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Review Article

What is the impact of patient attributes, implant characteristics, surgical techniques, and placement location on the success of orthodontic mini-implants in young adults? A Systematic Review and Meta-Analysis☆

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ABSTRACT

Background: Temporary anchorage devices (TADs) address challenges in traditional orthodontic anchorage like patient compliance and precision, showing significantly improved clinical outcomes, particularly for cases requiring maximum anchorage.

Materials and Methods: A systematic electronic search was performed in five research databases, focusing on studies published between 2015 and 2023. The ROBINS-I tool from the Cochrane Bias Methods Group assessed the risk of bias. Data analysis included categorical and numerical variables, with categorical variables analyzed using Cohen's method in a random effects model to account for variability. Sensitivity and heterogeneity were evaluated using a 'leave-one-out' approach and the I^2 statistic, respectively. At the same time, publication bias was checked using Egger's test, with findings presented through Forest and Funnel plots. Numerical variables were subjected to weighted regression analysis.

Results: Examination of 15 studies involving 1981 patients and 3272 orthodontic mini-implants identified key factors affecting implant stability. Failure rates varied significantly, influenced by factors such as the characteristics and insertion site of the orthodontic mini-implants (OMIs), patient-specific variables, and operator experience. Notably, the insertion site and implant characteristics like size did not significantly affect failure rates, but there was a negative correlation between the magnitude of force applied and failure rates.

Conclusion: The success of orthodontic mini-implants is broadly consistent across patient demographics and is not significantly impacted by gender or age, though failure rates were higher in males and when implants were placed in the maxilla. These findings suggest that higher applied forces might reduce failure rates.

Clinical Significance: This review underlines mini-implant efficacy across varied patient demographics, emphasizing the importance of site selection, jaw location, and force application in enhancing success rates and guiding tailored treatment strategies.

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1. Introduction

Orthodontic mini-implants (OMIs), also known as Temporary Anchorage Devices (TADs), have emerged as an alternative to conventional orthodontic treatments due to their distinct advantages, including patient compliance and precision in treatment (Zawawi, 2014; Leo et al., 2016; Wehrbein and Göllner, 2007). While OMIs offer improved outcomes, particularly for patients needing significant anchorage, their success depends on several critical factors. The ability to establish solid initial stability and the judicious application of force play a pivotal role in the effectiveness of these devices (Sandler et al., 2014; Herrmann et al., 2005). Moreover, factors such as the age-related development of the patient's skeletal structure and the integrity of the bone tissue significantly influence treatment feasibility and force application,

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thereby necessitating preoperative assessments such as quantitative computed tomography (QCT) for optimal bone quality evaluation (Chen et al., 2009; Ramírez-Ossa et al., 2020).

Despite their transformative role in orthodontic treatment, OMIs are exposed to potential risks and complications. These challenges, alongside considerations for mitigating them, have been explored and detailed, offering clinicians guidelines for achieving successful outcomes (Truong et al., 2022). By examining several factors ranging from patient demographics to procedural specifics, this review aims to understand the complex factors contributing to the success rates of OMIs.

2. Materials and methods

2.1. Objective

This research aims to understand the elements that play a role in the failure rate of orthodontic mini-screws (OMIs), such as patient-specific attributes, the implant features, the methodology adopted for orthodontic surgery, and the location of OMIs placement in determining their success. A particular area of interest for the investigators is the influence of age – drawing a line of comparison between adolescents and adults – on the incidence of OMIs failures. This focus is rooted in the frequent application of OMIs for correcting malocclusions typically found in younger people. The study further assesses other potential variables that may sway the results of using OMIs in orthodontic treatments, aiming to improve current clinical methodologies.

In alignment with established standards for conducting systematic reviews and meta-analyses, this investigation adhered to the guidelines set forth by PRISMA (Page et al., 2021). The methodological framework of this review was based on the PICO model (da Costa Santos et al., 2007). Considering the nature of this review, which synthesizes published literature, the requirement for ethical approval was circumvented. The research received a registration number from PROSPERO, specifically CRD42023411955, ensuring compliance with the database's prescriptive benchmarks.

The main aspects of the PICO strategies are:

- Population: Young orthodontic patients (adolescents and young adults), regardless of gender or type of malocclusion or orthodontic appliances used.
- Intervention: All orthodontic treatment procedures involving the OMI insertion.
- Outcomes: OMIs failure or success rate concerning patient-related factors, implant-related factors, and technique-related factors.

In their methodological approach, the researchers conducted both univariate and multivariate meta-analyses. While the multivariate analysis, as documented in previous studies (Crismani et al., 2010), tends to be more prevalent due to its capacity to evaluate the collective influence of variables like age, gender, and treatment modalities on the likelihood of OMI failure, the authors also implemented a univariate Meta-Analysis. This latter analysis investigates the impact of isolated factors, one by one, to determine their singular effect across various research studies.

2.2. Search strategy

The search was carried out across multiple academic databases, including PubMed-MEDLINE, Scopus, Cochrane, Web of Science (WOS), and ScienceDirect. For each database, specific search terms were employed, covering a range of synonyms and related terms to encompass the concept of mini-implant success and failure in adolescent and young adult patients. The search was unrestricted by language, but the focus was on papers in English published from 2010 to 2023, specifically excluding non-journal literature, reviews, and Meta-Analyses. The search was refreshed periodically to catch the latest studies. Additionally, studies identified through manual search methods were also included.

Two independent authors screened titles and abstracts, filtering out studies that did not pertain to the targeted age demographic. The same reviewers examined those that met the preliminary criteria in full text for compliance with the established inclusion parameters. Considering the extensive literature on the subject, a strategic decision was made to confine the review to articles released from 2015 onwards, thus prioritizing contemporary findings. The final phase of the research involved detailed data extraction and an evaluation of the potential bias within the selected studies.

2.3. Data extraction

Microsoft Excel was used to record the extracted data. In addition, the Nested Knowledge Systematic Review Software (Kallmes et al., 2021), MATLAB (The MathWorks Inc, 2022), and R (R Core Team, 2021) were employed for data comparison and analysis.

2.3.1. Selection criteria

The selection of studies for this analysis was based on specific criteria, including: 1. Align with the systematic review's central research question and goals. 2. Studies focusing on the characteristics of orthodontic adolescents and young adult patients, OMIs design, or orthodontic surgical approaches impacting OMIs stability or failure rates. 3. Inclusivity of all patient genders, types of malocclusions, and orthodontic devices employed.

The selection process was finalized on October 5, 2023. *In vitro* studies were omitted to ensure the relevance of the data to clinical scenarios. This was to disregard findings from studies using FEM (Finite Element Method) or experimental models on animals or synthetic constructs, which might lead to non-representative results. Included in the review were observational clinical studies, randomized controlled clinical trials, and other human-based studies. Excluded from consideration were *in vitro* analyses, FEM investigations, and any Systematic Reviews or Meta-Analyses.

2.4. Quality assessment and risk of bias

The evaluation of the articles' methodological integrity and bias risk was conducted using the Cochrane Bias Methods Group's ROBINS-I tool (Sterne et al., 2016). To visually represent the findings, the Risk-of-bias VISualization (Robvis) tool (McGuinness and Higgins, 2021) was utilized to generate "traffic light" plots that display domain-level evaluations for each study outcome, along with weighted bar charts that illustrate the distribution of bias risk assessments across various domains.

2.5. Data synthesis and statistical analysis

The synthesis of data and the statistical analysis for this Systematic Review were carried out using Microsoft Excel, MATLAB (The MathWorks Inc, 2022), R (R Core Team, 2021), and the Nested Knowledge systematic review software (Kallmes et al., 2021).

3. Results of the multivariate Meta-Analysis

3.1. Research

The search strategy resulted in 599 articles initially identified from various databases: PubMed contributed 152, Scopus 49, ScienceDirect 238, Google Scholar 67, with an additional 116 articles sourced manually. After removing 151 duplicates in the preliminary sorting phase, 448 articles remained. Upon further review of titles and abstracts, 247 articles were excluded for not meeting the inclusion criteria, leaving 201 articles. Of these, 181 were inaccessible, narrowing the selection to 20 potentially relevant articles. Following a detailed eligibility assessment, 15 of these articles were included for comprehensive analysis in the review.

