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MDPI

Systematic Review

Fracture and Deflection of Orthodontic Miniscrews—A Systematic Review

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Abstract: Orthodontic miniscrews (MSs) are used for enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether. Despite MSs' popularity, their clinical application is not lacking in complications. The limited space of the insertion site (inter-radicular space), temporary use (limiting osseointegration) and the necessity to minimize the biological cost of insertion (bone incision) required the size of this auxiliary to be reduced, making it susceptible to mechanical failure. This review aimed to investigate factors influencing MS plastic deformation and fracture. The search applied five engines: PubMed, PMC, Web of Science, Scopus, Embase, and Ebsco. Quality assessment was performed according to the QUIN tool. After a thorough search process, 22 articles were included in this review. The most important factor influencing miniscrews' plastic deformation and fracture was the screw diameter. The MS length and metal alloy did not influence its plastic deformation or fracture. The cylindrical design of the screw is preferable. If the cortical bone thickness in the insertion site exceeds 3 mm, predrilling upon insertion is recommended. Orthodontic MSs should not be reused. There is a need for high-quality clinical studies on the subject of MS deformation and fracture. The PROSPERO number is CRD42024509895.

Keywords: orthodontic mini-implants; orthodontic screw; TAD; miniscrew; skeletal anchorage; fracture; deflection; plastic deformation; distortion

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1. Introduction

Orthodontic mini-implants, also known as miniscrews (MSs), are temporary orthodontic devices used for enhancing orthodontic anchorage either by supporting the teeth of the reactive unit (indirect anchorage) or by obviating the need for the reactive unit altogether (direct anchorage of orthodontic appliances with sprigs, clamps, elastomers, etc.). Temporary use of miniscrews requires subsequent removal upon completing clinical tasks [1]. Most commonly, MSs are made of grade V titanium alloy or stainless steel [2]. The introduction of miniscrews has greatly expanded the limit of clinical orthodontics by facilitating difficult teeth movements and limiting patient compliance [3]. MSs' popularity has become widespread due to the relatively low cost regarding the effects attained as well as their ease of insertion [4].

However, the clinical application of MSs is not lacking in complications. The most common problems related to MSs are root contact upon insertion or in the course of teeth movement, the loss of MS stability, inflammation caused either by the patient's compromised hygiene or mechanical irritation caused by the MS head or auxiliaries attached to it, and plastic deformation and fracture of the MSs [5,6].

Iatrogenic root contact may occur if the MS is inserted in the narrow inter-radicular space. This may lead to potential loss of tooth vitality, osteosclerosis, and dentoalveolar ankylosis [7].

The proximity of the root also significantly increases the risk of miniscrew mobility and often causes MS failure. The loss of MS stability during the course of teeth movement is a common cause of screw relocation [8]. Alternatively to inter-radicular location, MSs are also inserted into extra-radicular sites such as the infrazygomatic crest in the maxilla and the buccal shelf in the mandible [9]. Considering the severity of clinical management, more troublesome than the root contact is MSs' deformation or fracture upon insertion or removal. Since both occurrences could be very demanding, they are best to be avoided. The aim of the present study is to investigate factors influencing the miniscrews' plastic deformation and fracture in accordance with the present state of scientific knowledge.

2. Materials and Methods

2.1. Search Strategy

The review process was performed in conformity with the PRISMA 2020 reporting guidelines [10]: Supplementary Material S1 and S2 and the guidelines from the Cochrane Handbook for Systematic Reviews of Interventions [11]. The final search strategy was determined through several pre-searches of popular tags and mesh terms in the topic studied. The search applied five popular search engines: PubMed, PubMed Central, Web of Science, Scopus, Embase, and Ebsco Dentistry & Oral Sciences source. The final search was performed on 24 January 2024. The keywords used in the search strategy were as follows: ("orthodontic screw" OR "miniscrew" OR "mini-implant" OR "TAD" OR "temporary anchorage device" OR "skeletal anchorage") AND ("orthodontics" [MeSH Terms] OR "malocclusion" [MeSH Terms] OR "Tooth Movement Techniques" [MeSH Major Topic]) AND ("mechanical properties" OR "mechanical characteristics" OR "mechanical test" OR "torsional test" OR "flexural test" OR "insertion torque") AND ("deformation" OR "distortion" OR "fracture"). The final search strings for each search engine were as follows:

Pubmed—("orthodontic screw" OR "miniscrew" OR "mini-implant" OR "TAD" OR "temporary anchorage device" OR "skeletal anchorage") AND ("orthodontics" [MeSH Terms] OR "malocclusion" [MeSH Terms] OR "Tooth Movement Techniques" [MeSH Major Topic]) AND ("mechanical properties" OR "mechanical characteristics" OR "mechanical test" OR "torsional test" OR "flexural test" OR "insertion torque") AND ("deformation" OR "distortion" OR "fracture").

