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3D finite element assessment of insertion angle influence on mini screw stress distribution and its clinical implications: A Systematic review

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Abstract
To systematically review 3D finite element analysis (FEA) studies assessing how orthodontic miniscrew insertion angle impacts stress distribution in surrounding bone. Fourteen *in vitro* 3D-FEA studies up to June 2025 were identified through searches of PubMed, Cochrane Library, Semantic Scholar, and Google Scholar. Inclusion criteria required comparison of stress around miniscrews inserted at different angles. Two independent reviewers screened articles and extracted data via a predesigned form. A customized risk-of-bias tool-evaluating mesh quality, material properties, boundary conditions, and loading protocols-was applied. The majority of included studies indicated that miniscrews inserted at 90° relative to cortical bone exhibited lower stress concentrations at the implant-bone interface compared to oblique angles (30°-60°). Oblique insertion was associated with elevated cortical stress and increased displacement risk. Stress distribution was more favorable in the maxilla than in the mandible, likely due to cortical thickness differences. Within the limitations of computational modeling, perpendicular (90°) insertion of orthodontic miniscrews offers biomechanical advantages by reducing peri-implant stress. Clinicians should consider this insertion angle to enhance primary stability and minimize miniscrew failure.

Keywords: Orthodontic miniscrews, insertion angle, stress distribution, Finite Element Analysis (FEA), biomechanics, cortical bone thickness, miniscrew failure, primary stability, implant-bone interface, bone-implant interaction

1. Introduction

Temporary Anchorage Devices (TADs), particularly orthodontic miniscrews, have revolutionized clinical orthodontics by providing skeletal anchorage with minimal patient compliance [1]. Their small size, ease of insertion and removal, and ability to be placed in various intraoral locations make them indispensable tools in modern treatment protocols [2]. However, their success depends significantly on biomechanical stability, which is influenced by multiple factors including bone quality, screw design, insertion torque, and notably, insertion angulation [3, 4].

Insertion angle plays a pivotal role in stress distribution across both the miniscrew and surrounding bone [5]. Several clinical investigations have reported miniscrew failure rates ranging between 10% and 30%, primarily due to biomechanical inadequacies and improper insertion techniques [1]. One of the key variables affecting stability is the insertion angle, which influences both the load distribution and the bone-implant interface. For instance, factors such as cortical bone thickness, insertion torque, and screw angulation have been associated with success rates of miniscrews [6]. Chen *et al.* observed that with appropriate case selection and proper placement techniques, high clinical success rates could be achieved with both miniscrews and miniplates used as temporary anchorage devices [7].

In a clinical evaluation by Motoyoshi *et al.*, the cortical bone thickness at the site of insertion was found to be a significant predictor of stability miniscrews placed perpendicular to the bone surface (90°) and in areas with cortical thickness ≥1 mm had significantly better outcomes [3]. These findings highlight the importance of tailoring insertion angle based on anatomical and structural bone characteristics to minimize the risk of biomechanical failure.

Suboptimal angulations may lead to excessive stress concentrations, compromising primary stability and potentially causing loosening or failure [8, 9]. Understanding how different angulations affect the resulting stress distribution is essential to optimize miniscrew placement strategies [9].

Finite Element Analysis (FEA) has become a powerful, non-invasive computational method for evaluating the biomechanical behavior of miniscrews under various conditions [1]. Through FEA, stress distribution patterns in three-dimensional bone structures can be visualized, allowing researchers to simulate conditions that are difficult to replicate in clinical or laboratory environments [10]. Multiple FEA studies have assessed the effects of insertion angle on biomechanical stability, but findings remain inconsistent likely due to differing assumptions in modeling, variations in bone density, insertion site, and force directions [11, 12].

Given the increasing use of temporary anchorage devices in orthodontics and the biomechanical significance of insertion angle, it becomes crucial to evaluate available literature systematically. This review aims to analyze how varying insertion angles of orthodontic miniscrews influence stress distribution patterns as determined by three-dimensional finite element analysis. By integrating and interpreting current evidence, the review seeks to identify biomechanical patterns and provide clinical recommendations for optimal insertion strategies [13].

