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Survival and Clinical Performance of Zirconia Implants Supporting Locator-Retained
Mandibular Overdentures: A Retrospective Clinical Study

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List of Abbreviations:

	Term	Abbreviation
1	Alumina-toughened zirconia	(ATZ)
2	Bone-to-implant contact	BIC
3	Dental patient-reported outcomes	dPROMs
4	Hydroxyapatite	HA
5	Locator-retained overdentures	LRODs
6	Magnetic resonance imaging	MRI
7	Marginal bone levels	MBL
8	Oral health impact profile	OHIP-14+
9	Oral health-related quality of life	OHRQoL
10	Patient-reported outcome measures	PROMs
11	Single-implant mandibular overdentures	SIMOs
12	Titanium	Ti
13	Titanium-zirconium	TiZr
14	Yttria-stabilized tetragonal zirconia polycrystal	Y-TZP
15	Zirconia	ZrO ₂)
16	Zirconia-toughened alumina	ZTA
17	B-tricalcium phosphate	β-TCP)

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1 Graphical Abstract

Keywords:

Zirconia implants, removable overdenture, edentulous mandible, locator attachment, ceramic implants, implant survival, OHIP-14, patient satisfaction

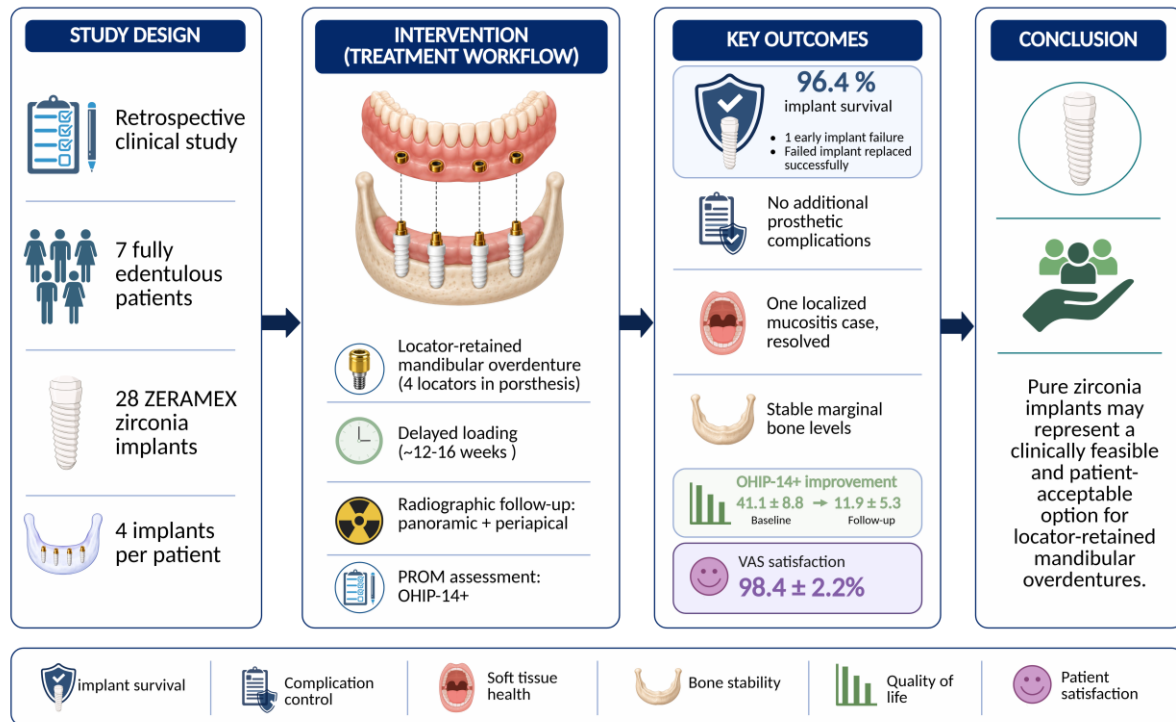


Figure 1 Graphical Abstract

Survival and clinical Performance of Zirconia Implants Supporting Locator retained Mandibular overdenture

2 Introduction

2.1 Epidemiology of edentulism

Edentulism remains a significant public health concern, particularly among the aging population. According to WHO data, the prevalence of complete edentulism increases with age, affecting up to 30–40% of individuals aged over 65 years in some populations (Kassebaum, Bernabé et al. 2014). The mandibular arch is disproportionately affected, often presenting greater functional challenges due to anatomical and prosthetic retention limitations (Thakur, Cleetus et al. 2025). Research consistently shows that the mandibular arch is disproportionately affected by anatomical and prosthetic retention limitations, leading to greater functional challenges than the maxilla (Kook, Choi et al. 2024). Advanced attachment systems, implant-supported options, and digital techniques can mitigate these issues, but anatomical constraints remain a significant barrier to optimal outcomes (Jain and Rathee 2020). In Germany, epidemiological data confirm a high rate of edentulous mandibles, especially among geriatric patients (Jordan, Micheelis and Cholmakow-Bodechtel 2016).

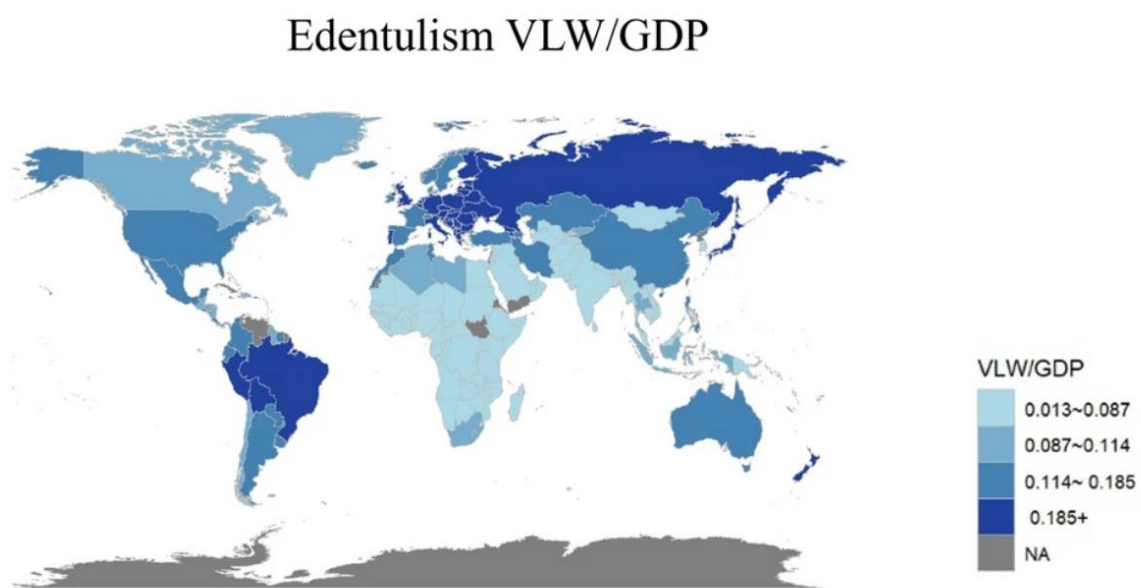


Figure 2 Global VLW/GDP heat maps (2021) by country for edentulism (Yang, Zhang et al. 2025) modified

VLW/GDP: Value of Lost Welfare / Gross domestic product

2.2 Implantology Evolution in edentulous mandibles

Dental implants have revolutionized the rehabilitation of edentulous mandibles. Mandibular overdentures retained by implants offer superior retention, stability, and oral function compared to conventional complete dentures (Schimmel, Araujo et al. 2023). The introduction of dental

implants revolutionized the treatment of edentulous mandibles, particularly through the use of two- or four-implant-supported overdentures. Clinical consensus and systematic reviews suggest that even two mandibular implants significantly enhance prosthetic retention, masticatory efficiency, and patient satisfaction compared to conventional dentures (Feine, Carlsson et al. 2002, Abou-Ayash, Fonseca et al. 2023). The 2002 McGill Consensus (Feine, Carlsson et al. 2002) recommended the two-implant overdenture as the standard of care for the edentulous mandible, a position reaffirmed in the York Consensus (Thomason, Feine et al. 2009).

2.3 Titanium limitations and rationale for ceramic

Titanium remains the gold standard in implantology, but aesthetic concerns, the discussion about possible allergic reactions, and the potential for peri-implantitis due to metal ion release have led to interest in ceramic alternatives such as zirconia (Manicone, Iommetti and Raffaelli 2007, Sculean, Gruber and Bosshardt 2014). According to latest ITI Consensus (Al-Nawas, Lambert et al. 2023), zirconia implants offer biocompatibility, low plaque accumulation, and high aesthetics. Ceramic implants, especially newer two-piece designs, are being investigated for their mechanical stability and long-term outcomes. Although one-piece zirconia implants show high survival rates at 5 years (mean 97.2%), evidence for two-piece designs and full-arch use is still emerging (Al-Nawas, Lambert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

Beyond aesthetic considerations, increasing attention has been directed toward the biological interaction between implant materials and peri-implant tissues (Wang, Zhang et al. 2018). Experimental and clinical studies suggest that zirconia surfaces may accumulate less bacterial biofilm and exhibit a more favourable soft tissue response compared with titanium surfaces (Bienz, Hilbe et al. 2020). Furthermore, recent evidence indicates that implant surface characteristics can influence local immune responses and the peri-implant inflammatory microenvironment (Rafikova, Piatnitskaia et al. 2023, Tang, Luo et al. 2023). Although current evidence does not conclusively demonstrate superior clinical outcomes for zirconia implants, these biological properties have renewed interest in ceramic implant systems, particularly in patient groups at increased risk for peri-implant inflammatory complications (Liu and Chen 2026).

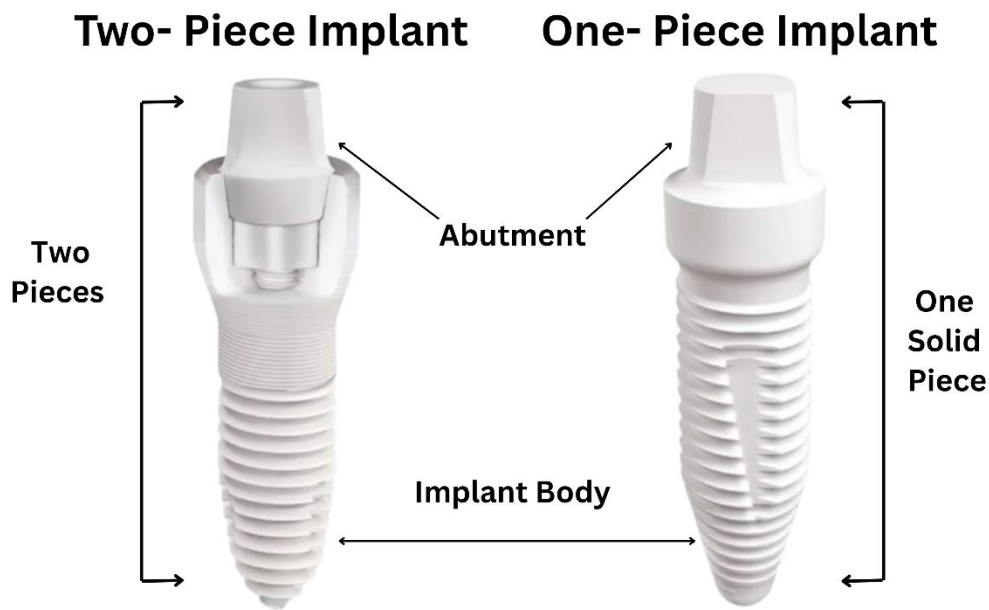


Figure 3 One piece vs Two Pieces Implant Construct

2.4 Role of removable overdentures

Implant-supported overdentures are well-established in mandibular rehabilitation. They offer better maintenance, hygiene access, and lower costs compared to fixed solutions (Schimmel, Araujo et al. 2023). Locator-retained removable overdentures supported by implants offer several advantages: easier hygiene maintenance, cost-effectiveness, and retrievability. Particularly in elderly or systemically compromised patients, they represent a less invasive and more manageable solution than fixed full-arch prostheses (Leles, de Resende et al. 2024). Clinical evidence consistently demonstrates that such prostheses significantly enhance oral health-related quality of life (OHRQoL), patient satisfaction, and functional outcomes over conventional dentures (Duong, Rocuzzo et al. 2022).

Non-splinted attachment systems such as locators are associated with patient satisfaction and ease of maintenance (Patel and Vaishnav 2025). The ITI Consensus confirms that dental patient-reported outcomes (dPROMs) improve significantly with implant overdentures, regardless of splinting method (Schimmel, Araujo et al. 2023).

2.5 Evidence gap on pure zirconia implants in overdenture use

Despite the increasing use of zirconia implants, there is a paucity of clinical data evaluating their performance in removable overdentures, especially those using locator systems. Most published studies focus on fixed zirconia prosthetics or one-piece implants. The ITI Consensus highlights the lack of high-quality studies investigating two-piece zirconia implants in full-arch

removable rehabilitations (Al-Nawas, Lambert et al. 2023, Schimmel, Araujo et al. 2023). To our knowledge, no prior study has documented clinical outcomes of mandibular overdentures supported by four two-piece zirconia implants using locator attachments, leaving a critical gap in the literature.

Although zirconia implants are increasingly studied for fixed prosthetic use, robust clinical data on their application in removable overdentures remain scarce. Most available literature focuses on titanium or titanium-zirconium implants. Only a few pilot studies and case series have investigated pure zirconia implants with removable locator-based full-arch prostheses, and long-term data are lacking (Askar and Haggag 2022, Vozzo, Azevedo et al. 2023). This limits the generalizability of ceramic implants for broader prosthetic concepts, despite promising biocompatibility and short-term survival rates exceeding 95%.

Although zirconia implants have been increasingly investigated during the last decade, the available evidence remains concentrated on single-tooth restorations, fixed partial dentures, and fixed full-arch rehabilitations (Al-Nawas, Lambert et al. 2023, Roehling, Gahlert et al. 2023, Bollen, Hakobayan and Jörgens 2024). In contrast, clinical evidence supporting the use of zirconia implants in removable prosthodontics remains scarce. Most available overdenture studies have been performed using titanium or titanium–zirconium implants, whereas zirconia-specific data are largely limited to isolated case reports, small case series, or overdentures retained by splinted bar or telescopic concepts (Rinke, Buergers et al. 2015, Peláez, Gelfo-Flores et al. 2022, Schimmel, Araujo et al. 2023).

Furthermore, the majority of published zirconia overdenture reports involve one-piece implant systems, which differ substantially from contemporary two-piece zirconia implants in terms of surgical flexibility, prosthetic design, and biomechanical behaviour (Al-Nawas et al., 2023; Bollen et al., 2024). Consequently, the clinical performance of locator-retained mandibular overdentures supported by non-splinted two-piece zirconia implants remains largely unknown (Roehling, Gahlert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

To the best of our knowledge, no previous clinical investigation has specifically evaluated the combination of four two-piece zirconia implants supporting a locator-retained mandibular overdenture while simultaneously assessing implant survival, peri-implant tissue health, marginal bone stability, prosthetic complications, and patient-reported outcomes. This represents a significant gap in the current literature and forms the rationale for the present study (Al-Nawas, Lambert et al. 2023, Schimmel, Araujo et al. 2023, Bollen, Hakobayan and Jörgens 2024)

2.6 Aim and relevance of the current study

This study aims to close this research gap by evaluating the clinical performance, survival, and complication rates of full-arch removable overdentures retained with locator attachments on zirconia implants in the edentulous mandible. This is among the first known structured clinical investigations of such a prosthetic concept.

3 Literature Review

3.1 Historical background of zirconia implants

Ceramic implants have become an increasingly viable alternative to metallic systems, particularly titanium, owing to their high biocompatibility and mechanical stability. Among ceramics, zirconia (ZrO_2)—primarily fabricated from yttria-stabilized tetragonal zirconia polycrystal (Y-TZP)—has emerged as the dominant material for clinical use. Its composition, high biocompatibility, and favourable aesthetic properties make it especially suitable for patients with metal sensitivities or for placement in the anterior aesthetic zone (Schimmel, Araujo et al. 2023). From a mechanical standpoint, zirconia exhibits high fracture toughness and flexural strength, though it remains more brittle than titanium. To mitigate this, modern implant designs utilize monolithic structures with increased diameters and optimized thread geometries to enhance stress distribution and minimize fracture risk. According to the ITI Consensus Report, one-piece zirconia implants used in single-tooth and three-unit fixed prostheses show no increased risk of fracture compared to titanium, with five-year survival rates between 93.8% and 100% (mean 97.2%), demonstrating clinical reliability comparable to conventional titanium implants (Al-Nawas, Lambert et al. 2023).

