



The Impact of Combining Engaging and Non-Engaging Abutments in Multi-Unit Implant Prosthesis

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Abstract Objectives: The selection of abutment type plays a decisive role in the long-term success of multiunit implant-supported prostheses. Engaging abutments are designed to enhance mechanical stability through anti-rotational features, yet their use in multiunit situations often complicates the achievement of a passive fit. In contrast, non-engaging abutments allow greater flexibility for non-parallel implants but may increase the risk of screw loosening and prosthetic complications. Hemi-engaging configurations have been introduced as a hybrid approach to balance stability with prosthetic adaptability in multiunit prostheses. The aim is to provide clinicians with an updated overview of the mechanical implications of hemi-engaging abutments, supporting evidence-based decision-making in multiunit implant prosthesis. This review analyzes experimental evidence from *in vitro* mechanical testing and finite element analysis published over the last 15 years that evaluate the mechanical behavior associated with these abutment types. Searches were conducted in PubMed, Scopus and Google Scholar. The review highlights variations in stress distribution and component durability associated with each abutment type, while also identifying inconsistencies across studies. Key findings reveal that Non-Engaging (NE) configurations offer superior tolerance to prosthetic misfit, while Hemi-Engaging (HE) designs demonstrate a dramatic increase in fatigue life and fracture resistance-up to 17-fold in some studies. Evidence on stress distribution remains conflicting and no significant advantage was found for HE designs in maintaining screw preload or minimizing microgaps. The current lack of clinical evidence highlights the need for well-designed trials to confirm laboratory findings and guide evidence-based practice.

Key Words Engaging Abutments, Non-Engaging Abutments, Hemi-Engaging Abutments, Stress Distribution, Screw loosening, Finite Element Analysis

INTRODUCTION

Dental implant-supported Fixed Prosthesis (FDP) provides reliable long-term restorations for replacing missing teeth in patients with partial or complete edentulism, significantly enhancing oral function, aesthetics and improving overall quality of life [1]. Their long-term clinical success, however, depends not only on osseointegration of the implant fixtures but also on the biomechanical harmony of the prosthetic superstructure [2]. Among the critical determinants of this success, achieving a passive fit remains one of the most discussed and challenging objectives [3]. Passive fit refers to the intimate and strain-free adaptation of the prosthesis to the underlying implants [4]. This precise adaptation is essential in preventing mechanical stress on implant components and the surrounding bone, thereby reducing the risk of biological complications, such as peri-implant bone loss and mechanical complications, including screw loosening, component fracture, or framework deformation [5,6]

Although minor misfits up to 150 μ are considered clinically acceptable, minimizing misalignment remains crucial for ensuring prosthesis longevity [7,8]. The challenge of achieving passive fit increases significantly in multi-unit restorations, especially when implants are not parallel due to anatomical or surgical limitations. In such situations, the Implant-Abutment Interface (IAI) - the junction between the implant fixture and the restorative abutment-plays a crucial role [9,10]. The IAI contributes to the even distribution of occlusal forces, the maintenance of screw preload, the reduction of micromotion and microgaps and the long-term mechanical stability of the prosthesis [9-11]. Over the years, various abutment designs have been introduced to optimize these functions. Among them, the two main types of abutments, concerning their engagement with the implant's anti-rotational features, are Engaging (E) and Non-Engaging (NE). Engaging abutments, characterized by their anti-rotational features, are primarily indicated for single crowns,