The progression of this selection process is depicted in the PRISMA 2020 Flow Diagram (Fig. 1). Details regarding the primary characteristics of the studies included in our review are systematically outlined in Table 1.

3.2. Characteristics of included studies

Table 1 presents the characteristics of the selected study for data analysis. Ten studies were classified as retrospective cohort studies (Uribe et al., 2015; Yi Lin et al., 2015; Lee et al., 2016; Hourfar et al., 2017; Uesugi et al., 2017; Haddad and Saadeh, 2019; Ichinohe et al., 2019; Azeem et al., 2019a; Azeem et al., 2019; Bungău et al., 2022), while five were a prospective cohort study (Motoyoshi et al., 2015; Tsai et al., 2016; Motoyoshi et al., 2016; Aly et al., 2018; Gill et al., 2023) A total of 1981 patients were evaluated.

Male and female subjects were included without discrimination, although two studies did not provide precise quantification in this regard (Gill et al., 2023; Yi Lin et al., 2015). A total of 3272 orthodontic mini-implants were placed. Five studies used titanium mini-implants 24–28, while one used steel TADs 23. The dimensions of the mini-implants ranged from a minimum diameter of 1.2 mm (Lee et al., 2016) to a maximum of 4.1 mm (Uribe et al., 2015). The minimum recorded length was 4 mm (Uribe et al., 2015), while the maximum was 14 mm (Gill et al., 2023). All studies conducted clinical evaluations. Only four articles show the radiographic examinations that the authors used to support their diagnosis (Motoyoshi et al., 2015; Lee et al., 2016; Motoyoshi et al., 2016; Uesugi et al., 2017). The failure rates of the mini-implants ranged from 5,40% (Motoyoshi et al., 2016) to 100% (Gill et al., 2023). On the other hand, the success rate ranged from 44.4% (Ichinohe et al., 2019) to 100% (Bungău et al., 2022; Gill et al., 2023).

3.2.1. Overall mini-screws success-failure rate

The key findings from several studies reviewed in this paper are presented below.

Motoyoshi et al. (2015) analyzed the effect of maxillary buccal alveolar bone insertion on OMIs stability, with a specific focus on cases of sinus perforation. Their findings highlighted a failure rate of 12.5% in the perforation group compared to 5.4% in the non-perforation group. Notably, despite similar placement torque and vertical inclination, perforated cases showed significantly thinner sinus floor measurements. Importantly, post-diagnostic radiographic assessments detected no instances of sinusitis in the perforated cases. The study underscored a crucial link between sinus perforation and a sinus floor thickness below 6.0 mm (Motoyoshi et al., 2015).

Uribe et al. (2015) investigated a range of factors that could affect OMIs failure in the infrazygomatic crest area, including patient demographics (age, gender, medical conditions), implant specifics (length, diameter), orthodontic variables (force, movement type), surgical experience, and maintenance factors (oral hygiene, inflammation). They documented a 21.8% failure rate, noting variability influenced by factors like age and oral hygiene, although these did not reach statistical significance in relation to implant failure (Uribe et al., 2015).

Yi Lin et al. (2015) focused on mini-screw placement across various maxillary and mandibular regions, including the retromolar area and hard palate. Their analysis considered patient age, gender, skeletal and dental malocclusion, and specific implant characteristics such as type, length, and diameter. They reported a high initial success rate of 94.7% at T1 (the day of orthodontic loading) that decreased to 83.3% by T2 (12 months post-insertion). They found that mini-screw length significantly impacted success at both time points, with vertical skeletal malocclusion correlating with success at T2 (Yi Lin et al., 2015).

Tsai et al. (2016) assessed mini-screws in the maxilla and mandible, reporting an overall success rate of 85.8%. Their study considered patient factors such as age (<20 years, 20–30 years, and > 30 years),

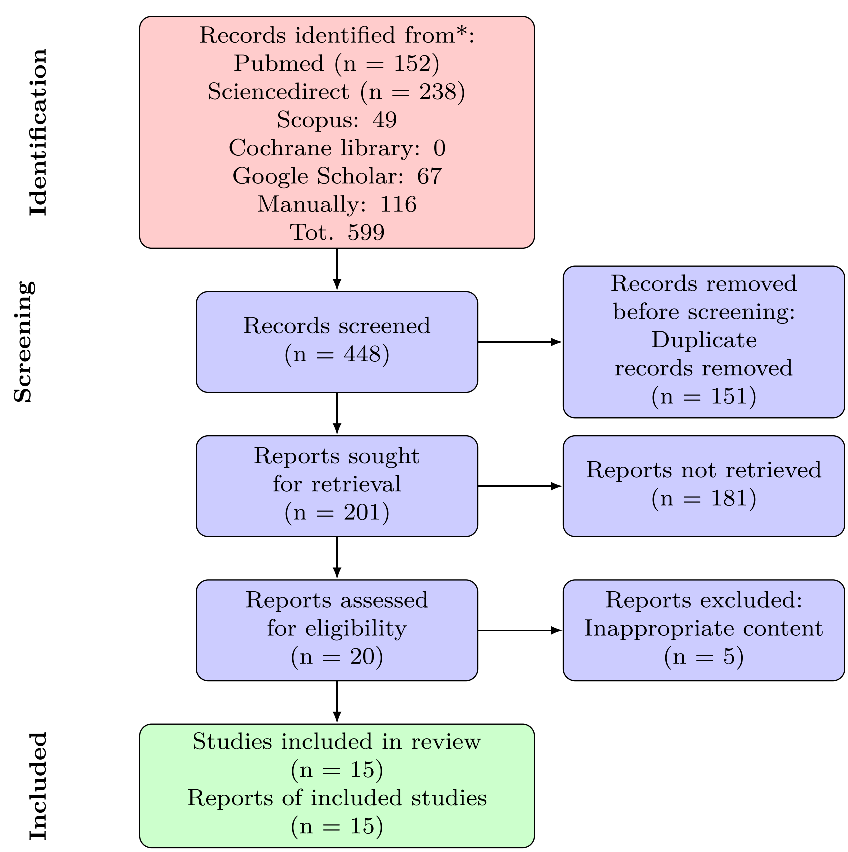

Fig. 1. PRISMA 2020 Flow Diagram.

Table 1
The primary characteristics of included studies. * C: Canines; Pm: Premolars; M: Molars; CBT: Cortical Bone Thickness, MB: Maxillary Buccal area; MP: Midpalatal suture area.