3.2 Biomechanical and biological properties of ceramic implants

Biomechanically, zirconia and other advanced ceramic materials—such as zirconia-toughened alumina (ZTA) and alumina-toughened zirconia (ATZ)—display excellent load-bearing properties and efficient stress distribution under functional forces. Finite element analyses have shown that zirconia implants distribute occlusal and oblique loads more uniformly than titanium, reducing stress concentrations in the surrounding bone and improving long-term stability (Ferraz, Barros et al. 2019). Similarly, comparative evaluations of different implant configurations indicate that two-piece ceramic systems exhibit lower peak stress values and better strain distribution than single-piece counterparts, suggesting enhanced biomechanical efficiency (Serrato-Pedrosa, Villanueva-Fierro et al. 2025). These findings highlight that the structural optimization and geometric design of ceramic implants play a crucial role in their mechanical performance.

Furthermore, surface modification and coating techniques have been widely employed to improve the biomechanical and biological integration of ceramic implants. The application of bioactive coatings, such as hydroxyapatite (HA) and bioactive glass, enhances the implant–bone interfacial stiffness, shear strength, and energy absorption capacity, leading to improved osseointegration (Pobloth, Mersiowsky et al. 2019). Similarly, calcium phosphate ceramic coatings contribute to improved adhesion and bone bonding through their chemical resemblance to natural bone minerals (Furko and Balázs 2020). Together, these modifications bridge the gap between mechanical performance and biological functionality, reinforcing the clinical reliability of ceramic implants.

From a biological perspective, zirconia implants exhibit excellent soft and hard tissue compatibility, supporting both osseointegration and soft tissue attachment. Several clinical studies and meta-analyses have shown that zirconia implants achieve bone-to-implant contact (BIC) and marginal bone levels (MBL) comparable to titanium. Reported mean marginal bone loss values of approximately 1.1 mm and probing depths around 3 mm after five years indicate stable peri-implant conditions and healthy tissue adaptation (Mijiritsky, Elad et al. 2023, Mohseni, Soufi and Chrcanovic 2023). These outcomes confirm that zirconia provides a biologically favourable environment for long-term osseointegration (Mussano, Genova et al. 2016).

In terms of soft tissue response, zirconia demonstrates superior mucosal compatibility compared to titanium (Van Brakel, Meijer et al. 2012, Bienz, Hilbe et al. 2020, Al-Nawas, Lambert et al. 2023). Its low surface free energy and smooth surface morphology result in reduced bacterial adhesion and plaque accumulation, which in turn decreases the risk of peri-implant mucositis and peri-implantitis. Additionally, fibroblasts exhibit strong adhesion and proliferation on zirconia surfaces, contributing to the formation of a stable mucosal seal that enhances the soft tissue barrier around the implant (Rafikova, Piatnitskaia et al. 2023). The favourable immune-compatibility of ceramic materials, particularly their limited interaction with macrophages and low inflammatory potential, further supports their use in long-term implant therapy (Liu and Chen 2026).

Ceramic implants also show promising osteo-inductive and osteo-conductive properties. Bioactive ceramics such as β -tricalcium phosphate (β -TCP) and zirconia composites facilitate bone regeneration, vascularization, and mineralized tissue formation, making them suitable for regenerative dental and orthopaedic applications (Mangano, Riberti and Mangano 2025). Moreover, surface functionalization techniques such as self-assembled monolayers (SAMs) have been developed to enhance the biological activity of otherwise inert ceramics, promoting cell adhesion and accelerating tissue integration (Böke, Schickle and Fischer 2014).

Patient-reported outcome measures (PROMs) further support the clinical application of zirconia implants. Due to their tooth-like colour, zirconia implants offer superior aesthetic outcomes, particularly in the anterior maxilla, where titanium may cause greyish gingival discoloration. Studies have shown no significant difference in patient satisfaction, biological complications, or aesthetic outcomes between zirconia and titanium abutments over one- to five-year follow-ups (Schimmel, Araujo et al. 2023). However, most of the existing clinical data pertain to one-piece zirconia implants, while evidence regarding two-piece systems—which offer enhanced prosthetic flexibility—remains limited (Bollen, Hakobayan and Jörgens 2024). Consequently, the ITI Consensus emphasizes the need for long-term comparative clinical trials to confirm the performance of multi-piece zirconia implant systems in diverse clinical settings (Al-Nawas, Lambert et al. 2023, Papaspyridakos, Sinada et al. 2024).

In summary, current scientific and clinical evidence supports zirconia and other advanced ceramics as reliable and biocompatible alternatives to titanium in implant dentistry. Their success depends on appropriate case selection, precise surgical and prosthetic execution, and meticulous maintenance care. With ongoing innovations in material science, surface engineering, and clinical protocols, ceramic implants are poised to play an increasingly central role in the future of both dental and orthopaedic implantology.

3.3 Attachment Concepts for Implant-Supported Overdentures

Various attachment systems have been developed for implant-supported overdentures to improve prosthesis retention, stability, and patient comfort. These attachment systems differ in their biomechanical behaviour, vertical space requirements, maintenance needs, and ability to compensate for implant divergence. Traditional systems with primary and secondary splinting such as bar and ball attachments have demonstrated long-term clinical success; however, modern secondary splinting low-profile attachments, including Locator, Locator R-Tx, Nocaloc, Od Secure and Docklocs systems, Figure 4 have gained increasing popularity due to their improved resilience, reduced prosthetic space requirements, and enhanced tolerance to implant angulation (Sabbagh, Jarjour et al. 2026). The selection of an appropriate attachment system should therefore be based on careful evaluation of anatomical conditions, prosthetic design, hygiene accessibility, and long-term maintenance considerations.

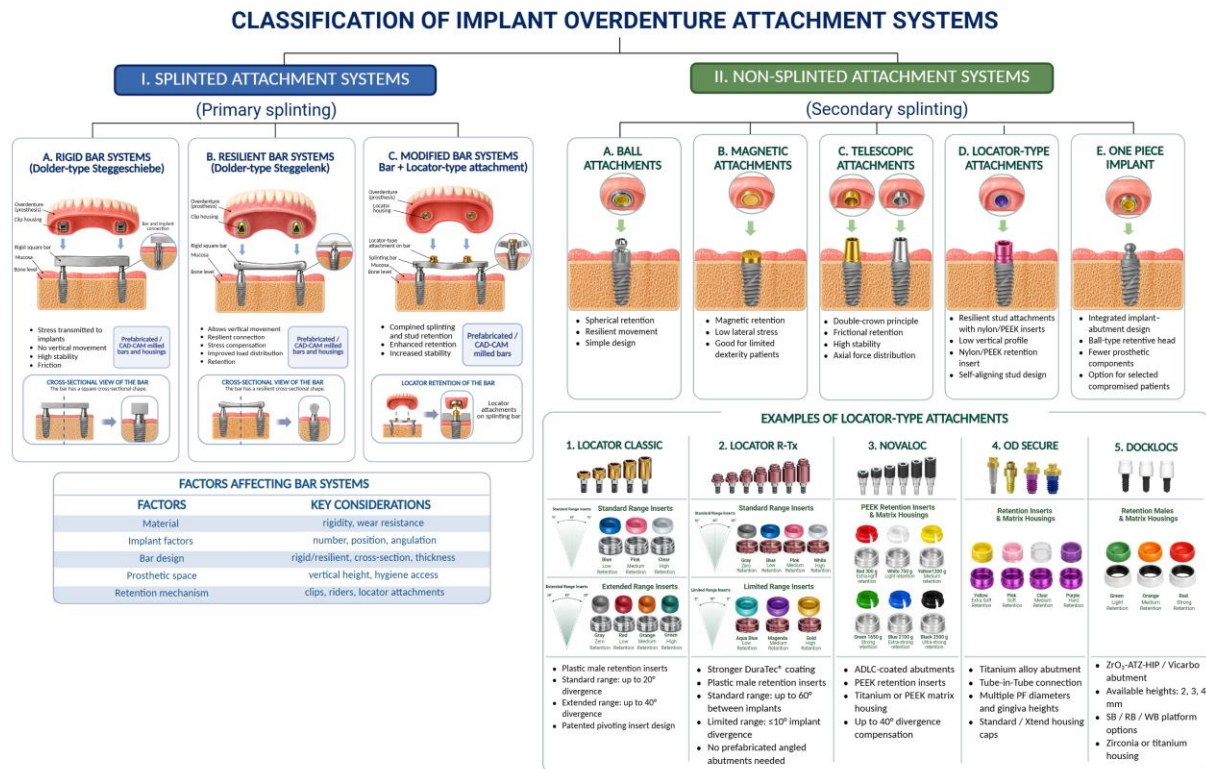


Figure 4: Schematic Representation of Different Removable Overdenture Attachment Systems:

A comparative evaluation of overdenture attachment systems is essential for understanding the biomechanical and clinical factors that influence long-term treatment success. Attachment systems differ substantially in their vertical restorative space requirements, capacity to compensate for implant divergence, retention characteristics, maintenance demands, and stress distribution patterns (Sabbagh, Jarjour et al. 2026). Traditional bar-retained overdentures generally provide superior prosthetic stability and more favourable load distribution through primary splinting of the implants; however, they require greater inter-arch restorative space and may complicate oral hygiene procedures.

In contrast, contemporary low-profile attachment systems such as Locator and OD Secure attachments offer improved prosthetic versatility, particularly in cases with limited restorative space or non-parallel implant positioning (Miranda, Bollero et al. 2025, Sabbagh, Jarjour et al. 2026). The Locator-Type attachment system demonstrates smaller vertical profiles and a high capacity for angulation compensation. Moreover Locator attachments are supported by extensive clinical documentation and demonstrate predictable retention and maintenance behaviour over time (Çakarer, Can et al. 2011, Sabbagh, Jarjour et al. 2026).

Attachment System	Vertical Space Required	Implant Divergence Compensation	Main Advantages	Main Disadvantages
Ball Attachment	~10–12 mm	Limited ($\approx 10\text{--}15^\circ$)	Simple design, low cost, easy laboratory procedures	Higher maintenance, wear of matrices, lower retention over time
Bar Attachment	~13–14 mm	Minimal (requires relatively parallel implants)	Excellent stability, splinting effect, improved load distribution	Increased hygiene difficulty, greater prosthetic complexity, higher restorative space requirement
Locator Attachment	~8–9 mm	High (up to $\sim 40^\circ$)	Low profile, self-aligning, easy hygiene access, widely used clinically	Nylon insert wear, periodic replacement and maintenance required
Modified Locator Attachment	~7–8 mm	Very high (up to $\sim 60^\circ$ depending on system)	Ultra-low vertical profile, suitable for limited restorative space, good esthetics	Retention may decrease over time, technique-sensitive component replacement
Magnetic Attachment	~6–8 mm	Moderate	Easy insertion/removal, reduced lateral stress, suitable for patients with limited dexterity	Lower retention forces, possible corrosion/demagnetization over long-term use
Telescopic Attachment	~12–14 mm	Moderate to high	Excellent stability and force distribution, favourable long-term retention	Technique sensitive, expensive laboratory fabrication, increased prosthetic space requirement

Table 1 Consequently, the selection of an attachment system should be based on a comprehensive assessment of anatomical limitations, implant distribution and angulation, prosthetic design requirements, anticipated maintenance burden, patient dexterity, and long-term functional expectations in order to optimize clinical outcomes and patient satisfaction.

Attachment System	Vertical Space Required	Implant Divergence Compensation	Main Advantages	Main Disadvantages
Ball Attachment	~10–12 mm	Limited ($\approx 10\text{--}15^\circ$)	Simple design, low cost, easy laboratory procedures	Higher maintenance, wear of matrices, lower retention over time
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Attachment System	Vertical Space Required	Implant Divergence Compensation	Main Advantages	Main Disadvantages
		parallel implants)	improved load distribution	restorative space requirement
Locator Attachment	~8–9 mm	High (up to ~40°)	Low profile, self-aligning, easy hygiene access, widely used clinically	Nylon insert wear, periodic replacement and maintenance required
Modified Locator Attachment	~7–8 mm	Very high (up to ~60° depending on system)	Ultra-low vertical profile, suitable for limited restorative space, good esthetics	Retention may decrease over time, technique-sensitive component replacement
Magnetic Attachment	~6–8 mm	Moderate	Easy insertion/removal, reduced lateral stress, suitable for patients with limited dexterity	Lower retention forces, possible corrosion/demagnetization over long-term use
Telescopic Attachment	~12–14 mm	Moderate to high	Excellent stability and force distribution, favourable long-term retention	Technique sensitive, expensive laboratory fabrication, increased prosthetic space requirement

Table 1: Comparison of Common Attachment Systems for Implant-Supported Overdenture (adapted from (Sabbagh, Jarjour et al. 2026))

3.4 Locator-retained overdentures: performance, satisfaction and complications

Locator-retained overdentures (LRODs) have become a popular and reliable treatment option for edentulous patients, offering enhanced stability, retention, and patient satisfaction compared to conventional complete dentures (Gupta, Bansal and Shukla 2022, Mathew, Kurian et al. 2024). These systems utilize resilient attachments that allow for limited movement of the denture while maintaining retention, which helps protect the underlying implants from excessive forces (Mhm and Ah 2022).

3.5 Performance and Patient Satisfaction

Locator-retained overdentures are widely recognized for high patient satisfaction, improved OHRQoL, and reliable retention. Studies consistently show that patients report greater satisfaction with Locator attachments compared to conventional dentures and, in many cases, compared to other attachment systems such as ball or telescopic attachments (Alamanos, Stöckle et al. 2018). Figure 4

The key advantages of LRODs include ease of use, low vertical profile, self-aligning design, and suitability for patients with limited manual dexterity or inter-arch space (Sutariya, Shah et al. 2021). Both single and two-part-implant Locator overdentures significantly improve comfort, chewing ability, speech, and overall quality of life (Patil and Seow 2021).

3.6 Complications and Maintenance

While Locator attachments provide strong retention, they require periodic maintenance due to wear of the nylon inserts and housing components. (Boven, Meijer et al. 2019, Mathew, Kurian et al. 2024)

The most common complications include: Figure 5

- Loss of retention requiring insert replacement due to friction
- Wear and deformation of the nylon matrix
- Relining needs due to alveolar bone resorption
- Occasional acrylic base fractures

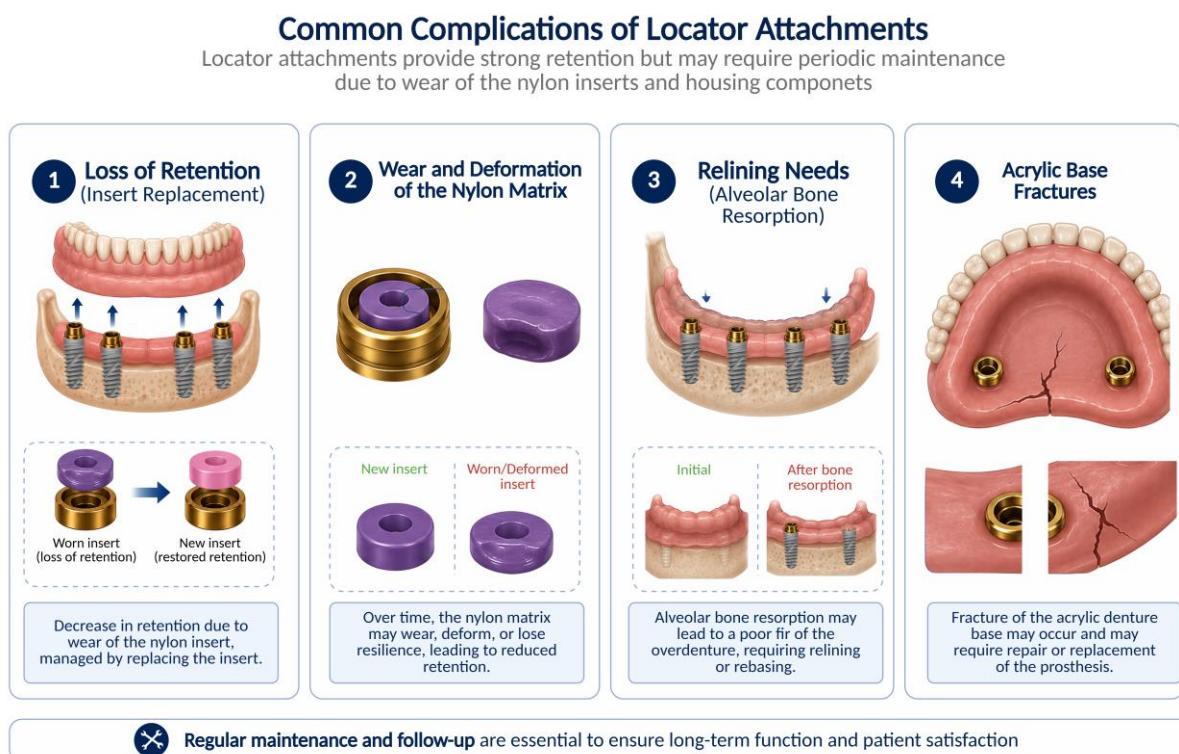


Figure 5: Common Complications of Locator Attachments

Locator attachments provide strong retention but may require periodic maintenance due to wear of the nylon inserts and housing components.