PMC—("orthodontic screw"[All Fields] OR "miniscrew"[All Fields] OR "mini-implant"[All Fields] OR "TAD"[All Fields] OR "temporary anchorage device"[All Fields] OR "skeletal anchorage"[All Fields]) AND ("orthodontics"[MeSH Terms] OR "malocclusion"[MeSH Terms] OR "Tooth Movement Techniques"[MeSH Major Topic]) AND ("mechanical properties"[All Fields] OR "mechanical characteristics"[All Fields] OR "mechanical test"[All Fields] OR "torsional test"[All Fields] OR "flexural test"[All Fields] OR "insertion torque"[All Fields]) AND ("deformation"[All Fields] OR "distortion"[All Fields] OR "fracture"[All Fields]).

Web of Science—("orthodontic screw" OR "miniscrew" OR "mini-implant" OR "TAD" OR "temporary anchorage device" OR "skeletal anchorage") AND ("orthodontics" OR "malocclusion" OR "Tooth Movement Techniques") AND ("mechanical properties" OR "mechanical characteristics" OR "mechanical test" OR "torsional test" OR "flexural test" OR "insertion torque") AND ("deformation" OR "distortion" OR "fracture") [All fields].

Scopus—TITLE-ABS-KEY (("orthodontic screw" OR "miniscrew" OR "mini-implant" OR "TAD" OR "temporary anchorage device" OR "skeletal anchorage") AND ("orthodontics" OR "malocclusion" OR "Tooth Movement Techniques") AND ("mechanical properties" OR "mechanical characteristics" OR "mechanical test" OR "torsional test" OR "flexural test" OR "insertion torque") AND ("deformation" OR "distortion" OR "fracture")).

Embase—('orthodontic screw' OR 'miniscrew'/exp OR 'miniscrew' OR 'mini-implant' OR 'tad' OR 'temporary anchorage device'/exp OR 'temporary anchorage device'

OR 'skeletal anchorage'/exp OR 'skeletal anchorage') AND ('orthodontics'/exp OR 'orthodontics' OR 'malocclusion'/exp OR 'malocclusion' OR 'tooth movement techniques'/exp OR 'tooth movement techniques') AND ('mechanical properties'/exp OR 'mechanical properties' OR 'mechanical characteristics' OR 'mechanical test'/exp OR 'mechanical test' OR 'torsional test' OR 'flexural test' OR 'insertion torque'/exp OR 'insertion torque') AND ('deformation'/exp OR 'deformation' OR 'distortion'/exp OR 'distortion' OR 'fracture'/exp OR 'fracture').

The articles included in this paper discuss the deformation and fracture resistance of different orthodontic miniscrews. The PICO(S) for this review were as follows: Population: artificial or animal bone blocks; Intervention: miniscrew insertion and removal; Comparison: deformation of various miniscrews in different environments; Outcome: torsional torque, difference in micrometers, deflection in micrometers; Studies: in vitro studies. The PICO(S) question was as follows: Do orthodontic miniscrews deflect during insertion or removal, and how?

2.2. Inclusion Criteria

The following inclusion criteria were applied for this systematic review: (a) randomized clinical trials, (b) in vitro studies, and (c) prospective and retrospective clinical trials.

The exclusion criteria were as follows: (a) case reports, (b) book chapters, (c) editorials, (d) research without quantitative evaluation, (e) conference abstracts, (f) records unrelated to the topic of orthodontic miniscrew deformation, (g) reports not written in the English language.

2.3. Data Extraction

All records were retrieved from the databases. Every single title and abstract was analyzed following the inclusion and exclusion criteria by two authors (KS and MJ). If a disagreement occurred, it was resolved by forwarding the decision on article inclusion to the study supervisor (JJO). The full text of each record related to the topic was read and analyzed to ensure that it was suitable for inclusion. The authors extracted the results in order to compare the data retrieved with other studies. The Cohen's K coefficient for agreement between the authors on whether to include each study was high and yielded 0.98. Authorship, year of publication, type of study, outcome compared within the study, and main results were extracted by one author (KS) and examined and corrected by another author (MJ). Moreover, the references of each article set for inclusion in the review were then searched for additional reports. The protocol was registered in the PROSPERO database with registration number CRD42024509895.