Study	Design	N. Of Patients	Age (Average)	N. Of OMI	OMI Type	OMI Dimension	Region of Interest	Percent Failure Data	Percent Success Data	Statistically Significant Findings
Motoyoshi M, 2015 (Motoyoshi et al., 2015)	PCS	45 (28 F, 17 M)	23.3 ± 8.9 years	82	Biodent, Tokyo, Japan	1.6 × 8 mm	Maxilla	12.5% in perforation group - 5.40% in no perforation group		Sinus floor thickness < 6.0 mm significantly affects maxillary sinus perforation (P < 0.001).
Uribe F, 2015 (Uribe et al., 2015)	RCS	30 (42 F, 13 M)	22.2 ± 11 years	55	Lomas, Imtec, Aarhus, Dual Top	Various dimensions	Infrazygomatic region	21.8% - <18 years 20.69% - ⩾18 years 23.08% - poor Oral hygiene 35.71% - Insertion site: left 25%, right 18.52%		N/A
Yi Lin S, 2015 (Yi Lin et al., 2015)	RCS	136	N/A	414	VectorTAS or AbsoAnchor	Various dimensions	Maxilla and Mandible, various regions		94.7% (<20 years 94.6; ⩾20 years 95.1) at T1 and 83.3% (<20 years 80.7; ⩾20 years 90.0) at T2	OMIs lenght was significantly associated with success at T1 and T2.
Tsai CC, 2016 (Tsai et al., 2016)	PCS	139 (114 F, 25 M)	25.7 ± 7.5	254	Ancer, Bio-Ray	1.6 × 6 mm	Maxilla and mandible		85.8% -cumulative 1-year survival rate 81.6% - <20 years: 88.2, 20–30 years: 84.5% >30: 69.6; Maxilla: 81.1% Mandible: 85.1%; Position: Anterior 73.6% Posterior 82% - Site: Left: 85%, Right: 80.7% - Healing time Early loading (⩽3 weeks): 81.9%, Late loading (>3 weeks): 79.8%	Patient age significantly affects survival (P < 0.05).
Lee MY, 2016 (Lee et al., 2016)	RCS	71 (53 F, 18 M)	9.2 ± 6.63	127	AbsoAnchor SH1312-08 [self-dril- ling and tapered]	1.2–1.3 × 8 mm	Maxillary buccal alveolar bone		85%	Cancellous bone density and total bone density significantly affect success rates (P < 0.05)
Motoyoshi M, 2016 (Motoyoshi et al., 2016)	PCS	110 (79 F, 31 M)	21.3 ± 6.9	202	Biodent, Tokyo, Japan	1.6 × 8 mm	Maxillary buccal alveolar bone	18.3% in root contact group	98.8% (no contact); 81.1% (root contact)	Higher failure rate in OMI root contact, left side, male and high PTV (P<0.01)
Hourfar J, 2017 (Hourfar et al., 2017)	RCS	239 (137 F, 102 M)	13.8	387	OrthoEasyő, Forestadent, Germany	1.7 × 8 mm	Maxilla and mandible	29.5% in > 30 years: 20–30 years: 14.8%; 6–20 years: 13.3%)	84.8% - 98.9% (palatal), 71.1% (interradicular)	A significant difference in success rates was noted in group 6–20 years (p < 0.01), and in male (p<0.05). Insertion site and the failure rate of OMIs were statistically significant (p < 0.001).
Uesugi S, 2017 (Uesugi et al., 2017)	RCS	238 (176 F, 62 M)	27.9 ± 8.4	471	Dualtop; Jeil Medical, Seoul, Korea	1.4,1.6, 1.6, 2.0 × 6.0, 8.0 mm	Maxillary buccal area (MB) and the midpalatal suture area (MP).		MB primary success rate 79.1%, secondary success rates 58.1%. MP 84.5% - secondary success rates 88.9% <20 in MB: 76.4%, 20-30 years: 78.1%, >30 years: 83.0%; <20 years in MP: 88.2%, 20-30 years: 82.9%, >30 years: 84.6%	Secondary success rate in MP is significantly better than MB and The success rate for insertion into the MP was significantly higher than in the MB (P <0.05).
Aly SA, 2018 (Aly et al., 2018)	PCS	82 (58 F, 24 M)	21.41	180	3 M ESPE, Neuss, Germany; Jeil Medical, Seoul, Korea; Morelli, Sorocaba, Brazil	1.5, 1.6, 1.8 × 6, 8, 10	Maxilla and mandible		82.2% - ⩽20 years: 68.6 %, >20 years: 83.5%; Oral Hygiene (excellent 71.9%- good 87.3%- fair: 88.9% poor: 65.2%) - Insertion site: buccal (83.3%) - palatal (75.0%)	Patient age over 20 years and good oral hygiene significantly affect success (P < 0.05).
Haddad R, 2019 (Haddad and	RCS	260 (129 F, 131 M	23.45	293	AbsoAnchor (Dentos, Korea)– Imtec (3 M, USA)-	1.4 × 8 mm)– 1.8 × 8 mm	Maxilla and mandible		88.1% <20 years: 87.5%, 20–30 years: 86.4% >30 years: 93.6% - Insertion site: Maxilla: 90%,	Patient age, mini-implant site, and crown-root distance

(*continued on next page*)

Table 1 (*continued*)

Study	Design	N. Of Patients	Age (Average)	N. Of OMI	OMI Type	OMI Dimension	Region of Interest	Percent Failure Data	Percent Success Data	Statistically Significant Findings
Saadeh, 2019)									mandible: 80.4% 88.0 (C PM) 86,7 Pm1-Pm2 91.6 Pm2-M1 82.4 M1-M2	
Ichinohe M, 2019 (Ichinohe et al., 2019)	RCS	25 (18 F, 7 M)	23.4 ± 5.6	N/A	BIODENT, Tokyo, Japan	2.0 × 9.0 mm	Maxilla: median palate		Insertion site: anterior 76%, posterior 92%; Nasal cavity perforation yes 86.6% - no 82.8%; Age <20 years: 80%, >20 years: 70%; Screw-suture distance <1.5 mm: 75%, >1.5 mm 100%; CBT <1.5 mm: 50%, >1.5: 92.5%; Insertion depth <4.5 mm: 44.4%, >4.5 mm: 92.6%	Thickness of palatal cortical bone, screw-suture distance ⩾1.5 mm, and insertion depth > 4.5 mm significantly affect success ($P < 0.01$).
Azeem M, 2019 (Azeem et al., 2019b)	RCS	102 (52 F, 55 M)	18.6 ± 5.2	110	Absoanchor; Dentos, Korea	1.3, 2 × 8, 10	buccal RM area	23.2%. - <18 years: 21.11%; >18 years: 19.76% - Side of mini-implant: Left 23.42% Right 44.45% - Inflammation 29.21%.		Right side and inflammation significantly affect failure rates ($P < 0.05$).
Azeem M, 2019 (Max. Tuberosity (Azeem et al., 2019a)	RCS	40 (23 F, 17 M)	20.1 ± 8.9	60	Absoanchor; Dentos, Korea	1.3, 1,5 × & 1.5 × 8, 10	MT area	26.3.1%. - <18 years: 21.34%; >18 years: 19.23% - Side of mini-implant: Left 21.53%,Right 28.04% - Inflammation 25%; No inflammation 20.04% - Poor oral hygiene: 27.09%, good 22.35%		Operator experience (p: 0.001)
Bungău TC, 2022 (Bungău et al., 2022)	RCS	432 (243 F, 189 M)	14.31 ± 1.625	573		1.6 - 2 × 6-8, 8–10 mm	Buccal maxilla and mandible, Infrazygomatic, Palatal and Lingual		1 month: Buccal Maxilla: 81.1%/ M2: 95.3% M3: 97.6%; >: 97.5%- infrazygomatic: M1: 89.3% M2: 100% M3: 100% > M3: 92; Palatal: M1: 91.7%% M2: 100% M3: 97.7% > M3: 90.7. Buccal Mandible: M1: 75.6%% M2: 93.5% M3: 96.6% > M3: 96.4. Lingual: M1:90.5%, M2:89.5% M3: 100 > M3: 88.2%.	Insertion site (infrazygomatic region after M3 ($P = 0.008$), lingual region at M1 ($P = 0.025$), M2 ($P = 0.009$), and after M3($P = 0.009$) and dimensions of mini-implants significantly affect success rates ($P < 0.05$).
Gill, Gauri (Gill et al., 2023)	PCS	32	25	64	IZC Mini Implants ASTM B 265 Gr.5; SK Surgicals, Hyderabad, India	2.0 × 12, 14 mm	Maxilla	28.1% - insertion site: 31.3% left, 25.0% right - Age: <18 years: 58.3%, >=18 years: 20% - Loading: immediate: 39.1%, >2 weeks: 100% - Oral hygiene: good: 20%, fair: 16.7%, poor: 55.6%, inflammation: 47.4% - Mandibular plane angle: hight: 50%, average 17.9% - Implant mobility: yes: 53.1%, no: 3.1% - Angulation placed between 46–90: 30%	100% in no inflammation and low mandibular plane angle and angulation of 0–45	Timing of loading, oral hygiene, inflammation, mandibular plane angle, and mobility significantly affect implant failure ($P < 0.05$).

gender, Angle's occlusion classification, facial divergence, and implant dimensions. The findings highlighted age as a significant determinant, with individuals in the 20–30-year range exhibiting higher success rates than those older than 30. Additionally, factors like implant location, loading period, and facial divergence all influenced the success rates of OMIs (Tsai et al., 2016).

Lee MY et al. (2016) analyzed OMIs placed in the maxillary buccal alveolar bone and considered how bone density could influence the OMIs success rate. The overall success rate was 85%. The cancellous bone density and total bone density significantly affect success rates ($P < 0.05$) (Lee et al., 2016).