where rotational stability is crucial. Conversely, Non-Engaging (NE) abutments are often preferred for multi-unit, screw-retained FDPs as they can accommodate minor implant misalignments, facilitating a passive fit [9,10]. While NE abutments simplify the prosthetic procedure in such cases, they transfer the entire stress of resisting rotational and functional forces to the abutment screws, potentially increasing screw stress and the incidence of mechanical complications, such as loosening or fracture [12]. To address the need for both passive fit and anti-rotational stability, the concept of Hemi-Engaging (HE) abutment configurations was proposed. This design incorporates at least one engaging abutment within a multi-unit FDP, while the remaining abutments are non-engaging; the rationale, as described by Schoenbaum and colleagues, is that the engaging abutment provides rotational resistance and stabilizes the prosthesis, while the non-engaging abutments permit the prosthesis to seat passively [13]. This hybrid approach seeks to combine the mechanical advantages of both systems, offering a practical compromise for complex clinical situations [13-15]. Some in vitro investigations and computational analyses have offered some support for the potential benefits of HE configurations. Certain in vitro studies suggest advantages, such as increased fracture resistance in cantilevered FDPs when the engaging component is strategically placed [15]. Finite element analyses have also indicated potentially favorable stress distribution patterns with HE configurations compared to fully non-engaging designs [14]. However, other investigations report no significant differences in outcomes like screw preload maintenance or microgap formation when comparing HE to fully NE systems [16,17]. Given these diverse findings and the increasing clinical interest in optimizing multi-unit implant restorations, this review aims to provide a comprehensive assessment of the available evidence on the mechanical

impact of hemi-engaging abutment configurations in multi-unit, screw-retained, implant-supported prostheses compared to fully non-engaging designs, focusing on parameters such as stress distribution, screw stability, micromotion and overall stability.

METHODS

A comprehensive literature search was conducted to identify studies evaluating the mechanical performance of engaging, non-engaging and hemi-engaging abutments in multi-unit screw-retained implant-supported prostheses. Studies were included if they assessed multi-unit implant prostheses using any of these abutment types, reported at least one biomechanical outcome and were published in English within the last 15 years. Eligible study designs included in vitro experiments, Finite Element Analyses (FEA) and clinical trials. Exclusion criteria were applied to maintain focus on multi-unit prostheses and relevant abutment configurations. Specifically, studies were excluded if they assessed single-unit restorations, cement-retained prostheses, or non-abutment-related interventions. Additionally, case reports, narrative reviews, expert opinions and studies not reporting relevant biomechanical outcomes were excluded. The search was performed across PubMed, Google Scholar and Scopus in June 2025, using keywords engaging, non-engaging, prosthesis type, abutment design and Mechanical parameters such as stress distribution, screw loosening or fracture, micromotion, misfit and prosthesis stability. Additionally, to ensure thorough coverage, reference lists of all included articles were manually screened to identify any additional relevant studies that may not have been retrieved through electronic searching.

Figure 1 provides an overview of the study selection process, including screening, eligibility assessment and final inclusion.

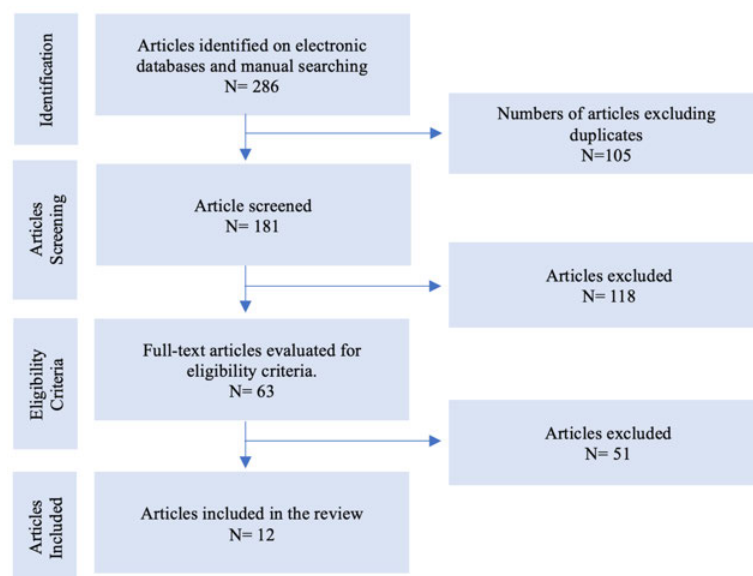


Figure 1: Flowchart Showing the Study Selection from Database Searches

RESULTS

A total of 12 studies fulfilled the inclusion criteria, consisting of nine *in vitro* investigations and three Finite Element Analysis (FEA) studies. Collectively, these studies explored the mechanical performance of screw-retained multi-unit implant-supported prostheses using different abutment configurations-Engaging (E), Non-Engaging (NE) and Hemi-Engaging (HE) designs. To facilitate interpretation, the findings were divided into three primary categories. The first category, stress and strain distribution (4 studies), examined how different abutment configurations influence the transmission of occlusal loads to the implant-abutment complex and surrounding bone. These studies, predominantly FEA-based, provided insights into localized stress concentrations and potential risk areas for mechanical failure.