Review

Materials and Method

Study design and registration: This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The protocol was prospectively registered with PROSPERO (International Prospective Register of Systematic Reviews) ID CRD420251054517.

Eligibility criteria

The eligibility criteria for study inclusion are summarized in Table *1*. The inclusion criteria were defined using the PICO framework. The population (P) included orthodontic mini-implants (miniscrews) inserted in human maxillary or mandibular alveolar bone models. The intervention (I) involved miniscrew placement at varying insertion angles. The Comparison (C) included studies that compared outcomes between different insertion angles, such as 30°, 60°, and 90°. The outcome (O) was stress distribution around the miniscrews, typically assessed via finite element analysis (FEA). Exclusion criteria included case reports, case series, animal studies, cadaveric studies, *in vitro* and laboratory-based studies not employing FEA methodology, and studies that did not include a comparative analysis of different insertion angles.

Search strategy and study selection

The search strategy and study selection process are presented in Table *2*. A comprehensive literature search was conducted across multiple electronic databases, including PubMed, ScienceDirect, Cochrane Library, Semantic Scholar, and Google Scholar, for articles published up to June 30, 2025. The selection process adhered to the PRISMA guidelines, with duplicates removed and full-text articles screened based on predefined eligibility criteria. To optimize search efficiency and citation retrieval from Google Scholar, the Publish or Perish software was utilized. All retrieved articles were exported to the Rayyan AI platform to facilitate blinded and independent screening of titles, abstracts, and full texts by two reviewers. Rayyan AI allowed for efficient identification and removal of duplicate records and streamlined the screening process. Disagreements that arose during the screening process were settled either by consensus or through the arbitration of a third reviewer.

Full-text articles meeting the inclusion criteria were assessed for eligibility, and reasons for exclusion were documented. The final set of included studies was used for qualitative synthesis and risk of bias assessment.

Data extraction and quality assessment

Data extracted from the included studies comprised author information, publication year, study design, software used, model characteristics, insertion angles, insertion site, force application, bone type, and stress analysis outcomes.

To enhance translational relevance, the biomechanical findings from Finite Element Analysis (FEA) studies were qualitatively compared with published clinical studies on miniscrew stability, insertion angle, and failure rates.

Risk of bias assessment

The risk of bias assessment for the included finite element analysis (FEA) studies is presented in Table *3*. Given the computational nature of these studies, traditional clinical risk of bias tools such as ROB-2 and ROBINS-I were not applicable. Instead, a customized qualitative framework was employed, tailored to the methodological characteristics of FEA. The criteria assessed included model validation, input parameters (force magnitude, insertion angle, and geometry), mesh quality, boundary conditions, software transparency, and clarity of reporting.

Most studies (n=7) had a low risk of bias due to comprehensive methodological reporting, validated models, and clearly stated force applications. Four studies showed moderate to high risk due to partial explanation of boundary conditions or unclear mesh or validation details.

Results

The study selection process is illustrated in Figure 1. The comprehensive literature search initially identified 121 articles from multiple databases, including PubMed, ScienceDirect, Cochrane Library, Semantic Scholar, and Google Scholar. After duplicate removal and initial screening of titles and abstracts, 92 articles were excluded due to irrelevance or not meeting inclusion criteria. The remaining 29 full-text articles were assessed for eligibility. Seventeen articles were further excluded due to reasons such as unavailability of full text (n = 10), studies not comparing different miniscrew insertion angles (n = 5), and non-English language (n = 1) and non-FEA methodologies (n = 2). Ultimately, 11 studies were included in the qualitative synthesis.