Hourfar et al. (2017) focused on the effects of placement sites–either buccally between the teeth or palatally at the level of the third palatal rugae–alongside patient-related factors such as oral hygiene, age, and gender. They reported a failure rate gradient influenced by age: 29.5% in patients over 30, 14.8% in those aged 20–30, and 13.3% in the 6–20 age group, with statistically significant differences in success related to age and gender (Hourfar et al., 2017).

Uesugi et al. (2017) analyzed OMIs in the maxillary buccal and midpalatal sutures. They examined how patient demographics, implant characteristics, and surgical techniques affected success rates. The maxillary buccal area showed a primary success rate of 79.1%, decreasing in subsequent assessments, while the midpalatal suture area had higher and more stable success rates (Uesugi et al., 2017).

Aly et al. (2018) considered a range of factors, including patient age, oral hygiene habits, and the physical characteristics of the implants. They noted an overall success rate of 82.2%, with variations depending on patient age and oral hygiene, highlighting that these factors were significant predictors of implant success (Aly et al., 2018).

Haddad et al. (2019) explored how factors such as patient gender, age, and specific anatomical placement sites influenced OMIs outcomes. They found that age and specific placement sites, like between premolars or near alveolar bones, were critical in predicting lower failure rates, with an overall success rate of 88.1% across all demographics (Haddad and Saadeh, 2019).

Ichinohe et al. (2019) investigated the impact of cortical bone thickness, soft-tissue thickness, screw-suture distance, and nasal cavity perforation on OMIs inserted in the maxilla's median palate. Their findings indicated that anterior placement led to a 76% success rate, compared to 92% for posterior placement. Nasal cavity perforation and screw-suture distance also significantly influenced success rates, with longer distances and thicker cortical bone correlating with higher success rates (Ichinohe et al., 2019).

Azeem M et al. (2019-a) explored how patient-related factors such as age and sex, alongside mini-implant characteristics like length and diameter, affected OMIs positioned in the retromolar area. They noted a general failure rate of 23.2%. Specifically, individuals under 18 years exhibited a 21.11% failure rate, which was slightly higher than the 19.76% observed in adults over 18. Positional differences also impacted outcomes, with implants on the right side failing more frequently at 44.45% compared to 23.42% on the left. Furthermore, the presence of inflammation significantly raised failure rates to 29.21%, illustrating the critical impact of inflammatory conditions on implant stability (Azeem et al., 2019b).

Azeem M et al. (2019-b) assessed OMIs in the maxillary tuberosity area, considering similar patient demographics, implant features, and surgical and maintenance factors like the operator's experience and oral hygiene. They found an overall failure rate of 26.31%. Younger patients, those under 18, showed a slightly higher failure rate of 21.34% compared to those older than 18, with a failure rate of 19.23%. Implants on the left side experienced a lower failure rate (21.53%) than those on the right (28.04%). Oral hygiene significantly affected implant success, with poor hygiene leading to a higher failure rate of 27.09%. Additionally, the operator's experience was a significant determinant of outcomes, with more experienced operators generally achieving better success rates (Azeem et al., 2019a).

Bungău et al. (2022) examined how different insertion sites and patient demographics affected the stability of OMIs over various time frames. They found that specific sites, particularly after three months and in different mandibular and maxillary regions, showed differing success rates, suggesting the importance of site selection in implant stability (Bungău et al., 2022).

Gill et al. (2023) considered a wide array of factors, including mandibular plane angle, implant length, and patient demographics, in their study on OMIs in the maxilla. They noted a high variability in success rates, heavily influenced by patient age, oral hygiene, inflammation, and implant mobility. Particularly, implants were more successful when loading was delayed, and hygiene was maintained (Gill et al., 2023).

3.3. Risk of bias and quality assessment of the studies

The assessment of the risk of bias, according to the ROBINS-I tool (Sterne et al., 2016). The 75% of the included studies had a moderate overall risk of bias, and the remaining 25% is associated with a high risk (Fig. 2). In Table 2, the levels of risk assessment are depicted based on the evaluated parameters.

The evaluation of bias risk, conducted using the ROBINS-I tool (Sterne et al., 2016), revealed that 75% of the studies included in this review were classified as having a moderate overall risk of bias, while the other 25% were found to have a high risk of bias (see Fig. 2). The specific levels of risk, according to the assessed parameters, are detailed in Table 2.

4. Results of the multivariate Meta-Analysis

The Meta-Analysis started by classifying variables either categorical or numerical. Failure rates were calculated for the categorical variables, and the effect size was determined using Cohen's method (Cohen, 2013), along with their corresponding confidence intervals. A random effects model was employed to handle variations within and across the studies (Rosenblad et al., 2009). To test the robustness of these findings, a sensitivity analysis using the 'leave-one-out' method was conducted, wherein each study was sequentially excluded to assess its influence on the overall effect size (Sutton et al., 2000).

Heterogeneity was examined by estimating the I^2 statistic and τ^2, indicating the between-study variance (Sutton et al., 2000). An Egger's test was also performed to detect any potential publication bias. The results were visually represented through forest and funnel plots to enhance the interpretation of the meta-analysis Egger et al. (2008).

For the numerical variables, a weighted regression analysis was applied, with weights based on the number of screws per failure rate for each measured variable. This analysis included detailed reporting of fit statistics such as R-squared, p-values, and standard errors.

Significant heterogeneity was noted, with I^2 values often surpassing 80%. As a result, the analysis focused on variables like age, gender, implant placement side (left or right), the recipient jaw (maxilla or mandible), and the operator's experience. Due to high heterogeneity and sparsely populated categories, multicategorical variables such as

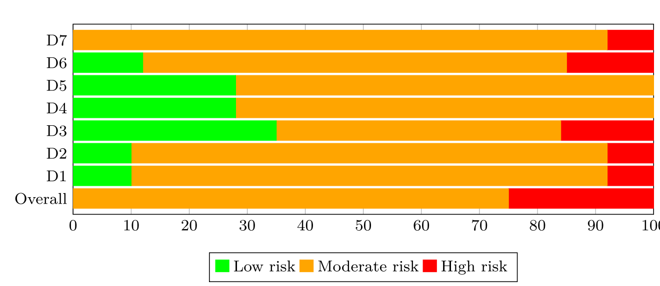

Fig. 2. Risk of Bias and Quality Assessment - Robvis.

Table 2
Risk of bias assessment of included studies, where the domains are: D1: Bias due to confounding. D2: Bias due to selection of participants. D3: Bias in the classification of interventions. D4: Bias due to deviations from intended interventions. D5: Bias due to missing data. D6: Bias in measurement of outcomes. D7: Bias in the selection of the reported result.

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Motoyoshi et al. (2015) (Motoyoshi et al., 2015)	✗	✗	✗	✗	✗	✗	✗	✗
Uribe et al. (2015) (Uribe et al., 2015)	✗	○	✗	✗	✗	✓	✗	○
Yi Lin et al. (2015) (Yi Lin et al., 2015)	✗	✗	✗	✗	✓	○	○	○
Tsai et al. (2016) (Tsai et al., 2016)	✗	○	✗	✗	✓	✗	✗	○
Lee et al. (2016) (Lee et al., 2016)	✗	✓	✗	✗	✓	✓	✓	✗
Motoyoshi et al. (2016) (Motoyoshi et al., 2016)	○	✗	✗	✗	✓	✗	✗	○
Hourfar et al. (2017) (Hourfar et al., 2017)	✗	✗	✓	✗	✗	✗	✗	✗
Uesugi et al. (2017) (Uesugi et al., 2017)	✗	✗	✓	✓	✗	✗	✗	✗
Aly et al. (2018) (Aly et al., 2018)	✗	✗	✗	✗	✗	○	✗	○
Haddad et al. (2019) (Haddad and Saadeh, 2019)	✗	✗	✓	✓	✗	✗	✗	✗
Ichinohe et al. (2019) (Ichinohe et al., 2019)	✗	✗	✗	✗	✗	✗	✗	✗
Azeem et al. (2019a) (Azeem et al., 2019a)	✗	✗	✗	✗	✗	✗	✗	✗
Azeem et al. (2019b) (Azeem et al., 2019)	✗	✗	✗	✗	✗	✗	✗	✗
Bungău et al. (2022) (Bungău et al., 2022)	✗	✓	✗	✓	✗	✗	✗	✗
Gill et al. (2023) (Gill et al., 2023)	✗	✗	✓	✓	✓	✗	✗	✗

Bias: ○ Serious ✗ Moderate ✓ Low.

placement site and oral hygiene were excluded from detailed analysis. Instead, the emphasis was placed on binary variables or those that could be dichotomized. Numerical factors considered included characteristics of the OMI design, such as length and diameter, and the mechanical force applied, quantified in grams.