The second category, interface integrity (5 studies), focused on the quality of fit between the prosthetic framework and the supporting implants. This included assessments of passive fit, misfit tolerance and microgap formation at the implant-abutment junction.

The third category, screw stability (3 studies), addressed the mechanical reliability of the screw joint, a critical factor for the long-term success of screw-retained prostheses. These studies assessed parameters such as preload maintenance, torque loss after cyclic loading and incidence of screw loosening or fracture. The findings highlighted the relationship between

abutment design and the ability of the screw to resist functional stresses over time. The key findings of these studies are summarized in Table 1.

DISCUSSION

This review provides a comprehensive evaluation of hemi-engaging abutment configurations in multi-unit implant-supported prosthesis. Through laboratory investigations and FEA, the study explores how different abutment designs influence stress distribution, prosthetic fit and screw stability; evaluating these mechanical behaviors is essential for assessing the durability of implant restorations.

Stress and Strain Distribution

Selection of an abutment configuration, engaging, non-engaging, or hemi-engaging, is a critical determinant of how occlusal loads are transferred through the prosthetic superstructure to the implant components, surrounding bone and prosthetic screws [14,18].

Finite Element Analysis (FEA) serves as a crucial computational tool in implant dentistry, enabling the simulation and prediction of complex biomechanical responses under various loading conditions. By creating detailed three-dimensional models of the implant, abutment, prosthesis and surrounding bone, FEA can map the distribution and concentration of stresses, most commonly evaluated using the von Mises stress criterion [19].

Table 1: Summary of Mechanical Performance across Engaging, Hemi-Engaging and Non-Engaging Abutments

| Study (Author, Year) | Study Type | Prosthesis Type | Configurations Compared | Parameter Investigated | Key Finding |
|------------------------------|---|-------------------------------|---------------------------------|---|--|
| Cho <i>et al.</i> [20] | FEA | NA | E-E, NE-NE | Stress Distribution | Internal engagement features affected stress peaks and load transfer mechanisms. |
| Sakar <i>et al.</i> [10] | FEA | 6-unit FPD | E-E, NE-NE | Stress Distribution | Abutment type and location significantly affected stress distribution. |
| Savignano <i>et al.</i> [14] | FEA | NA | E-E, E-NE, NE-NE | Stress Distribution | The fully Engaging (E-E) configuration resulted in the lowest and most balanced stress distribution. |
| Epprecht <i>et al.</i> [9] | <i>In-vitro</i> (Strain Gauge Analysis) | 4-unit zirconia FPDs | E-E, NE-NE | Strain Distribution | Strain levels significantly increased after torque, but there were no significant differences between designs. |
| Rutkunas <i>et al.</i> [8] | <i>In-vitro</i> | 2-implant zirconia frameworks | E-E, E-NE, NE-NE | Misfit Tolerance (Screw Rotation) | NE frameworks demonstrated the best misfit tolerance with the lowest screw rotation. |
| Kwan <i>et al.</i> [6] | <i>In-vitro</i> | 2-unit FPDs | E-NE, NE-NE | Prosthesis Stability and Screw Fracture | HE configurations were 17 times more stable and resistant to screw fracture. |
| Rutkunas <i>et al.</i> [23] | <i>In-vitro</i> (Stereomicroscope) | 2-implant zirconia frameworks | E-E, E-NE, NE-NE | Misfit Tolerance (Gap Size) | NE frameworks tolerated misfits better (smaller gaps); E-E frameworks were most sensitive to distortion. |
| Rutkunas <i>et al.</i> [24] | <i>In-vitro</i> (Radiographic) | NA | E-E, NE-NE, HE | Misfit Tolerance | NE-NE frameworks showed superior tolerance to misfit, followed by HE, with E-E being the least tolerant. |
| Alzoubi <i>et al.</i> [12] | <i>In-vitro</i> (SEM) | NA | E-E, NE-NE | Microgap Formation | No significant difference in microgap size was found between engaging and non-engaging abutments. |
| Alzoubi <i>et al.</i> [17] | <i>In-vitro</i> | 3-unit FPDs | E-NE, NE-NE | Screw Preload (RTV) | No significant difference in preload was found between the groups. |
| Alzoubi <i>et al.</i> [16] | <i>In-vitro</i> | 3-unit FPDs | E-NE, NE-NE | Screw Surface Wear | No significant difference in screw surface wear was observed between groups. |
| Dogus <i>et al.</i> [15] | <i>In-vitro</i> | 3-unit cantilevered FPDs | E (distal), NE (distal), All NE | Fracture Resistance (Cantilever) | Placing an engaging abutment at the distal position improved screw fracture resistance. |