2.4. Risk of Bias Assessment

According to the PRISMA Statement, the assessment of methodological quality indicates the strength and relevance of the scientific evidence found within the study, as flaws in methods can result in bias [10]. In order to perform proper quality assessment, study-type-specific risk-of-bias assessment tools were introduced in this study. Due to the fact that two types of studies, animal studies and in vitro studies, were found, two different tools were applied. In the case of one animal study, the SYRCLE bias assessment tool was applied, which focused on five main bias sources: selection bias, performance bias, detection bias, attrition bias, and reporting bias [12]. The assessment in this scale is primarily descriptive, then qualitative. For in vitro studies, the QUIN assessment tool was used. This tool consists of twelve different criteria that thoroughly assess the quality of the study. The following scoring system was used by two authors: (i) adequately specified (2–1 points); (ii) not specified (0 points); not applicable (excluded from the calculation). All points were then summed up. To classify the risk of bias, the total score for the given study was calculated. Studies with a score of 70% and above were considered to have a low risk of bias, studies with a score of 50–70% were considered to have a medium risk of bias, and studies with a score of 50% and below were considered to have a high risk of bias [13].

3. Results

3.1. Search Results

The search strategy identified 154 potential records from five different search engines. Subsequently, 49 duplicates were found and removed, and the included 105 articles were analyzed. All articles were identified which had titles concordant with the topic of the present review. During the search, the authors decided to manually add one article as it was cited by many studies already included and suited the search criteria well. Two studies were excluded due to lack of statistical analysis, twenty-five studies were excluded because their subject did not cover the application of MSs, and fifty-seven reports were excluded due to lack of reference to the fracture or plastic deformation of MSs. Therefore, 22 articles were included in this review and are presented in Table 1.

The Prisma flow diagram (Figure 1) thoroughly describes the search process.