Table 3 presents the aggregated failure rates. The second and third columns show the failure rates, while the fourth column calculates the relative percentage difference between these groups. Subsequent columns report the statistics following the methodology described in the previous paragraphs.

Fig. 3 displays selected forest and funnel plots for the considered studies on the age effect on the failure of OMI.

In the following subsections, each parameter is evaluated separately.

4.1. *Effect of age on the OMI failure rate*

This subsection analyses the effect of age on OMIs failure rates. The wide range of effect sizes underscores the varying impact of age on OMIs failure rates, which is corroborated by a high I^2 value. Although Egger's test indicates no significant publication bias, the substantial heterogeneity and broad confidence intervals call for a cautious interpretation of the aggregated effect sizes. Further analysis confirms these findings, with specific studies like Aly et al. (2018) appearing outside the funnel plot, see Fig. 3(a), indicating a considerable risk of bias. Regarding clinical implications, the minor negative effect size suggests that age alone may not be a critical determinant in OMI failure rates. The meta-analysis demonstrates stability across the studies included, showing no substantial influence from individual studies and no detectable publication bias. This reinforces the need for careful consideration of the clinical relevance of age in the context of OMI success.

4.2. *Effect of gender on the OMIs failure*

This subsection analyses the effect of gender (male vs. female) on the OMIs failure rate. The data manifest higher failure rates in males. The p-values are significant in most studies, indicating a statistically significant difference in failure rates between genders. Nonetheless, the variation in the confidence intervals across studies suggests differing side effects. The sensitivity analysis, as in the previous subsection, confirms the robustness of the Meta-Analysis result. Most studies report significant p-values, proving a statistically meaningful distinction in gender failure rates. However, the variability in confidence intervals among studies suggests potential variations in associated side effects. A sensitivity analysis akin to the one conducted in the preceding subsection further substantiates the reliability of the Meta-Analysis findings.

The forest plot in Fig. 3(c) shows a mix of negative and positive effect sizes, revealing that some studies found higher failure rates in females while others found higher rates in males. The overall effect size is slightly negative, meaning that males have a small higher failure rate. However, this must be interpreted cautiously, given the high heterogeneity (I^2=95). The funnel plot in Fig. 3(d) indicates no significant publication bias, as supported by Egger's test p-value of 0.830. Still, as already remarked, the spread of studies outside the inverted funnel shape indicates substantial heterogeneity.

Table 3
Meta-Analysis statistics for failure rates (FR) across studies. Yes and no exp stand for experience and no experience of the operator, respectively.

Study	FR Young	FR Adult	Delta FR	p-value	CI Lower	CI Upper	Effect sizes	Leave-One-Out
Mean	0.32	0.33	−22.86%	4.54E-03	−0.19	0.16	−0.05	−0.09
CoV	0.95	0.89	−3.87	2.69	−0.57	1.22	−5.34	−0.35
Study	FR Female	FR Male	Delta FR	p-value	CI Lower	CI Upper	Eff. Size	Leave-One-Out
Mean	0.26	0.27	−0.33	0.00	−0.15	0.12	−0.03	−0.02
CoV	0.94	0.98	−3.61	2.86	−0.98	0.67	−7.53	−1.22
Study	FR Maxilla	FR Mandible	Delta FR	p-value	CI Lower	CI Upper	Eff. Size	Leave-One-Out
Mean	0.28	0.25	0.14	0.00	−0.06	0.12	0.10	0.10
CoV	1.26	1.28	0.98	2.05	−0.64	0.41	1.11	0.25
Study	FR yes exp.	FR no exp.	Delta FR	p-value	CI Lower	CI Upper	Eff. Size	Leave-One-Out
Mean	0.15	0.31	−5.63	0.00	−0.32	0.00	−0.43	−0.46
CoV	0.11	0.10	9.39	0.00	0.19	0.26	0.58	0.35

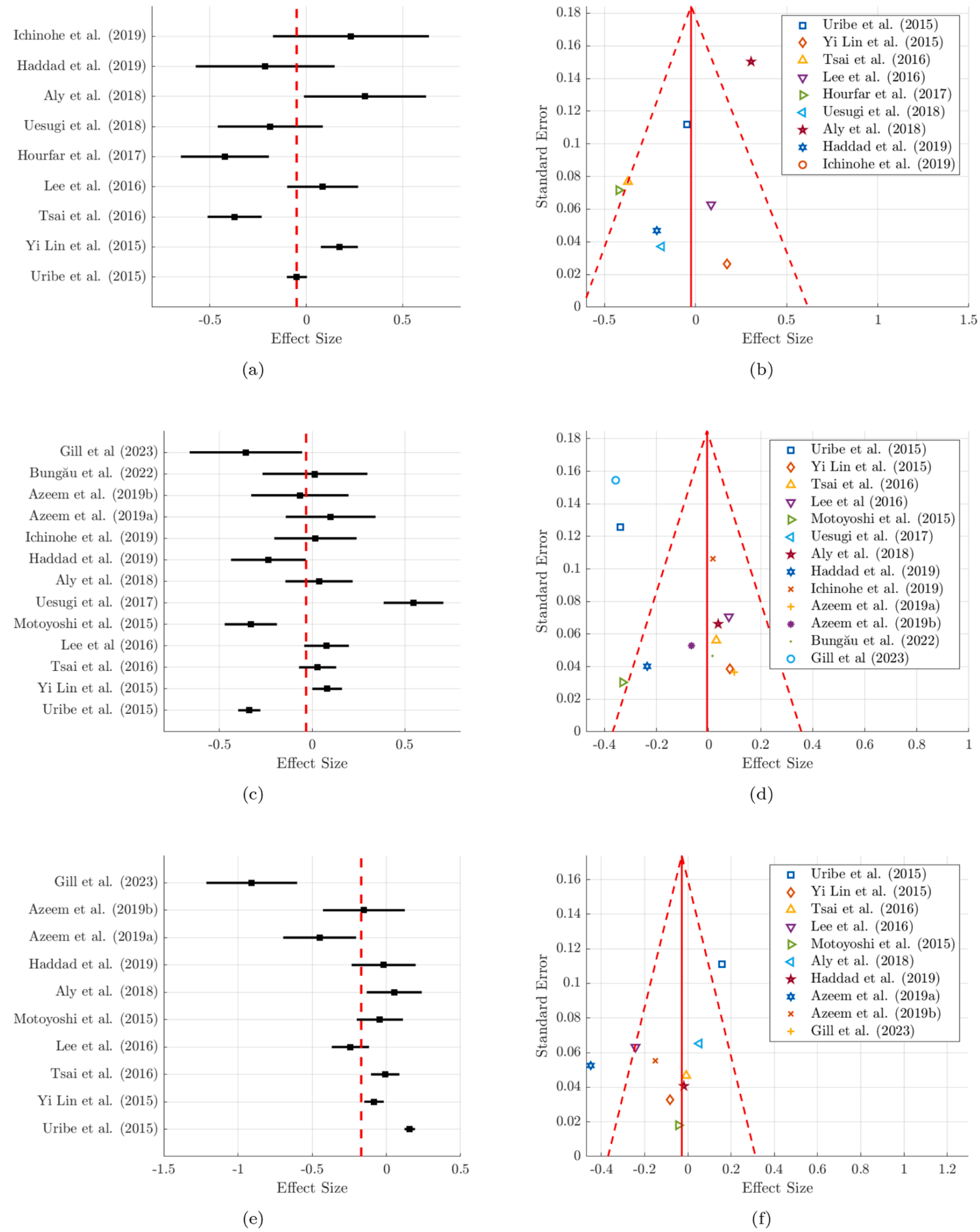

Fig. 3. (a) Forest and Funnel plots for the considered studies on the (a)-(b) age, (c)-(d) gender and (e)-(f) recipient jaw effect on the failure of OMI.