A critical examination of the FEA literature reveals a significant conflict regarding which abutment configuration is biomechanically superior. The included FEA studies confirm that abutment configuration significantly influences both the magnitude and location of stress concentrations in multi-unit implant-supported prostheses [19]. However, discrepancies exist regarding which configuration is biomechanically superior. Savignano's analysis of a two-implant FDP in the molar and premolar regions, using four abutment configurations, found that a dual-engaging (mE–pmE) design produced the lowest overall stress, whereas the dual non-engaging (mNE–pmNE) configuration generated the highest stress. Yet, even in the low-stress engaging design, peak stresses were concentrated on the implant body and the upper threads of the abutment screws; areas prone to complications such as screw loosening when stresses exceed the material's yield strength. Hemi-engaging designs exhibited stress values between the fully engaging and non-engaging configurations [14]. In contrast, Cho *et al.* [20] reported that engaging abutments were associated with higher stress concentrations, while non-engaging designs demonstrated more favorable and evenly distributed stress across supporting structure. Similarly, Sakar's study on a six-unit prosthesis found that using all engaging abutments produced the highest amount of stress, with the highest von Mises values in the implant neck; whereas the fully non-engaging configuration yielded the lowest overall stress distribution [10]. This divergence underscores a key clinical consideration: Lower total stress values do not necessarily indicate a superior design if localized peaks compromise component integrity.

While FEA provides a comprehensive theoretical map of internal stress distribution, Strain Gauge Analysis (SGA) studies offer a complementary, experimental approach by physically measuring surface deformation (strain) at specific location [10,21]. In a study done on 4-unit zirconia FDPs combining engaging and non-engaging abutments, Epprecht *et al.* [9] found a significant increase in strain from baseline after screw tightening to 35 Ncm for all designs ($p < 0.05$). However, there was no statistically significant difference in mean strain between the engaging and non-engaging groups. This lack of difference may be due to methodological limitations; FEA provides a detailed theoretical map of stress distribution, identifying internal stress peaks, whereas SGA measures strain only at the physical gauge locations. If gauges are not positioned at the peak stress sites identified in FEA, differences may be undetected [9,21].

Current evidence from both FEA and SGA indicates that abutment configuration affects stress distribution in multi-unit implant-supported prostheses significantly; however, there is no clear consensus on the optimal design. FEA studies present conflicting results; some indicate that engaging abutments reduces overall stress [14]. While others associate them with higher localized stress concentrations, particularly at the implant-abutment interface [10,20]. Hemi-engaging configurations generally produce intermediate stress levels [10,14,20]. SGA studies report no statistically

significant difference in strain between engaging and non-engaging designs [2]. Overall, the literature suggests that no configuration is universally superior; instead, clinical selection should balance the need for stress reduction with the risk of localized peaks, with hemi-engaging designs serving as a reasonable compromise.