Over long-term use, Locators have been shown to have higher rates of minor prosthetic issues compared to bar attachments, though both systems show similar implant survival and overall prosthesis longevity (Ibrahim and Ragheb 2019). A seven-year study showed acceptable maintenance costs (about 19% of initial treatment cost) with regular professional care, despite frequent retention cap replacements (D'haese, Matthys et al. 2020).

Locator-retained overdentures demonstrate excellent clinical performance, high patient satisfaction, and manageable complication rates (Gul, Günel et al. 2025). Their mechanical design supports ease of use, effective retention, and good long-term function. While routine maintenance—particularly replacement of retention inserts—is necessary, the overall survival and comfort outcomes remain highly favourable (Mathew, Kurian et al. 2024). Locators are thus considered a clinically sound and patient-preferred attachment system for implant-retained overdentures, particularly in the mandible.

The most common complication is loss of retention due to wear of the nylon insert, necessitating regular maintenance and periodic replacement of retentive elements. Other complications include matrix activation/renewal, denture relining, and occasional prosthesis or tooth fracture, but these are generally manageable (Sabbagh, Jarjour et al. 2026). Compared to ball attachments, Locator systems often require fewer maintenance visits and have lower rates of denture fracture and soft tissue complications (Çakarar, Can et al. 2011). However, some studies note that Locator attachments may require more frequent post-insertion aftercare than bars (Miranda, Bollero et al. 2025, Sabbagh, Jarjour et al. 2026).

3.6.1 Performance

Locator systems demonstrate excellent clinical performance as a minimum standard of care for edentulous mandibles supported by at least two implants. They offer several mechanical advantages, including low vertical profile, self-aligning features, and versatility in angulation, which simplify insertion and maintenance for elderly patients (Alamanos, Stöckle et al. 2018). Long-term studies show implant survival rates exceeding 95–100% when LRODs are properly maintained (Aktas 2015).

A randomized trial comparing Locator and OT Equator attachments found both systems effective for early-loaded overdentures, with minimal complications and no prosthesis failures after one year (Tallarico, Fiorillo et al. 2023). In single-implant mandibular overdentures (SIMOs), Locators have shown significant improvement in denture stability, masticatory efficiency, and oral health-related quality of life compared with conventional dentures (Mathew, Kurian et al. 2024).

3.6.2 Patient Satisfaction

Multiple studies confirm high levels of patient satisfaction and quality of life with Locator-retained overdentures (Mhm and Ah 2022). LRODs provide superior comfort, retention, and chewing efficiency compared to complete dentures and are comparable in satisfaction to bar-retained overdentures (Ibrahim and Ragheb 2019). Patients report improved oral health-related quality of life and functionality, especially regarding speech, mastication, and denture stability (Alamanos, Stöckle et al. 2018, Indriksone, Vitols et al. 2022).

Gupta et al found no significant difference between ball vs. locator attachments in patient satisfaction, but Locator systems tended to have lower long-term maintenance demands (Gupta, Bansal and Shukla 2022). Similarly, a study comparing angled Locator and ball attachments in maxillary overdentures showed significantly higher satisfaction and better speech, comfort, and psychological outcomes with Locator systems (Aboelez, Abo Elezz et al. 2022).

3.7 TiZr vs pure zirconia vs titanium: current evidence

3.7.1 Mechanical and Structural Properties

Commercially pure titanium (Ti) has long been the gold standard in implantology because of its strength, ductility, and corrosion resistance. However, in small-diameter implants, pure Ti shows limited fatigue strength, which can lead to micro fractures under high functional loads (Osman and Swain 2015). Zirconia (ZrO_2) implants, typically Y-TZP, are extremely hard, corrosion-resistant, and aesthetically superior. However, they are brittle under tensile and bending stress and have lower fracture toughness compared to metals. Small-diameter zirconia implants are particularly prone to catastrophic fracture (Gupta 2016).

Titanium-Zirconium (TiZr) Alloy (typically 13–17% Zr, known commercially as Roxolid) provides up to 40% greater tensile and fatigue strength than grade IV titanium, while retaining comparable corrosion resistance and biocompatibility (Grandin, Berner and Dard 2012). Nanoindentation and microstructure analyses confirm TiZr's finer grain size and lower elastic modulus, which better match cortical bone and improve load distribution (Sharma, Waddell et al. 2020).

Material	Strength	Fracture Toughness	Elastic Modulus	Fatigue Resistance
Titanium (Ti)	High	High	~110 GPa	Moderate

Material	Strength	Fracture Toughness	Elastic Modulus	Fatigue Resistance
Zirconia (ZrO ₂)	Very high (compressive)	Low (brittle)	~200 GPa	Low
TiZr Alloy	Very high	High	~90–100 GPa	Very high



	Titanium (Grade 4)	Titanium Alloy (Ti-6Al-4V)	TiZr Alloy (Roxolid)	Zirconium Dioxide (Y-TZP)
Composition	Unalloyed titanium	Titanium 6% Aluminium 4% Vanadium	85 % Titanium Zirconium 15%	ZrO ₂ With yttrium oxide Y-TZP
Tensile/Flexural Strength	~550 MPa	860–930 MPa	~953 MPa	800–1,000 MPa
Expected Lifespan	10+ years (97–99% success)	10+ years (95–98% success)	10+ years	9+ years (96% survival)
Appearance	Grey metal	Grey metal	Grey metal	Tooth-coloured
Corrosion Resistance	High (oxide layer)	High	Excellent	Superior (bio-inert)

Figure 6 Material comparison summary (Ti vs TiZr vs ZrO₂)

3.7.2 Surface Characteristics and Osseointegration

Titanium: Roughened (SLA/SLActive) Ti surfaces promote osteoblast attachment and BIC. Hydrophilicity and micro topography are key to its high osseointegration rates (Kabir 2025). Zirconia: Modified zirconia surfaces (etched, blasted, or nano-textured) achieve BIC values comparable to titanium, with histological studies showing ~41–50% bone contact after 3 months (Kubasiewicz-Ross, Hadzik and Dominiak 2018). Zirconia also supports fibroblast adhesion and limits plaque accumulation (Hisbergues, Vendeville and Vendeville 2009). TiZr: Laser and acid-etched TiZr surfaces exhibit increased roughness and osteogenic activity compared to untreated Ti, leading to enhanced cell adhesion and mineralization (Charles, Anandapandian and Samuel 2016). Surface chemistry studies found higher hydrogen incorporation and nanostructuring, which may further improve wettability and early bone response (Frank, Walter et al. 2013).

3.7.3 Biological and Clinical Performance

Titanium implants have long-term success rates exceeding 95–98%, but may accumulate more plaque and occasionally elicit metal hypersensitivity reactions in rare cases (Shrivastava, Quadri et al. 2024). Zirconia demonstrates excellent soft tissue compatibility and reduced bacterial adhesion compared to titanium, contributing to better mucosal health. However, higher rates of implant head fractures (up to 20–30%) have been reported in early one-piece designs (Gupta 2016). Newer two-piece systems show promising survival rates (~94–97% after 5 years) (Kabir 2025)

Moreover studies confirm TiZr osseointegration equivalent to titanium and improved mechanical resistance in narrow-diameter implants. Removal torque and BIC percentages are similar for both Ti and TiZr surfaces ($\approx 75\%$) (Berner, Dard et al. 2009). TiZr also promotes a favourable macrophage and fibroblast response, supporting better soft tissue integration (Wang, Zhang et al. 2018).

3.7.4 Esthetics and Imaging Behaviour

Zirconia's tooth-like colour provides superior aesthetic outcomes, especially in thin gingival biotypes. Moreover, zirconia causes fewer Magnetic Resonance Imaging (MRI) artefacts than metallic implants, making it radiographically advantageous (Smeets, Schöllchen et al. 2017). TiZr and titanium both produce typical radiographic artefacts but no significant clinical impact.

3.7.5 Summary and Clinical Implications

Titanium, zirconia, and titanium-zirconium (Ti-Zr) alloy implants exhibit distinct mechanical, biological, and aesthetic characteristics that influence their clinical applications in implant dentistry (Al-Faraj, Alsubhi et al. 2024). While titanium remains the gold standard due to its proven long-term success and excellent mechanical reliability, zirconia implants offer superior esthetics and favourable soft tissue response, whereas Ti-Zr alloys combine enhanced mechanical strength with excellent biocompatibility, particularly in high-load clinical situations (Mostovei, Feier and Solomon 2025). Table 2

Property	Titanium (Ti)	Zirconia (ZrO ₂)	Ti-Zr Alloy (Roxolid)
Mechanical Strength	High	Moderate–High (brittle)	Very high ($\uparrow 40\%$ vs Ti)

Property	Titanium (Ti)	Zirconia (ZrO ₂)	Ti-Zr Alloy (Roxolid)
Fracture Resistance	Excellent	Fair (risk of crack propagation)	Excellent
Biocompatibility	Excellent	Excellent	Excellent
Osseointegration	Proven, predictable	Comparable to Ti	Equal or superior to Ti
Esthetics	Grey metallic	Tooth-coloured	Metallic (grey)
Corrosion Resistance	High	Very high	High
Peri-implant Health	Good	Superior (less plaque)	Comparable to Ti
Best Use	Universal	Metal-free or aesthetic zones	Narrow implants / high-load areas

Table 2: Comparative Properties of Most Common Dental Implant Materials

Titanium remains the most extensively validated and reliable implant material with predictable outcomes. Zirconia offers superior esthetics and biocompatibility but still faces limitations in mechanical resilience and long-term data. TiZr represents an optimized hybrid solution—combining the strength and toughness of titanium with enhanced corrosion resistance and biocompatibility, making it especially suitable for narrow-diameter and high-stress applications.

3.8 Summary of gaps and justification for the current research

Although zirconia (ceramic) implants have gained increasing attention as a metal-free alternative to titanium implants, clinical evidence regarding their use in removable prosthodontics remains limited. Most clinical investigations conducted during the last decade have focused on single-tooth restorations, fixed partial dentures, and fixed full-arch rehabilitations, whereas comparatively little research has evaluated zirconia implants supporting removable overdentures. Consequently, the available evidence for zirconia-supported overdentures is largely restricted to isolated case reports, small case series, and retrospective observational studies (Peláez, Gelfo-Flores et al. 2022).

Nevertheless, the limited available data suggest promising clinical outcomes. A 12-year clinical case report demonstrated successful long-term rehabilitation of an edentulous mandible using four zirconia implants supporting an overdenture, with stable peri-implant tissues and no signs of peri-implantitis throughout the observation period (Peláez, Gelfo-Flores et al. 2022). Similarly, a retrospective study evaluating zirconia implant-supported double-crown overdentures reported high implant survival rates and low biological complication rates after a mean follow-up of six years, while emphasizing the need for larger prospective clinical investigations (Rinke, Buegers et al. 2015). However, long-term comparative studies between zirconia and titanium overdenture systems remain scarce, and most available evidence originates from fixed prosthetic concepts rather than removable rehabilitations (Duncan, Ma et al. 2022).

Importantly, most published overdenture studies involving zirconia implants have been performed using one-piece implant systems and splinted attachment concepts such as bars or telescopic restorations (Rinke, Buegers et al. 2015) (Peláez, Gelfo-Flores et al. 2022) (Schimmel, Araujo et al. 2023). These treatment approaches differ substantially from contemporary two-piece zirconia implants with locator-retained overdenture designs in terms of surgical flexibility, prosthetic versatility, maintenance requirements, and biomechanical behaviour. Consequently, clinical evidence regarding non-splinted locator-retained overdentures supported by two-piece zirconia implants remains extremely limited (Al-Nawas, Lambert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

While attachment systems for implant-supported overdentures have been extensively investigated in titanium implant therapy, comparable data for zirconia implants are largely lacking (Duong, Rocuzzo et al. 2022, Schimmel, Araujo et al. 2023, Leles, de Resende et al. 2024). This represents a clinically relevant knowledge gap because removable overdentures remain an important treatment option for elderly and medically compromised patients, many of whom may benefit from metal-free implant rehabilitation concepts due to aesthetic, biological, or patient-specific considerations (Feine, Carlsson et al. 2002, Al-Nawas, Lambert et al. 2023, Schimmel, Araujo et al. 2023).

In addition to the limited clinical evidence, important biological questions remain unresolved. Although titanium, titanium–zirconium (TiZr), and zirconia implants demonstrate favourable osseointegration and clinical performance, relatively few studies have directly compared their biological behaviour under standardized conditions. Experimental investigations suggest that zirconia surfaces may exhibit reduced bacterial adhesion, lower inflammatory responses, and favourable fibroblast and osteoblast interactions compared with titanium surfaces (Wang, Zhang et al. 2018). Likewise, TiZr alloys have demonstrated osteoconductive properties

comparable to titanium and may promote enhanced early bone healing (Grandin, Berner and Dard 2012). However, direct comparisons of cellular responses among titanium, TiZr, and zirconia remain limited and occasionally contradictory.

Recent systematic reviews have further highlighted the need for a more comprehensive understanding of the biological mechanisms underlying implant integration and long-term tissue stability. While zirconia and titanium implants generally achieve comparable bone-to-implant contact and clinical outcomes, the influence of implant material and surface characteristics on osteogenic differentiation, inflammatory signalling pathways, host response, and peri-implant tissue homeostasis remains incompletely understood (Balmer, Spies et al. 2020, Bienz, Hilbe et al. 2020).

Taken together, these limitations indicate that current knowledge remains incomplete at both the clinical and biological levels. Clinical studies provide valuable information regarding implant survival, marginal bone stability, peri-implant tissue health, prosthetic performance, and patient-reported outcomes but offer limited insight into the biological mechanisms underlying long-term treatment success (Al-Nawas, Lambert et al. 2023) (Roehling, Gahlert et al. 2023). Conversely, laboratory investigations enable detailed analysis of cellular responses and material–tissue interactions but often lack direct clinical correlation and long-term validation (Wang, Zhang et al. 2018, Balmer, Spies et al. 2020). Therefore, a comprehensive understanding of zirconia implants requires the integration of clinical observations with biological evidence. Such an approach may contribute to a more precise evaluation of the factors governing osseointegration, peri-implant tissue stability, host response, and long-term prosthetic success in zirconia implant-supported rehabilitations.

The scarcity of robust clinical data on locator-retained mandibular overdentures supported by two-piece zirconia implants, together with the limited biological evidence directly comparing implant materials, underscores the need for integrated clinical and translational research. Addressing these knowledge gaps may improve our understanding of the long-term performance, biological stability, and patient-centred outcomes of zirconia implant-supported prosthetic rehabilitations.

3.9 Aim of the study

The aim of the present retrospective clinical study was to evaluate the short- to medium-term clinical performance of locator-retained mandibular overdentures supported by four two-piece zirconia implants in fully edentulous patients. Particular emphasis was placed on implant survival, marginal bone stability, peri-implant tissue health, prosthetic complications, and

patient-reported outcomes, including oral health–related quality of life and overall treatment satisfaction.

By investigating a treatment concept with limited current clinical evidence, this study seeks to contribute to the growing body of knowledge on the feasibility, safety, and clinical applicability of zirconia implants in removable full-arch rehabilitation. Furthermore, the study provides one of the first structured clinical evaluations of non-splinted locator-retained mandibular overdentures supported exclusively by two-piece zirconia implants, thereby addressing a significant gap in the contemporary implant literature.

4 Materials and Methods

4.1 Study design: Retrospective cohort

This study was designed as a retrospective cohort investigation evaluating the clinical performance of locator-retained mandibular overdentures supported by four two-piece zirconia implants in fully edentulous patients. The primary outcomes included implant survival, marginal bone level changes, peri-implant tissue health, prosthetic complications, and patient-reported outcomes. Patients were followed for a period ranging from 21 to 30 months, with a mean follow-up of 23 ± 3.8 months.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision) and reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for observational research (Von Elm, Altman et al. 2007). The retrospective design was chosen to evaluate the clinical feasibility and short- to medium-term outcomes of a treatment concept for which only limited clinical evidence is currently available.