Descriptive summary of study characteristics

The characteristics of the included studies are summarized in Table *4*. All selected studies employed three-dimensional finite element analysis (3D FEA) to evaluate stress distribution around orthodontic miniscrews inserted at varying angles. Variability was observed in screw dimensions, insertion angles, anatomical sites (maxilla or mandible), applied force magnitude and direction, and bone modeling parameters. Most studies utilized advanced simulation software such as ANSYS and Abaqus to replicate clinically relevant biomechanical conditions.

Insertion angles ranged from 30° to 150°, with 90° being the most commonly analyzed for its biomechanical advantages. Several studies assessed different screw diameters (1.2-1.8 mm) and lengths (6-12 mm), examining their influence on stress patterns. Synthetic blocks, CT-derived models, and *in vitro* simulations were used to replicate bone characteristics. Most models included cortical and cancellous bone layers, and some included Periodontal Ligament (PDL) modelling.

The majority of studies used standard orthodontic retraction forces ranging from 150 g to 2 N. Von Mises stress was the primary outcome measure in most models, though some also reported principal stresses and displacement. Key findings across the literature revealed that perpendicular (90°) insertion tends to distribute stress more favorably in cortical bone, enhancing primary stability. Studies also indicated that deeper insertion depth and larger diameter screws reduce stress concentrations. The design of the thread, the thickness of the cortical bone (CBT), and the direction of the force vector have been identified as critical factors affecting the success of the implant.

Interestingly, the FEA-derived biomechanical findings aligned well with existing clinical outcome data. For example, studies by Motoyoshi *et al*. (2009) and Chen *et al*. (2006) clinically demonstrated that miniscrews inserted perpendicular (90°) to the cortical surface, especially in areas with adequate bone thickness, yielded higher primary stability and lower failure rates [3, 7]. These observations corroborate FEA studies such as those by Lee *et al*. (2013) [5]. This consistency across simulation and clinical data enhances the clinical credibility of the biomechanical conclusions drawn from the current review.

Discussion

The present 3D finite element analysis evaluated stress distribution around orthodontic miniscrews inserted at varying angulations in both maxillary and mandibular regions. Our findings indicate that insertion at 90° resulted in the most favorable stress distribution in both arches, while insertion at 30° produced the highest stress concentrations, particularly in the cortical bone region.

Lee *et al*. evaluated insertion angles and cortical bone stress distribution using nonlinear FEA and found the lowest von Mises stress values at 90°, corroborating our present findings [5]. Park *et al*. also observed that perpendicular insertion minimizes stress concentrations, especially when subjected to horizontal orthodontic loads [6]. Chen *et al*., in a clinical study of 614 miniscrews, highlighted that insertion angle and cortical bone engagement were key predictors of miniscrew success [7]. These clinical results validate the FEA observations that 90° insertion provides more uniform stress distribution, enhanced anchorage, and lower failure rates.

Our findings also align with the clinical literature. Kuroda *et al*. observed that excessive insertion angulation increased the risk of soft tissue inflammation and screw failure due to higher stress accumulation at the bone-screw interface [12]. Similarly, Machado *et al*. noted that cortical bone stress significantly increased at steeper insertion angles, especially in the maxilla [13]. Consistent with the findings of Thomková *et al*., who demonstrated that insertion angulation and site significantly influence the biomechanical performance of implants in the mandible, our study also highlights the critical role of insertion angle in optimizing stress distribution around miniscrews [14]. Sana *et al*. also demonstrated that 90° insertion led to minimal peri-implant stress and optimal bone-implant contact [15]. Perillo *et al*. concluded that insertion angles greater than 90° were associated with elevated stress and greater displacement, while oblique angles below 60° increased torque stress on the screw neck and apical tip [16]. Duaibis *et al*. (2012) reported that increased insertion angles resulted in greater stress concentration in the cortical bone, emphasizing the importance of optimizing angulation to minimize the risk of bone damage and implant failure [17]. Hirai *et al*. supported perpendicular insertion, stating that in areas of low bone density, such as the posterior maxilla, the 90° angulation helps engage more cortical bone and distribute forces efficiently [18]. In agreement with Choi *et al*., who found that surface design significantly affects the rotational resistance and primary stability of orthodontic miniscrews in 3D finite element models, our results further emphasize that biomechanical factors such as insertion angle and geometry play a pivotal role in stress distribution and overall miniscrew performance [19]. Lin and Tsai (2013), using finite element analysis, demonstrated that insertion angle, cortical bone thickness, and force direction significantly influenced the magnitude and distribution of stress around miniscrews, highlighting the need to consider multiple biomechanical factors in clinical planning [20]. Sivamurthy and Sundari (2016) observed that combined retraction and intrusion forces produced higher stress levels at the mini-implant site compared to individual force applications, underscoring the importance of biomechanical control during complex tooth movements [21]. Meher *et al*. demonstrated that cortical bone thickness, force magnitude, and insertion angle interactively affect stress distribution and deflection around miniscrews [22]. Therefore, choosing the appropriate insertion angle is not merely a biomechanical preference but a vital clinical decision. However, this choice should be made while considering patient-specific factors such as cortical bone thickness, screw design, force direction, and anatomic constraints. Insertion at 90° appears to offer the most favorable biomechanical outcome when feasible.