In conclusion, there is significant heterogeneity among the studies. However, despite that, the absence of publication bias suggests the Meta-Analysis results are not influenced by selective publication. There is a marginal trend towards higher failure rates in males, but given the heterogeneity and variability in effect sizes, this finding should also be interpreted with caution.

4.3. *Effect of the side of the implant on the OMIs failure rate*

This subsection focuses on the effect of the insertion site (left vs. right side) on the OMIs failure rate. Positive values indicate a higher failure rate on the left side, and negative ones indicate a higher rate on the right side. The p-values are mostly very low, indicating the statistical significance of the single studies. However, as noticed in the previous studies, the confidence intervals vary significantly, while the sensitivity analysis proves the Meta-Analysis's robustness. The I^2 statistic is very high at 92%, indicating substantial heterogeneity, so the study outcomes are inconsistent. Parallelly, the between-study variance (τ^2) is relatively low, while the p-value from Egger's test is 0.370, proving no significant publication bias.

In conclusion, the analysis underscores a statistically significant disparity in failure rates between OMIs placements on the left and right sides. With a mean effect size of -0.17 across studies, there appears to be a slight inclination towards a higher failure rate for OMIs on the right side. However, given the substantial heterogeneity observed, it's imperative to approach this interpretation cautiously.

4.4. *Effect of the recipient jaw on the OMIs failure*

This subsection examines the recipient jaws (maxilla vs mandible) on the OMIs failure rate. Several studies could not be considered since they only refer to a single jaw, like Uesugi et al. (2018) on the maxilla. As shown in Table 3, positive values suggest higher failure rates in the maxilla, while negative values suggest higher rates in the mandible. The p-values across the studies are extremely low, indicating a statistically significant difference in failure rates between the maxilla and mandible placements. The confidence intervals vary significantly across studies, indicating different precision levels. The effect size (Eff. Size) values are mostly positive, suggesting a trend towards higher failure rates in the maxilla, except for one study (Aly et al. (2018)Aly et al., 2018), which shows a negligible negative effect size, with slightly higher failure rates in the mandible, as can be seen in the forest plot in Fig. 3(e). The sensitivity analysis proves the stability of the results. There is a high I^2 value of 85.160%, highlighting the considerable variation in the effect sizes across the studies. The τ^2 and the random effects combined standard error are relatively low. The p-value from Egger's test of 0.765 suggests no significant publication bias affecting the Meta-Analysis; see also the funnel plot in Fig. 3(d).

In conclusion, there is a significant difference in failure rates between OMIs placed in the maxilla versus the mandible, with a slight trend towards higher failure rates in the maxilla. Still, the mean effect size is 0.10, indicating that this trend is consistent but not strong. As observed in the previous subsections, the studies are heterogeneous. The absence of publication bias supports the Meta-Analysis findings, but the high level of heterogeneity suggests caution in interpreting the results.

4.5. Effect of the operator experience on the OMIs failure

Regarding the effect of operator experience on the OMIs failure rate, the authors did not consider Tsai et al. (2016) since they do not categorize the experience in positive (yes) or negative (no) but claim to have based the findings on three operators. So, this study cannot be included since it is not comparable.

The univariate Meta-Analysis focuses on only three studies. Table 3 reports negative values with a higher failure rate when the operator is less experienced. The p-values are very low, indicating that the differences observed are statistically significant. Still, the wide CI intervals and the limited number of studies indicate substantial uncertainty. The effect size is negative in all studies, indicating, as expected, that less experienced operators have higher failure rates. Nonetheless, compared to previous subsections, the analysis is not robust, as proven in the sensitivity analysis. Also, the heterogeneity is exceptionally high at 99.260%, indicating almost complete heterogeneity and the wide spread of the studies in the funnel plot Fig. 3(f). The τ^2 and the random effects combined standard error is also high.

In conclusion, a clear trend indicates that operator experience is inversely related to failure rates. However, the exceptionally high heterogeneity suggests that the magnitude of this effect is likely influenced by a variety of other factors not captured in this analysis. This necessitates a cautious approach to generalizing these findings across different settings or populations.

4.6. Effect of screw diameter and length, and force on the OMIs failure rate

As anticipated at the beginning of this section, the effect of numerical variables is examined through regression analysis, specifically focusing on the diameter, length and force magnitude.

The two linear models, weighted and not weighted, for predicting the failure rate given the diameter have a similar pattern: as the diameter increases, the failure rate decreases (negative slope). Nonetheless, the coefficient of determination (R^2) is low for both models (0.06 and 0.03), indicating that diameter alone does not explain much of the variance in failure rates, and the effect size is relatively small. The p-values confirm that the relationship between diameter and failure rate is not statistically significant. Again, two models were used for the OMIs length: non-weighted and weighted linear regression. The slope is near zero for both models, indicating no clear relationship between length and failure rate. The p-values for the slope are very high (well above 0.05), confirming the relationship's lack of statistical significance.

In conclusion, neither diameter nor length significantly affects the OMIs failure rates when considering the entire dataset. The low R^2 values and non-significant p-values support this. The plots visually confirm these findings, showing a lot of variability in failure rates that is not explained by diameter or length alone. The weighted model has a coefficient of determination (R^2) of 0.12. Thus, the force magnitude explains 12% of the variability in failure rates, a modest but non-negligible amount. Contrary to expectations, the analysis suggests a potential negative relationship between force magnitude and failure rates, meaning that higher forces might be associated with lower failure rates. However, this relationship is not strong or statistically significant in the weighted model. The weighted model more clearly shows the effect of force magnitude on failure rates. Conversely, the non-weighted model shows no significant relationship between force magnitude and failure rates.

5. Discussion

The review delves into the multifaceted factors influencing the OMIs success or failure rates, drawing insights from a comprehensive examination of 15 studies involving 1981 young patients and 3272 mini-implants. Failure rates ranged widely from 5.40% to 100%, while success rates varied from 44.4% to 100%. Several critical factors impacting OMIs stability were identified: patient characteristics, oral hygiene and inflammation, OMIs design, orthodontic mechanics, implantation site, cortical bone thickness, and recipient jaws.

Proper oral hygiene and inflammation control play crucial roles in maximizing mini-implant success. Moreover, inadequate orthodontic force design and inappropriate superstructures emerged as common causes of OMIs failure, particularly during the initial healing phase. The significance of meticulous treatment planning in achieving optimal outcomes was emphasized, considering factors such as the surgeon's experience, the patient's growth pattern, and genetic predisposition.

Studies also explored the influence of anatomical factors Nucera et al. (2022),Sabec et al. (2015), such as bone quality, cortical thickness Amini et al. (2017);Chrcanovic et al. (2017); Marquezan et al. (2014); Mohammed et al. (2018); Motoyoshi et al. (2009);Stahl et al. (2009), and interradicular distances, on OMIs stability (Gintautaitė and Gaidytė, 2017). Findings suggest that thicker cortical bone and optimal insertion sites contribute to better OMIs stability. However, discrepancies exist regarding the success rates between the maxilla and mandible Jing et al. (2016);Manni et al. (2011); Suzuki et al. (2013);Uesugi et al. (2017), with some studies suggesting higher success rates in the maxilla Devadkar et al. (2022);Lee et al. (2021); Palone et al. (2022) and others in the mandible.

Regarding the mechanical behaviour of OMIs, it is advisable to refer to the experimental tests conducted by Valeri et al. These studies provide detailed insights into their mechanical behaviour under various conditions, helping to understand their performance and limitations in practical applications (Valeri et al., 2024).

Moreover, while the Meta-Analysis revealed that age is not a determining variable for OMIs success or failure, literature presents varied perspectives on its importance (Xin et al., 2022; Farnsworth et al., 2011; Choi et al., 2016; Tang et al., 2021; Migliorati et al., 2023), along with additional factors like soft tissue thickness (Parmar et al., 2016), smoking habits (Melo et al., 2016), and radiation history Konermann et al. (2015). The diversity of findings underscores the complexity of OMIs outcomes and the need for standardized criteria to assess risk factors systematically.