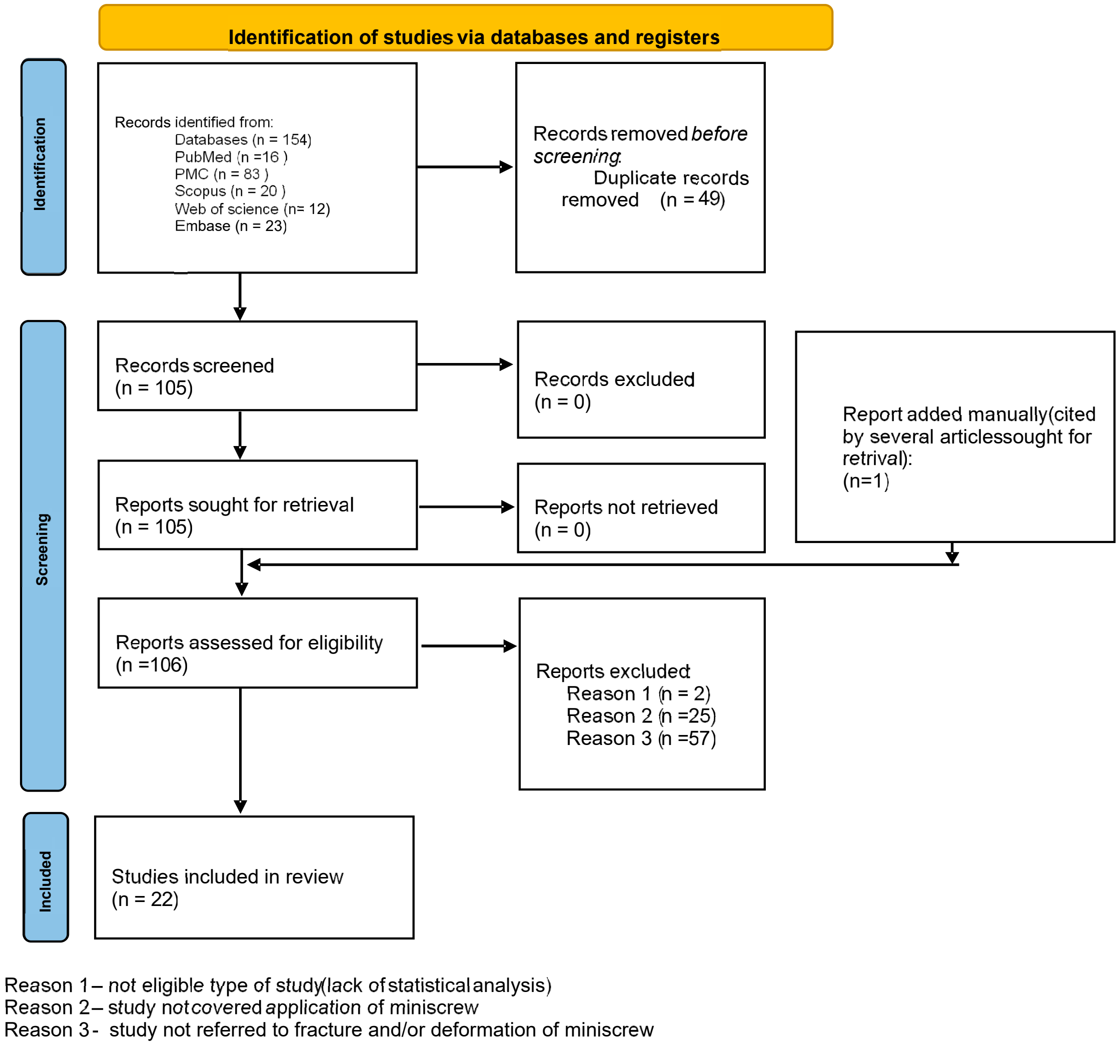

Figure 1. PRISMA 2020 flow diagram.

The methods and main findings of the included studies (in alphabetical order) have been presented in Table 1.

Table 1. The methods and main findings of the studies included.

Author and Year	Type of Study	No of Subjects	Comparison Made	Measurement Unit	Results
Alavi S. et al., 2020 [14]	Experimental study (in vitro)	36	- Change in insertion and fracture torques after steam and dry heat sterilization.	N.cm	- Steam sterilization had no effect on fracture torque and insertion torque values. - Dry heat sterilization lowered fracture torque value - Steam sterilization had no detrimental effects on torque values of miniscrews; dry heat sterilization affected their mechanical properties.
Assad-Loss T.F. et al., 2017 [15]	Experimental research (in vitro)	50	Five brands of titanium alloy MS: - Design and dimensions; - Torsional fracture strength in the neck and the tip; - Insertion torque values.	N.cm μm	- Fracture torque of the neck: 23.45 N.cm 34.82 N.cm, of the tip: 9.35 N.cm (CON) to 24.36 N.cm (NEO). - Insertion torque values ranged from 6.6 N.cm (RMO) to 10.2 N.cm (NEO). - Fracture torque resistance is determined by: outside diameter, internal diameter, ratio of inner and outer diameter, and milling in the apical region. - The fracture torques of both the tip and neck were higher than the torque required to insert MSs.
Barros S.E. et al., 2021 [16]	Experimental research (in vitro)	252 (SS-MS) 252 (TiA-MS)	- Two MS alloys: stainless steel (SS-MS) and titanium alloy (TiA-MS); - Correlation of MS diameter (1.2–1.8 mm) with torsional fracture and deflection resistance; - Thread resistance to morphological damage after insertion.	N.cm (fracture torque) N (flexural force)	- SS-MSs were 13.2% and 20.2% more resistant to torsional fracture and deflection. - MS diameter explained 90.3% of the total variation in fracture torque, 2.2% was explained by the metallic alloy. - Flexural strength of SS and TiA-MSs at 1 mm and 2 mm deflection was 18.21 N and 17.55 N. - No noticeable morphological damage to the threads of SS-MSs and TiA-MSs. - The use of SS-MSs can reduce the fracture risk without increasing the MS diameter.
Barros S.E, Janson G, et al., 2011 [17]	Experimental research (in vitro)	405	- Correlation of MS diameter (1.2–2 mm) with placement torque value, axial placement load, fracture torque value, and self-drilling efficacy.	N.cm	- Increases in MS diameter increased the placement torque and fracture torque, which reduced the fracture risk. - The self-drilling efficacy was not strongly influenced by diameter.
Cho I-S. et al., 2013 [7]	Experimental study (in vitro)	100	Different insertion angles and MS thread types (single, dual). - Insertion torque, total insertion energy, and peak time.	N.cm, J, s	- Increase in insertion angle increased insertion torque values in both thread groups. - Dual-thread MS: more fracturing than deformation compared to single-thread MSs.