Clinical implications

Moreover, CBCT imaging should be employed preoperatively to assess cortical bone thickness, particularly in areas of anticipated miniscrew placement. Motoyoshi *et al*. (2009) recommended a cortical thickness of ≥1 mm for enhanced stability, especially when planning a 90° insertion [3]. In anatomically constrained regions, oblique insertion angles may be necessary to avoid root proximity or sinus perforation. However, clinicians should recognize that insertion angles deviating significantly from 90° may increase cortical stress and compromise primary stability, as supported by both FEA and clinical literature [12].

The clinical implications derived from this systematic review are summarized in Table 5. Although Finite Element Analysis (FEA) represents a computational model rather than a clinical trial, it offers valuable biomechanical insights that support evidence-based orthodontic decision-making. Findings from multiple FEA studies, corroborated by clinical reports, consistently indicate that a perpendicular (90°) insertion angle minimizes stress concentration at the miniscrew-bone interface. This biomechanical advantage may translate into enhanced clinical stability and a reduced risk of failure due to bone resorption, screw loosening, or soft tissue inflammation.

Therefore, clinicians are encouraged to individualize the insertion angle based on CBCT-assessed bone morphology, planned force vectors, and available interradicular space ensuring the best balance between biomechanical advantage and anatomic feasibility.

Table 1: PICO elements

PICO component	Inclusion criteria	Exclusion criteria
Population	Studies using 3D finite element models of orthodontic miniscrews inserted into maxillary or mandibular alveolar bone	Studies involving skeletal anchorage devices other than miniscrews; clinical trials or animal studies without FEA component
Intervention	Insertion of orthodontic miniscrews at oblique angles (e.g., 30°, 45°, 60°)	Studies that do not mention insertion angles, or use only a single fixed angle (e.g., only 90°) without comparative angulation
Comparison	Miniscrews inserted at perpendicular angles (typically 90°) used as a control or comparison within the same FEA simulation	Studies without a comparative group for insertion angle (i.e., no internal control for stress analysis)
Outcome	Outcomes reporting stress distribution in bone and/or implant using 3D Finite Element Analysis (FEA) (e.g., von Mises stress, principal stress)	Studies that do not perform FEA or do not report stress distribution as a primary outcome
Study Design	3D Finite Element Analysis (FEA) studies (in silico simulations), published in full-text, peer-reviewed journals, available in English	Abstract-only papers, conference posters, reviews, letters to editor, editorials, non-English studies, non-FEA based methodologies

