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Review Article

# The mechanical complications and behavior of angulated dental implant abutment systems versus conventional abutments, a narrative review

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ABSTRACT

*Background:* Angulated screw channel (ASC) abutment allows off-axis dental implants to be used in dental restorations without the need for cementation. As this is a relatively new system, research on its clinical performance is limited.
*Objectives:* To summarize the available in-vitro and in-vivo studies on the mechanical and technical issues associated with the ASC system and compare its clinical performance with that of conventional implant-supported abutments.
*Methods:* A comprehensive literature search in PubMed, Web of Science, and ScienceDirect databases was performed, focusing on articles about angulated (angled) screw channel (ASC) systems published in English between January 2015 and November 2023. Only in-vitro and in-vivo studies were included.
*Results:* After analyzing the recorded articles, 26 studies (11 in vivo and 15 in vitro) were included in the final discussion and review.
*Conclusion:* Although the ASC system is still relatively new, and is presently outperformed by conventional abutment systems in terms of technical and mechanical properties, in short- and medium-term in-vivo studies, it was shown reliable for retaining single or multiple-unit implant restorations in both posterior and anterior zones. Still, further long-term clinical research is needed to fully elucidate the risk factors associated with ASC failures.

## 1. Introduction

Dental implants are increasingly being used to replace missing teeth. However, their wider application is conditional on the successful selection of the appropriate abutments which provide a link between the implant fixture and prosthesis. Screw- or cement-retained systems are typically adopted for this purpose, whereby mechanical issues are more common in the former case, while the latter increases the risk of biological complications caused by cement residues (Gaddale et al., 2020; Hamed et al., 2020; Linkevicius et al., 2013a; Linkevicius et al., 2013b; Makke et al., 2017; Priest, 2017; Ragauskaitė et al., 2017; Wittneben et al., 2014).

In practice, screw-retained restorations are preferred due to the absence of cement, easy retrieval, and less prerequisite interdental arch space, even though they are technically more complex to execute (Assaf & Abu Gharbyeh, 2014; Carpentieri et al., 2019; Hamed et al., 2020). For screw-retained restorations, ideal implant positioning must be considered before surgical interventions, however anatomical factors may mandate the use of off-axis implants. The cement-retained system is a common option to correct the angulation of tilted implants. Garcia-Gazaui et al. (2015) proposed the ASC system as another solution Fig. 1.

The ASC system—first introduced in 2015 (Garcia-Gazaui et al., 2015)—reorients the screw access channel to an optimal location (within 30° of angulation) and is biologically safer due to the absence of cement. In some cases, it may also preclude the need for bone augmentation (Nakka et al., 2020), while the uniform restorative material thickness around the ASC abutment may yield better performance.

According to Edmondson et al. (2022), an angulated abutment system is needed in 74 % of implant restorations involving maxillary incisors, while Kan et al. (2023) posited that the ASC system is suitable for implant placement in the esthetic zone in 90 % of cases.

While research on its applications is relatively limited, available evidence points to certain drawbacks, such as porcelain fractures and incompatibility between the screwdriver head and the ASC abutment screws, potentially compromising the torsion resistance while complicating the retrieval process (Bai et al., 2023; Farre-Berga et al., 2020; Hu

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et al., 2019; Mulla et al., 2022; Opler et al., 2020).

Thus, further studies on the mechanical and technical complications, biocompatibility, patient satisfaction, and survival rate are needed to guide the practical use of this system. These findings should also be compared with those related to conventional abutments, for which 97.4 % and 98.9 % 5-year survival rates were reported for single and fixed dental prostheses, respectively (Corbella et al., 2021), with 96 % 10-year survival rate cited by Howe et al. (2019).

The challenges associated with cement-retained systems and the higher demand for a suitable abutment system for off-axis implants have led researchers to investigate ASC systems more extensively in recent years. In the literature, two systematic review articles on ASC systems were published in 2022, which include 17 studies on ASC systems conducted between 2015 and 2022 (Pitman et al., 2022; Rasaie et al., 2022). However, this narrative review is needed as nine new in-vivo and in-vitro studies were published in 2023, providing dentists with an up-to-date summary and suggestions.

The main objective of this narrative review is to summarize the available in-vitro and in-vivo studies about the ASC system's mechanical and technical complications and address what is known about its clinical behavior compared to conventional implant-supported abutments.

