	↓ 60.9%	Jae-Hyun Lee	2021	Finite Element Analysis
Bone Strain (Vertical Load)	0.0084 mm/mm	0.0015 mm/mm	↓ 82.1%	Jae-Hyun Lee	2021	Finite Element Analysis
Bone Strain (Oblique Load)	0.012 mm/mm	0.002 mm/mm	↓ 83.3%	Jae-Hyun Lee	2021	Finite Element Analysis

Implant Retention Strategies

The literature reports that in cement-retained restoration, implants that have cement remnants such as methacrylate-based cements, have are 85% more likely to develop peri-implantitis, especially in patients with a history of periodontitis. (13)



(Figure 4) Illustrates higher stress concentrations on implant with cement-retained crowns compared to screw-retained crowns that distribute stress more evenly. (Staubli N.) (13)

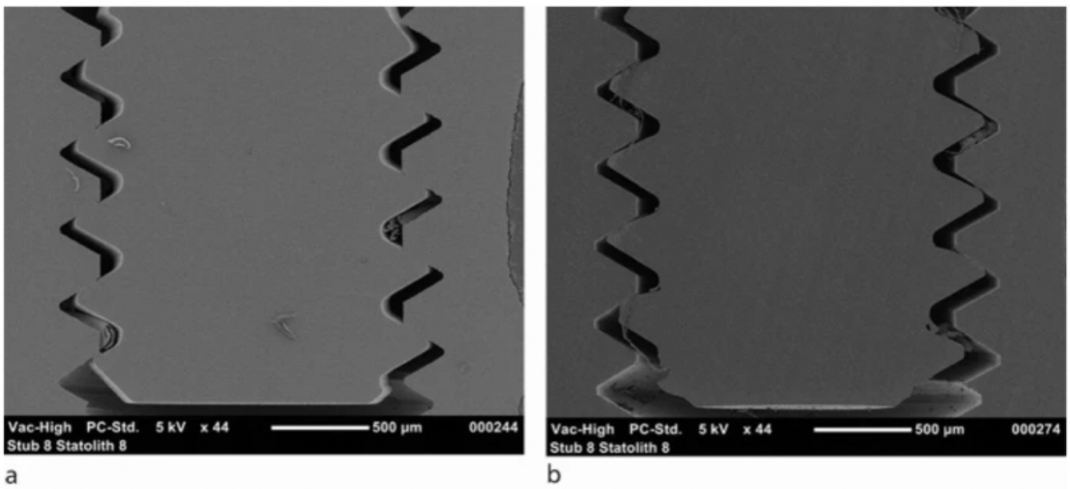


(Figure 5) Illustrates higher stress concentrations on the bone with cement-retained crowns compared to screw-retained crowns that distribute stress more evenly and show their biomechanical advantage. (Staubli N.) (13)

Clinical evidence demonstrates that hybrid restoration reduces inflammation markers by 35% compared to cement-retained prostheses. (14)

The Role of Original Components

Non-original components present important risks associated with their compromised fit and increase in plaque retention. (15) Studies show that using non-original components has 20% more risks of complications. (13,16) Scanning electron microscopes have revealed that there are discrepancies in the surface morphology between original and no-original components. (17) The misfit seen between non-original abutments and implants was associated with higher mechanical failures rate. (17) Some findings report that non-original abutments have vertical misfit discrepancies that are above 10 microns. (18) Furthermore, non-original components have shown an increase in rotational misfit. (18) A study on non-original abutments demonstrated that they exhibit increased variation in torque loss. (18) Furthermore, non-original abutments generate micro-movements at the level of the implant abutment interface. (18)



(Figure 6) Illustrates images from scanning microscope electrons showing the difference in fit between (a) original and (b) non original components. (Galindo-Moreno P.) (8)

Parameter	Findings	Author	Year	Study Design
Emergence Angle Definition	Angle between restoration curve and implant axis	Adam Hamilton	2023	Literature Review
Over-Contouring Threshold	EA >30° = Over-contoured restoration	Adam Hamilton	2023	Literature Review
Emergence Profile Types	Convex, Concave, or Straight	Adam Hamilton	2023	Literature Review
Risk of Convex EP (>30°)	Strong link to inflammation and bone loss	Nicola Alberto Valente	2020	Systematic Review
MBL: Concave vs. Divergent/Parallel	0.209 mm less MBL with concave (95% CI: 0.070–0.347)	Nicola Alberto Valente	2020	Systematic Review
MBL with Concave + Platform Switching	0.147 mm less MBL (95% CI: 0.082–0.212, P<.001)	Nicola Alberto Valente	2020	Systematic Review
PES Score: Convex vs. Concave	No significant PES difference (P=0.306)	Nicola Alberto Valente	2020	Systematic Review
Soft Tissue Volume and Adaptation	Improved stability, volume, and soft tissue adaptation	Nicola Alberto Valente	2020	Systematic Review
Mucosal Recession at 12 Months	64.3% recession in convex vs. 14.3% in concave	Marina Siegenthaler	2020	Randomized Controlled Trial
Recession Risk: Convex vs. Concave	Convex profiles = 12.6x more risk of recession	Marina Siegenthaler	2020	Randomized Controlled Trial

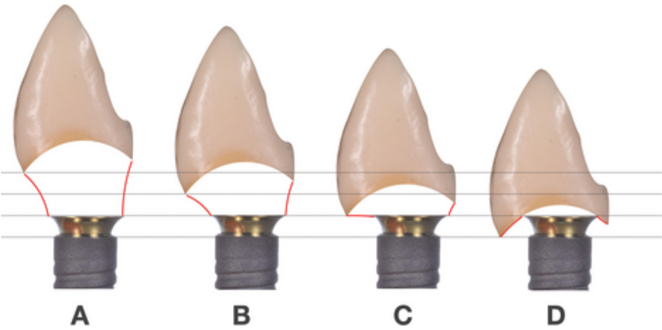
Parameter	Findings	Author	Year	Study Design
Importance of Correct Positioning	Ensures proper cleansability in implant-supported restorations	Stefano Corbella	2023	Retrospective Study
Buser's Criteria (Mesio-Distal)	1.5–2 mm between implant neck and adjacent tooth CEJ	Stefano Corbella	2023	Retrospective Study
Buser's Criteria (Inter-Implant)	Minimum 3 mm between adjacent implant necks	Stefano Corbella	2023	Retrospective Study
Consequence of Inadequate Spacing	Inadequate spacing often results in steep emergence profile >45°	Stefano Corbella	2023	Retrospective Study
Correlation Between Distance and Plaque Accumulation	Shorter inter-implant distances increase plaque in interproximal zones ($r = -0.326$, $p < 0.05$)	Samer Abi Nader	2014	Comparative Study (20 patients)
Consideration of Implant Size and Positioning	Implant size and placement must be considered to optimize outcomes	Stefano Corbella	2023	Retrospective Study

Vertical Implant Placement Strategy	Clinical Implication	Author	Year	Study Design
Shallow Placement	Sharper contour, reduced subcritical zone, limited prosthetic options	Hamilton A.	2023	Review
Deep Placement	Improved emergence profile but when placed too deeply linked to higher peri-implantitis risk	Hamilton A.	2023	Review
2 mm Lingual Placement	Preserves buccal bone, improves aesthetics and hygiene	Dab, Sandeep	2022	Review
2–3 mm Apical to Cervical Contour	Enhances emergence profile, cleaning and aesthetics	Dab, Sandeep	2022	Review
Mathematical Formula (D=2×H)	Aids in determining optimal implant depth (H= the horizontal space under the contact point)	Dab, Sandeep	2022	Review

Bucco-Lingual Implant Placement Strategy	Clinical Implication	Author	Year	Study Design
Palatal Placement (<3 mm)	Creates a buccal contour, generally favorable	Dab, Sandeep	2022	Review
Palatal Placement (>3 mm)	Leads to exaggerated contour, may affect function/speech	Dab, Sandeep	2022	Review
Buccal Placement	Under-contoured, compromises strength and tissue stability	Dab, Sandeep	2022	Review
Excessive buccal placement	Creates over prominent palatal contour, can affect function and speech	Dab, Sandeep	2022	Review