Table 2: Electronic search strategy for each database

Information source	Website	Search terminology (Boolean operators used)	Number of references retrieved
Google Scholar	https://scholar.google.com	("orthodontic miniscrews" OR "temporary anchorage devices" OR "TADs") AND ("insertion angle" OR "angulation" OR "implant angulation") AND ("stress distribution" OR "biomechanics" OR "stress analysis") AND ("finite element analysis" OR "FEA" OR "3D finite element modeling")	507
Cochrane Library	https://www.cochranelibrary.com	("orthodontic miniscrew" OR "orthodontic microimplant" OR "temporary anchorage device" OR TAD OR "miniscrew" OR "miniscrews" OR "mini screw" OR "mini screw implant" OR "miniscrew implant" OR "mini implant" OR "micro implant" OR "microimplants" OR "micro screw implant" OR "orthodontic implant" OR "microimplant" OR "orthodontic screw" OR "skeletal anchorage") AND ("angulation" OR "insertion angle" OR "angle of insertion" OR "insertion angulation" OR "inclination" OR "orientation" OR "tilt" OR "trajectory" OR "angled insertion") AND ("stress distribution" OR "biomechanics" OR "stress pattern" OR "stress analysis" OR "force distribution" OR "strain" OR "displacement" OR "von Mises stress" OR "mechanical stress" OR "strain distribution")	8
Science direct		("Orthodontic miniscrews" OR "Temporary anchorage devices") AND ("Insertion angle" OR "Angulation") AND ("Finite element analysis" OR "3D FEA") AND ("Stress distribution")	21
Semantic scholar		("orthodontic miniscrew" OR "orthodontic microimplant" OR "temporary anchorage device" OR TAD OR "miniscrew" OR "miniscrews" OR "mini screw" OR "mini screw implant" OR "miniscrew implant" OR "mini implant" OR "micro implant" OR "microimplants" OR "micro screw implant" OR "orthodontic implant" OR "microimplant" OR "orthodontic screw" OR "skeletal anchorage") AND ("angulation" OR "insertion angle" OR "angle of insertion" OR "insertion angulation" OR "inclination" OR "orientation" OR "tilt" OR "trajectory" OR "angled insertion") AND ("stress distribution" OR "biomechanics" OR "stress pattern" OR "stress analysis" OR "force distribution" OR "strain" OR "displacement" OR "von Mises stress" OR "mechanical stress" OR "strain distribution")	147
pubmed		("orthodontic miniscrew" OR "orthodontic microimplant" OR "temporary anchorage device" OR TAD OR "miniscrew" OR "miniscrews" OR "mini screw" OR "mini screw implant" OR "miniscrew implant" OR "mini implant" OR "micro implant" OR "microimplants" OR "micro screw implant" OR "orthodontic implant" OR "microimplant" OR "orthodontic screw" OR "skeletal anchorage") AND ("angulation" OR "insertion angle" OR "angle of insertion" OR "insertion angulation" OR "inclination" OR "orientation" OR "tilt" OR "trajectory" OR "angled insertion") AND ("stress distribution" OR "biomechanics" OR "stress pattern" OR "stress analysis" OR "force distribution" OR "strain" OR "displacement" OR "von Mises stress" OR "mechanical stress" OR "strain distribution")	75

Table 3: Risk of bias assessment of included studies

Study No.	Author	Year	Model validation	Mesh quality	Boundary conditions	Force parameters	Reporting clarity	Risk of bias
1	Motoyoshi *et al.* [3]	2010	Yes	Good	Clear	Strong	Excellent	Low
2	Lee *et al.* [5]	2013	Yes	Good	Described	Strong	Excellent	Low
3	Park *et al.* [6]	2015	Partial	Adequate	Unclear	Described	Adequate	Moderate
4	Machado *et al.* [13]	2014	Partial	Adequate	Described	Clear	Moderate	Moderate
5	Sana *et al.* [15]	2020	Yes	Adequate	Appropriate	Standard (150 g)	Clear	Low
6	Perillo *et al.* [16]	2015	Yes	Moderate	Partially explained	Clear	Adequate	Moderate
7	Duaibis *et al.* [17]	2012	Yes	Excellent	Detailed	Clear	Very Clear	Low
8	Hirai *et al.* [18]	2021	Unclear	Adequate	Unclear	Defined	Moderate	High
9	Lin *et al.* [20]	2013	Yes	Good	Adequate	Described	Excellent	Low
10	Sivamurthy & Sundari [21]	2016	Yes	Adequate	Defined	Clear	Clear	Low
11	Meher *et al.* [22]	2012	Partial	Moderate	Defined	Good	Clear	Moderate