## 2. Methods

The search strategy of this narrative review consists of the following steps: (1) Define the question, (2) plan eligibility criteria, (3) a comprehensive literature search, (4) study selection, (5) eliminate irrelative data, (6) analyze and present results and (7) conclude. A comprehensive literature search in the PubMed, Web of Science, and ScienceDirect databases using search terms "angulated screw channel" and "angled screw channel", focusing on in-vitro and in-vivo articles (excluding case reports) on the ASC system published in English between January 2015 and November 2023 was performed. The retrieved publications were evaluated for their relevance through titles, abstracts and full texts, and those retained for a detailed review were analyzed to draw conclusions regarding the ASC performance Fig. 2.

## 3. Results

As shown in Fig. 2, the initial search across multiple databases yielded a total of 312 articles, with 123 references found on PubMed, 151 on Web of Science, and 38 on ScienceDirect). A total of 139 articles were excluded due to duplication. The titles, abstracts and full texts were used to screen the 173 remaining references, of which 147 were excluded due to irrelative content (n = 134), case report (n = 7), languages other than English (n = 3), systematic reviews (n = 2) and technical report (n = 1). The remaining 26 articles comprised in-vivo (n = 11) and in-vitro (n = 15) studies, which were analyzed and chosen for the final review.

## 4. Discussion

### 4.1. Preload and reverse torque values (screw loosening)

In the Glossary of Prosthodontic Terms (9th edition), preload is ''the tension created in a screw, especially the threadings, when tightened''. A significant amount of clamping force can be lost upon function. This phenomenon can affect the performance of screw-retained restorations, rendering them prone to loosening (Assaf & Abu Gharbyeh, 2014; B. J. Goodacre et al., 2018; C. J. Goodacre et al., 1999; Schwarz, 2000).

Screw loosening can also yield other adverse effects, including implant − abutment connection failure (Binon, 2000), abutment screw fracture (Hoyer et al., 2001), microleakage (Sahin & Ayyildiz, 2014), and bacterial infection (Jung et al., 2008; Theoharidou et al., 2009).

These issues can be mitigated through the improvements in screw and screwdriver design (Mulla et al., 2022), control of input torque (Mulla et al., 2022; Swamidass et al., 2021), abutment system changes (Swamidass et al., 2021), screw-channel angulation adjustments (Çakmak et al., 2023; Mulla et al., 2022; Swamidass et al., 2021), lateral force limitation (Khraisat et al., 2004; Londhe et al., 2020), a better choice of internal connection type (Çakmak et al., 2023) and appropriate implant diameter (Londhe et al., 2020), as these factors have been shown to exhibit a direct or indirect impact on the clamping force.

According to the comparison of torque values of one straight and three 20°ASC abutment systems obtained before and after simulated functional cyclic loading equivalent to 12-month usage conducted by Swamidass et al. (2021), no differences in torque loss were noted.

Likewise, Goldberg et al. (2019) reported no significant differences among the reverse torque values in 0°, 25°, and 28° ASC abutments (dynamic abutment, Dynamic Abutment Solutions) following 1,200,000 cycles of 40 N axial load. These observations were also supported by the outcome study conducted by Chen et al. (2023).

On the other hand, they were countered by the work of Opler et al. (2020), who noted a 23 % reverse torque reduction in 25° and 28° ASC abutments (3.0 Dynamic Abutment; Talladium International Implantology) as well as screw head deformations relative to 0°, 10° and 15° abutments.

More recently, Mulla et al. (2022) conducted a similar study, concluding that 25° ASC abutments had statistically significantly lower reverse torque values relative to the control group (universal base, 0°). Their findings provided support for those published by Farre-Berga et al. (2020) indicating that 20° and 30° angulation reduced the torque values in custom-made abutment screws (made of Ti6Al4V grade 5 alloy) by 22 % and 37 %, respectively, in comparison to the control group.