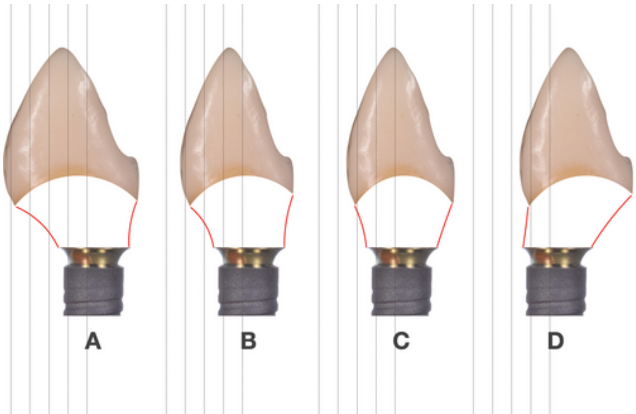
Vertical Implant Placement

The relationship between implant depth, the prosthetic free gingival margin, and the contour of the restoration is shown, with (A) that represents the ideal depth, and (D) indicating a shallower placement necessitates a ridge-lap contour. (19)



(Figure 7) Illustrates the relationship between implant depth and the emergence profile. (Hamilton A.) (19)

Bucco-Lingual Positioning

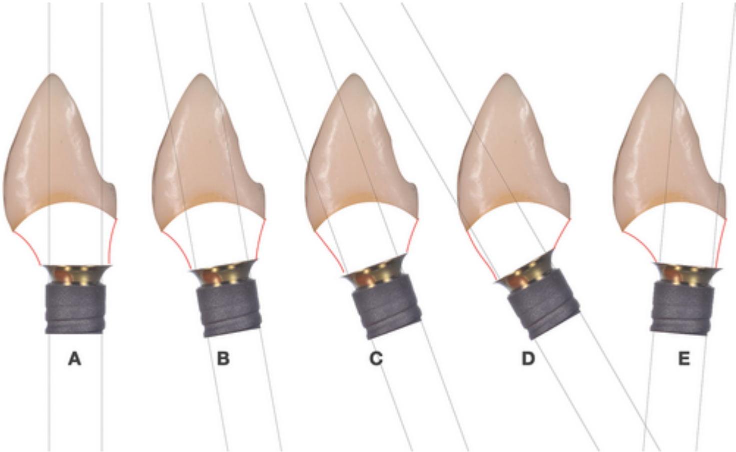


(figure 8) Illustrates the relationship between implant bucco-lingual positioning and its impact on the restorative design.

(Hamilton A.) (19)

Bucco-Lingual Inclination

Example of a tissue defect resulting from excessive buccal inclination.



(figure 9) Illustrates the relationship between implant bucco-lingual inclination and the prosthesis emergence profile. (Hamilton A.) (19)

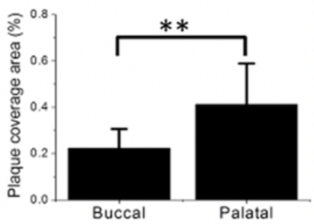
Implants bucco-lingual inclination can have repercussions on the different restorative options and health of surrounding soft tissues. The relationship between the prosthesis emergence profile and facio-lingual implant angulation is represented in the (figure 9). (A) an ideal screw access and contour; (B) small buccal angulation that requires an angulated screw channel or a cemented restoration; (C) increased buccal angulation, needing a customized cement-retained restoration; (D) compromised placement with exaggerated buccal angulation, with possible explantation; and (E) small lingual angulation. As represented in (Figure 9), the angulation of an implant has a direct influence on the position of the screw channel and how screw-retained restorations can get accessed. If a screw-retained restoration is not possible (>15 °-25°), a cement-retained restoration can be used as an alternative.

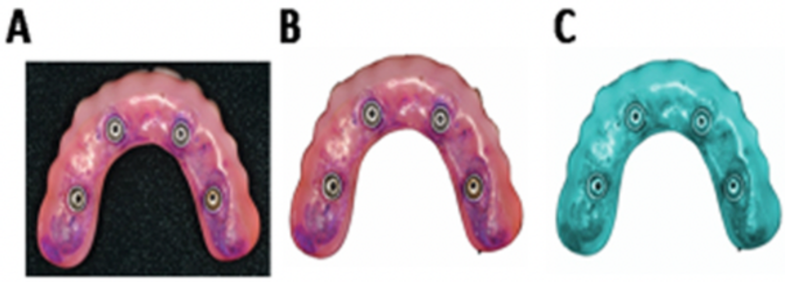
Implant Restoration Strategy	Clinical Implication	Author	Year	Study Design
Splinted Implants	May distribute occlusal forces; harder to achieve passive fit, more challenging cleaning access, increased peri-implantitis risk (6x)	Hamilton Al.	2023	Review
Non-Splinted Implants	Comparable bone loss and complication rates; easier access for maintenance	Dab, Sandeep / J. Mish	2022	Review

Parameter	Removable Overdentures	Fixed Prostheses	Author	Year	Study Design
Peri-Implantitis Rate	5.56–5.86%	2.72–3.42% (complete), 2.49–3.07% (partial)	Tord Berglundh	2003	Systematic Review (159 analysis)
Soft Tissue Complications	Higher	Lower	Tord Berglundh	2003	Systematic Review (159 analysis)
Bone Loss ≥2.5 mm	4.76%	3.78% (full-arch), 1.01% (partial fixed)	Tord Berglundh	2003	Systematic Review (159 analysis)
Implant Loss after 5 Years	>5%	2–3%	Tord Berglundh	2003	Systematic Review (159 analysis)
Mechanical Complications (Implant Components)	1.56 per patient	Lower	Tord Berglundh	2003	Systematic Review (159 analysis)
Mechanical Complications (Suprastructure)	1.90 per patient	Lower	Tord Berglundh	2003	Systematic Review (159 analysis)
Patient Preference	Less preferred for comfort	Preferred for comfort	Adam Hamilton	2023	Literature Review
Cleanability	Easier to clean	Harder to clean	Adam Hamilton	2023	Literature Review
Biological Complications	25% peri-implantitis, higher mucositis	12.68% peri-implantitis, lower mucositis	Adam Hamilton	2023	Literature Review
Plaque Accumulation	3x more on palatal/lingual	Lower	Adam Hamilton	2023	Literature Review
Recommended Clearance for Hygiene	1–2 mm clearance recommended	1–2 mm clearance recommended	Adam Hamilton	2023	Literature Review

Prosthetic Design Considerations in Full-Arch Rehabilitations

An optimal design must incorporate flanges and extensions that don't obstruct the access for cleaning devices like interdental brushes or floss. (20) For implant rehabilitations that are fixed, it is recommended to place tall abutments that can go up to 4mm in height and are free from tissue contact, with a 1-2 mm clearance for hygiene. (19) In other words, it is recommended for prosthesis designs to have at least a 1-2 mm clearance beneath the restorations in order to improve cleaning. (19) Regarding the emergence profile contours, a steep or over contoured emergence profile, especially when exceeding 30° and reaching or exceeding 45° can create subgingival niches that can lead to an accumulation of plaque and biofilm. (20) It was demonstrated that about one-third (28.3%) of the surface of "All on 4 prostheses" were covered in plaque. (21) Studies show that the accumulation of plaque is much higher on the palatal side (52.5%) when compared to the buccal side (17.3%). (19)