Interface Integrity

The mechanical performance of any abutment configuration is ultimately dependent on the quality of the interface between the prosthetic framework and the supporting implants. Achieving a passive fit is a foundational objective in implant prosthodontics [3,22]. This section discusses the concept of passive fit and examines how different abutment designs influence the prosthesis ability to tolerate unavoidable misfit.

Passive fit is defined as a "minimal-stress" or "strain-free" interface, where the prosthetic superstructure makes simultaneous and complete contact with all supporting abutments without inducing any tension or strain in the implants, screws, or surrounding bone upon tightening; while achieving a perfect, zero-strain fit is a theoretical ideal that is not clinically feasible, the primary goal is to minimize misfit to a clinically acceptable level, often cited as being within a range of 30 to 150 μm [3,4,7].

Regarding interface integrity, evidence from multiple studies indicates that non-engaging abutments provide superior misfit tolerance at the implant–abutment interface when compared to other abutment configurations. Experimental findings studies by Rutkunas *et al.* [8,23] demonstrated differences in misfit tolerance through *in-vitro* testing, which measured the angle of screw rotation required for seating and the resulting framework deviation. In a study by Rutkunas *et al.* [8,23] they found that dual Non-Engaging (NE-NE) frameworks exhibited the best performance; required the lowest angle of rotation and showed the least vertical and horizontal deviation after screw tightening. Dual-Engaging (E-E) frameworks showed the lowest tolerance to misfit, requiring the highest angle of rotation and resulting in the greatest deviations. Hemi-Engaging (E-NE) frameworks performed at an intermediate level. These differences were found to be statistically significant, emphasizing the ability of non-engaging systems to manage prosthetic inaccuracies. Notably, across all configurations, vertical misfit was better tolerated than horizontal misfit. Additionally, the author did another study to detect the misfit radiographically using different misfit levels utilizing (E-E), (E-NE) and (NE-NE) abutments, demonstrating that prosthetic configurations using (NE-NE) abutments exhibited greater tolerance to misfit, particularly under simulated horizontal discrepancies. Based on the findings of Rutkunas *et al.* [24] studies, findings highlight the importance of abutment selection in achieving optimal fit and stability in implant-supported prostheses.

Beyond the macroscopic concept of passive fit, the micro-integrity of the seal at the IAJ is another critical determinant of prosthetic performance and long-term implant success. Microgaps at this interface can serve as potential sites for bacterial colonization, mechanical wear and

stress concentration, all of which may compromise the longevity of the restoration and peri-implant tissue health. Studies utilizing high-resolution imaging techniques, such as Scanning Electron Microscopy (SEM), have provided detailed insights into the size and behavior of these microgaps under functional loading conditions. Alzoubi *et al.* [12] conducted SEM analyses to evaluate the microgap size of engaging and non-engaging abutments both before and after cyclic loading. Their results indicated that there is no significant difference in microgap size between the two designs, suggesting that the type of abutment engagement does not inherently affect the micro-integrity of the IAJ under controlled laboratory conditions.

Taken together, these findings indicate that abutment configuration influences the ability of a prosthesis to tolerate misfit, with non-engaging abutments showing the highest tolerance, particularly for horizontal discrepancies. Hemi-engaging abutments provide a practical compromise, combining partial anti-rotational stability with sufficient adaptability to accommodate misalignment. Importantly, the capacity to tolerate misfit does not appear to affect the size of the microgap at the implant–abutment junction, which remains similar across different abutment designs.

Screw Stability

The long-term success of a screw-retained prosthesis is often dictated by the screw stability. Screw loosening is one of the most common technical complications in implant dentistry and its prevention is a primary goal of prosthetic design². The following discussion analyzes the factors influencing screw stability, which is achieved through preload, the clamping force generated within the screw as it is tightened and elastically elongated. This force holds the prosthetic components together and resists functional loads that would otherwise cause separation or micromovement. However, this initial preload is not static. It begins to diminish almost immediately due to the "settling effect," where microscopic surface irregularities on the threads and mating surfaces flatten under pressure [25-27], causing a slight relaxation of the screw and a loss of 2-10% of the initial preload [28]. Over time, cyclic loading from mastication can lead to further preload loss through material fatigue. This gradual loss of clamping force is the primary precursor to screw loosening [26].