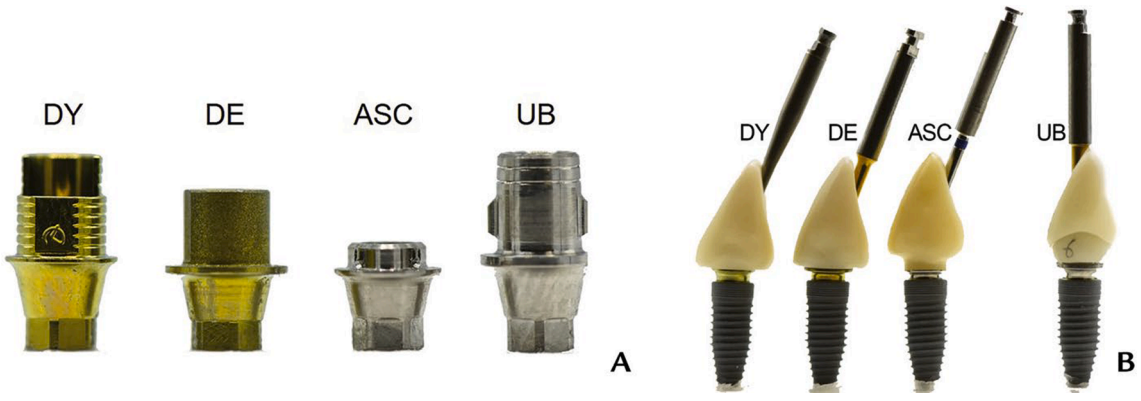


**Fig. 1.** Some of the available angulated screw channel systems: A. Shows angulated screw channel titanium bases; Dynamic Abutment Solutions dynamic tibase (DY), Dess Dental Smart Solutions anglebase (DE), Nobel BioCare angulated screw channel (ASC) and Nobel BioCare universal base (UB), B. Shows the lateral aspect of the assembled systems (25° and 0° of angulations) and zirconia-based restorations along with their unique screwdrivers. Courtesy of (Mulla et al., 2022).