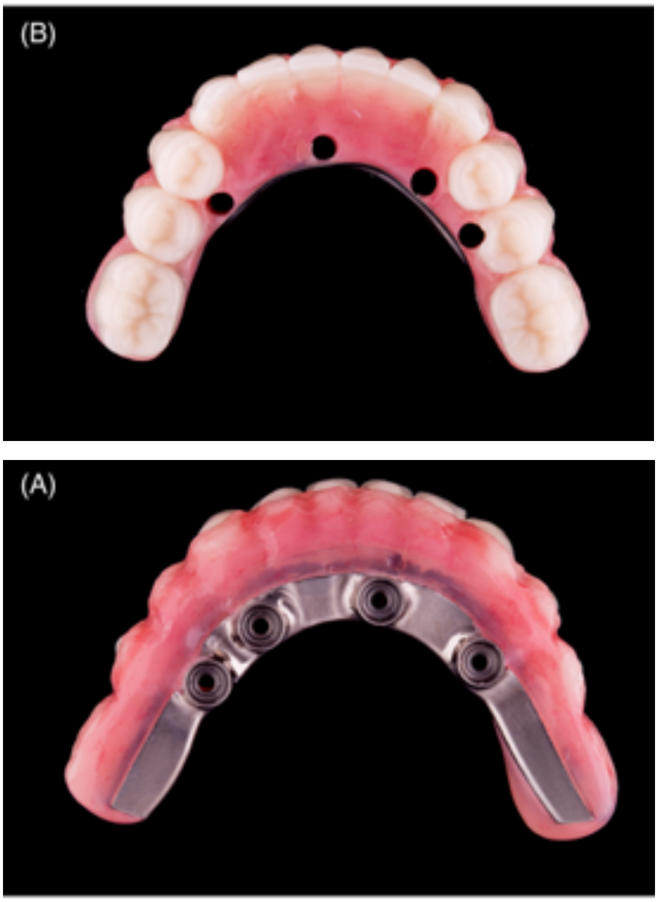




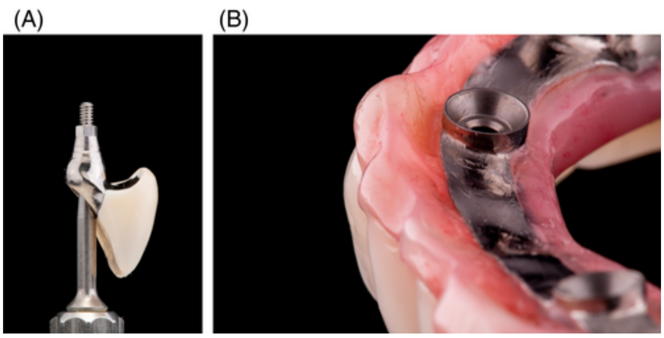
(Figure 10) Illustrates the higher amount of plaque count in palatal on a "All on 4 prostheses". (Hamilton A.) (19)

(Figure 11) Illustrates a picture of a "All on 4 prostheses" using erythrosine to locate new plaque in pink/red and older plaque in blue/purple. (Hamilton A.) (19)

An optimal cleansable prosthetic design must feature a minimal bucco-lingual. Excessive bucco-lingual contours are often created when an implant is placed in a position in relation to its adjacent teeth. (19) When an implant is placed too shallowly excessively lingually, this can lead to a concave design, referred to as a ridge lap. (19) A ridge lap design can create an embrasure that will trap plaques. (19)



(Figure 12) Shows a prosthesis with a correct design that minimizes palatal extensions. (Hamilton A.) (19)



(Figure 13) shows a ridge lap design due to excessive lingual implant placement. (Hamilton A.) (19)

Zirconia Type	Surface Roughness (Ra)	Bacterial Adhesion	Author	Year	Study Design
Polished Monolithic Zirconia	≤ 0.2 µm	Lower accumulation Contact angle: 79.5°, Surface Free Energy: Lower	Sabharwal M.	2020	In vitro
Glazed Monolithic Zirconia	Smooth initially, deteriorates over time	Higher accumulation (776 × 10^3 CFU, p=0.009)	Sabharwal M.	2020	In vitro
Polished Non-Glazed Zirconia	8.0 nm	9.3% lower biofilm thickness vs. unpolished (33% decrease (in vivo)) Contact angle: 79.5°, Surface Free Energy: Lower	Chen Al.	2020	In vitro
Unpolished Conventional Zirconia	45.9 nm	Higher	Chen Al.	2020	In vitro
Unpolished Self-Glazed Zirconia	33.0 nm	Higher	Chen Al.	2020	In vitro

Material	Surface Roughness (Non-aged, μm)	Surface Roughness (Aged, μm)	Biofilm Thickness (μm)	Bacterial Adhesion (OD)	Author	Year	Sample Size	Study Design
Lithium Disilicate	**1.23**	**2.8**	**7.25**	**0.74**	**Shlomo Matalon**	**2020**	**75**	**In vitro**
Zirconia	**0.638**	**1.9**	**4.43**	**0.75**	**Shlomo Matalon**	**2020**	**75**	**In vitro**
Cobalt-Chrome Metal	**0.36**	**1.51**	**3.56**	**0.94**	**Shlomo Matalon**	**2020**	**75**	**In vitro**

Occlusal Factor	Clinical Implication	Author	Year	Study Design
Bruxism	Associated with increased risk of mechanical and technical complications (20.5x), including screw loosening, prosthetic fractures. Also increases peri-implantitis risk (5.875x) in univariate analysis, but not in multivariate. Stronger effects seen in posterior regions.	Yerke et al.	2023	Retrospective Study
Occlusal Overload	Contributes to ceramic chipping (20.31%), screw loosening (2.57–5.3%), and rare implant fractures (~0.5%). Can worsen bone loss in compromised tissues even without peri-implantitis. Bone loss may be reversible after occlusal adjustments without surgery or antibiotics.	Romanos et al.	2023	Systematic Review
Posterior Implant Location	Bruxism impact is higher in posterior zones; more prone to screw loosening, prosthetic frame fractures, and technical complications due to higher force concentrations.	Yerke et al.	2023	Retrospective Study
Minimal Implant Support	Two implants supporting long-span bridges have higher risk of failure in bruxers due to force concentration and reduced distribution capacity.	Yerke et al.	2023	Retrospective Study
Loss of Anterior Guidance & Interproximal Contact	Absence of anterior guidance increases stress on posterior implants. Loss of interproximal contact (affecting ~29% of implant restorations) results in occlusal instability and contributes to mechanical overload.	Romanos et al.	2023	Systematic Review

Factor	Clinical Implication	Prevalence / Risk	Author	Year	Study Design
Bruxism	Significantly increases risk of mechanical complications: up to 20.5× more risk for prosthetic fractures, screw loosening, and framework issues; associated with higher risk in posterior zones.	5.875× increased risk of peri-implantitis in univariate analysis; not predictive in multivariate.	Yerke et al.	2023	Retrospective Study
Occlusal Overload	Acts as an aggravating factor in presence of inflammation; may contribute to bone loss even without peri-implantitis; some cases show bone recovery after occlusal adjustment without surgery or antimicrobials.	Bone loss seen in overload cases with funnel-shaped radiographic defects; differs from crater-like patterns of peri-implantitis.	Romanos et al.	2023	Systematic Review
Restorations with Minimal Implant Support	High failure rate in bruxers with minimal support (e.g., 2 implants for long-span bridges); requires careful biomechanical planning.	Especially problematic in posterior restorations; significantly higher failure risk in bruxers.	Yerke et al.	2023	Retrospective Study

Absence of Anterior Guidance	Increases stress on posterior implants, contributing to mechanical overload and potential complications; ensures anterior guidance in planning to mitigate overload risks.	Frequently overlooked; increased posterior overload from lack of proper guidance.	Yerke et al.	2023	Retrospective Study
Loss of Interproximal Contact	Affects ~29% of implant restorations; causes occlusal instabilities, food impaction, and may contribute to progressive peri-implant bone loss and prosthetic issues.	Affects nearly a third of implant cases; often leads to complications in hygiene and prosthesis stability.	Romanos et al.	2023	Systematic Review

5. Discussion:

5.1 Platform-Switching Implants

Multiple systematic review and meta-analyses have evaluated the efficacy of PSW implants with margin bone loss and the longevity of implant, these interests reflect the growing interest in platform-switching (PSW) as a preventive measure. The findings demonstrated significant reduction in crestal bone loss compared to regular platform (RP) implants. (22) These findings demonstrate that PSW implants can be a valuable tool for maintaining peri-implant bone stability, which is a critical factor for preventing peri-implantitis risk.