Reverse Torque Value (RTV), the amount of torque required to loosen a screw, is used as a clinical measure of the remaining preload [25]. A study evaluating preload maintenance, Alzoubi and Sadowsky compared hemi-engaging and fully non-engaging FDPs after one million load cycles by measuring the difference between initial and final RTV. They found no statistically significant difference in the mean RTV between the two groups ($p = 0.340$). This finding suggests that, under these specific loading conditions, the presence of a single engaging component does not confer a significant advantage in maintaining the screw's clamping force overtime [17], this was further corroborated by SEM analysis from Alzoubi *et al.* [12,16] which found no significant difference in the patterns of screw surface wear or damage between engaging and non-engaging designs after cyclic loading.

While the assessment of preload maintenance provides valuable information, a more critical measure of long-term stability is the component's resistance to catastrophic failure under prolonged functional stress [29]. A study by Kwan *et al.* [6] on splinted FDPs subjected to fatigue-to-failure testing revealed a difference in performance. Prostheses supported by hemi-engaging abutments survived a mean of 457,890 cycles. In contrast, those on fully non-engaging abutments failed at a mean of 27,180 cycles—a 17-fold difference in fatigue life. The analysis of failure modes in the Kwan study provides the mechanical explanation for this difference. In the fully non-engaging group, 90% of failures were due to abutment screw fracture; this is because the non-engaging design, lacking any anti-rotational feature, transfers all rotational and off-axis forces directly into the prosthetic screw, which acts as the sole element resisting these torques. The screw becomes the focal point of stress concentration and fails rapidly via fatigue. In the hemi-engaging group, the failure mode shifts to involve both the implant housing and the screws, reflecting a redistribution of stress within the system [6]. The presence of a single engaging component provides a "positive lock" that resists these destructive rotational forces. This lock alters the biomechanics of the system, forcing catastrophic loads to be distributed across the entire implant-abutment complex, preventing the screw from being the point of failure [30].

The mechanical advantage of the hemi-engaging design is maximized through the strategic placement of the engaging component, especially in cantilevered restorations. Fatigue studies by Dogus *et al.* [15] on three-unit cantilevered FDPs compared three configurations: engaging abutment away from the cantilever, engaging abutment next to the cantilever and a fully non-engaging control. The results showed that placing the engaging abutment on the implant furthest from the cantilever significantly increased the prosthesis's resistance to fracture. This strategic placement creates a more stable fulcrum, effectively bracing the restoration against the high-leveraging forces generated by the cantilever [13]. The engaging component acts as a rigid mechanical fulcrum, protecting the screw on the implant closer to the cantilever from the excessive torque and bending moments that are the primary contributors of failure in such restorations; suggests that, in clinical situations with higher functional loads or cantilever extensions, incorporating at least one strategically placed engaging abutment may enhance long-term prosthesis survival and reduce screw-related complications.

CONCLUSION

The hemi-engaging abutment configuration provides a valuable compromise between biomechanical stability and clinical handling, particularly in cases with favorable implant parallelism, long-span, or cantilever restorations in patients with high occlusal loads. The optimal choice depends on a careful evaluation of key clinical variables, including implant parallelism, the span of the restoration

and the precision of the fabrication workflow. Its self-centering design facilitates prosthesis insertion and its main strength lies in improving fatigue resistance and reducing the risk of catastrophic component failure, though it does not eliminate screw loosening. Current *in vitro* and computational evidence is inconsistent and no abutment type-engaging, non-engaging, or hemi-engaging - can be considered universally superior. Therefore, abutment selection should be guided by case-specific biomechanical priorities and risk assessment. The current literature is limited and sometimes conflicting, highlighting the need for high-quality, long-term randomized clinical trials to validate *in vitro* and simulation findings. Such studies should directly compare complication rates-including screw loosening, component fracture and bone loss-among engaging, non-engaging and hemi-engaging abutments to establish definitive, evidence-based guidelines for multi-unit restorations.

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