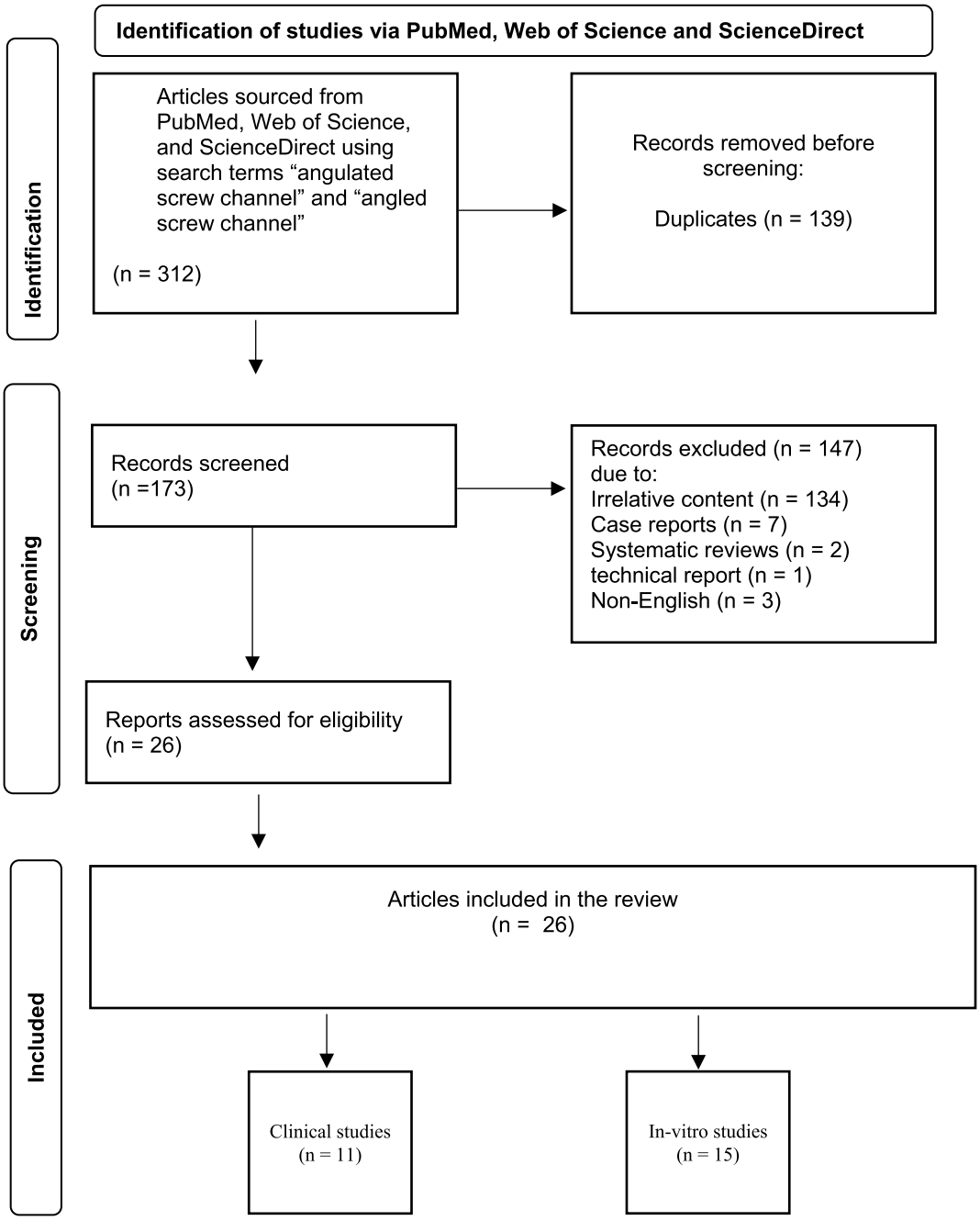


**Fig. 2.** Prisma diagram showing the literature search steps.

As a part of their study on narrow implants, Bhumpattarachai et al. (2023) evaluated the impact of cyclic loading on screw loosening in different ASC systems: (1) 0° ASC solutions (Noble BioCare), (2) 20° ASC solutions (Noble BioCare), (3) 20° Atlantis CustomBase Solutions (Dentsply Sirona), and (4) 20° Dynamic TiBase (Dynamic Abutment Solutions). Group 2 significantly outperformed other systems in terms of the preload percentage loss, as no screw loosing, mechanical complications, or restoration fractures occurred after 1,000,000 cycles.

It is also worth noting that only four screw loosening incidents over a 12 – 36 follow-up period were reported by other researchers (Anitua et al., 2018; Di Fiore et al., 2023; Greer et al., 2017), even though the ASC system has been subjected to a significant body of clinical research (Anitua et al., 2018, 2020; Di Fiore et al., 2023; Friberg & Ahmadzai, 2019; Greer et al., 2017; Lv et al., 2021; Nastri et al., 2021; Pol et al., 2020; Rella et al., 2021; Varshney et al., 2023; Yang et al., 2023). Moreover, findings yielded by the systematic review performed by Pitman et al. (2022) reported that none of the existing ASC systems was superior in terms of screw loosening resistance.

In sum, while screw loosening does not seem to be a prevalent issue in implants based on the ASC system, straight abutments are still superior due to the greater ease with which the required input torque can be delivered. Given that, at 20° or more of angulation, ASC screws were less torsion-resistant, exploring alternative screw head/screwdriver geometries (Farré-Berga et al., 2018) and coatings (e.g., titanium nitride or diamond-like carbon) may alleviate this issue. Additional standardized and controlled clinical studies are also needed.

### 4.2. *Fracture resistance*

Fracture resistance, i.e., resistance to crack propagation, in the

context of dental implant restorations primarily depends on the direction and amount of occlusal forces (Koenig et al., 2013; Lorenzoni et al., 2010; Tribst et al., 2018), implant – abutment connection fit (Binon, 2000), restoration thickness (Tribst et al., 2018), and implant – abutment – restoration material congruence (Acar & Kalyoncuoğlu, 2021). ASC systems are mostly used with zirconia-based restorations due to the high elastic modulus (>200 GPa) and flexure strength (>1000 MPa) of this material, even though it is not uncommon to fracture (Miura et al., 2021; Sailer et al., 2018).

Accordingly, Garcia-Hammaker et al. (2021) investigated the fracture resistance of straight and 25° ASC abutments for restorations based on monolithic zirconia crowns by applying a static load to a failure point. Most fractures occurred in the palatogingival area where zirconia was the thinnest, and the ASC abutments were found to be inferior to the controls, the performance of which coincided with that reported by other authors (Adatia et al., 2009; Aramouni et al., 2008; Yildirim et al., 2003). Accordingly, zirconia restorations on ASC abutments have a significantly lower fracture resistance.

Similarly, Drew et al. (2020) compared the fracture strength of ASC and straight abutments after cycling load, with zirconia-based restorations. Catastrophic failure was noted in 80 % of the restorations on ASC abutments compared to only 40 % of those on straight abutments. Moreover, all fractures occurred in the cingulum part of the crown, suggesting that zirconia thickness plays a significant role in the ASC system performance.