Ethical approval was obtained from the Ethics Committee of the Landesärztekammer Rheinland-Pfalz (approval number: 2025-18402-retrospektiv), which raised no ethical or legal objections to the retrospective anonymous analysis and publication of the clinical data.

4.2 Inclusion/exclusion criteria

Inclusion criteria:

- Fully edentulous patients rehabilitated with locator-retained mandibular overdentures supported by four ZERAMEX® XT zirconia implants between 2021 and 2023.
- Patients restored according to a delayed loading protocol with a minimum clinical and radiographic follow-up of 12 months.

- Patients who participated in regular supportive maintenance visits and demonstrated satisfactory oral hygiene according to the treating clinician's documentation.
- Availability of complete clinical documentation, including medical history, radiographic records, and patient-reported outcome measures, to permit reliable retrospective evaluation of treatment outcomes.

Exclusion criteria:

- Patients presenting with systemic conditions known to adversely affect implant osseointegration or wound healing, including uncontrolled diabetes mellitus, recent head and neck radiotherapy, or other medically relevant contraindications to implant surgery.
- Active periodontal disease or untreated oral infection at the time of implant placement.
- Immediate loading protocols or restoration with fixed prosthetic designs.
- Incomplete clinical documentation or missing follow-up radiographs.
- Heavy smokers (>10 cigarettes/day)

4.3 Number of patients (n=7), implant system (ZERAMEX® XT), loading protocol (delayed)

A total of seven fully edentulous patients rehabilitated with locator-retained mandibular overdentures supported by ZERAMEX® XT two-piece zirconia implants were included in this retrospective cohort study. Each patient received four implants in the mandible, resulting in a total of 28 implants available for evaluation.

All implants were placed according to a delayed loading protocol, with prosthetic rehabilitation initiated following confirmation of satisfactory osseointegration after the healing phase. The use of four implants was intended to provide favourable prosthetic support, load distribution, and retention for the locator-retained overdenture design.

Clinical outcomes were assessed at both the patient level (oral health–related quality of life, patient satisfaction, and prosthetic performance) and the implant level (implant survival, peri-implant tissue health, and marginal bone stability).

4.4 Surgical and prosthetic protocol

Surgical phase:

All surgical procedures were performed under local anaesthesia using a standardized implant placement protocol. After crestal incision and full-thickness flap elevation, the implant sites were prepared according to the manufacturer's drilling sequence under copious saline irrigation. ZERAMEX® XT zirconia implants were inserted in the interforaminal region of the edentulous mandible, with implant distribution planned to support a locator-retained removable overdenture. Primary stability was assessed clinically at the time of placement, and the implants were not immediately loaded. Flaps were repositioned and closed with resorbable sutures.

Prosthetic phase:

Following a healing period of approximately 12–16 weeks, prosthetic rehabilitation was initiated after clinical and radiographic verification of osseointegration. The definitive prosthetic phase included placement of locator-type abutments and fabrication or adaptation of mandibular removable overdentures. All prostheses were adjusted to ensure passive seating, balanced occlusion, adequate retention, and sufficient hygiene accessibility.

A delayed loading protocol was selected to minimize early micro movement during osseointegration and to reduce the risk of overload during the healing phase, which is particularly relevant for ceramic implant systems and removable prosthetic concepts (Al-Nawas, Lambert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

4.5 Radiographic evaluation: baseline and $23 \pm 3, 8$ (Range 21–30 months) follow-up (panoramic + periapical)

Radiographic assessment was performed using digital panoramic radiographs and standardized periapical radiographs obtained immediately after implant placement, at prosthetic loading, and during follow-up examinations. Periapical radiographs were used as the primary modality for marginal bone level assessment whenever available because of their higher resolution and reduced distortion compared with panoramic imaging (Roehling, Schlegel et al. 2018).

Marginal bone levels were evaluated at the mesial and distal aspects of each implant using calibrated digital image-analysis software (SIDEXIS neXt Generation, Dentsply Sirona, Bensheim, Germany). Measurements were performed from the implant shoulder to the most coronal bone-to-implant contact (BIC), a reproducible radiographic landmark that is widely used in implant studies evaluating crestal bone changes (Albrektsson, Zarb et al. 1986, Roehling, Schlegel et al. 2018).

To compensate for radiographic magnification, calibration was performed using the known implant dimensions and thread geometry provided by the manufacturer. Marginal bone loss was calculated as the difference between baseline and follow-up measurements for both the mesial and distal implant surfaces. Results were recorded separately for each implant aspect and additionally expressed as mean values per implant.

Radiographic bone level changes were reported in millimetres as mean $\pm$ standard deviation. Comparison between baseline and follow-up measurements was planned using the Wilcoxon signed-rank test because of the small sample size and the anticipated non-normal distribution of the data. Statistical significance was defined as $p < 0.05$.

4.6 Clinical measures (mobility, mucositis, implant loss)

Clinical assessments were performed at follow-up appointments by a calibrated examiner and included evaluation of implant mobility, peri-implant soft tissue health, and implant survival. Implant mobility was assessed clinically by manual palpation and percussion testing. Any detectable clinical mobility was considered indicative of implant failure and loss of osseointegration.

Peri-implant soft tissue conditions were evaluated for the presence of erythema, swelling, and bleeding on probing (BOP). Peri-implant mucositis was defined according to the 2017 World Workshop classification as an inflammatory lesion confined to the peri-implant mucosa characterized by bleeding on probing with or without visual signs of inflammation and without progressive radiographic bone loss beyond physiological remodelling (Berglundh, Armitage et al. 2018, Heitz-Mayfield and Salvi 2018).

Implant survival was defined as the presence of the implant in situ and in function at the time of follow-up. Surviving implants were required to be clinically stable, free of persistent infection, and capable of supporting the planned prosthetic restoration (Albrektsson, Zarb et al. 1986, Papaspyridakos, Chen et al. 2012).

In addition, technical and prosthetic complications, including implant fracture, abutment-related complications, attachment-related complications, and prosthesis fractures, were recorded throughout the observation period.

4.7 OHIP-14+ questionnaire for patient satisfaction

Patient-reported outcomes were assessed using the Oral Health Impact Profile (OHIP-14+) questionnaire. The OHIP-14+ is a validated and widely used instrument for the assessment of

OHRQoL and has been extensively applied in studies evaluating implant-supported prosthetic rehabilitation (Slade 1997, John, Patrick and Slade 2002).

The questionnaire evaluates the impact of oral conditions on daily life across multiple domains, including functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. Responses are recorded using a five-point Likert scale ranging from 0 (“never”) to 4 (“very often”), with higher scores indicating a greater negative impact on oral health–related quality of life.

OHIP-14+ questionnaires were completed before treatment and at follow-up after prosthetic rehabilitation. Changes in OHIP-14+ scores were used to evaluate the patient-perceived benefit of treatment with zirconia implant-supported mandibular overdentures. In addition to clinical and radiographic outcomes, patient-reported outcome measures were considered an essential component of treatment evaluation, reflecting the functional, psychological, and social impact of implant rehabilitation (Feine, Carlsson et al. 2002, Schimmel, Araujo et al. 2023).

4.8 Ethical approval and consent

The study protocol was reviewed and approved by the Ethics Committee of the Landesärztekammer Rheinland-Pfalz (approval number: 2025-18402). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision) and applicable national regulations governing retrospective clinical research.

This investigation was based exclusively on retrospectively collected clinical and radiographic data obtained during routine patient care. All data were anonymized prior to analysis to ensure patient confidentiality and data protection in accordance with the General Data Protection Regulation (GDPR).

The OHIP-14+ questionnaires analysed in this study had originally been collected as part of routine clinical follow-up and were not specifically obtained for research purposes. Because the study involved secondary analysis of anonymized existing clinical data without any additional intervention, risk, or patient contact, the requirement for individual informed consent was waived by the Ethics Committee in accordance with applicable ethical and regulatory guidelines (Council for International Organizations of Medical Sciences [CIOMS], 2016).

4.9 Statistical analysis plan

Statistical analyses were performed using GraphPad Prism software (GraphPad Software, San Diego, CA, USA). Descriptive statistics were calculated for all study variables. Continuous data are presented as mean $\pm$ standard deviation (SD), while categorical variables are reported as frequencies and percentages.

Clinical outcomes were evaluated at both the patient level and implant level. Patient-level outcomes included OHIP-14+ scores, pain scores, and overall treatment satisfaction, whereas implant-level outcomes included implant survival, peri-implant tissue health, marginal bone level changes, and complications.

Changes in marginal bone levels and OHIP-14+ scores between baseline and follow-up examinations were analysed using the Wilcoxon signed-rank test because of the limited sample size and the anticipated non-normal distribution of the data. Statistical significance was defined as $p < 0.05$.

Given the exploratory nature of the study and the limited sample size, the statistical analysis was primarily descriptive and intended to identify clinically relevant trends rather than establish definitive causal relationships.

5 Results

5.1 Patient Characteristics

Seven patients presenting with a completely edentulous mandible were included in this retrospective cohort study and rehabilitated with locator-retained mandibular overdentures supported by four ZERAMEX® XT two-piece zirconia implants each, resulting in a total of 28 implants available for evaluation. The study population consisted of five male and two female patients.

The mean age at the time of implant placement was 73.0 ± 6.7 years (range: 65–86 years). The mean follow-up period was 25.0 ± 3.9 months (range: 21.6–31.0 months). All patients completed the planned follow-up examinations and were included in the clinical, radiographic, and patient-reported outcome analyses.

Baseline demographic characteristics of the study population are summarized in

Table 3.

Patient	Sex	Age at Surgery (years)	Follow-up (months)	Number of Implants
1	Male	75.2	23.1	4
2	Male	70.7	30.5	4
3	Male	72.3	21.6	4
4	Male	72.0	27.0	4
5	Female	65.2	25.0	4
6	Male	74.7	21.8	4
7	Female	86.1	31.0	4
Mean ± SD	—	73.0 ± 6.7	23.7 ± 3.9	4.0

Table 3 Baseline Characteristics of the Study Population

5.2 Implant survival rate

During the 21–31 month follow-up period, one of the 28 originally placed ZERAMEX® XT zirconia implants failed during the early healing phase prior to definitive prosthetic loading, resulting in a cumulative implant survival rate of 96.4% (27/28 implants).

The failed implant was removed and replaced after an appropriate healing period. The replacement implant achieved uneventful osseointegration and was subsequently restored according to the original prosthetic treatment plan. No further biological or mechanical complications occurred at this implant site during the remaining observation period.

No additional early or late implant failures, clinically detectable implant mobility, or implant fractures were observed. Consequently, all seven patients retained fully functional locator-supported mandibular overdentures at the final follow-up examination.

Overall, the observed implant survival and successful management of the single early failure indicate favourable short- to medium-term clinical performance of two-piece zirconia implants supporting locator-retained mandibular overdentures...

5.3 Clinical and Radiographic Documentation of the Study Cohort

Figures 7–13 present the complete clinical and radiographic documentation of all seven patients included in this study. For each patient, representative images obtained during the

preoperative, surgical, prosthetic, and follow-up phases are provided to illustrate the standardized treatment protocol and the clinical outcomes achieved with locator-retained mandibular overdentures supported by two-piece zirconia implants.

The documentation includes preoperative clinical and radiographic findings, intraoperative photographs demonstrating implant placement, immediate postoperative radiographs, and follow-up clinical and radiographic examinations performed between 21 and 31 months after prosthetic loading. Collectively, these images demonstrate stable peri-implant hard and soft tissue conditions, successful prosthetic rehabilitation, and favourable clinical integration of the zirconia implant-supported overdentures



Figure 7: Clinical and radiographic documentation of Patient 1

Patient 1 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture.

(1a) Preoperative clinical view of the edentulous mandible. (1b) Full-thickness flap elevation during surgical exposure of the mandibular ridge. (1c) Osteotomy preparation for implant placement following the manufacturer's drilling protocol. (1d) Preoperative panoramic radiograph demonstrating the edentulous mandible and residual dentition in the maxilla. (2a) Intraoperative placement of zirconia implants. (2b) Clinical view after placement of four zirconia implants with healing components in situ. (2c) Primary wound closure with interrupted sutures following implant placement. (2d) Immediate postoperative radiograph confirming implant positioning. (3a) Intaglio surface of the mandibular overdenture demonstrating the incorporated

locator attachment housings. (3b) Clinical follow-up after 23 months showing stable peri-implant soft tissue conditions around the zirconia implants. (3c) Intraoral view of the locator-retained mandibular overdenture in function at the 23-month follow-up. (3d) Follow-up radiograph after 23 months demonstrating stable implant positioning and maintained peri-implant bone levels.

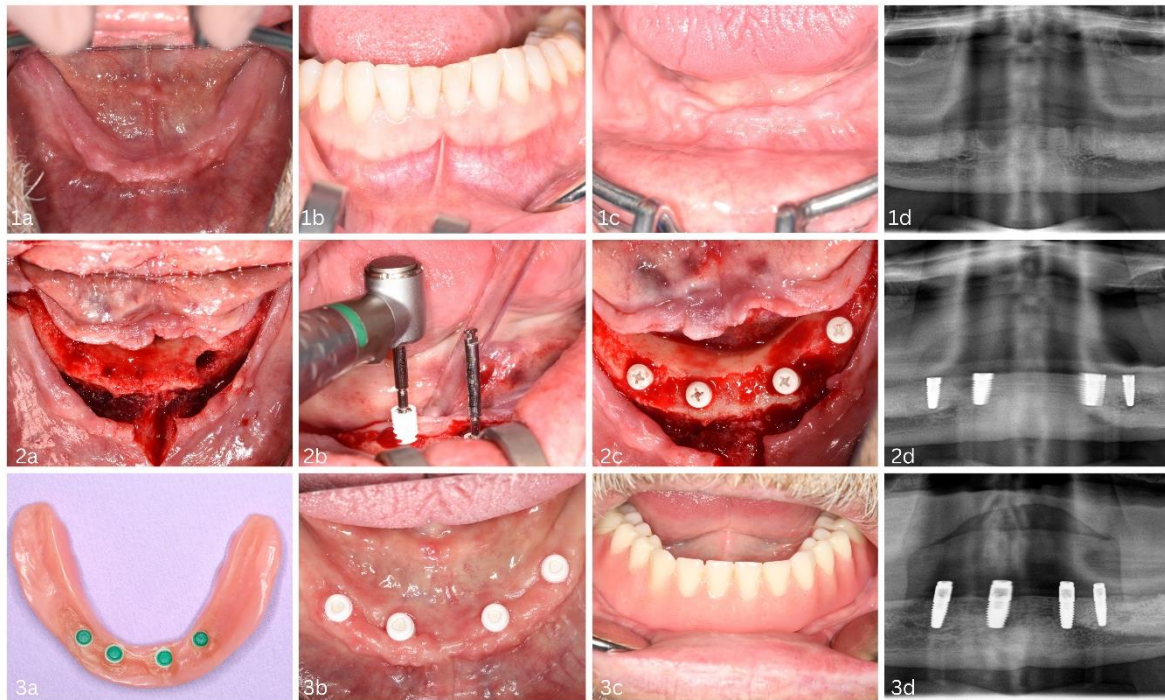


Figure 8 : Clinical and radiographic documentation of Patient 2

Patient 2 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Preoperative clinical view of the edentulous mandible. (1b) Preoperative view of the patient's removable mandibular denture in function. (1c) Preoperative close-up view of the edentulous mandibular ridge. (1d) Preoperative panoramic radiograph demonstrating the edentulous mandible and residual dentition in the maxilla. (2a) Full-thickness flap elevation exposing the edentulous mandibular ridge prior to osteotomy preparation. (2b) Intraoperative placement of zirconia implants demonstrating parallel implant positioning. (2c) Clinical view following placement of four zirconia implants in the edentulous ridge. (2d) Immediate postoperative panoramic radiograph confirming implant positioning and alignment. (3a) Intaglio surface of the mandibular overdenture demonstrating the incorporated locator attachment housings. (3b) Clinical follow-up after 30 months showing stable peri-implant soft tissue conditions around the zirconia implants. (3c) Intraoral view of the locator-retained mandibular overdenture in function at the 30-month follow-up. (3d) Follow-up radiograph after 30 months demonstrating stable implant positioning and maintained peri-implant bone levels.