The horizontal switch of the abutment interface has a direct influence in soft tissue attachment as it helps limit peri-implant inflammation by increasing the distance between the inflammatory infiltrates and the bone crest, which protects the peri-implant tissues. (23) (22) By shifting the inflammatory zone away from the bone, PSW implants improve the resilience of tissue. Another outcome of platform switching is that the collagen fibers can arrange themselves in a circular way around the abutment. (7) This creates a “ring-like” arrangement and this stabilizes the connective tissue, which offers to reinforce the soft tissue barrier and help better protect the bone underneath. (7)

In addition, PSW implants offer mechanical outcomes by moving the area of stress concentration away from the cervical bone and moving it toward the implant body. (7) This redistribution of stress helps maintain bone, however it also increases the amount of stress generated on the abutments screw, and can lead to mechanical complications such as screw loosening and bacterial infiltrations, which are also a risk factor for peri-implant diseases. (7)

The study found that increased follow-up periods and implant abutment mismatches that are larger lead to better preservation of peri-implant bone. (22) Despite finding strong evidence supporting the use of PSW implants in lowering marginal bone loss, some studies reported results that are conflicting. A systematic review with follow-up times from 12 to 62.5 months found that while many reported less bone loss with PSW implants, approximately 50% showed no significant difference when compared to NPS implants. (24) These differences highlight the need for more standardized studies using longer follow ups in order to make more relevant conclusions. (24) Despite these conflicting results, all the outcomes mentioned highlight that PSW implants still might offer some extra benefits over RP implants. (24)

5.2 Healing Abutment Diameter Guidelines and Selection

The selection of the optimal prefabricated healing abutments should be based on the tooth being replaced. Healing abutments shouldn't be too large and should allow enough space for connective tissues, this allows to have a better prognosis and less recessions. For maxillary laterals or mandibular incisors, a 5mm diameter healing abutment is usually used. In the case of molars or maxillary central incisors, a 6mm or 7.5mm healing abutment is more suitable, however this depends on each case. The abutment selection process takes into account several factors for the choice between prefabricated, custom, or hybrid designs. (25) Both prefabricated abutments in titanium or zirconia offer good aesthetics and require less cost and chair time. In addition titanium abutments provide dependable strength and are recommended for posterior sites. Prefabricated abutments are compatible with most standard implant positions however, though modification options can be limited. On the other hand, fully custom abutments (whether titanium or zirconia) are optimal in esthetic demanding areas and can be precisely adapted to complex cases with excessive angulations or challenging soft tissues profiles. (25) Fully custom abutments have for advantages to have better papilla height retention, less gingival recession and a more natural tissue contour, however they often require more chairtime and higher costs compared to prefabricated abutments. (25)

Hybrid abutment consists of a titanium base added to a zirconia top and achieve an optimal balance between both materials. Hybrid abutments maintain the strength of the metal base and its reliable fit, while providing improved esthetic results through a zirconia crown interface. (25) Using this middle-ground approach has for advantage to be cost effective and offer some flexibility in customizing the emergence profile, which make hybrid abutments a practical option when durability and esthetics are the main priorities. (25)

5.3.1 Final Abutment: Emergence Profile Shape

Implant abutment emergence profiles (convex, concave or flat) play a key role in protecting the peri-implant tissues and ensuring the long-term success of the implant. Recent studies support the use of concave abutments due to their superior benefits when compared to convex abutments. (7) (26) A 3-year study showed that convex abutments led to greater bone loss, while concave ones had better bone preservation. (26) CBCT scans revealed that concave designs also increased soft tissue thickness above the bone crest following one year. (26) In contrast, flat profiles shifted the biological width apically and caused more bone resorption. (19) Regarding mucosal margin changes, they were comparable, with convex and concave profiles showing no major soft tissue difference. (26) Such findings suggest that concave abutment designs are the most efficient at preserving marginal bone and provide increased soft tissue stability. (26)

5.3.2 Final Abutment: Emergence Angle Design

These results highlight the importance and influence of transmucosal abutment design, in preserving bone around the implant. Wide abutments showed to shift more marginal bone apically, unlike narrow designs. (6) Histologic images confirmed better soft tissue and bone integration in narrow abutments compared to wide ones. (6)

A study showed that wide emergence abutments increased vertical bone remodeling and loss compared to narrow ones. (6) In order to avoid the problems associated with large and convex abutments, most studies highlight the importance of using abutments with a 30° emergence angle or less and this correlates with the results from the Micro-CT scans. The results showed that a 45° wide abutment caused more divergence and bone remodeling, while a 15° narrow abutment maintained bone closer to the platform. (6) A narrower design offers a smoother transition from the implant to the crown, minimed over-contouring, and better access facilitating cleaning. This allows for the establishment of a stable biological width around the implant, lowers the formation of plaque, reduces the risk of marginal bone loss and ultimately peri-implantitis. (7) (26) Despite the significant benefits seen in narrow designs, both designs maintained similar biologic width dimensions, including epithelial and connective tissue attachment. (6)

5.3.3 Final Abutment: Transmucosal Profile Design: Its Role in Soft Tissue Integration and Bone Maintenance

In dental implantology, the abutment transmucosal profile is a key element in the peri-implant tissue stability and bone preservation. Convergent abutments have an inward taper design from the implant platform until the prosthetic crown. Abutments designed convergently, feature an inward taper or curved indentation. Such a design configuration encourages the migration and organization of circular collagen fibers allowing an “O-ring” effect within the concavity, which has the advantage to strengthen the soft tissue seal and protect the adjacent bone from resorting. (10)

In contrast, parallel abutments adopt a uniform diameter throughout their length. This design is frequently found in older tissue-level systems. Due to their constant profile, they do not actively promote soft tissue proliferation, which could explain their association with increased bone loss. (10) Divergent abutments taper outward in a “funny” shape from the implant platform until the crown. This may be explained due to the outward spread that position the implant abutment microgap closer to the bone crest, which can facilitate bacterial colonization and inflammatory stress, especially in combination with wide emergence angles or large diameter mismatches between abutment and implant. (9) Overall, the evidence shows that convergent abutments result in better soft tissue and bone outcomes, while divergent abutments are associated with more bone loss. Furthermore, when compared to concave designs, parallel abutments may not provide the additional biological benefits and outcomes seen in contoured designs.

5.3.4 Final Abutment: Abutment Height and Width

Abutment height is a key component into preserving marginal bone surrounding dental implants. The abutment height is one of the prosthetic variables most associated with MBL. (8) Interestingly, this association doesn’t seem to be affected by the thickness of soft tissues; some studies suggest that even in patients with thinner biotypes the similar outcomes were seen. One of the main outcomes of long abutments is that they have shown to lower this marginal bone loss in the short run but also in the long run. (11) Taller abutments help mitigate early bone remodeling by positioning the abutment-crown interface farther from the bone crest and offer more space for the establishment of a stable supracrestal mucosal seal. (7) In addition, beyond the first year, long abutment showed a tendency to minimize late marginal bone loss however, the evidence supporting this effect is less robust. (11) These findings support the concept of using longer abutments with a height of 2mm or more, in order to promote long-term peri-implant health and minimize marginal bone loss. In other words, raising the abutment height seems to provide more space for the supracrestal tissue to reattach, and increases the distances of the implant-abutment microgap form the underlying bone. (11)

5.3.5 Clinical Considerations for Final Abutment Selection

The abutment selection process in implant-supported fixed prosthodontics is a complex and critical process in order to ensure predictable, esthetic and functional outcomes. The use of a systematic and organized approach can simplify this selection process by categorizing the different types of abutments based on their properties. There are many forms of abutments such as standard, conical, cylindric, angulated, cementable core post, and custom options, which allow clinicians to precisely match any abutment to each clinical case. The implant position is one of the first most critical factors, since an implant placed correctly relative to the planned restoration and adjacent teeth allows proper biological contours and access openings, on the other hand, a mispositioned implant will require custom solutions. (27)

The angulation of an implant plays an important role: if the implant is more than 15° deviated from the ideal axis, an angulated or custom is usually recommended, especially for cement-retained restorations where the screw-access is not a concern. (27)

Regarding the interocclusal space, which refers to the vertical distance between the implant and the adjacent dentition also influences the abutment choice. If the available space is limited (less than 2.8mm), it will allow narrow or cylindric abutments. Whereas, for greater space (3.5 mm, 4.5 mm, 5 mm, 6 mm, or even 7.5 mm), it allows for more options, including angulated and cementable core posts. (27)

5.4 One-Time Abutment Protocol

In the recent years, dental implantology has increasingly focused on biological outcomes and maintaining long-term stability in peri-implant tissues, highlighting the need to protect bone-level stability from abutment-related issues. Repeated abutment disconnection and reconnection can damage the soft tissue barrier, allowing bacteria to penetrate into the implant mucosal interface, triggering inflammation and consequently disrupting the junctional epithelium and connective tissue integration. (28) This disturbance can consequently compromise the stability of the peri-implant tissues and bone. The results presented suggest that the one-time abutment approach shows some benefits over conventional repeated abutment approaches and may help preserve the soft tissue seal however, its clinical advantages appear limited. Using a one-time abutments protocol showed to reduce inflammation and revealed lower level of IL-1β, and lower bone loss level at 6 months. (29) In order to determine whether these results are meaningful regarding long-term peri-implant tissue stability, further long-term randomized clinical trials (longer than 6-12 months) with larger sample sizes should be conducted. (30) Those small differences suggest modest gains, and need further validation. In conclusion, the clinical differences reported are modest and would need further research, however, these findings are promising and highlights the importance and benefits of reducing the amount of repeated disconnections to ultimately better preserve peri-implant tissue stability.