One limitation of this Systematic Review, indeed, is the potential for publication bias, leading to an incomplete or biased understanding of the factors influencing OMIs success or failure.

Future research directions should aim to establish such criteria to facilitate comparability between studies and deepen our understanding of OMIs success determinants. Further exploration of additional risk factors is warranted to develop a comprehensive framework for predicting and optimizing mini-implant outcomes.

Standardized criteria should be established to assess the identified risk factors, allowing for better comparability between studies and a deeper understanding of the results. Future research should also examine and identify additional risk factors to gain a comprehensive understanding of the factors influencing the success of mini-implants.

6. Conclusion

The Meta-Analysis reveals several factors influencing the OMIs failure rates, though with some heterogeneity and variability in the effects observed. Age appears to have no significant impact on OMIs failure rates, suggesting that treatment can be equally effective across different age groups. A slight trend indicates higher failure rates in males compared to females. Additionally, OMIs placed on the right side of the mouth tend to have higher failure rates than those on the left. The maxilla is generally more prone to failures compared to the mandible. Operator experience is critical, as less experienced operators are associated with higher failure rates. Surprisingly, neither the diameter nor the length of the screw significantly influences failure rates. Interestingly, higher forces applied to OMIs might correlate with lower failure rates, although this finding should be cautiously approached. Based on these insights, it is recommended to prioritize training and skill development for operators, consider patient-specific anatomical factors when choosing the implantation site, and carefully monitor the application of forces during orthodontic treatment to optimize outcomes.

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.