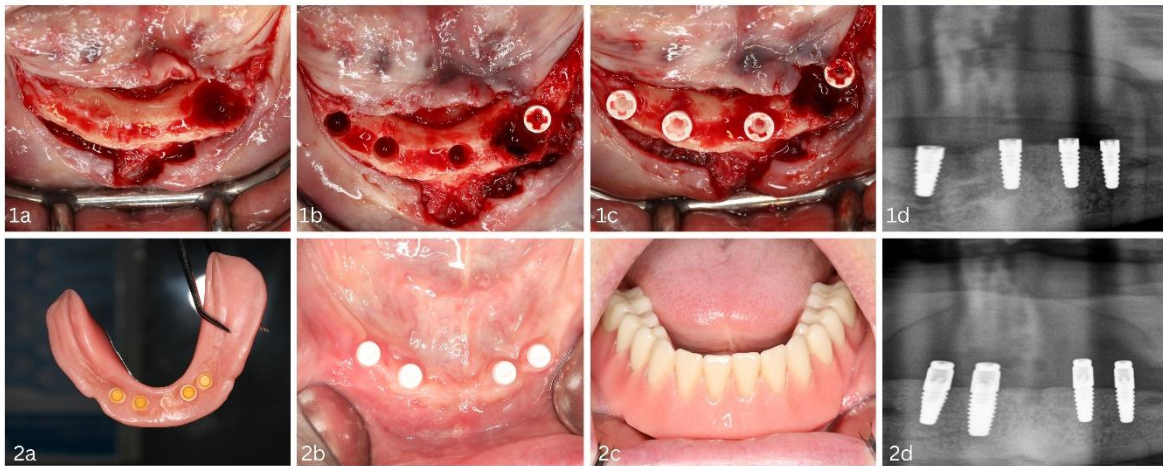


Figure 9: Clinical and radiographic documentation of Patient 3

Patient 3 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Intraoperative view following extraction of the remaining mandibular tooth and flap elevation exposing the edentulous ridge. (1b) Osteotomy preparation of the implant sites in the mandible. (1c) Clinical view after placement of four zirconia implants in the edentulous mandibular ridge. (1d) Immediate postoperative panoramic radiograph confirming implant positioning and alignment. (2a) Intaglio surface of the mandibular overdenture demonstrating the incorporated locator attachment housings. (2b) Clinical follow-up after 21 months showing stable peri-implant soft tissue conditions around the zirconia implants. (2c) Intraoral view of the locator-retained mandibular overdenture in function at the 21-month follow-up. (2d) Follow-up radiograph after 21 months demonstrating stable implant positioning and maintained peri-implant bone levels.

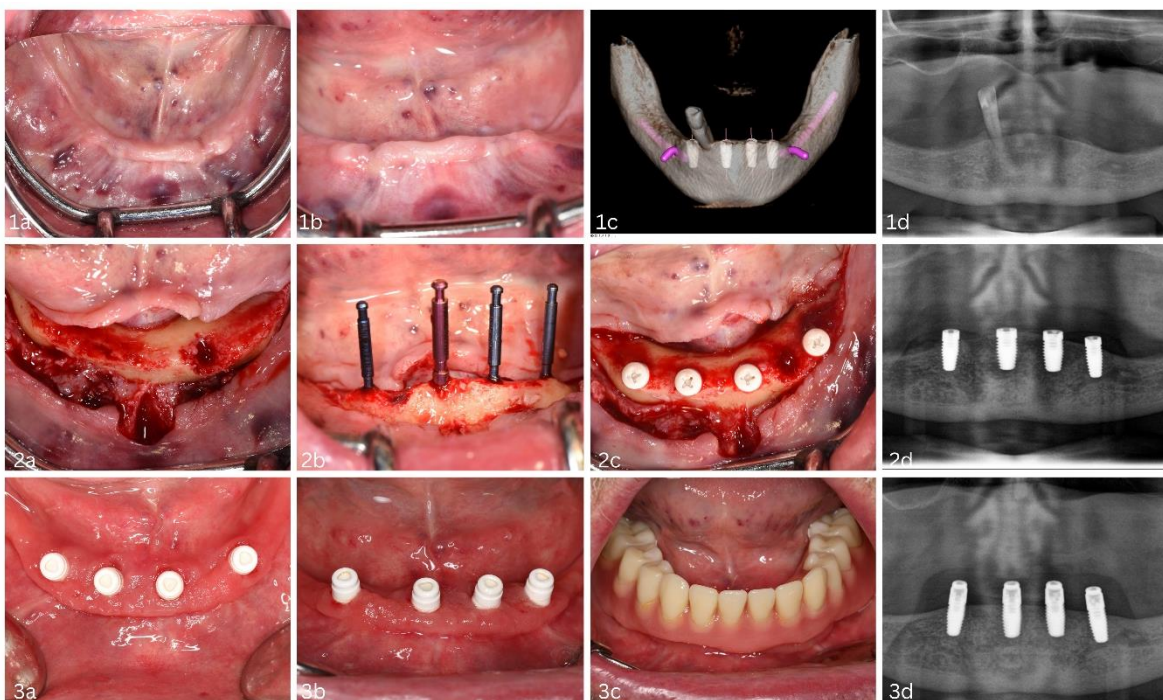


Figure 10 Clinical and radiographic documentation of Patient 4

Patient 4 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Preoperative occlusal view of the edentulous mandibular ridge. (1b) Preoperative intraoral labial view of the mandibular ridge. (1c) Three-dimensional digital implant planning of the mandible prior to surgery. (1d) Preoperative panoramic radiograph of the edentulous mandible. (2a) Intraoperative view following flap elevation exposing the mandibular ridge. (2b) Osteotomy preparation demonstrating parallel positioning of the four implant sites. (2c) Clinical view after placement of four zirconia implants in the mandibular ridge. (2d) Immediate postoperative radiograph confirming implant positioning and alignment. (3a) Occlusal intraoral follow-up view after 27 months demonstrating stable peri-implant soft tissue conditions around the zirconia implants without the overdenture in place. (3b) Labial intraoral follow-up view after 27 months showing healthy peri-implant soft tissue stability around the zirconia implants. (3c) Intraoral view of the locator-retained mandibular overdenture in function at the 27-month follow-up. (3d) Follow-up radiograph after 27 months demonstrating stable implant positioning and maintained peri-implant bone levels.

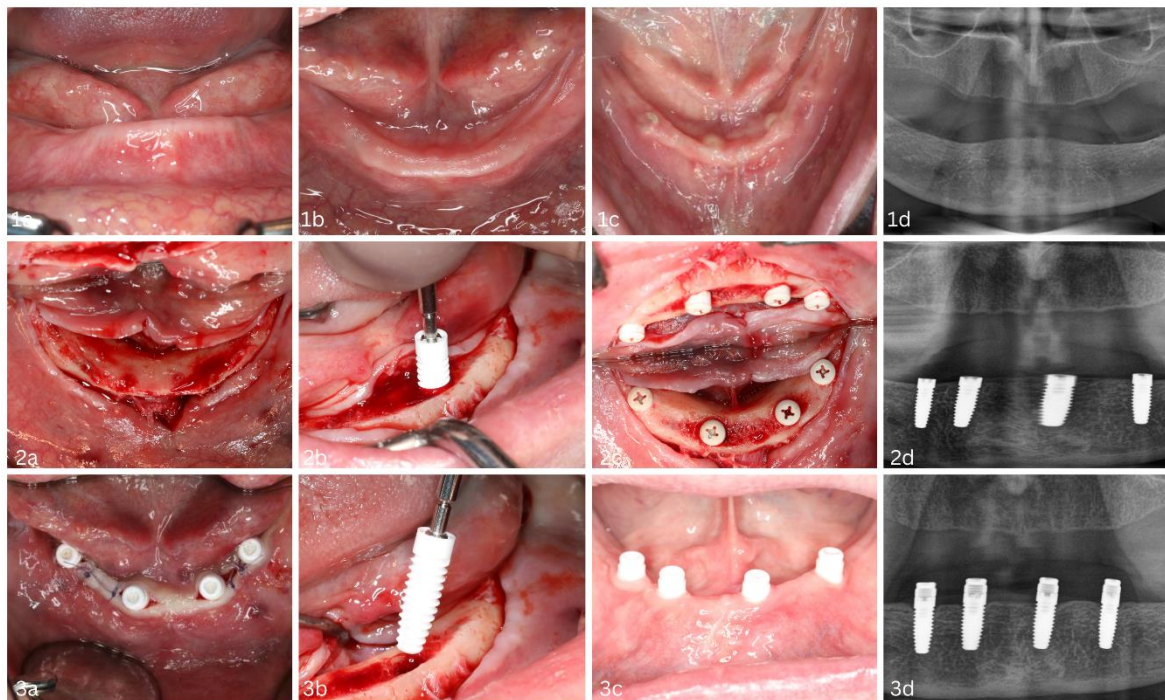


Figure 11: Clinical and radiographic documentation of Patient 5

Patient 5 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Preoperative intraoral labial view of the edentulous mandibular ridge. (1b) Preoperative occlusal view of the mandibular ridge. (1c) Additional preoperative intraoral view of the edentulous ridge. (1d) Preoperative panoramic radiograph of the edentulous mandible. (2a) Intraoperative view following flap elevation exposing the mandibular

ridge. (2b) Placement of a zirconia implant during surgery. (2c) Occlusal intraoperative view showing all four zirconia implants placed in the mandibular ridge. (2d) Immediate postoperative radiograph confirming implant positioning and alignment. (3a) Clinical view after suturing following implant placement. (3b) Ceramic Implant Placement during the Operation. (3c) Intraoral follow-up view after 25 months demonstrating stable peri-implant soft tissue conditions around the zirconia implants. (3d) Follow-up radiograph demonstrating stable implant positioning and maintained peri-implant bone levels at the 25-month follow-up.

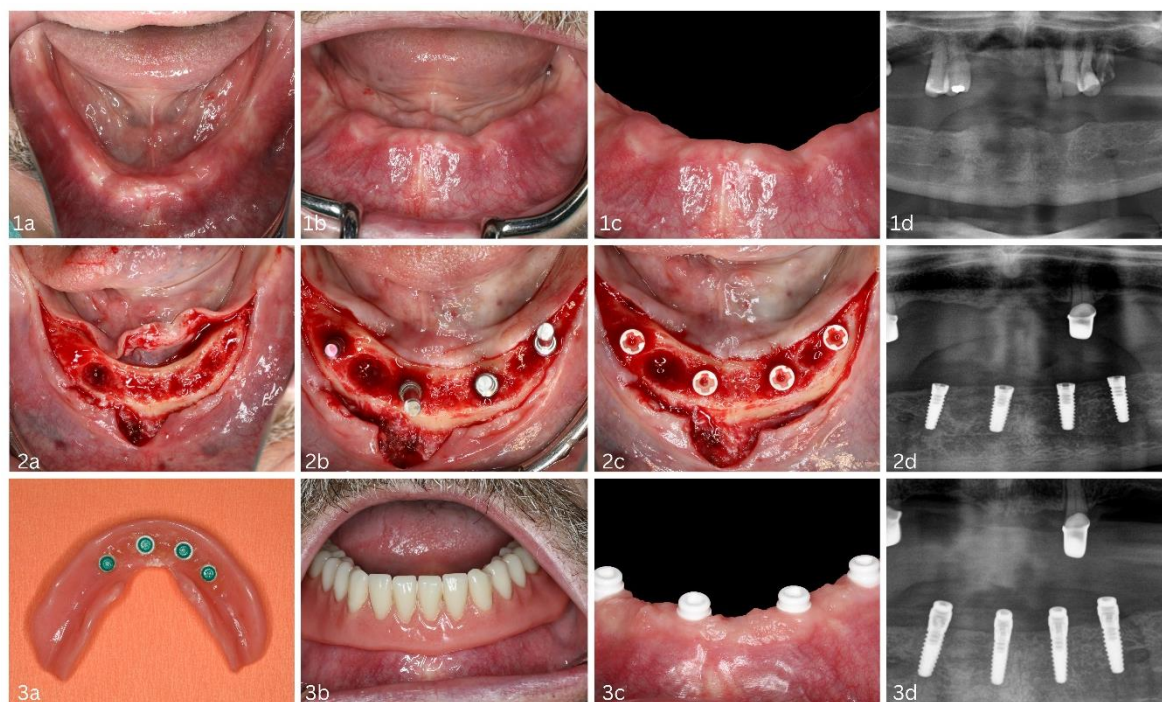


Figure 12: Clinical and radiographic documentation of Patient 6

Patient 6 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Preoperative intraoral occlusal view of the edentulous mandibular ridge. (1b) Preoperative frontal intraoral view of the mandibular ridge. (1c) Close-up preoperative view of the edentulous ridge morphology. (1d) Preoperative panoramic radiograph demonstrating the edentulous mandible and remaining maxillary dentition. (2a) Intraoperative view following flap elevation exposing the mandibular ridge. (2b) Intraoperative placement and parallel alignment of zirconia implants in the mandibular ridge. (2c) Occlusal intraoperative view showing all four zirconia implants in place. (2d) Immediate postoperative radiograph confirming implant positioning and alignment. (3a) Intaglio surface of the mandibular overdenture demonstrating the incorporated locator attachment housings. (3b) Intraoral view of the locator-retained mandibular overdenture in function during follow-up. (3c) Clinical follow-up view demonstrating stable peri-implant soft tissue conditions around the zirconia implants without the overdenture in place. (3d) Follow-up radiograph demonstrating stable implant positioning and maintained peri-implant bone levels.

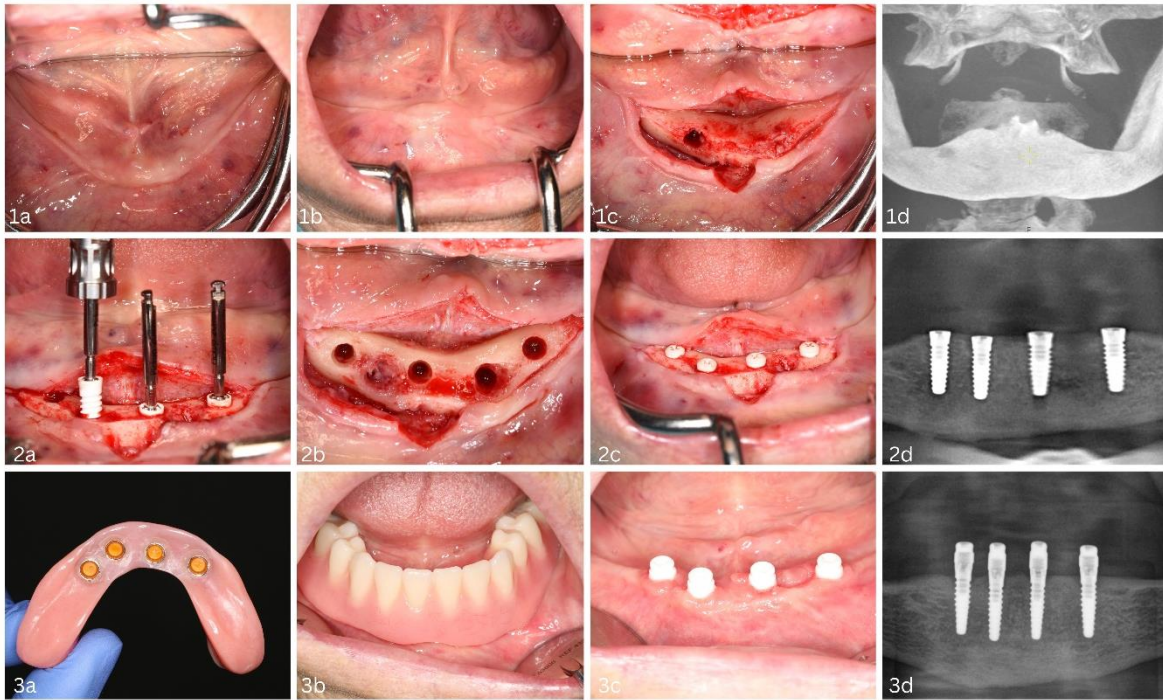


Figure 13 Clinical and radiographic documentation of Patient 7

Patient 7 treated with four ZERAMEX® zirconia implants supporting a locator-retained mandibular overdenture. (1a) Preoperative intraoral occlusal view of the edentulous mandibular ridge. (1b) Preoperative frontal intraoral view of the mandibular ridge. (1c) Intraoperative view following flap elevation exposing the mandibular ridge. (1d) Preoperative radiographic evaluation of the edentulous mandible. (2a) Osteotomy preparation and intraoperative placement of zirconia implants demonstrating parallel implant positioning. (2b) Occlusal intraoperative view showing the prepared implant sites and implant positioning within the mandibular ridge. (2c) Clinical view after placement of four zirconia implants in the mandibular ridge. (2d) Immediate postoperative radiograph confirming implant positioning and alignment. (3a) Intaglio surface of the mandibular overdenture demonstrating the incorporated locator attachment housings. (3b) Intraoral view of the locator-retained mandibular overdenture in function during follow-up. (3c) Clinical follow-up view demonstrating stable peri-implant soft tissue conditions around the zirconia implants without the overdenture in place. (3d) Follow-up radiograph demonstrating stable implant positioning and maintained peri-implant bone levels.