Chung CJ et al., 2014 [8]	Experimental study (in vitro)	84	- Unused and retrieved MSs: deformation of the tip, changes in insertion torque, insertion time, and insertion load; - Surface composition analysis of retrieved MSs.	N µm	- Tip deformation was found in 84.5% of retrieved MSs. - Insertion site or duration of insertion not associated with tip deformation. - Insertion load increased with tip deformation. - Changes in insertion torque similar to unused MSs. - Debris of carbon, calcium, and phosphorus on the MSs. - MSs retrieved exhibited decreased cutting ability due to deformation of the tip structure and surface contamination.
Fabi B.A.J, 2022 [18]	Experimental research (in vitro)	150	- Insertion torque of 3 types of TiA-MS vs. the insertion torque of the retrieved MS after root contact; - Structural and dimensional changes in as-received MSs and retrieved MSs after root contact (SEM).	N.cm µm	Deformation of MS upon root contact: dimensional changes (blunting) in the MS tip and threads, decreased cutting ability on reinsertion, increase in maximum torque insertion value - Excessive insertion force may hinder soft tissue healing, cause MS fracture, and induce microcracks and bone damage.
Francioli D., 2010 [1]	Experimental study (in vitro)	10 (ø1.5 mm) 10 (ø2 mm)	SS-MS: - Torsional resistance; - Flexural strength.	N.cm N	Torsional resistance: Ø1.5 mm: 26.5 N.cm, ø2 mm: 48.3 N.cm. Flexural strength: ø1.5 mm: 105,4 N, ø2 mm: 216.7 N. Higher fracture and deformation resistance for higher diameter.
Hosein Y.K., 2016 [19]	Experimental study (in vitro)	60	Six MS systems (Aarhus, Dual-top, OrthoEasy, Thomas-pin, Unitek, VectorTAS). - Torque ratio as fracture potential (insertion torque as % of fracture torque) in 3 mm cortical bone.	N.cm %	Highest ratio: Aarhus MS. Lowest ratio: Unitek. - Safe use of Unitek, VectorTAS, OrthoEasy, Dual-top in 3 mm bone without pre-drilling
Kang H-K, 2016 [20]	Research animal study (experimental in vitro)	48	SS-MS: - Machined vs. Nd-YAG laser surface-treated. - Surface roughness, texture, fracture resistance, bone–implant contact (BIC).	N.cm µm	- Higher surface roughness of laser-treated MSs. - No significant differences in fracture resistance and BIC between the two groups. - Laser treatment increased surface roughness without compromising fracture resistance. Despite increasing surface roughness, laser treatment did not improve bone–implant contact.
Lopes G.B., 2023 [9]	Experimental study (in vitro)	72 (24 per group)	Two MS alloys: stainless steel (SS-MS) ø1.5 mm and ø2 mm and titanium alloy (TiA-MS) ø1.5 mm. - Insertion torque, fracture torque, pull-out, degree of mobility on percussion, MS fracture pattern.	N/cm²	- Insertion torque and fracture torque similar for ø1.5 mm MI, higher for ø2 mm MI. - Pull-out and percussion tests presented similar values. - Fracture point was predominantly on 4th thread for SS-MS and on the 7th thread for TiA-MSs.