These observations were confirmed by Mulla et al. (2022) who found that three ASC samples from Noble Biocare had catastrophic failure after cyclic loading, with the cingulum area of the crowns and the apical part of the abutment screws as the main fracture sites. Mulla et al. (2022) and Wei et al. (2023) opined that direct fastening between zirconia and abutment screw could induce this fracture mode, as it may give rise to a wedging force, as shown in Fig. 3. Moreover, high stress at this region due to the levering effect could be a contributing factor.

Although restorations based on the ASC system have been shown in several in-vitro studies to exhibit lower fracture resistance compared to those on straight abutments, the reported values were typically higher than the maximum average forces (90 – 370 N) produced by adult incisors (Haraldson et al., 1979; Paphangkorakit & Osborn, 1997). Hence, several authors are of the view that, while the ASC system might work well in the anterior zone, it might not be a wise option in the posterior zone where the biting force is several times greater (Waltimo & Könönen, 1993). This assertion is, however, countered by the available evidence showing 92 – 100 % survival rates at 36-month follow-up for the posterior-region implants based on the ASC system and zirconia restorations (Di Fiore et al., 2023; Rella et al., 2021; Yang et al., 2023).

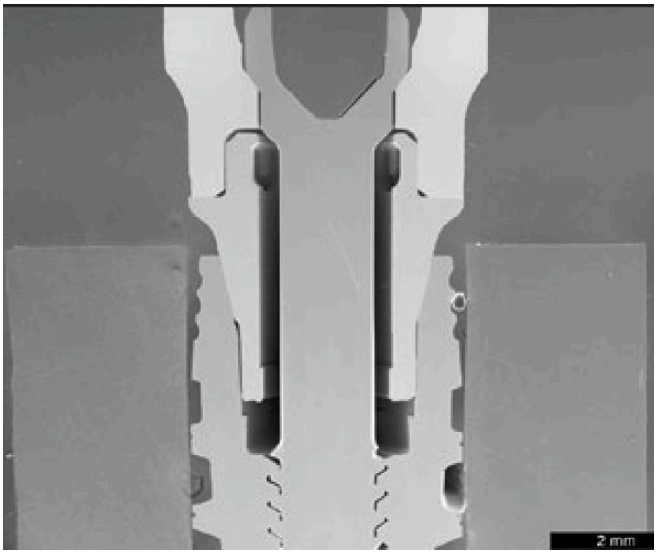


**Fig. 3.** Cross-section of an ASC system *in situ* showing the friction-fitted design. Courtesy of (Drew et al., 2020).

In several studies included in this review, the fracture resistance and pattern in ceramic and titanium implants from Straumann were compared to evaluate the performance of the 25° ASC system versus the straight screw channel system (0° and 25° RN Variobase AS, AH 4 mm and CI RD PURE Base, AL 3.5 mm, Straumann). No catastrophic failure was recorded at the restoration or abutment levels after functional cyclic loading equivalent to 5-year use, whereas implant-level fractures were observed in 100 % and 50 % of ceramic implants with the 25° and 0° ASC systems, respectively. On the other hand, the titanium implants and their components had a 100 % 5-year survival rate with only plastic deformations noticed at the implant-abutment connection level (Helal et al., 2023). The fracture mode in this study is completely different from that of previous reports (Drew et al., 2020; Garcia-Hammaker et al., 2021; Mulla et al., 2022). This could be attributed to the variation in mechanical properties of TI and CI.

Goldberg et al. (2019) evaluated the fracture strength of 0°, 25°, and 28° ASC dynamic abutment screws (Dynamic Abutment Solutions) and compared their performance with 0° gold screws using a universal mechanical testing machine. Although higher fracture strength values were obtained for gold screws, no statistically significant differences were found between the groups.

Nonetheless, based on the results yielded by the existing clinical studies on the ASC system (Anitua et al., 2018, 2020; Di Fiore et al., 2023; Friberg & Ahmadzai, 2019; Greer et al., 2017; Lv et al., 2021; Nastri et al., 2021; Pol et al., 2020; Rella et al., 2021; Varshney et al., 2023; Yang et al., 2023), veneering porcelain fracture is the most prevalent technical issue associated with this system (Anitua et al., 2018; Greer et al., 2017; Rella et al., 2021; Yang et al., 2023). This is not surprising, given that layered zirconia restorations are prone to such fractures (Sailer et al., 2015, 2018).