This complete cohort documentation aims to enhance the transparency and clinical interpretability of the presented results by illustrating peri-implant tissue conditions, prosthetic integration, radiographic bone stability, and overall treatment outcomes following rehabilitation with locator-retained mandibular overdentures supported by zirconia implants.

Collectively, the complete clinical documentation demonstrates consistent peri-implant soft tissue stability, successful prosthetic rehabilitation, and favourable radiographic outcomes across the entire study cohort.

5.4 Marginal Bone Level Changes

Radiographic evaluation demonstrated stable peri-implant bone conditions throughout the observation period. Marginal bone loss remained low at all implant positions, with no radiographic evidence of progressive crestal bone loss indicative of peri-implantitis.

The mean marginal bone loss values for each implant position are summarized in Table 4. The highest mean bone loss was observed at implant position 34 (0.29 ± 0.40 mm mesially and 0.52 ± 0.50 mm distally), whereas the lowest values were recorded at implant position 42 (0.05 ± 0.13 mm mesially and 0.22 ± 0.37 mm distally). Across all implant positions, mean marginal bone loss remained below 1 mm.

Implant Position	Mesial Bone Loss (mm)	Distal Bone Loss (mm)
	Mean $\pm$ SD	Mean $\pm$ SD
32	0.49 ± 0.49	0.39 ± 0.72
34	0.29 ± 0.40	0.52 ± 0.50
42	0.05 ± 0.13	0.22 ± 0.37
44	0.13 ± 0.23	0.20 ± 0.34

Table 4: Mean Marginal Bone Loss by Implant Position (mean $\pm$ SD)

Individual implant measurements are presented in Table 5, demonstrating consistently limited bone remodelling throughout the study cohort. Representative radiographic measurements are illustrated in Figure 14.

Overall, the radiographic findings indicate favourable peri-implant bone stability and successful osseointegration of the zirconia implants during the 21–31 month follow-up period.

Patient	32 M	32 D	34 M	34 D	42 M	42 D	44 M	44 D
1	0.52	0.00	0.80	0.86	0.00	0.80	0.32	0.77
2	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00
3	0.89	0.92	0.64	1.35	0.00	0.00	0.00	0.00

4	1.09	1.82	0.62	0.62	0.35	0.71	0.00	0.62
5	0.94	0.00	0.00	0.79	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5: Individual marginal bone loss values (mm) at mesial and distal aspects of implants in positions 32, 34, 42, and 44 for all patients at follow-up

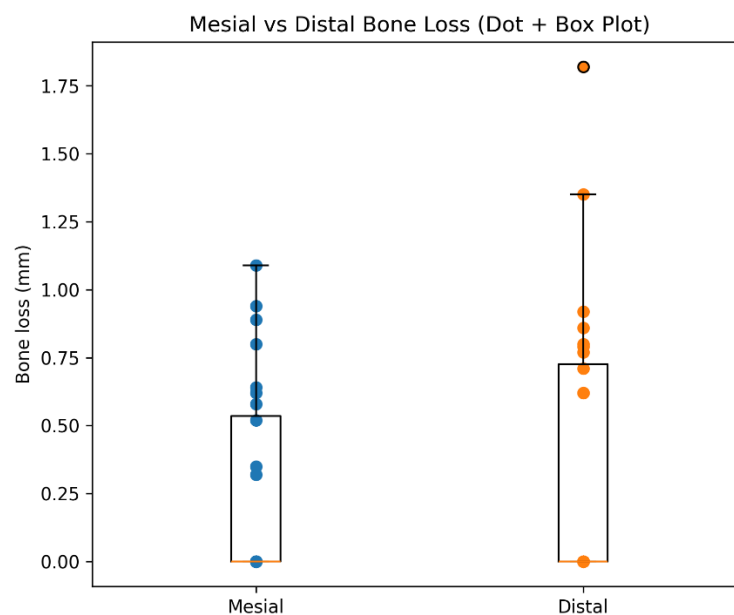


Figure 14: Representative radiographic bone level measurements.

Overall, the radiographic findings indicate stable osseointegration and favourable peri-implant hard tissue conditions during the 21–31 month follow-up period.

5.5 Complications: surgical, biological, prosthetic (if any)

Apart from the single early implant failure reported in Section 5.2, no additional major biological or prosthetic complications were observed during the follow-up period.

One patient developed localized peri-implant mucositis affecting a single implant at the 2-year follow-up. The lesion was characterized by localized erythema and bleeding on probing without radiographic evidence of progressive marginal bone loss or clinical implant mobility. The condition was successfully managed by non-surgical mechanical debridement, chlorhexidine mouth rinses (0.12%) for 14 days, and reinforcement of oral hygiene measures. Complete

clinical resolution was achieved at the subsequent follow-up examination, with no recurrence observed during the remaining observation period.

No cases of peri-implantitis, implant fracture, abutment fracture, prosthesis fracture, attachment-related complications, thread exposure, or clinically detectable implant mobility were recorded. Furthermore, no patient required prosthetic repair, replacement, or additional surgical intervention after definitive prosthetic loading.

The overall complication profile was therefore limited to one early implant failure and one reversible episode of peri-implant mucositis, supporting the favourable short- to medium-term biological and prosthetic performance of locator-retained mandibular overdentures supported by two-piece zirconia implants Table 6. No intraoperative or postoperative surgical complications were recorded.

Complication	Patients (n)	Implants (n)	Management	Outcome
Early implant failure	1	1	Implant removal and replacement	Successful osseointegration
Peri-implant mucositis	1	1	Mechanical debridement, chlorhexidine rinse, oral hygiene reinforcement	Complete resolution
Peri-implantitis	0	0	–	–
Implant fracture	0	0	–	–
Prosthetic complications	0	0	–	–
Implant mobility	0	0	–	–

Table 6: Biological and Prosthetic Complications Observed During Follow-up

5.6 OHIP-14+ analysis (quantitative and narrative)

Rehabilitation with locator-retained mandibular overdentures supported by zirconia implants resulted in a marked improvement in oral health-related quality of life. All seven patients demonstrated lower OHIP-14+ scores at follow-up compared with baseline.

The mean OHIP-14+ score decreased from 41.1 ± 8.8 before treatment to 11.9 ± 5.3 at the 2-year follow-up, corresponding to a mean improvement of 29.3 ± 7.7 points. Improvements were observed in every patient, with individual score reductions ranging from 14 to 36 points Table

7. The reduction in OHIP-14+ scores was statistically significant (Wilcoxon signed-rank test, $p < 0.05$).

The greatest improvements were reported in domains related to oral function, comfort during mastication, psychological well-being, and social confidence. Overall, the patient-reported outcomes indicate a substantial improvement in oral health-related quality of life following rehabilitation with zirconia implant-supported locator-retained mandibular overdentures.

Patient	Baseline (Op)	Follow-Up (Control)	Change (Δ)
P1	22	8	14
P2	41	12	29
P3	46	11	35
P4	45	15	30
P5	48	22	26
P6	42	6	36
P7	44	9	35
Mean $\pm$ SD	41.1 $\pm$ 8.8	11.9 $\pm$ 5.3	29.3 $\pm$ 7.7

Table 7 OHIP-14+ Scores before Treatment and at Follow-up

The OHIP-14+ scores decreased markedly from baseline to follow-up, indicating a substantial improvement in oral health-related quality of life following rehabilitation with locator-retained mandibular overdentures supported by zirconia implants. The mean OHIP-14+ score decreased from 41.1 ± 8.8 at baseline to 11.9 ± 5.3 at follow-up, corresponding to a mean reduction of 29.3 ± 7.7 points.

All seven patients demonstrated an improvement in their OHIP-14+ scores following treatment. Statistical analysis using the Wilcoxon signed-rank test confirmed a significant reduction in OHIP-14+ scores between baseline and follow-up ($p = 0.018$).

As illustrated in Figure 15, every patient experienced a marked reduction in OHIP-14+ score after treatment, demonstrating a consistent improvement in oral health-related quality of life across the entire study cohort.

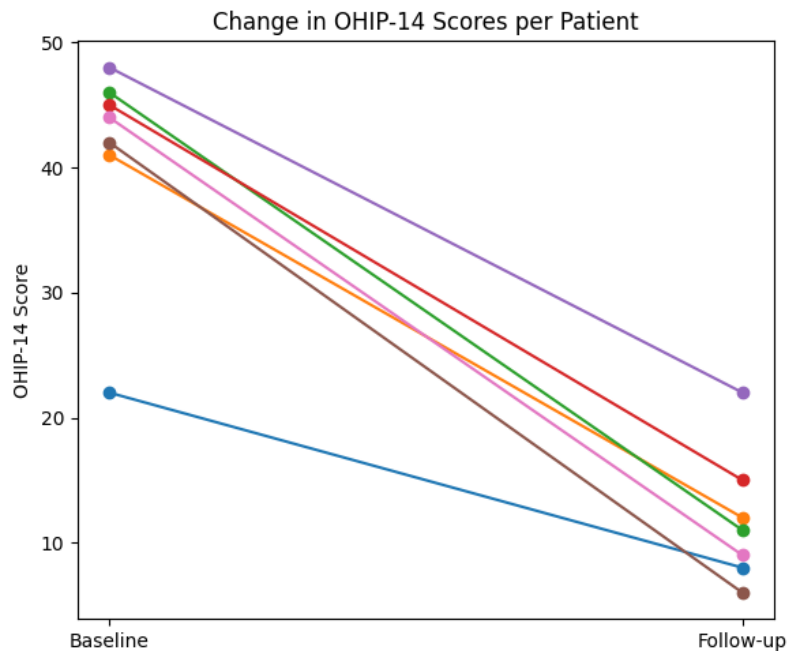


Figure 15: Paired line plot illustrating individual OHIP-14+ scores at baseline and follow-up.

Each line represents one patient, demonstrating the improvement in oral health-related quality of life following treatment with locator-retained mandibular overdentures supported by two-piece zirconia implants.

5.7 Patient-reported outcomes and satisfaction

In addition to the significant improvement in oral health-related quality of life demonstrated by the OHIP-14+ analysis, patients reported a high level of overall satisfaction with their implant-supported mandibular overdentures.

All patients expressed satisfaction with the functional and aesthetic outcome of the treatment. Improvements were consistently reported in chewing ability, denture stability, and comfort during daily function, speech, and overall confidence compared with their conventional mandibular dentures. None of the patients requested replacement of the prosthesis or expressed dissatisfaction with the treatment outcome during the follow-up period.

Pain associated with implant placement was generally reported as mild and transient, with no patient describing prolonged postoperative discomfort or persistent functional limitations. At the final follow-up examination, all patients confirmed that they would choose the same

treatment again and would recommend the procedure to other patients requiring mandibular implant-supported overdenture rehabilitation.

Patient-reported outcome measures (PROMs) were assessed at the final follow-up using visual analogue scales (VAS) for pain (0–100) and overall treatment satisfaction (0–100%). All seven patients completed the assessment and reported high levels of satisfaction with their zirconia implant-supported mandibular overdentures Table 8.

The mean pain VAS score was 4.0 ± 5.3 , indicating minimal postoperative or long-term discomfort. The mean overall satisfaction score was $98.4 \pm 2.2\%$, reflecting excellent patient acceptance of the treatment. No patient reported persistent pain, functional limitations, or aesthetic concerns related to the implants or prostheses.

Patient	Pain VAS (0–100)	Satisfaction VAS (0–100%)
P1	2	100
P2	0	94
P3	3	99
P4	5	96
P5	15	100
P6	0	100
P7	3	100
Mean $\pm$ SD	4.0 ± 5.3	98.4 ± 2.2

Table 8: Patient-reported outcome measures (PROMs) at the final follow-up, including pain and overall satisfaction assessed using visual analogue scales (VAS).

Patient feedback obtained during the follow-up examinations indicated that the implant-supported overdentures provided excellent comfort, stability, chewing ability, speech, and aesthetic satisfaction compared with the patients' previous conventional mandibular dentures. These findings are consistent with the significant improvement observed in the OHIP-14+ analysis and support the high level of patient acceptance of the zirconia implant-supported overdenture concept.

6 Discussion

6.1 Interpretation of findings compared to existing TiZr and zirconia studies

The present retrospective study demonstrated favourable short- to medium-term clinical outcomes for mandibular locator-retained overdentures supported by four two-piece zirconia implants. Of the 28 implants placed in seven patients, only one early implant failure occurred, resulting in an overall implant survival rate of 96.43% after a mean follow-up of 23 ± 3.8 months. Following implant replacement and an uneventful healing period, successful prosthetic rehabilitation was achieved without further implant loss or major biological or prosthetic complications. Collectively, these findings indicate that two-piece zirconia implants can provide predictable clinical performance when used to support removable mandibular overdentures under a delayed loading protocol.

The implant survival observed in the present study is consistent with the growing body of evidence demonstrating favourable clinical performance of contemporary two-piece zirconia implant systems. Recent systematic reviews have reported survival rates ranging from approximately 94% to 98%; however, the available evidence is derived predominantly from single-tooth restorations and fixed prostheses, whereas clinical data on removable overdenture therapy remain scarce (Al-Nawas, Lambert et al. 2023, Neugebauer, Schoenbaum et al. 2023, Roehling, Gahlert et al. 2023). Likewise, the recent ITI Consensus Statement concluded that current two-piece zirconia implants demonstrate promising short-term outcomes but emphasized that clinical evidence remains substantially more limited than for titanium implants (Al-Nawas, Lambert et al. 2023).

Direct comparison with previous zirconia overdenture studies remains challenging because of considerable differences in implant design, prosthetic concepts, and attachment systems. Most published reports have evaluated one-piece zirconia implants restored with splinted bar-retained or telescopic overdentures rather than contemporary two-piece systems restored with individual locator attachments. For example, Peláez et al. reported successful 12-year rehabilitation of a mandibular overdenture supported by four one-piece zirconia implants connected by a custom-milled zirconia bar, demonstrating excellent peri-implant tissue stability and prosthetic function in a single patient (Peláez, Gelfo-Flores et al. 2022). Similarly, Rinke et al. described favourable long-term outcomes of zirconia implant-supported double-crown overdentures but emphasized the limited number of treated patients and the need for larger clinical investigations (Rinke, Buergers et al. 2015). Consequently, direct comparison with the present study should be interpreted cautiously because both implant design and biomechanical loading conditions differ substantially from non-splinted locator-retained restorations.

One of the most relevant findings of the present study is the successful clinical performance of four non-splinted two-piece zirconia implants supporting locator-retained mandibular overdentures. To the best of our knowledge, this treatment concept has received only limited clinical investigation despite its considerable practical relevance. In contrast to splinted bar restorations, locator-retained overdentures represent one of the most frequently used attachment systems in routine implant prosthodontics because they combine simplified maintenance, reduced laboratory complexity, easier hygiene access, and lower treatment costs. Demonstrating favourable outcomes using this prosthetic concept therefore expands the currently available clinical evidence for zirconia implant-supported removable prostheses.

The single implant failure observed in the present study occurred during the early healing phase and was attributed to premature prosthetic loading before complete osseointegration had been achieved. Early loading has consistently been identified as a major risk factor for implant failure irrespective of implant material, particularly when primary stability or undisturbed healing may be compromised (Gupta 2016, Gupta, Bansal and Shukla 2022). Importantly, following implant replacement and adherence to the planned delayed loading protocol, no further failures occurred, suggesting that the event reflected a treatment-related complication rather than an inherent limitation of the zirconia implant system itself.

An additional noteworthy finding was the complete absence of implant fracture, abutment fracture, prosthetic instability, or attachment-related complications throughout the observation period. Historically, concerns regarding the mechanical reliability of zirconia implants have largely originated from early one-piece implant systems, in which fracture resistance and prosthetic flexibility represented recognized limitations (Cionca, Hashim and Mombelli 2017, Roehling, Schlegel et al. 2019).

Advances in material composition, implant macrodesign, manufacturing processes, and internal connection geometry have substantially improved the mechanical performance of contemporary two-piece zirconia implant systems. The absence of mechanical complications observed in the present study supports these developments and suggests that modern two-piece zirconia implants can provide sufficient mechanical stability for mandibular overdenture rehabilitation during short- to medium-term follow-up. Recent laboratory investigations on the ZERAMEX XT implant system demonstrated excellent fracture resistance under cyclic loading and hydrothermal aging, supporting the favourable mechanical outcomes observed clinically in the present study (Kohal, Schikofski et al. 2023).