Table 4: Study characteristics of included studies

Study No.	Author	Year	Study design	Software used	Sample/ model description	Insertion Angle(s)	Insertion Site	Maxilla/ Mandible	Force applied	Bone type	Stress analysis method	Outcome measures	Key findings
1	Motoyoshi *et al.* [3]	2010	Clinical + 3D FEA	Abaqus	CBT 0.5-1.5 mm models	30°-120°	Maxilla/Mandible	Both	2 N load	Cortical + cancellous	von Mises + principal	CBT & screw displacement	CBT ≥1 mm and perpendicular inserts best
2	Lee *et al.* [5]	2013	FEA + pull-out	SolidWorks	Bone block with Orlus screw	30°, 60°, 90°	Synthetic block	N/A	800 gf	Synthetic cortical + cancellous	von Mises + disp	Stress & displacement	90° lowest stress/displacement
3	Park *et al.* [6]	2006	3D FEA	Not stated	12 thread-shape types	Force directions 0°, 45°, 90°	Not specified	N/A	200 cN	Cortical bone	von Mises	Bone stress patterns	Shape negligible; force direction critical
4	Machado *et al.* [13]	2014	3D FEA	ANSYS	Screw 1.2-1.5 mm × 6-12 mm in buccal bone	30°-90°	Maxilla buccal bone	Maxilla	200 g perpendicular	Cortical + cancellous	von Mises	Stress patterns	Screw stress ↑ with angle; bone stress ↓ at 90°
5	Sana *et al.* [15]	2020	SEM + FEA	ANSYS	Synthetic block; screws 1.4-1.8×8 mm	60°, 90°	Synthetic block	N/A	150 g retraction	Synthetic cortical	von Mises	Thread shape, pull-out force	1.8 mm & 90° best strength & lowest stress
6	Perillo *et al.* [16]	2015	3D FEA	ANSYS	Mandible model; screw angles 30-150°	30°-150°	Mandible alveolar bone	Mandible	2 N load	Cortical + trabecular	von Mises	Bone stress	90° optimal; off-angles destabilize
7	Duaibis *et al.* [17]	2012	3D FEA	Abaqus	26 models varying screw/bone designs	30°, 60°, 90°	Alveolar bone block	N/A	2 N mesial	Cortical + cancellous	von-Mises + principal	Cortical bone stress	Diameter, head length ↑ cortical stress
8	Hirai *et al.* [18]	2021	3D FEA	Not specified	Titanium screw in bone	Vertical, oblique	N/A	N/A	Orthodontic force	Cortical + cancellous	Eq. & principal	Screw displacement & stress	Deeper & oblique insertion improve stability
9	Lin *et al.* [20]	2013	3D factorial FEA	ANSYS	27 models, 2 mm dia, variable length	30°, 60°, 90°	Mandible alveolar bone	Mandible	Orthodontic load	Cortical + cancellous	von Mises	Factor contributions	Exposure length (82%) >> angle (6%)
10	Sivamurthy & Sundari [21]	2016	3D FEA	ANSYS	Maxilla block; screws 1/1.3 mm, 6/8 mm long	30°, 60°	Posterior maxilla	Maxilla	2 N load	Cortical + cancellous	von Mises	Implant & bone stress	1.3×6 mm for retraction/intrusion; 1.3×8 mm for molar; 30° lowers stress
11	Meher *et al.* [22]	2012	3D FEA	Inventor + ANSYS	24 models CBT = 0.5-2 mm & insertion 30°, 60°, 90°	30°, 60°, 90°	Alveolar bone	N/A	2 N horizontal & oblique	Cortical + cancellous	von Mises & strain	Bone strain/stress	60° increases stress; horizontal load highest; thicker CBT lowers strain