In summary, the ASC system exhibits lower fracture resistance than straight abutment systems. As in the extant studies, failures mainly occurred at the restoration level (the most apical part in particular); the zirconia material used in restoration likely played a role, suggesting that it requires further investigation and development of new designs (Sakamoto et al., 2018). Due to the lower fracture resistance of the ASC system, caution needs to be taken when managing tilted implants in the posterior region. The fracture resistance of metal-ceramic restorations based on the ASC system is also presently underexplored and should thus be studied, along with the influence of patients' oral parafunctional habits, clinical crown-to-implant ratio, and occlusal scheme, among other factors.

### 4.3. *Biological complications and clinical survival rate*

As the oral environment is a complex and dynamic system, its interaction with dental materials needs to be carefully studied. Thus, when planning to introduce a new dental device, probing depth, gingival bleeding index, biomarkers in crevicular fluid, gingival inflammation, presence of fistulas, dehiscence/fenestrations, and marginal bone loss (MBL) in particular, need to be well understood (C. J. Goodacre et al., 2003). The longevity of dental implants is also affected by soft and hard tissue reactions to the constituent materials, as well as microbial plaque buildup (el Askary et al., 1999).

According to Rella et al. (2021) who conducted one of the first long-term clinical studies of the ASC system's cumulative survival by following 105 subjects with 162 implants over 42 months, both restorations and ASC abutments had a 92 % survival rate, which is lower than 97 – 98 % reported for conventional screw-retained restorations on straight abutments (Corbella et al., 2021). In addition, monolithic zirconia restorations (95 %) exhibited a higher success rate than layered zirconia restorations (90 %). This was expected, as the latter are prone to chipping (Sailer et al., 2015, 2018). Rella et al. (2021) nonetheless

concluded that ASC abutments provided a favorable outcome in both posterior and anterior regions when tilted implants were clinically indicated.

At 12-month follow-up, the authors cite 98 − 100 % clinical survival rate for implants and restorations on ASC abutments (Friberg & Ahmadzai, 2019; Lv et al., 2021; Pol et al., 2020) and this percentage remains relatively stable (96 − 100 %) at a longer-term (up to 36 months) follow-up (Di Fiore et al., 2023; Yang et al., 2023).

In their two-year-long study, Nastri et al. (2021) compared the esthetic outcome, *peri*-implant tissue health, and technical issues associated with the ASC system and cement-retained abutments and reported no statistically significant differences in any observed measures.

As progressive MBL is known to affect the long-term survival of dental implants, it has been extensively studied (Anitua et al., 2020; Di Fiore et al., 2023; Friberg & Ahmadzai, 2019; Lv et al., 2021; Nastri et al., 2021; Varshney et al., 2023; Yang et al., 2023). Thus, it is worth noting that, in a recent 12-month clinical study, the ASC system performed comparably to multi-unit abutments retaining single implants in terms of patient satisfaction, MBL, screw loosening, and survival rate (Varshney et al., 2023).

As adverse tissue reaction to a dental device is not an uncommon issue, as a part of their randomized controlled clinical study, Lv et al. (2021) focused on this aspect of performance. While no significant differences were found in any of the assessed parameters, higher levels of tumor necrosis factor alpha (TNF-α) were noted for the ASC system, which were subsequently confirmed by Yang et al. (2023) based on a mean 32-month follow-up.

In sum, both short- and medium-term clinical studies considering factors such as appearance, patient satisfaction, MBL, tissue reaction, mechanical complications, and survival rate suggest that the ASC system is a good alternative to the conventional cement-retained abutment system. Rasaie et al. (2022) drew the same conclusion. To increase its use in practice, however, surface modification should be considered, as it might reduce the risk of adverse tissue reactions and would also have an antibacterial effect. Since the ASC system was recently introduced to the dental field, such investigations would also be a valuable contribution to the limited clinical evidence based on long-term studies.

## 5. Conclusion

Within the limitations of this review, even though in-vitro studies indicate that conventional abutment systems are slightly superior to the ASC system in terms of technical and mechanical properties, findings yielded by short- and medium-term in-vivo studies suggest that it is a reliable abutment for single or multiple-unit implant restorations in both posterior and anterior zones of the oral cavity. Still, the risk factors contributing to ASC failures are not well understood and require further long-term clinical studies.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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