Although titanium and titanium–zirconium (TiZr) implants remain the clinical gold standard because of their extensive long-term evidence base, the present findings suggest that zirconia implants may represent a reliable alternative for selected patients requiring removable implant-supported rehabilitation. Beyond their favourable aesthetic properties, zirconia implants offer excellent biocompatibility, reduced plaque accumulation, and favourable peri-implant soft tissue integration, characteristics that may be particularly advantageous in patients seeking metal-free rehabilitation concepts or those with increased aesthetic demands. Nevertheless, direct comparisons with titanium or TiZr implants cannot be drawn from the present study because no control group was included, and such comparisons should therefore await adequately powered prospective comparative clinical trials.

Taken together, the present findings extend the currently limited evidence regarding removable prosthodontic applications of two-piece zirconia implants. The favourable implant survival, absence of mechanical complications, and successful clinical rehabilitation observed in this cohort support the feasibility of locator-retained mandibular overdentures on four non-splinted zirconia implants and provide an important clinical foundation for future prospective comparative studies with longer follow-up periods.

6.2 Patient-Reported Outcomes of Zirconia Implant-Supported Mandibular Overdentures

One of the most notable findings of the present study was the substantial improvement in patient-reported outcomes following rehabilitation with locator-retained mandibular overdentures supported by four two-piece zirconia implants. Oral health-related quality of life improved significantly, as demonstrated by the marked reduction in OHIP-14+ scores from a mean of 41.1 ± 8.8 at baseline to 11.9 ± 5.3 at follow-up. In addition, patients reported excellent overall satisfaction, with a mean VAS score of $98.4 \pm 2.2\%$, while postoperative pain remained minimal (VAS: 4.0 ± 5.3). Collectively, these findings indicate a high level of patient acceptance and functional success of the treatment concept.

The observed improvement in oral health-related quality of life is consistent with a substantial body of evidence demonstrating that mandibular implant-supported overdentures provide significant benefits over conventional complete dentures. Numerous randomized clinical trials, cohort studies, and recent systematic reviews have consistently reported significant improvements in oral function, comfort, masticatory efficiency, speech, social confidence, and overall quality of life following implant overdenture therapy (Elsyad, Al-Tonbary and Askar 2019, Kheur, Lakha et al. 2022, Rella, De Angelis et al. 2023, Bacher, Kasaliyska et al. 2024, Linn, Khaohoen et al. 2024). Similar improvements have been demonstrated across different overdenture concepts, including single-, two-, and three-implant overdentures, as well as bar-

retained and locator-retained attachment systems (Elsyad, Al-Tonbary and Askar 2019, Mifsud, Cortes and Attard 2020, Kheur, Lakha et al. 2022).

The favourable patient-reported outcomes observed in the present study are most likely explained by the improved retention and stability achieved through implant support. Reduced prosthesis mobility during mastication and speech has consistently been associated with enhanced chewing efficiency, greater comfort, improved phonetics, and increased patient confidence compared with conventional complete dentures (Elsyad, Al-Tonbary and Askar 2019, Sharka, Abed and Hector 2019, Gore, Padol et al. 2025). These functional improvements are reflected not only by the significant reduction in OHIP-14+ scores but also by the consistently high satisfaction ratings observed across the entire study cohort.

Importantly, the magnitude of improvement exceeded the reported minimal clinically important difference for OHIP-14+, indicating that the observed changes were not only statistically significant but also clinically meaningful (Rella, De Angelis et al. 2023) (Elsyad, Al-Tonbary and Askar 2019, Hassan and Helmy 2020, Elsyad, Abdraboh et al. 2022). Every patient experienced an improvement in oral health-related quality of life, suggesting that the benefits of treatment were consistent across the study population rather than being driven by isolated cases.

Direct comparisons with zirconia implant-supported overdentures remain difficult because published patient-reported outcome data for this treatment concept are currently scarce. Most available studies evaluating OHIP outcomes have investigated titanium implant-supported overdentures, whereas clinical studies specifically addressing two-piece zirconia implants with locator-retained mandibular overdentures are largely lacking. Nevertheless, the magnitude of improvement observed in the present study appears comparable to that reported for titanium implant-supported overdentures (Elsyad, Al-Tonbary and Askar 2019, Mifsud, Cortes and Attard 2020, Kheur, Lakha et al. 2022), suggesting that zirconia implants can achieve similarly favourable patient-reported outcomes.

Although zirconia implants have been associated with favourable soft tissue integration, reduced plaque accumulation, and excellent aesthetic properties, it remains uncertain whether these biological advantages translate into superior patient-reported outcomes compared with titanium implants. The present study was not designed to address this question, and no direct comparison with titanium implants was performed. Consequently, any potential patient-related advantages attributable specifically to the zirconia implant material remain speculative and should be investigated in future prospective comparative clinical trials.

6.3 Biological and mechanical implications of zirconia in removable prosthodontics

The present study demonstrated favourable biological and mechanical performance of locator-retained mandibular overdentures supported by four two-piece zirconia implants. Throughout the follow-up period, marginal bone remodelling remained limited, peri-implant soft tissue conditions were stable, only one reversible episode of peri-implant mucositis was observed, and no cases of peri-implantitis, implant fracture, abutment failure, prosthetic complications, or implant mobility occurred. These findings collectively support the biological stability and mechanical reliability of the investigated treatment concept during short- to medium-term follow-up.

The favourable peri-implant tissue conditions observed in the present study are consistent with previous experimental and clinical investigations demonstrating excellent soft tissue integration around zirconia implants. Zirconia has been shown to exhibit reduced bacterial adhesion and biofilm accumulation compared with titanium surfaces, which may contribute to lower inflammatory responses and improved peri-implant mucosal health (Roehling, Schlegel et al. 2019, Bienz, Hilbe et al. 2020, Al-Faraj, Alsubhi et al. 2024). Although only one patient developed localized peri-implant mucositis, the lesion resolved completely following non-surgical therapy, and no implant demonstrated radiographic or clinical signs of peri-implantitis during follow-up.

Radiographically, marginal bone loss remained limited and well below the success criteria originally proposed by Albrektsson et al., indicating stable peri-implant bone remodelling despite the functional demands associated with removable overdentures (Albrektsson, Zarb et al. 1986). These findings are in agreement with recent clinical studies and systematic reviews reporting comparable marginal bone stability for zirconia and titanium implants (Hashim, Cionca et al. 2016, Schiegnitz, Al-Nawas et al. 2016, Roehling, Gahlert et al. 2023, Maaty, Ragab et al. 2025). Although direct comparison is limited by the absence of a titanium control group, the radiographic outcomes observed in the present study suggest that two-piece zirconia implants can maintain stable peri-implant bone levels under functional loading.

Historically, concerns regarding zirconia implants have focused primarily on their mechanical reliability. Early one-piece zirconia implants exhibited increased susceptibility to fracture under unfavourable loading conditions and provided limited prosthetic flexibility because implant angulation could not be corrected after placement (Gupta 2016, Cionca, Hashim and Mombelli 2017, Roehling, Gahlert et al. 2023). Contemporary two-piece zirconia implant systems have addressed many of these limitations through improvements in yttria-stabilized zirconia materials, implant macrodesign, and internal implant–abutment connections, resulting in

enhanced mechanical stability and greater prosthetic versatility (Osman, Elkhadem et al. 2013, Bollen, Hakobayan and Jörgens 2024)

Consistent with these developments, no implant fractures, abutment complications, attachment failures, or prosthetic component failures were observed in the present study. Furthermore, all overdentures remained functional throughout the observation period without the need for prosthetic repair or replacement. These clinical findings suggest that the combination of a modern two-piece zirconia implant system, appropriate implant distribution, and a delayed loading protocol can provide predictable mechanical performance in mandibular overdenture therapy.

Despite these encouraging results, caution remains warranted when extrapolating the present findings to broader clinical practice. Long-term clinical evidence for two-piece zirconia implants remains considerably more limited than for titanium implants, particularly in removable full-arch rehabilitations. Consequently, current German S3 guidelines (DGI Leitlinie S3, 2021) recommend careful patient selection and comprehensive informed consent when ceramic implants are considered as an alternative to titanium. Future prospective multicenter studies with larger cohorts and extended follow-up periods are required to further establish the long-term biological and mechanical reliability of two-piece zirconia implants supporting removable overdentures.

6.4 Strengths and Limitations

The present study possesses several strengths that contribute to its clinical relevance. To the best of our knowledge, it represents one of the first clinical investigations evaluating locator-retained mandibular overdentures supported by four non-splinted two-piece zirconia implants. All patients were treated using a standardized surgical and prosthetic protocol, the same implant system and attachment concept, and underwent comprehensive clinical, radiographic, and patient-reported outcome assessments. Furthermore, complete clinical and radiographic documentation was available for every patient included in the cohort, providing a transparent evaluation of treatment outcomes.

Nevertheless, several limitations should be considered when interpreting the findings. First, the limited sample size of seven patients (28 implants) restricts statistical power and limits the generalizability of the results. Although small cohort studies are common during the early clinical evaluation of emerging implant materials and prosthetic concepts, uncommon biological or mechanical complications may not become evident in such populations (Roehling,

Schlegel et al. 2018, Mohseni, Soufi and Chrcanovic 2023). Accordingly, the present findings should be regarded as preliminary and hypothesis-generating rather than definitive.

Second, the retrospective observational design is inherently associated with the possibility of selection bias and uncontrolled confounding. Although all patients were treated according to a standardized clinical protocol by an experienced surgeon, retrospective studies cannot account for all patient-related variables, including oral hygiene compliance, occlusal loading, parafunctional habits, or systemic factors that may influence implant outcomes. Consequently, causal relationships cannot be established, and the findings should be interpreted within the limitations of observational clinical research (Von Elm, Altman et al. 2007).

Third, the mean follow-up period of approximately two years provides valuable information regarding early implant survival, peri-implant tissue stability, and patient satisfaction but does not permit conclusions regarding long-term biological or mechanical performance. In particular, fatigue-related complications, late implant fractures, and long-term prosthetic maintenance remain important considerations for contemporary two-piece zirconia implant systems. Recent systematic reviews and the ITI Consensus Statement emphasize that long-term clinical evidence extending beyond five years remains limited for ceramic implants and should be expanded through prospective investigations (Al-Nawas, Lambert et al. 2023, Roehling, Gahlert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

Fourth, the absence of a titanium or titanium–zirconium control group precludes direct comparison between implant materials. Consequently, the favourable outcomes observed in the present study cannot be attributed exclusively to the zirconia implant material itself, as similar clinical performance may also be achieved with established titanium implant systems. Well-designed randomized controlled trials comparing zirconia and titanium implants using identical overdenture protocols are therefore required to determine whether clinically relevant differences exist (Pjetursson, Sailer et al. 2021, Padhye, Calciolari et al. 2023).

Finally, although validated patient-reported outcome measures, including the OHIP-14+ questionnaire and visual analogue scales, were used to assess treatment success, these outcomes remain inherently subjective and may be influenced by individual expectations, psychological factors, and previous prosthetic experiences. Furthermore, the absence of a comparator treatment group limits assessment of the relative patient-perceived benefits attributable specifically to zirconia implant-supported overdentures (Papaspnyridakos, Chen et al. 2012, Schimmel, Araujo et al. 2023).

Taken together, the present study provides important preliminary clinical evidence supporting the feasibility of locator-retained mandibular overdentures on four two-piece zirconia implants. However, larger prospective multicenter studies with longer follow-up periods, standardized radiographic protocols, and appropriate titanium control groups are required to validate these findings and further define the role of zirconia implants in removable implant prosthodontics.

Despite its retrospective design, the present study possesses several methodological and clinical strengths that enhance the relevance of its findings. To the best of our knowledge, this is one of the first clinical investigations evaluating locator-retained mandibular overdentures supported by four non-splinted two-piece zirconia implants. This treatment concept addresses a clinically relevant yet insufficiently investigated indication within contemporary ceramic implantology.

A further strength is the use of a standardized treatment protocol. All patients were rehabilitated using the same implant system, surgical approach, delayed loading protocol, and prosthetic concept, thereby minimizing treatment-related variability and improving the internal consistency of the study.

Comprehensive outcome assessment represents another important strength. Clinical performance was evaluated using objective parameters, including implant survival, peri-implant tissue health, marginal bone level changes, and prosthetic complications, together with validated patient-reported outcome measures (OHIP-14+ and visual analogue scales). The inclusion of both clinician-reported and patient-reported outcomes provides a multidimensional assessment of treatment success and reflects current recommendations for implant outcome evaluation (Schimmel, Araujo et al. 2023).

Finally, complete clinical and radiographic documentation was available for all included patients. The presentation of the entire study cohort, rather than selected representative cases, enhances transparency and allows readers to independently evaluate the consistency of the clinical outcomes.

Collectively, these strengths provide valuable preliminary evidence supporting the clinical feasibility of locator-retained mandibular overdentures on two-piece zirconia implants and establish a solid foundation for future prospective comparative investigations.

6.5 Future research suggestions

The findings of the present study provide a foundation for future clinical and translational research on ceramic implant-supported removable prostheses. As clinical evidence for two-piece zirconia implants continues to emerge, future investigations should focus not only on

confirming their long-term clinical performance but also on improving our understanding of the biological mechanisms underlying successful osseointegration and peri-implant tissue stability.

A major priority should be well-designed prospective randomized controlled trials directly comparing zirconia, titanium, and titanium–zirconium (TiZr) implants restored with identical overdenture concepts. Such studies would enable meaningful evaluation of material-specific differences in implant survival, marginal bone stability, peri-implant soft tissue health, prosthetic maintenance requirements, and patient-reported outcomes under standardized clinical conditions. At present, most comparative evidence is derived from fixed prosthetic rehabilitations, limiting its applicability to removable implant-supported overdentures.

Long-term clinical follow-up extending beyond five and preferably ten years is also required. While the short- and medium-term outcomes of contemporary two-piece zirconia implants are encouraging, the long-term incidence of biological complications, mechanical failures, and prosthetic maintenance remains insufficiently documented. Continued longitudinal evaluation of the present patient cohort may contribute valuable long-term data to this evolving evidence base.

Future investigations should additionally incorporate standardized reporting of prosthetic maintenance, including attachment wear, retention loss, replacement intervals, and maintenance frequency. Because locator-retained overdentures represent one of the most frequently applied attachment concepts in contemporary implant prosthodontics, a better understanding of their long-term interaction with ceramic implant systems is essential for evidence-based treatment planning.

Beyond clinical outcome studies, translational research integrating clinical observations with laboratory investigations will be essential. Studies combining patient-derived cells, ex vivo bone models, and advanced in vitro systems may help elucidate how zirconia implant surfaces influence osteoblast function, immune modulation, microbial colonization, and peri-implant tissue remodelling. Such investigations have the potential to bridge the current gap between clinical performance and the underlying biological mechanisms governing implant success.

Ultimately, the integration of high-quality clinical trials with mechanistic biological research will be fundamental to defining the role of zirconia implants within contemporary implant dentistry. This combined clinical and translational approach may facilitate more evidence-based patient selection, optimize implant material choice, and support the continued development of personalized implant therapy for edentulous patients.

7 Conclusion

Within the limitations of this retrospective cohort study and a short- to medium-term follow-up period, the present investigation demonstrated that four two-piece zirconia implants (ZERAMEX® XT) can successfully support locator-retained mandibular overdentures in the edentulous mandible. A cumulative implant survival rate of 96.4% was achieved after a mean follow-up of 23 ± 3.8 months, with stable peri-implant hard and soft tissue conditions, minimal marginal bone remodelling, and no major prosthetic complications.

One early implant failure occurred during the healing phase and was successfully managed by implant replacement, after which no additional biological or mechanical complications were observed. Furthermore, patients experienced a substantial improvement in oral health-related quality of life, reflected by a significant reduction in OHIP-14+ scores and excellent overall satisfaction. Collectively, these findings indicate that locator-retained mandibular overdentures supported by two-piece zirconia implants represent a predictable and well-accepted treatment concept during short- to medium-term follow-up.

The present findings support the clinical feasibility of using four non-splinted two-piece zirconia implants to retain mandibular overdentures with Locator attachments. This treatment concept combines the advantages of removable prosthodontics, including simplified hygiene, retrievability, and reduced maintenance complexity, with the favourable biological and aesthetic characteristics associated with zirconia implants. Although titanium implants remain the clinical reference standard because of their extensive long-term evidence base, the present findings suggest that two-piece zirconia implants may represent a reliable alternative for appropriately selected patients seeking metal-free rehabilitation, provided that careful case selection, precise surgical execution, adherence to a delayed loading protocol, and regular supportive maintenance are ensured (Duong, Rocuzzo et al. 2022, Al-Nawas, Lambert et al. 2023, Schimmel, Araujo et al. 2023).