5.5 Screw Loosening: A Mechanical Pathway to Peri-Implantitis

Screw loosening is one of the most common mechanical complications in implant-supported prostheses, with an incidence rate going from 8% to 45% in single crowns. (15) This affects the stability of the abutment interface because it forms microgaps that allow bacterial invasion and colonize the area, which triggers inflammation in those tissues. (15) These micro gaps make the screws unstable and generate micro movements during dynamic loading and this leads to a "pumping effect" that attracts bacteria in the implant interface. In addition, this increase in bacteria colonization compromises the soft tissue seal, which further facilitates bacterial invasion. In other words, such mechanical complications translate into biological complications, highlighting the importance of preventing it.

There are multiple ways and strategies to minimize screw loosening. In terms of connections, external hexagon implants are more affected by screw loosening because they lack rotational resistance compared to internal connections. (31) To guarantee screws stability, during the manufacturing process, the laboratory should only use laboratory specific screws. Final titanium screws should only be used directly in patients mouths for trying or placing restorations. This helps minimize screw overuse and damaging the screws, which has a direct impact on the stability and long term performances of the screws. Gold-coated or diamond coated screws enhance the preload retention, and show better performances compared to standard titanium screws. (15) Retightening screws about 10 minutes post-torque significantly lowers any screw loosening. (15) Narrowing occlusal tables in molar diminished lateral forces and wider diameter implants in posterior both significantly reduce those risks. Material also has an impact, with metal ceramic restorations showing better results than acrylic resin against loosening. (15) In addition, during reconnection the use of Chlorhexidine plays a double role with its antibacterial capabilities and improves the stability of the joint screws. (15) Implementing the mentioned strategies can improve the longevity of implant-supported prostheses and reduce the mechanical and biological complications associated with it. (31)

5.6 Implant Retention Strategies

Retention methods for implant prosthesis can have a significant influence on peri-implant health. Cement-retained restorations are widely used due to their esthetic and functional advantage, however they are known to pose a greater risk of peri-implantitis, especially due to the potential residual cement.

Research highlights an 85% higher peri-implantitis risk with the presence of cement remnants, especially in patients with past periodontitis. (32) Methacrylate-based cements degrade over time and exacerbate the issue by promoting the formation of biofilm as well as bacterial colonization, which consequently can trigger inflammatory responses in those tissues. (33) Residual cement also reacts as foreign bodies and their presence can disrupt the natural soft tissue seal, which over time can promote chronic inflammation and bone resorption. Although cement-retained restorations have pushbacks, they have the advantage to offer better aesthetics, compensate and correct unfavorable implant angulation (>15°-25°angulations), and require lower laboratory production cost when compared to screw-retained options. Despite these benefits, cement-retained restorations show increased stress on the implants and surrounding bone. With 65.3 MPa under vertical load compared to 26.3 MPa for screw-retained ones, this means a 59.7% reduction in stress. (14) In other words, these lower values in stress exhibited on the implant and surrounding bone reduce the risk of implant components damages or bone resorption, which are crucial in the long-term success of restoration. In contrast, screw-retained prosthesis don't have the risk related with subgingival cement and offer better and easier access for any types of maintenance. The advancements of angulated screw channels (ASC) has improved their application and allowed them to overcome; angulation discrepancies, maintain retrievability and optimal fitting. (33) However, screw loosening affects up to 65% of single implant cases under heavy occlusal forces, making it a very common mechanical complication and this can lead to biological complications such as bacterial infiltration. (34)

Excess cement is one of the main complications associated to cemented-retained restoration. In order to manage and minimize excess cement, clinicians should place the crown margin at the level of the mucosal margin to ensure enough space and access for removing cement excess and avoid subgingival entrapment. (13) In addition, the soft tissue healing period should be prolonged to more than 4 weeks, this allows the formation of a more mature and stable supracrestal tissue attachment. This extended period allows to have a more solid soft tissue seal, and improves the removal of excess cements and lowers the risk of having inflammatory reactions. (13) Using radiopaque cements is recommended, such as zinc-bases cements, that improve the radiographic detection of residual cements.

Another approach help to mitigate the risk related to excess cement with hybrid screw-cemented approaches by cementing extraorally, followed by retaining the prosthesis with a screw. This technique, allows to combine the benefits of both retention systems and that same time minimize any complications associated with residual cement. This approach can be useful for full-arch restorations, since they require both retrievability and esthetic precision. (34) Hybrid options have been shown to lower inflammation markers by 35% compared to cement-retained designs. (14) The use of hybrid restoration also has for advantage to lower mechanical stress on implants and better preserve soft tissue heath, which minimize biological and mechanical complications. The selection of the most appropriate retention method can improve the long-term success of implant restoration, optimize esthetic and reduce peri-implant risks. To summarize, screw-retained prosthesis, particularly with conical connection and angulated screw channel offer better biomechanical and biological outcomes, reducing the risk of peri-implantitis. (14)

5.7 The Role of Original Components

Microgaps and poor fit revealed in non-original components increase both mechanical and biological risks. The use of manufacturer specific components is crucial to prevent complications, since non-original abutments have been linked with higher rates of micro leakages and 20% more mechanical complications. (16) (18) This can be explained due to their compromised fit and increase in plaque retention. (15) Scanning electron microscopes have revealed that there can be discrepancies above 10 microns in the surface morphology between original and no-original components, and this causes some micro gaps and can lead to the colonization of bacteria. (17) (18)

From a biological perspective, when microgaps and discrepancies are present in the implant abutment interface, it allows for bacterial colonization and can lead to peri-implant inflammation. (18) These microgaps make the screws unstable and create micromovements during dynamic loading, which lead to a “pumping effect” that attracts bacteria into the implant interface. Such gaps provide a pathway for the infiltration of bacteria, and can impact the stability of the surrounding tissues. Studies support those findings with non-original abutments showing higher levels of bacteria leakages, which increase the risk of peri-implant mucositis and ultimately losing crestal bone. (18)

Their discrepancies and compromised fit can also generate micro-movements at the level of the implant abutment interface and cause higher distribution of stress, leading to potential fatigue fractures over time. (18) They also exhibit more variation in torque loss, making them less predictable. (18) In addition non-original components show an increase in rotational misfit, consequently lowering the preload retention, which reduces screw stability and leads to complications such as screw loosening. (18)

Such discrepancies have a direct influence of screw loosening, occlusal instability and cause an increase wear in implant components, which can increase the risk of biomechanical complications over time. (18) Over time, this wear compromises the implant function when under load. Some studies mention that non-original can be clinically acceptable, however the lack of standardization in the third party manufacturing processes cause some variability and difference in the abutments fit, their surface morphology, and mechanical retention, which has a negative impact on the stability of the implants and the peri-implant health. (18) Despite being acceptable, these findings highlight the necessity of using original and high quality components to prevent complications such as marginal discrepancies, mechanical fatigue, and bacterial infiltration. (18)

5.8 Minimizing Overcontouring in Emergence Profiles

In a restoration, the combination of over contouring and convex emergence profiles severely increase the risk of peri-implantitis by facilitating plaque accumulation. Convex profiles with angles above 30° are strongly associated with increased bone loss. (35) On the other hand, concave emergence profiles clearly show more favorable results since they allow better tissue adaptation around the prosthesis and improved long-term stability. The advantages of using concave designs goes beyond bone preservation, with benefits also seen in soft tissues. They boost soft tissue stability, reducing mucosal recession up to 14.3% vs. 64.3% for convex profiles at 12 months. (36) For maximizing implant long term stability, it is crucial to minimize any convexity near the bone level and mucosal margin, since excessive convexity increases the retention of plaque and onset inflammatory responses. Some relevant findings state that convexity at the level of the emergence profile increases by 12.6 times the probability of creating recession. (36)

In terms of prevention of peri-implantitis, it was demonstrated that platform-switching combined with optimal concave profiles further minimize bone loss. (9) With the use of a concave emergence profile, clinicians can clearly minimize the risks of marginal bone loss, improve soft tissue integration, and promote the long-term success of implants.