Table 5: Correlation between insertion angle and stress distribution outcome

Study No.	Study (Author, year)	Insertion angle(s)	FEA findings (von mises stress)	Clinical Outcome	Correlation
1	Motoyoshi *et al.*, 2009 [3]	30°, 60°, 90° (clinical)		90° in areas with sufficient bone = best stability, especially with CBCT planning	Strong
2	Lee *et al.*, 2013 [5]	30°, 60°, 90°	Stress minimized at 90°, oblique insertions showed higher	90° used in clinical protocols with fewer failures	Strong
3	Chen *et al.*, 2006 [7]	Not defined		Stability correlated with perpendicular insertion and cortical thickness ≥1 mm	Moderate

4	Kuroda *et al.*, 2007 [12]	Not angle-specific		Failures linked to poor angle planning and inflammation	General biomechanical support
5	Sana *et al.*, 2020 [15]	30°, 60°, 90°	90° = least stress; 30° = highest stress	90° insertions reported higher miniscrew stability clinically	Strong
6	Meher *et al.*, 2012 [22]	45°, 60°, 90°	60° and 90° better than 45°	Higher success rates clinically at 60° and 90°	Moderate to Strong

Conclusion

Based on this systematic review of 14 finite element analysis (FEA) studies, the insertion angle of orthodontic miniscrews plays a decisive role in modulating stress distribution across the bone-implant interface. A perpendicular (90°) insertion consistently demonstrated biomechanical superiority by minimizing von Mises stress and displacement, which supports enhanced primary stability and potentially greater clinical success.

These findings are corroborated by clinical studies that have linked perpendicular insertion and sufficient cortical bone thickness (≥1 mm) with increased miniscrew survival and reduced complications such as inflammation, loosening, and failure. This highlights the translational validity of FEA simulations in guiding practical orthodontic protocols.

While individual anatomic considerations may necessitate oblique insertions in certain cases, clinicians are advised to utilize pre-treatment CBCT to assess cortical bone thickness and interradicular space, enabling insertion angle selection that balances biomechanical advantage and anatomic feasibility.

Future clinical trials and prospective cohort studies are needed to validate the stress trends observed in FEA and to establish definitive, evidence-based guidelines for optimal miniscrew placement in diverse clinical contexts.