The present study contributes valuable clinical evidence to a field in which data remain limited. Future prospective multicenter studies with larger patient cohorts, extended follow-up periods, and direct comparisons between zirconia, titanium, and titanium–zirconium implants are required to further define the role of ceramic implants in removable prosthodontics. Furthermore, integrating long-term clinical investigations with translational biological research may improve our understanding of the biological mechanisms governing osseointegration, peri-implant tissue stability, and host responses to different implant materials. Such an approach will facilitate evidence-based patient selection and support the continued development of personalized implant therapy (Al-Nawas, Lambert et al. 2023, Roehling, Gahlert et al. 2023, Bollen, Hakobayan and Jörgens 2024).

The integration of clinical outcomes with translational biological investigations presented in this thesis contributes to a more comprehensive understanding of zirconia implant performance and provides a foundation for the continued development of evidence-based, patient-centred implant therapy.

8 Summary

Background

Two-piece zirconia implants have emerged as a promising metal-free alternative to titanium implants in contemporary implant dentistry. Although their clinical performance has been increasingly documented for single-tooth and fixed prosthetic rehabilitations, evidence supporting their use in locator-retained mandibular overdentures remains limited.

Objective

The aim of this retrospective clinical study was to evaluate the clinical performance of locator-retained mandibular overdentures supported by four two-piece zirconia implants per patient. Primary outcome measures included implant survival, peri-implant hard and soft tissue stability, biological and prosthetic complications, marginal bone level changes, and patient-reported outcomes.

Methods

Seven patients with a completely edentulous mandible were rehabilitated with four ZERAMEX® XT two-piece zirconia implants (Dentalpoint AG, Spreitenbach, Switzerland) followed by delayed loading with locator-retained mandibular overdentures. Clinical examinations, radiographic assessments, and patient-reported outcome measures (OHIP-14+ and visual analogue scales) were performed during a mean follow-up period of 23 ± 3.8 months.

Results

Twenty-eight zirconia implants were placed. One early implant failure occurred during the healing period, resulting in a cumulative implant survival rate of 96.4%. Following implant replacement, no further implant failures were observed. Apart from one reversible episode of peri-implant mucositis, no biological complications, implant fractures, or prosthetic complications occurred during follow-up. Marginal bone remodelling remained limited, indicating stable peri-implant hard tissue conditions. Patient-reported outcomes demonstrated a significant improvement in oral health-related quality of life, with OHIP-14+ scores decreasing

from 41.1 ± 8.8 at baseline to 11.9 ± 5.3 at follow-up ($p = 0.018$). Overall treatment satisfaction was high, with a mean visual analogue scale score of $98.4 \pm 2.2\%$.

Conclusion

Within the limitations of its retrospective design, limited sample size, and short- to medium-term follow-up, this study demonstrates that locator-retained mandibular overdentures supported by four two-piece zirconia implants represent a clinically feasible treatment concept with favourable implant survival, stable peri-implant tissues, minimal prosthetic complications, and excellent patient-reported outcomes. These findings contribute valuable clinical evidence to the growing body of literature on ceramic implant-supported removable prosthodontics and support further prospective long-term comparative investigations.

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Yang, J., Q. Zhang, D. Zheng and F. Hou (2025). "The economic consequences of oral disorders at global, regional, and national levels." BMC Oral Health **25**(1): 1802.



DR. AYA KHAMIS

Klinische Wissenschaftlerin – Zahnärztin - Oralpathologin

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Berufserfahrung

04/2022 – Aktuell

Leitende Wissenschaftliche Zahnärztin

Univ.-Prof. Dr. Dr. B.Al-Nawas

Klinik für Mund-Kiefer-Gesichtschirurgie, Plastische Operationen

Universitätsmedizin der Johannes Gutenberg-Universität Mainz

- Wissenschaftliche und organisatorische Leitung des Masterstudiengangs „Master of Personalized Oral Implantology and Periodontology (MPOIP)“
- Leitung von präklinischen und klinischen Forschungsprojekten.
- Leitung des Masterstudiengangs für Oral Implantologie und Parodontologie.
- Betreuung von ITI-Scholars, Master-Studenten und Doktoranden-innen.
- Koordination klinischer Studien & Masterstudiengang zum Thema “Implantat”.
- Koordination und Entwicklung internationaler Kooperationen
- Zahnärztliche Untersuchungen und Behandlungen durchführen

01/2025 – 01/2027

TransMed Clinical Scientist Fellowship

04/2019 – 10/2023

TransMed Promovierende - Wissenschaftliche Mitarbeiterin

Univ.-Prof. Dr. R. Stauber

Molekulare und zelluläre Onkologie, HNO-Klinik, Universitätsmedizin, Mainz

- Intensive Forschung im Bereich der Molekularen Onkologie und Krebs.
- Durchführung von Labor-Experimenten zur Krebsforschung.
- Datenanalyse für wissenschaftliche Studienprojekte.
- Wissenschaftliche Veröffentlichungen, Konferenzpräsentationen.
- Lehre für Masterstudenten und Doktoranden.

02/2012 – 04/2019

Zahnärztin und Dozentin

Orale Pathologie, Fakultät für Zahnheilkunde, Universität Alexandria (Ägypten)

- Unterricht in Oralpathologie für Studenten und Masterstudenten.
- Fachkenntnisse in der oralen Pathologie und bei Mundschleimhauterkrankungen.
- Klinische und histopathologische Diagnose von Kopf- und Halsläsionen und Tumoren.
- Diagnose von Biopsien aus verschiedenen Fachbereichen und Berichte schreiben.
- Mundkrebs-Forschung.

11/2011 – 11/2018

Zahnärztin und Geschäftsführerin

Dr. Nadia Sobhy Privatpraxis, Alexandria (Ägypten)

- Klinikmanagement und Unternehmensführung.
- Diagnostik und Behandlung von Mundhöhlen- und Kiefergelenkerkrankungen.
- Sicherstellung der Einhaltung von Qualitätsstandards und Vorschriften.

11/2010 – 11/2011

Praktikum - Zahnärztlicher Pflichtdienst Internship

Fakultät für Zahnheilkunde, Universität Alexandria (Ägypten)

07/2006 – 10/2010

Zahnärztliche Assistentin

Prof. Dr. Zaazou, Alexandria (Ägypten)

Schul- und Hochschulausbildung

01/2025 – Aktuell	●	Dr. med. Dent Promotion <i>Klinik für Mund-Kiefer-Gesichtschirurgie, Plastische Operationen Universitätsmedizin der Johannes Gutenberg-Universität Mainz</i> » Survival and Clinical Performance of Ceramic Implants in Mandibular Full-Arch Cases
Titel		
04/2019 – 10/2023	●	Promotion (Ph.D.) Summa cum laude (Note 1.0) <i>Molekulare und zelluläre Onkologie, HNO-Klinik Universitätsmedizin, Mainz</i> » The Role of Vitamin D and Vitamin D Receptor in Head and Neck Cancer
Titel		
10/2021	●	Strahlenschutz Fachkunde (24 Unterrichtsstunden)
06/2021	●	Deutsche Approbation als Zahnärztin <i>Landesamt für Soziales, Jugend und Versorgung, Koblenz</i>
09/2015 – 07/2018	●	Promotion (Ph.D.) Kurse Orale Pathologie (GPA 3.905) <i>Fakultät der Zahnheilkunde und Chirurgie, Universität Alexandria</i>
09/2012 – 07/2015	●	Master of Science in Orale Pathologie (GPA 3.736) <i>Fakultät der Zahnheilkunde und Chirurgie, Universität Alexandria</i> » Diagnostic and prognostic value of cancer stem cell marker cd44 and soluble cd44 in the peripheral blood of patients with oral squamous cell carcinoma.
Titel		
09/2005 – 07/2010	●	Bachelor of Science Zahnmedizin und Chirurgie (84.8 %) <i>Fakultät der Zahnheilkunde und Chirurgie, Universität Alexandria</i> » Sehr Gut und Ehrendiplom » Einstufung als (12) aus (308) Absolventen
Note Einstufung		
09/2002 – 06/2005	●	American Diploma <i>Pioneer American Schule, Alexandria Ägypten</i> » SAT I: 1320/1600 » SAT II: 1480/1600
Note		

Ausgewählte Weiterbildungen

Wissenschaftlich	●	Mainzer Entrepreneurship Programm <i>JGU, Mainz / UnternehmerTUM, München</i>
	●	Prüfarztkurs für klinische Studien mit Medizinprodukten <i>Medizinische Fakultät Heidelberg, Heidelberg</i>
	●	Projektmanagement (IPMA) Basiszertifikate <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Medizinprodukterecht (MPG und MPDG) (5 Punkten) <i>Interdisziplinäre Zentrum Klinische Studien (IZKS), Mainz</i>
	●	From career choice to career goal (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Strategic Career Crafting (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Writing and Publishing Research Articles (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Leadership and Communications (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Profiling and Positioning in Networks (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Introduction to Mass Spectrometry-based Proteomics <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Good Scientific Practice (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>
	●	Scientific Writing (TransMed) <i>Johannes Gutenberg-Universität, Mainz</i>

Zahnmedizinisch

- **How to build, develop, and use a professional network**
Institute for Molecular Biology, Mainz
- **Research design and methodology** - 19 Continuing Education credits.
Osteology Foundation (Deutschland)
- **Röntgenfortbildung** - 2 Tage
Universität Alexandria (Ägypten)
- **Tissue Engineering Kurse** - Prof Dr. Mona Marie - 4 Tage
Universität Alexandria (Ägypten)
- **Transmissions- und Rasterelektronenmikroskop** - 3 Tage
Naturwissenschaftliche Universität Alexandria
- **Evidence based Dentistry Kurs** - 4 Tage
Universität Alexandria (Ägypten)
- **Aspekte der kleinen Oralchirurgie** - 2 Wochen
Universität Alexandria (Ägypten)
- **Füllung Therapie mit Kompositen** - 30 Stunden
Zahnärztekammer Alexandria (Ägypten)
- **Endodontie Kurs** - 30 Stunden
Zahnärztekammer Alexandria (Ägypten)
- **Prothetik Kurs " Ideal Cavity Preparation"** - 6 Stunden
Zahnärztekammer Alexandria (Ägypten)

Qualifikationen

Sprache

- **Arabisch** (*Muttersprache*)
- **Englisch** (*fließend*)
- **Deutsch** (*fließend*)

Software

- **Microsoft Office** (*Experte*)
- **GraphPad Prism** (*Experte*)
- **EndNote , Mendley** (*Experte*)
- **Biorender, Canvas, Canva** (*Experte*)
- **SAP Business Client** (*Sehr gute Kenntnisse*)

Laboratory Skills

- **2D & 3D Cell Culture, Cell Transfection** (*Experte*)
- **Western Blot, Transfection, Single Cell analysis** (*Experte*)
- **Immunohistochemistry , H&E, Fluorescence Staining** (*Experte*)
- **Cell Sorting , Fluorescence Microscopy** (*Experte*)
- **FACS , PCR, RNA & DNA extraction** (*Competent*)

Publikationen

Total: 17; h-index: 8; citations: 168

Ancient and Emerging Nanostructures for Innovations to Fight Head and Neck Cancer. Nina Kummer, Ömür Acet, Burcu Önal Acet, Mike Blueggel, **Aya Khamis**, Désirée Gül, Shirley K. Knauer, and Roland H. Stauber. DOI:10.3390/cells15040339 (**Cells**, 2026)

Autologous Blood Concentrates: Platelet-Rich Plasma (PRP) and Platelet-Rich Fibrin (PRF) in Oral Implantology – Clinical Rationale, Protocols, and Evidence with an Emphasis on Immediate Placement. **Aya Khamis***, Keyvan Sagheb, Eik Schiegnitz. DOI: 10.63580/ITI.FI.45767 (**FORUM IMPLANTOLOGICUM**)

Vitamin D: Diagnostische und therapeutische Relevanz für die orale Implantologie. **Aya Khamis***, Bilal Al-Nawas, Désirée Gül, Joscha Werny, Moritz Schlenz, Nina Kummer, Keyvan Sagheb, Eik Schiegnitz (**Implantologie**, 2/2025)

Exploring the tumor-suppressive role of miRNA-200c in head and neck squamous cell carcinoma: Potential and mechanisms of exosome-mediated delivery for therapeutic applications. Mohamed S. Kishta, **Aya Khamis**, Hafez AM, Abdelrahman H. Elshaar, Désirée Gül. (**Translational Oncology**, 2025)

Vitamin D: Rolle in der hormonellen Regulation und Prävention von Parodontitis. **Aya Khamis ***, Eik Schiegnitz, Bilal Al-Nawas, Keyvan Sagheb, Désirée Gül*. (**Parodontologie**, 4/2024)

The Effect of Oral Potentially Malignant Disorders (OPMD) on Dental Implants Survival—A Systematic Review. Sebahat Kaya, Christian Walter, **Aya Khamis**, Lena Katharina Müller-Heupt, Stefanie Zimmer, Lorena Cascant Ortolano, Keyvan Sagheb, Bilal Al-Nawas and Eik Schiegnitz. (**Dentistry Journal**, 2025)

Vitamin D Risk Analysis Algorithm. **Aya Khamis ***, Eik Schiegnitz, Bilal Al-Nawas, Knut Grotz, Désirée Gül*. (**undersubmission**, 2024)

The magic Triangle in Oral Potentially Malignant Disorders: Vitamin D, Vitamin D Receptor, and Malignancy. **Aya Khamis ***, Lara Salzer, Eik Schiegnitz, Roland H. Stauber, Désirée Gül *. **IJMS** (2023)

Exploiting Vitamin D Receptor and Its Ligands to Target Squamous Cell Carcinomas of the Head and Neck. Laura Koll, Désirée Gül, Manal I. Elnouaem, Hanaa Raslan, Omneya R. Ramadan, Shirley K. Knauer, Sebastian Strieth, Jan Hagemann, Roland H. Stauber* and **Aya Khamis***. **IJMS** (2023)

The Vitamin D Receptor–BIM Axis Overcomes Cisplatin Resistance in Head and Neck Cancer. **Aya Khamis***, Désirée Gül, MaditaWandrey, Qiang Lu, Shirley K. Knauer, Christoph Reinhardt, Sebastian Strieth, Jan Hagemann and Roland H. Stauber*. **Cancers** (2022)

Impact of osteoblast-specific factor 2 in promoting metastatic progression of head and neck cancer Désirée Gül *, Andrea Schweitzer, **Aya Khamis**, Shirley K. Knauer, Guo-Bin Ding, Laura Freudelsperger, Ioannis Karampinis, Sebastian Strieth, Jan Hagemann, Roland H. Stauber*. **Cancers** (2022)

Profiling Cisplatin Resistance in Head and Neck Cancer: A Critical Role of the VRAC Ion Channel for Chemoresistance. Siemer, S., Fauth, T., Scholz, P., Al-Zamel, Y., **Khamis, A.**, Gül, D., Freudelsperger, L., Wollenberg, B., Becker, S., Stauber, R.H., et al. **Cancers** (2021).

Identification of cytokeratin24 as a tumor suppressor for the management of head and neck cancer. Gül, D., Habtemichael, N., Dietrich, D., Dietrich, J., Gößwein, D., **Khamis, A.**, Deuss, E., Künzel, J., Schneider, G., Strieth S., Stauber RH*. **Biological chemistry** (2021).

Nano Meets Micro-Translational Nanotechnology in Medicine: Nano-Based Applications for Early Tumor Detection and Therapy

S. Siemer, D. Wünsch, **A. Khamis**, Q. Lu, A. Scherberich, M. Filippi, M. Krafft, J. Hagemann, C. Weiss, Guo-Bin Ding, R. Stauber, A. Gribko*. **Nanomaterials** (2020)

Clinical Management Protocol for Dental Implants Inserted in Patients with Active Lichen Planus. Part II 4-Year Follow-Up.

AK Khamis*, MN Aboushelib, MH Helal. **Journal of Prosthodontics** (2018)

The influence of local delivery of bisphosphonate on osseointegration of dental implants

AK Khamis*, S Elsharkawy. **Evidence-based dentistry - Nature** (2018)

Diagnostic and prognostic value of cancer stem cell marker CD44 and soluble CD44 in the peripheral blood of patients with oral Squamous cell carcinoma.

AK Khamis*, HA Fouad, HS Raslan, MM Fata, Al Fayad. **Open Science Journal** (2017)