References

Aly, S.A., Alyan, D., Fayed, M.S., Alhammadi, M.S., Mostafa, Y.A., 2018. Success rates and factors associated with failure of temporary anchorage devices: A prospective clinical trial. J. Investig. Clin. Dent. 9, e12331.
Amini, F., Alipanahi, M., Rakhshan, V., Shahab, S., Niktash, A., 2017. Facial growth patterns and insertion sites of miniscrew implants. Implant Dent. 26, 112–120.
Azeem, M., Haq, A.U., Awaisi, Z.H., Saleem, M.M., Tahir, M.W., Liaquat, A., 2019a. Failure rates of miniscrews inserted in the maxillary tuberosity. Dental Press J. Orthod. 24, 46–51.
Azeem, M., Haq, A.U., Awaisi, Z.H., Saleem, M.M., Tahir, M.W., Liaquat, A., 2019b. Failure rates of miniscrews inserted in the maxillary tuberosity. Dental Press J. Orthod. 24, 46–51.
Azeem, M., Saleem, M.M., Liaquat, A., Ul Haq, A., Ul Hamid, W., Masood, M., 2019. Failure rates of mini-implants inserted in the retromolar area. Int. Orthod. 17, 53–59.
Bungău, T.C., Vaida, L.L., Moca, A.E., Ciavoi, G., Iurcov, R., Romanul, I.M., Buha, C.L., 2022. Mini-implant rejection rate in teenage patients depending on insertion site: A retrospective study. J. Clin. Med. 11, 5331.
Chen, Y., Kyung, H.M., Zhao, W.T., Yu, W.J., 2009. Critical factors for the success of orthodontic mini-implants: a systematic review. Am. J. Orthod. Dentofacial Orthop. 135, 284–291.
Choi, S.H., Shi, K.K., Cha, J.Y., Park, Y.C., Lee, K.J., 2016. Nonsurgical miniscrew-assisted rapid maxillary expansion results in acceptable stability in young adults. Angle Orthod. 86, 713–720.
Chrcanovic, B.R., Albrektsson, T., Wennerberg, A., 2017. Bone quality and quantity and dental implant failure: A systematic review and meta-analysis. Int. J. Prosthodont. 30, 219–237.
Cohen, J., 2013. Statistical power analysis for the behavioral sciences. Academic press.
da Costa Santos, C.M., de Mattos Pimenta, C.A., Nobre, M.R.C., 2007. The PICO strategy for the research question construction and evidence search. Rev. Lat. Am. Enfermagem 15, 508–511.
Crismani, A.G., Bertl, M.H., Čelar, A.G., Bantleon, H.P., Burstone, C.J., 2010. Miniscrews in orthodontic treatment: review and analysis of published clinical trials. American Journal of Orthodontics and Dentofacial Orthopedics 137, 108–113.
Devadkar, R.S., Potnis, S., Toshniwal, N., Pharande, S., Vinay, V., 2022. Success rate of mini-implants based on side of insertion and type of jaw in adult patients undergoing orthodontic treatment – a systematic review and meta-analysis. APOS Trends Orthod. 12, 295–305.
Egger, M., Smith, G.D., Altman, D., 2008. Systematic reviews in health care: meta-analysis in context. John Wiley & Sons.
Farnsworth, D., Rossouw, P.E., Ceen, R.F., Buschang, P.H., 2011. Cortical bone thickness at common miniscrew implant placement sites. Am. J. Orthod. Dentofacial Orthop. 139, 495–503.
Gill, G., Shashidhar, K., Kuttappa, M.N., Kushalappa P B, D., Sivamurthy, G., Mallick, S., 2023. Failure rates and factors associated with infrazygomatic crestal orthodontic implants - a prospective study. J. Oral Biol. Craniofac. Res. 13, 283–289.
Gintautaitė, G., Gaidytė, A., 2017. Surgery-related factors affecting the stability of orthodontic mini implants screwed in alveolar process interdental spaces: a systematic literature review. Stomatologija 19, 10–18.
Haddad, R., Saadeh, M., 2019. Distance to alveolar crestal bone: a critical factor in the success of orthodontic mini-implants. Prog. Orthod. 20, 19.
Herrmann, I., Lekholm, U., Holm, S., Kultje, C., 2005. Evaluation of patient and implant characteristics as potential prognostic factors for oral implant failures. International Journal of Oral & Maxillofacial Implants 20.
Hourfar, J., Bister, D., Kanavakis, G., Lisson, J.A., Ludwig, B., 2017. Influence of interradicular and palatal placement of orthodontic mini-implants on the success (survival) rate. Head Face Med. 13.
Ichinohe, M., Motoyoshi, M., Inaba, M., Uchida, Y., Kaneko, M., Matsuike, R., Shimizu, N., 2019. Risk factors for failure of orthodontic mini-screws placed in the median palate. J. Oral Sci. 61, 13–18.
Jing, Z., Wu, Y., Jiang, W., Zhao, L., Jing, D., Zhang, N., Cao, X., Xu, Z., Zhao, Z., 2016. Factors affecting the clinical success rate of miniscrew implants for orthodontic treatment. Int. J. Oral Maxillofac. Implants 31, 835–841.
Kallmes, K., Holub, K., Mead, S., Nested knowledge systematic review software. URL: https://nested-knowledge.com/. available online.
Konermann, A., Appel, T., Wenghoefer, M., Sirokay, S., Dirk, C., Jäger, A., Götz, W., 2015. Impact of radiation history, gender and age on bone quality in sites for orthodontic skeletal anchorage device placement. Ann. Anat. 199, 67–72.
Lee, D.W., Park, J.H., Bay, R.C., Choi, S.K., Chae, J.M., 2021. Cortical bone thickness and bone density effects on miniscrew success rates: A systematic review and meta-analysis. Orthod. Craniofac. Res. 24 (Suppl 1), 92–102.
Lee, M.Y., Park, J.H., Kim, S.C., Kang, K.H., Cho, J.H., Cho, J.W., Chang, N.Y., Chae, J. M., 2016. Bone density effects on the success rate of orthodontic microimplants evaluated with cone-beam computed tomography. Am. J. Orthod. Dentofacial Orthop. 149, 217–224.
Leo, M., Cerroni, L., Pasquantonio, G., Condò, S.G., Condò, R., 2016. Temporary anchorage devices (TADs) in orthodontics: review of the factors that influence the clinical success rate of the mini-implants. Clin. Ter. 167, e70–7.
Manni, A., Cozzani, M., Tamborrino, F., De Rinaldis, S., Menini, A., 2011. Factors influencing the stability of miniscrews. a retrospective study on 300 miniscrews. Eur. J. Orthod. 33, 388–395.
Marquezan, M., Mattos, C.T., Sant'Anna, E.F., de Souza, M.M.G., Maia, L.C., 2014. Does cortical thickness influence the primary stability of miniscrews?: A systematic review and meta-analysis. Angle Orthod. 84, 1093–1103.
McGuinness, L.A., Higgins, J.P.T., 2021. Risk-of-bias VISualization (robvis): An R package and shiny web app for visualizing risk-of-bias assessments. Res. Synth. Methods 12, 55–61.
Melo, A.C.M., Andrighetto, A.R., Hirt, S.D., Bongiolo, A.L.M., Silva, S.U., Silva, M.A.D.d., 2016. Risk factors associated with the failure of miniscrews - a ten-year cross sectional study. Braz. Oral Res. 30, e124.
Migliorati, M., De Mari, A., Annarumma, F., Aghazada, H., Battista, G., Campobasso, A., Menini, M., Lo Giudice, A., Cevidanes, L.H.S., Drago, S., 2023. Three-dimensional analysis of miniscrew position changes during bone-borne expansion in young and late adolescent patients. Prog. Orthod. 24, 20.
Mohammed, H., Wafaie, K., Rizk, M.Z., Almuzian, M., Sosly, R., Bearn, D.R., 2018. Role of anatomical sites and correlated risk factors on the survival of orthodontic miniscrew implants: a systematic review and meta-analysis. Prog. Orthod. 19, 36.
Motoyoshi, M., Inaba, M., Ono, A., Ueno, S., Shimizu, N., 2009. The effect of cortical bone thickness on the stability of orthodontic mini-implants and on the stress distribution in surrounding bone. Int. J. Oral Maxillofac. Surg. 38, 13–18.
Motoyoshi, M., Sanuki-Suzuki, R., Uchida, Y., Saiki, A., Shimizu, N., 2015. Maxillary sinus perforation by orthodontic anchor screws. J. Oral Sci. 57, 95–100.
Motoyoshi, M., Uchida, Y., Inaba, M., Ejima, K.I., Honda, K., Shimizu, N., 2016. Are assessments of damping capacity and placement torque useful in estimating root proximity of orthodontic anchor screws? Am. J. Orthod. Dentofacial Orthop. 150, 124–129.
Nucera, R., Costa, S., Bellocchio, A.M., Barbera, S., Drago, S., Silvestrini, A., Migliorati, M., 2022. Evaluation of palatal bone depth, cortical bone, and mucosa thickness for optimal orthodontic miniscrew placement performed according to the third palatal ruga clinical reference. Eur. J. Orthod. 44, 530–536.
Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372, n71.
Palone, M., Darsiè, A., Maino, G.B., Siciliani, G., Spedicato, G.A., Lombardo, L., 2022. Analysis of biological and structural factors implicated in the clinical success of orthodontic miniscrews at posterior maxillary interradicular sites. Clin. Oral Investig. 26, 3523–3532.
Parmar, R., Reddy, V., Reddy, S.K., Reddy, D., 2016. Determination of soft tissue thickness at orthodontic miniscrew placement sites using ultrasonography for customizing screw selection. Am. J. Orthod. Dentofacial Orthop. 150, 651–658.
R Core Team, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Ramírez-Ossa, D.M., Escobar-Correa, N., Ramírez-Bustamante, M.A., Agudelo-Suárez, A. A., 2020. An umbrella review of the effectiveness of temporary anchorage devices and the factors that contribute to their success or failure. J. Evid. Based. Dent. Pract. 20, 101402.
Rosenblad, A., et al., 2009. Introduction to meta-analysis by michael borenstein, larry v. hedges, julian pt higgins, hannah r. rothstein. International Statistical Review 77, 478–479.
Sabec, R.d.C., Fernandes, T.M.F., de Lima Navarro, R., Oltramari-Navarro, P.V.P., Conti, A.C.d.C.F., de Almeida, M.R., Poleti, M.L., 2015. Can bone thickness and inter-radicular space affect miniscrew placement in posterior mandibular sites? J. Oral Maxillofac. Surg. 73, 333–339.
Sandler, J., Murray, A., Thiruvenkatachari, B., Gutierrez, R., Speight, P., O'Brien, K., 2014. Effectiveness of 3 methods of anchorage reinforcement for maximum anchorage in adolescents: A 3-arm multicenter randomized clinical trial. Am. J. Orthod. Dentofacial Orthop. 146, 10–20.
Stahl, E., Keilig, L., Abdelgader, I., Jäger, A., Bourauel, C., 2009. Numerical analyses of biomechanical behavior of various orthodontic anchorage implants. J. Orofac. Orthop. 70, 115–127.
Sterne, J.A., Hernán, M.A., Reeves, B.C., Savović, J., Berkman, N.D., Viswanathan, M., Henry, D., Altman, D.G., Ansari, M.T., Boutron, I., et al., 2016. Robins-i: a tool for assessing risk of bias in non-randomised studies of interventions. bmj 355.
Sutton, A.J., Abrams, K.R., Jones, D.R., Sheldon, T.A., Song, F., 2000. Methods for meta-analysis in medical research, volume 348. Wiley Chichester.
Suzuki, M., Deguchi, T., Watanabe, H., Seiryu, M., Iikubo, M., Sasano, T., Fujiyama, K., Takano-Yamamoto, T., 2013. Evaluation of optimal length and insertion torque for miniscrews. Am. J. Orthod. Dentofacial Orthop. 144, 251–259.
Tang, H., Liu, P., Liu, X., Hou, Y., Chen, W., Zhang, L., Guo, J., 2021. Skeletal width changes after mini-implant-assisted rapid maxillary expansion (MARME) in young adults. Angle Orthod. 91, 301–306.
The MathWorks Inc, 2022. Matlab. https://www.mathworks.com/products/matlab.html. Version: 9.13.0.
Truong, V.M., Kim, S., Kim, J., Lee, J.W., Park, Y.S., 2022. Revisiting the complications of orthodontic miniscrew. Biomed Res. Int. 2022, 8720412.
Tsai, C.C., Chang, H.P., Pan, C.Y., Chou, S.T., Tseng, Y.C., 2016. A prospective study of factors associated with orthodontic mini-implant survival. J. Oral Sci. 58, 515–521.
Uesugi, S., Kokai, S., Kanno, Z., Ono, T., 2017. Prognosis of primary and secondary insertions of orthodontic miniscrews: What we have learned from 500 implants. Am. J. Orthod. Dentofacial Orthop. 152, 224–231.
Uesugi, S., Kokai, S., Kanno, Z., Ono, T., 2018. Stability of secondarily inserted orthodontic miniscrews after failure of the primary insertion for maxillary anchorage: Maxillary buccal area vs midpalatal suture area. Am. J. Orthod. Dentofacial Orthop. 153, 54–60.
Uribe, F., Mehr, R., Mathur, A., Janakiraman, N., Allareddy, V., 2015. Failure rates of mini-implants placed in the infrazygomatic region. Prog. Orthod. 16, 31.
Valeri, C., Aloisio, A., Quinzi, V., di Stefano, G., Marzo, G., 2024. Characterizing orthodontic mini-screws in the hard palate of pigs: An experimental and finite-element study. Heliyon 10.
Wehrbein, H., Göllner, P., 2007. Skeletal anchorage in orthodontics–basics and clinical application. J. Orofac. Orthop. 68, 443–461.
Xin, Y., Wu, Y., Chen, C., Wang, C., Zhao, L., 2022. Miniscrews for orthodontic anchorage: analysis of risk factors correlated with the progressive susceptibility to failure. Am. J. Orthod. Dentofacial Orthop. 162, e192–e202.
Yi Lin, S., Mimi, Y., Ming Tak, C., Kelvin Weng Chiong, F., Hung Chew, W., 2015. A study of success rate of miniscrew implants as temporary anchorage devices in singapore. Int. J. Dent. 2015, 294670.
Zawawi, K.H., 2014. Acceptance of orthodontic miniscrews as temporary anchorage devices. Patient Prefer. Adherence 8, 933–937.