References

1. Papageorgiou SN, Zogakis IP, Papadopoulos MA. Failure rates and associated risk factors of orthodontic miniscrew implants: a meta-analysis. Am J Orthod Dentofacial Orthop. 2012;142(5):577-595. DOI: 10.1016/j.ajodo.2012.05.016.
2. Reynders R, Ronchi L, Bipat S. Mini implants in orthodontics: a systematic review of the literature. Am J Orthod Dentofacial Orthop. 2009;136(5):564-571. DOI: 10.1016/j.ajodo.2008.09.026.
3. Motoyoshi M. 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. 2009;38(1):13-18. DOI: 10.1016/j.ijom.2008.09.006.
4. Liou EJW, Pai BCJ, Lin JCY. Do miniscrews remain stationary under orthodontic forces? Am J Orthod Dentofacial Orthop. 2004;126(1):42-47. DOI: 10.1016/j.ajodo.2003.06.018.
5. Lee J. Effects of placement angle and direction of orthopedic force application on the stability of orthodontic miniscrews. Angle Orthod. 2013;83(4):667-673. DOI: 10.2319/090112-703.1.
6. Park HS, Jeong SH, Kwon OW. Factors affecting the clinical success of screw implants used as orthodontic anchorage. Am J Orthod Dentofacial Orthop. 2006;130(1):18-25. DOI: 10.1016/j.ajodo.2004.11.032.
7. Chen Y. Stability of miniplates and miniscrews used for orthodontic anchorage: Experience with 492 temporary anchorage devices. Clin Oral Implants Res. 2008;19(12):1188-1196. DOI: 10.1111/j.1600-0501.2008.01571.x.
8. Baek SH, Cha HS, Cha JY. Three-dimensional finite element analysis of the deformation of the human mandible: A preliminary study from the perspective of orthodontic mini-implant stability. Korean J Orthod. 2012;42(4):159. DOI: 10.4041/kjod.2012.42.4.159.
9. Wilmes B, Drescher D. Impact of insertion depth and predrilling diameter on primary stability of orthodontic mini-implants. Angle Orthod. 2009;79(4):609-614. DOI: 10.2319/071708-373.1.
10. Marimuthu VK. Finite element analysis of stress and displacement around mini-implant using different insertion angles and various directions of orthodontic force in maxilla and mandible. J Indian Orthod. 2015;49(1):61-66. DOI: 10.4103/0301-5742.162235.
11. Suzuki A. Changes in stress distribution of orthodontic miniscrews and surrounding bone evaluated by 3-dimensional finite element analysis. Am J Orthod Dentofacial Orthop. 2011;140(6):721-729. DOI: 10.1016/j.ajodo.2011.06.025.
12. Kuroda S. Clinical use of miniscrew implants as orthodontic anchorage: Success rates and postoperative discomfort. Am J Orthod Dentofacial Orthop. 2007;131(1):9-15. DOI: 10.1016/j.ajodo.2005.02.032.
13. Machado GL. Effects of orthodontic miniscrew placement angle and structure on the stress distribution at the bone miniscrew interface – A 3D finite element analysis. Saudi J Dent Res. 2014;5(2):73-80.
14. Thomková B. Biomechanical performance of dental implants inserted in different mandible locations and at different angles: A finite element study. J Prosthet Dent. 2024;131(1):22-29. DOI: 10.1016/j.prosdent.2023.10.012.
15. Sana S, Reddy. Evaluation of stability of three different mini-implants, based on thread shape factor and numerical analysis of stress around mini-implants with different insertion angles, with relation to en-masse retraction force. Dent Press J Orthod. 2020;25(6):59-68. DOI: 10.1590/2177-6709.25.6.059-068.oar.
16. Perillo L, Jamilian. Finite element analysis of miniscrew placement in mandibular alveolar bone with varied angulations. Eur J Orthod. 2014;37(1):56-59. doi: 10.1093/ejo/cju006.
17. Duaibis R, Kusnoto. Factors affecting stresses in cortical bone around miniscrew implants. Angle Orthod. 2012;82(6):875-880. DOI: 10.2319/111011-696.1.
18. Hirai Y. Influence of insertion depth on stress distribution in orthodontic miniscrew and the surrounding bone by finite element analysis. Dent Mater J. 2021;40(5):1270-1276. DOI: 10.4012/dmj.2020-400.
19. Choi JY, Cho. Effect of different surface designs on the rotational resistance and stability of orthodontic miniscrews: A three-dimensional finite element study. Sensors. 2021;21(6):1964. DOI: 10.3390/s21061964.
20. Lin T, Tsai. Factorial analysis of variables affecting bone stress adjacent to the orthodontic anchorage mini-implant with finite element analysis. Am J Orthod Dentofacial Orthop. 2013;143(2):182-189. DOI: 10.1016/j.ajodo.2012.09.012.
21. Sivamurthy G, Sundari S. Stress distribution patterns at mini-implant site during retraction and intrusion a three-

dimensional finite element study. Prog Orthod. 2016;17(1):1. DOI: 10.1186/s40510-016-0117-1.

22. Meher AH, Shrivastav. Deflection and stress distribution around mini-screw implants: A finite element investigation into the effect of cortical bone thickness, force magnitude, and direction. J Orthod. 2012;39(4):249-255. DOI: 10.1179/1465312512z.00000000037.

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