5.9.1 Strategic Inter-Implant Spacing

Implant positioning is a critical step for abutment selection. Implants should be placed precisely in relation to the future restoration and its adjacent teeth in order to get optimal biological contours and access. A precise placement should have a mesio-distal gap of 1.5-2mm to the

CEJ and 3mm between implants. (37) When those values are not respected, the implant might be considered misplaced, and can have repercussions on esthetics, hygiene access and lead to a non axial loading, which will disrupt the prosthesis designs and results in abnormal contours that could compromise its function and long-term stability. Misplacement often creates steep profiles (>45°), increasing plaque buildup by 20-30% in spaces that are tight. (37) When the distances are shorter, it correlates with higher interproximal plaque, which increases the risks of peri-implant inflammation and bone loss. (21) This suggests that if possible, it is beneficial to increase the distance between implants, because it promotes better cleaning and also a reduced risk of peri-implantitis. (21) Although general guidelines exist, clinical limitations such as spacing and anatomic constraints can prevent adhering to those guidelines. Following them when possible supports a more favorable prognosis for the implants.

5.9.2 Vertical Implant Positioning

Placing the implant superficially or shallowy is known to reduce the subcritical zone of the restoration and result in shaper and more pronounced contour that can lead to problematic crown configuration. (19) Shallow placement makes the subcritical zone smaller, which consequently forces a crown design with exaggerated convex contours or a ridge-lap that will trap plaque. (19) Such design limits prosthetic options and hygiene access, which highlight the importance of placing implants in an optimal depth. (19) On the other hand, implants that are placed too deeply also show increased peri-implantitis rates, because it impairs the cleaning access, disrupts the biologic width, and allows more bacterial infiltration. (19) It is recommended placing 2mm lingual to preserves buccal bone and aids cleaning. (19) Implants placed 2-3 mm apical to the cervical contour optimize the emergence profiles. (38) The D=2x formula (e.g., 2mm gap = 4mm depth). (38) These approaches help ensure the prosthesis is not over-contoured and not positioned too deeply, since those factors can interfere with plaque removal and the access for cleaning. (38) Despite being recommended, those guidelines remain general since it is not always possible to follow such guidelines as every clinical situation is different and present their own challenges with for example, bone or anatomic limitations.

5.9.3 Bucco-Lingual Positioning and Inclination

The bucco-lingual position of the implant also has a direct influence on the prosthetic design. When placing an implant too buccally this will lead to a design with a reduced prosthetic thickness, making it less resistant and prevent the creation of an ideal emergence profile. (19)

On the other hand, implants that are placed too far palatally can create an over prominent palatal contour, which can affect function and speech. If an implant cannot be placed in an acceptable position and when the three-dimensional position of an implant is compromised because of insufficient bone in buccal, an augmentation of hard and soft tissue should be considered. (19) The position buccal or palatal placement of an implant should be in balance between aesthetic and functional stability in order to guarantee good prosthetic outcomes.

5.9.4 Bucco-Lingual Inclination

The bucco-lingual inclination of implants directly affects the restorative choices and tissue health. When there is excessive buccal angulation, there is a risk of defects and explantation, while a lingual angulation can support screw-retained options, cement-retained restorations are alternatives when angulation (>15 °-25°) complicates screw access. It is crucial that the embrasure design allows enough space for interproximal brushes over flossing for better hygiene and tissue stabilit.y (19)

5.10 Splinted vs. Non-Splinted Implant Restorations

Despite potential biomechanical advantages such as the distribution of forces, splinting implants do not reduce bone loss or complications compared to non-splinted restorations. Splinted restoration presents challenges like achieving passive fit and hygiene access. Findings demonstrated conflicting results and no significant benefits in splinted restoration. This could be explained due to their limited access to the central implant, making it harder to clean and allowing plaque and bacteria to accumulate around the implant. In addition, they create stress concentrations at the level of the implant-abutment interface when not perfectly fitted, which further promote inflammation. (20) Furthermore, if the implant uses a conical connection, achieving a passive fit is even more challenging. (20) Splinted restoration should be carefully selected based on hygiene access and the passive fit.

5.11 Full-Arch Fixed Implant Prosthesis vs. Removable Overdentures

Understanding the differences between removable overdentures and fixed prostheses helps clinicians create treatments responding to patient needs and that offer improved long-term stability. Often the designs of removable overdentures limits the access for probing and hygiene, which complicates clinicians diagnosis and peri-implant diseases management. (39) Overdentures show higher peri-implantitis rates (5.56–5.86% vs. 2.72–3.42%) and bone loss

(4.76% vs. 3.78% full arch) because their design restricts hygiene access and their flanges trap more bacteria. (39) With normally fewer implants (2–4 vs. 4–6), overdenture are also prone to more mechanical stress (1,90 complications for implant components vs 1,56), this is due to the greater occlusal stress, especially in the maxilla where bone is weaker, causing more inflammation and bone resorption. (39) In addition, they have more tissue seal disruption, because they are frequently removed, which can disrupt overdentures mucosal seal, unlike in fixed prostheses. In addition, overdentures have higher rate of implant loss (>5% vs. 2–3%). This means fixed prosthesis have about twice less implant loss, that makes them more predictable to prevent peri-implant complications, so they should be prioritized for high risk patients, despite their high cost. Fixed prostheses, despite having a higher initial costs, they are usually more durable because of their stable and non-removable design. On the other hand, initially overdentures are generally less costly but may require higher maintenance expenses over time due to their higher rate of complications (1,90 vs 1,56). (39) To conclude, fixed prostheses should be prioritized for high-risk patients, including smokers, those with poor oral hygiene, a history of periodontal disease, and bruxers, to enhance durability and outcomes.

5.12 Prosthetic Design Considerations in Full-Arch Rehabilitations

The design of an implant-supported prosthesis has a direct role in the prevention of peri-implantitis and can influence how effectively patients maintain their oral hygiene. Plaque accumulation has a direct correlation with prosthetic contours and emergence profiles. It was demonstrated that plaque accumulation is higher on the palatal side (52.5%) compared to the buccal side (17.3%), which reflects how important minimizing palatal extension is in order to improve cleansability. (39)These findings also show that most patients inadvertently push plaque toward the palatal area, which worsen the accumulation of bacteria in that zone. Therefore, patients should be educated and instructed to use their cleaning devices such as irrigators from both buccal and palatal directions.

B

(Figure 14) Illustrates the zones where plaque accumulates most, this includes the palatal and lingual zones behind implants. (Abi Nader S)(21)

In addition, findings show that emergence profiles that are steep or over-contoured exceeding 30°–45° are more prone to create subgingival niches, and become accumulating reservoirs for plaque and biofilm. (20) Such anatomical traps make it difficult for patients to have good access and correctly clean, and this can to peri-implant inflammation. To avoid limited access for hygiene, it is recommended to use a “high and dry” design. This design emphasizes using tall transmucosal abutments, up from 2.5 to 4 mm in height with a 1–2 mm clearance, beneath the prosthesis in order to allow easier hygiene access and reduce contact with tissues. (19)

In cases of extensive bone resorption, large amounts of pink tissue must be replaced, which leads to restorations designed with wide bucco-lingual contours and shapes that are pronounced horizontally. Consequently, this complicates both the aesthetic and hygiene. In such cases, it is important using a convex prosthetic design to allow proper self cleaning and prevent food getting trapped in the overcontoured zones. (19)

When anatomical parts such as the maxillary sinus or inferior alveolar nerve affect the implant position, short or tissue-level implants should be used in order to optimize the access for hygiene. (20) Additionally, when placing the restorative margins less than 1.5 mm from the bone crest, this violates the supracrestal tissue attachment (STAd), which increases the risk of peri-implantitis. (20)

A poor implant position can also lead to hygiene complications. A ridge lap design is created when implants are placed too lingually or shallowly and this creates a concave embrasures that will trap plaque and make maintenance more challenging. (19)

Such limitations in designs further reflect the importance of having a prosthetically driven implant placement approach that consists of carefully planning the angulation and spacing of the future prosthesis. This approach ultimately helps to avoid design problems such as over contouring and interproximal access that are limited. In addition, anatomical features of the maxilla such as natural curvature can create zones between the implants that are hidden and where plaque will accumulate, emphasizing the importance of creating designs that allow for cleaning. (19)

In order to confirm if a new prosthetic design is valid, an effective strategy is to use a provisional prosthesis that mimic the final restoration, which would serve as a diagnostic instrument to monitor and evaluate the effectiveness of a patient to properly clean a prosthesis before moving to the permanent restoration. (19) Using such a strategy will help minimize the risks associated to limited cleaning due to challenging prosthesis design.

A key finding showing the importance of establishing an optimal design with correct hygiene protocols revealed that 28.3% of the surface area of "All-on-4" prostheses are recovered in plaque. (21) This shows the importance of following a strict maintenance strategy that needs to combine optimal prosthetic designs, patient education and regular professional care. (21)

5.13 Patient-Guided Design Modifications to Enhance Cleansability

For implant supported prostheses, a careful prosthetic planning is key, however the addition of design modification can be an effective complementary strategy. As many patients using implant supported prosthesis are older, those patients are often more subject to physical and cognitive limitations related to age. Adding design modifications that improve the accessibility and visibility for cleaning can enhance oral hygiene and lower the peri-implant inflammation. For example, using small superficial notches in the prosthesis flange filled with a blue light-polymerized composite resin can be useful by being visual markers that help to guide patients in properly inserting cleaning devices in critical zones. (40) Such a design strategy facilitates the cleaning efficiency and highlights the most critical zones that need to be cleaned. If patients maintain those critical zones clean, this lowers the biofilm accumulation, and the risks related peri-implantitis. In addition, it can also improve patient compliance with hygiene protocols, which is crucial for the prosthetic's long-term success. (40)

(Figure 15) Illustrates visual marker to guide and help patients clean critical zones (Matalon S.) (41)

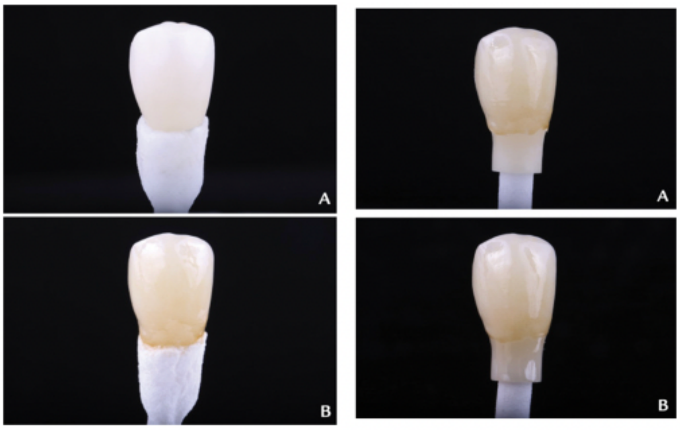
5.14 Optimizing Zirconia Surface Characteristics

The surface of implant-supported restoration plays a key role in bacterial adhesion, and can have a direct influence on the onset of peri-implantitis. This underscores the need to optimize surface treatments to prevent peri-implantitis. Zirconia has been one of the most evolving and used materials in recent years. Its popularity reflects its strength and versatility, but surface finish critically affects its performance. Zirconia is a strong material usually manufactured in a monoblock form, it is often glazed in order to improve its esthetic appearance. While glazing enhances aesthetics, it compromises bacterial resistance over time. As glazed zirconia deteriorates over time and creates a rough surface that can accumulate bacteria. This degradation shifts glazed zirconia from an initially smooth state to a biofilm-prone surface, increasing peri-implantitis risk.

Clinically, only polished non glazed zirconia should be used for subgingival areas because of its stable smooth surface of Ra of 8.0 nm, which is 33% less rough compared to glazed zirconia. A careful surface treatment helps to minimize bacterial adhesion and peri-implant inflammation and this approach prioritizes biological stability in high-risk zones. The amount of glaze applied should be minimized as much as possible, especially in zones that are at high risk of accumulating biofilm. With a surface roughness that can reach 33.0 nm, limiting glaze is key in preventing biofilm formation in critical areas. (42) Following any chairside adjustments, zirconia surface roughness can be as high as 45.9 nm , so an optimal polishing should be performed to assure a smooth and bacterial resistant surface to prevent any degradation of the peri-implant soft tissues and ensure their long-term health. In addition, polished zirconia show a higher contact angle (79.5°), this means it is more resistant to wetting and this lowers the ability of fluid and the bacteria it carries to adhere, meaning less bacterial retention. (42) Furthermore, polished zirconia showed lower surface free energy. contributing to lower bacterial retention. (42)

5.15 Glazing strategy to minimize bacterial adhesion

To effectively minimize and prevent bacterial adhesion on zirconia, a proposed technique helps maintain the subgingival zirconia surface, non glazed and polished. This method balances esthetics and function. This approach prevents unintentionally applying glaze and pigments in the critical subgingival zone that could degrade overtime. Protecting this zone is key to reducing biofilm. (43) The technique proposed in (figure 17) uses a firing paste and uses it as a shield in the subgingival area during the glazing process, which ensures that only the supragingival zone gets covered by glaze. Following the removal of the paste, the subgingival area should be polished with zirconia diamond-impregnated rubber discs and finished with polishing paste, which will help achieve an Ra of approximately 20 nm. A Ra of 20 nm has been shown to lower bacterial colonization and improve the integration of soft tissue. (43) With a subgingival surface free of glaze, this helps obtaining a transmucosal seal that improves the adhesion of gingival fibroblast minimizes peri-implant inflammation, and contribute to the stability of the peri-implant tissue. (43)



(Figure 16) The use of a firing paste as a shield to protect subgingival areas (Chen L.) (42)

5.16 Crown Material Aging and Surface Roughness

Factors such as the surface characteristics and aging behaviors of restorative materials have a direct influence on the adhesion of bacteria and the formation of biofilm. This relationship highlights how different material and their properties can have an influence on peri-implant health outcomes. The aging of the restorative material can lead to some surface roughness and increase bacterial adhesion. The findings showed that lithium disilicate's roughness had the highest increase with high biofilm formation, meaning greater peri-implantitis risk in vulnerable patients. (41) Zirconia known for its strength, showed more mild roughness increase and moderate biofilm. While Cr-Co metal had the lowest roughness change and the least bacterial retention, making it ideal for high-risk areas. (41) The findings show that lithium disilicate presents a more significant degradation on its surface, higher accumulation of biofilm and can be less suitable for implant-supported restorations reaching critical subgingival zone, especially for patients that are at high risk of developing peri-implantitis. Finally, Cr-Co metal showed to be the most favorable material against bacterial resistance, meaning it could be better suited for restorations in posterior or placed subgingivally, where the risk of peri-implantitis is higher. These findings highlights how careful material selection and surface treatment strategies can have an impact on minimizing bacterial colonization to preserve an optimal peri-implant health. By aligning material choice with patient risk profiles and incorporating maintenance like polishing, clinicians can better prevent peri-implantitis, balancing esthetics, function, and biological stability effectively. On the other hand, zirconia showed better performances, However all material surfaces still showed some roughness and bacterial accumulation over time, which reflects the importance of performing maintenance work on prosthetic parts such as performing mechanical polishing in order to improve the prosthetic biocompatibility.

5.17 Occlusal Load Control and Bruxism Management

Unlike natural teeth, dental implants don't have a periodontal ligament, which serves as a shock absorber and provides sensory feedback. This makes the implant more vulnerable to occlusal overload, which increases the risk of adverse problems such as mechanical failures and bone loss. (44)

Bruxism drastically increase the risk of peri implantitis with 5.875 times in univariate analysis. This can be explained through its association to increased mechanical complications (20.5-increase), and especially in the posterior zones where the forces are stronger. (45) In addition, it can trigger overload induced bone resorption, due to the generated mechanical stress that accelerates bone remodeling, particularly with the absence of a periodontal ligament to absorb forces. (46) This is why a proper occlusal planning prevents excessive forces and keeps the forces within the physiological limits of the surrounding bone, ultimately protecting it. Radiographically it is possible to differentiate between overload or peri-implantitis induced bone resorption. Overload presents a funnel-shaped pattern that resembles bone loss that gradually narrows inwards and appears conical as it is wide at the top and narrows downwards. Unlike per-implantitis that radiographically present crater-like defects. It is a strong diagnostic advantage for clinicians to be able to recognize and differentiate between both types of defects, since overload induced defects can often be mistaken with peri implant disease.

Unlike peri-implantitis related bone loss, occlusion-related bone loss often reverses simply with adjustments, and doesn't require surgical treatment. Findings show that bone loss is more pronounced in compromised tissues and can happen even without active inflammation, with some bone recovery possible following simple occlusal adjustments. (47)

Bruxism was shown to increase peri-implantitis risk 5.875 times in univariate analysis, however, in multivariate analysis, bruxism was not reported as a predictor of peri-implantitis, suggesting its influence is more important with pre-existing inflammation. (45) This reflects that bruxism and overload do not directly cause peri-implantitis but act more as aggravating factors when inflammation is present. (47)

The selection of a proper occlusal scheme is crucial in reducing overload and its associated risks. Bruxism and overload was shown to have more negative repercussion in long span bridges and large occlusal tables. (15) (This highlights the needs of narrowing the occlusal tables in bruxers and ensuring there is anterior guidance to minimize any lateral forces during posterior stresses. (15) In addition, the loss of interproximal contact affecting 29% of implant restoration is an indicator of occlusal instability and it exacerbates plaque induced inflammation. (46)

Using a structured protocol for occlusal maintenance that tracks symptoms such as bite changes, discomfort, bruxism, wear, fracture is key in minimizing the biomechanical and biological complication related to overload. (46) For bruxers, making guards, adjusting occlusion and monitoring interproximal stability is crucial to minimize any associated risk to overload. (46) Occlusal splints have also shown to be an effective proactive tool for occlusal control and preventing excessive forces, which is critical for the long-term success of implant restoration. (48)

In conclusion, occlusal management designed to mitigate bruxism and overload through precise planning, adjustments, and splints, is crucial to minimize mechanical failures, reversible bone resorption, and inflammation, which help ensure the long-term stability of dental implants.

6. Conclusion

As a multifactorial disease, peri-implantitis is often the result of a combination of biological and mechanical factors that are associated and sometimes caused by prosthetic decisions. Consequently, this makes the prosthetic phase a contributing factor but also in many cases a modifiable one since clinicians can proactively take decisions and actions that lower those risks associated with peri-implantitis. To a certain extent, systemic and anatomic limitations can't be controlled by clinicians, however, prosthetic factors are usually under their control. This means that it is crucial to have a deep understanding of how design, material, retention, and load distribution impact peri-implant health. This thesis explored some of the key prosthodontic strategies that contribute to prevent or minimize peri-implant disease, through recommendations and clinical protocols backed by scientific evidence. One of the goals was to present how to identify some risk factors but also propose solutions that can be introduced into clinicians daily practice.

In order to assure long-term peri-implant healths, it requires a multidisciplinary approach that combines a comprehensive treatment plan including 3D digital planning, skilled surgeon that place implants with a prosthetically guided approach where the prosthetic dictate the implants position, selecting reputable implants system backed scientifically, and a skilled prosthodontist that ensure a prosthetic design that is functional, retrievable and hygienically accessible. In addition, it is also vital for clinicians to make sure that patients are motivated and comply to the instructions, receive adequate personalized instructions, and adhere to a strict long-term maintenance protocol.

Regular check-ups, particularly 1–3 times per year, are critical for early detection and intervention. (49) Individualized recall intervals that range from 3 to 12 months should be planned according to the patient's oral hygiene practices, smoking status, and other risk factors. (50) It was demonstrated that patients that don't attend regular maintenance have a 4.25-fold higher risk of peri-implantitis, which relfects the importance of consistent long-term maintenance. (51) Together, this factor help reduce risks and detect early signs of peri-implantitis.

Based on the evidence presented and analyzed in this review, the following prosthodontic strategies and clinical recommendations are proposed to help clinicians minimize the risk of peri-implantitis and increase the probability of long-term success in their implant-supported restorations.

6.1 Recommended Prosthodontic Strategies and Clinical Recommendations to Prevent Peri-Implantitis

Implant-Abutment Interface Design

· Use platform-switching implants to move the inflammatory zone away from the bone crest.

· Convergent and concave profiles promote the "O-ring" effect, improving collagen fiber architecture and soft tissue stability.

· Moves the stress away from the cervical bone, which improves long-term stability.

Abutment Selection

· If possible use personalized abutments. If not, prioritize convergent and taller abutments (≥2 mm, ideally 4 mm) to maintain marginal bone and strengthen the mucosal seal.

· Promotes the formation of circular collagen fiber and increases the soft tissue seal.

- Excessively divergent and parallel abutments are subject to greater bone loss and should be avoided.
- For healing abutments: use customized or hybrid abutments in complex cases to improve fit, function, and esthetics.

One-Time Abutment Protocol

- Use a intermediary element (Multi-Unit ™) as a final abutment to minimize disconnections to preserve the soft tissue attachment and minimize inflammatory responses.
- Clinical differences are modest, however the protocol shows promise for long-term peri-implant stability.

Screw Stability

· Technicians should only use laboratory screws, and final titan screws should only be used when placing restorations in patients' mouths to minimize their overuse.

- Favor internal connections, gold or diamond-coated screws, and apply chlorhexidine to improve the screw stability.
- Retighten screws 10 minutes post-torque to improve the preload retention and prevent loosening.
- Manage occlusal forces by narrowing the occlusal table and use wider implants in posterior regions to minimize stress on the interface.

Retention Strategies

- Favor screw-retained prosthesis because there is lower biological risk with no risk of subgingival cement entrapments and lower stress distribution on the interface.
- Cement-retained restorations should be managed carefully:
  - Place margins at the mucosal level
  - Allow ≥4 weeks healing time before cementing
  - Use radiopaque cements (example: zinc-based cements) for easier radiographic detection of excess cement

Use of Original Components

- Always use original components from initial manufacturer to reduce the risks of:
  - Microgaps
  - Screw loosening
  - Torque loss
  - Bacterial infiltration through the "pumping effect"
  - Crestal bone loss

Prosthetic Design Considerations

- Avoid convex emergence profiles >30° to reduce recession and bone loss (>30° is considered overcontoured).
- Use concave profiles to improve adaptation of soft tissue and long-term results.
- For implants follow spatial and positioning guidelines:
  - 1.5–2 mm mesio-distal spacing to adjacent teeth
  - ≥3 mm inter-implant spacing
  - 2 mm lingual positioning to preserve buccal bone
  - 2–3 mm apical placement to support a natural emergence profile
  - Apply the D = 2x formula to optimize implant depth based on horizontal spacing
  - Shallow placement will lead to over contoured crowns

Full-Arch Prosthetic Design

- Avoid excessive flange extensions and palatal extensions, where plaque accumulation is 3x higher than buccally.
- Follow the "high and dry" strategy:
  - Use tall transmucosal abutments (2.5–4 mm)
  - Keep 1–2 mm clearance under the prosthesis for hygiene access

- Place restoration margins ≥1.5 mm from the bone crest to preserve the supracrestal tissue attachment (STAd).
- Evaluate hygiene effectiveness with a provisional restoration before the final work.
- Perform annual hygiene visits for removing accumulated bacteria in zones that are challenging to clean and accumulate plaque (behind implants and in palatal area)

Fixed vs. Removable Full-Arch Restorations

- Fixed full-arch prostheses offer better peri-implant results compared to removable overdentures:
    - Reduced bone loss, inflammation, and implant failure
    - Better hygiene access and more stable soft tissue seal
- Prioritize fixed prostheses for high-risk patients (smokers, bruxers, poor hygiene, or history of periodontitis), despite higher initial costs.

Zirconia Surface Optimization

- Avoid self-glazed zirconia subgingivally due to its deterioration and its high roughness (Ra ~33.0 nm).
- Subgingivally use polished zirconia (Ra ~8.0 nm) to reduce bacterial adhesion and support the integration of soft tissue.
- Protect subgingival zones using a firing paste that acts as a shield during glazing and finish by performing final polishing.

Occlusal Overload and Bruxism Management

- Bruxism and overload do not directly cause peri-implantitis but act as aggravating factors in environments that are inflamed.
- Bruxism increases mechanical complications by 20.5-fold and overload can accelerate bone loss even without an active infection.
- Assure correct anterior guidance, design occlusal splints for bruxers, narrow the occlusal tables, and perform routine occlusal checks.
- Bone loss caused by overload may be reversible through occlusal adjustments.
- Overload creates "funnel shaped" defects unlike peri-implantitis with "crater-like" defects

6.2 Limitations:

Some of the evidence presented in this review can somewhat be considered limited such as the results presented in the "one time abutment protocol" since the study included short duration data (<6 months), which can explain why the results were not as conclusive. In addition, the different systematic reviews regarding platform switching presented conflicting results, which makes it more challenging to draw a final conclusion at this point of time.

6.3 Future research:

More long-term clinical studies, especially regarding the "one time abutment protocol" and platform switching in order to have more robust data and draw more accurate conclusions, especially since those two prosthetic topics are popular subjects that have been drawing lots of interest. In addition, more studies should focus on common errors and mistakes seen in prosthodontic dentistry, in order to highlight those errors and offer solutions. Such work, would make clinicians more aware of potential problems, better detect prosthodontic issues and ultimatley, minimize their occurances, which would directly contribute to the prevention of peri-implantitis.

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