Pithon M.M., 2013 [21]	Experimental study (in vitro)	405	MSs of different lengths: 6, 8, 10 mm: - Cortical bone thicknesses (1–6 mm); - Insertion torque, fracture torque, deformation.	N/cm^2	- Insertion torque increased with screw length and cortical bone thickness. - Length of MSs did not influence fracture strength on insertion, flexural strength, fracture strength on flexion - Increase in screw length does not increase the mechanical strength of the implant.
Quraishi E., 2014 [5]	Experimental study (in vitro)	40	Five MI systems: - Max insertion torque under 1 and 3 kg load (fracture risk).	N.cm	MSs of cylindrical and mixed designs fractured at higher torque values compared to tapered designs for both loads of 1 and 3 kg. - Pressure of 3 kg increased risk of bending tapered MS before fracture.
Reicheneder C., 2008 [6]	Experimental study (in vitro)	50	Five MS systems: - Plastic deformation under insertion and flexural loading. - Material composition of MSs.	mm	- All systems: deformations of approximately 0.15–0.25 mm, depending on the insertion depth. - Comparable elemental composition. - Differences in mechanical properties are attributed to screw design; partial insertion increases fracture risk upon flexural loading.
Reimann S., 2016 [22]	Experimental study (in vitro)	17	Eight MS systems: - Fracture torque; - Deformation torque.	N.cm	- Fracture torque increased with the increase in MS diameter. - Plastic deformation often occurred below the industrial standard torque values (20 N.cm).
Santos R., 2014 [23]	Experimental study (in vitro)	10	- Insertion torque of MSs in different cortical thicknesses; - Resistance to fracture of MS tip and neck; - MS surface morphology before and after mechanical test.	N.cm	- Insertion torque for 1 mm (7.60 N.cm) and 2 mm (13.27 N.cm) cortical thicknesses. - Mechanical resistance to fracture (tip 22.14 N.cm and neck 54.95 N.cm): higher than insertion torque. - No changes in MS surface morphology before and after tests. - Safe placement of MS in 1 and 2 mm cortical thickness; in 3 mm and dense bones, authors recommend pre-drilling before insertion.
Scribante A., 2018 [4]	Experimental study (in vitro)	70	Two MS alloys: stainless steel (SS-MS) and titanium alloy (TiA-MS) ø1.5 mm and ø2 mm. - Deflection and maximum load.	N	- MSs of ø2 mm showed higher bending and fracture resistance than ø1.5 mm diameter MSs. - No significant differences between TiA-MSs and SS-MSs with the same diameter.
Serra G., 2013 [24]	Experimental study (material research)	15	Three MS materials: commercially pure titanium (cpTi), Ti-6Al-4V alloy, nanostructured titanium (nTi).	N.mm	- Maximum torque resistance of nTi higher than cpTi, similar to Ti-6Al-4V. - Similar surface finishing and fracture processes among the 3 types of MSs.

			- Maximum torque resistance, surface morphology, fracture surface characteristics.		
Sfondrini M.F., 2018 [25]	Experimental study (in vitro)	70	Seven diameters of Ti-6Al-4V miniscrews: forces to bend at 0.1 mm, 0.2 mm magnitude of deflections and at maximum load.	N	- At 0.1 mm or 0.2 mm deflections and at maximum load, highest forces were reported with 1.7, 1.8, 1.9, and 2.0 mm TADs. - The lowest values were reported with 1.6, 1.5, and 1.3 mm MSs. - No significant differences between 1.6 mm and 1.7 mm screws.
Smith A., 2015 [3]	Experimental study (in vitro)	90	Six brands of titanium MS (ø1.4–1.8 mm): fracture torques during insertion.	N.cm	Unitek (72 N.cm) > Tomas-pin (36 N.cm) > Dual-Top (32 N.cm) ≈ VectorTAS (31 N.cm) > OrthoEasy (28 N.cm) > Aarhus (25 N.cm). Weak correlation between mini-implant diameter and fracture resistance.
Walter A., 2013 [26]	Experimental study (in vitro)	12	Twelve designs of MS: - Design (shape); - Pullout strength, insertion torques and, torsional fracture.	Mm N.cm	- Cylindrical MSs: higher pull-out strength, lower insertion torque values. - Outer and inner MS diameters correlated with pull-out strength, insertion torque, and torsional fracture values. - Greater thread depth was related to greater pull-out strength values. - Torsional fracture depended on the MS inner and outer diameters. - Thread-depth-to-outer-diameter ratio increased torsional fracture risk by 40%. - MS outer and inner diameters are the most important factors for primary stability.
Wilmes B.,Panayotidis A., 2011 [27]	Experimental study (in vitro)	41	Different designs and diameters of MSs: - Insertion and fracture torque (with pre-drilling).	N.mm	- Fracture torque varied depending on MS design. - Increasing fracture torque value with increased MS diameter.

All studies included were in vitro analyses and the materials used comprised artificial (polyurethane foam) bone blocks or pig bone blocks, whereas one article contained an animal study (MSs were introduced in beagle dogs). The total sample size of miniscrews in all studies included was 2097 MSs of different materials, diameters, and lengths. All studies included covered the deformation of orthodontic MSs and their resistance to deflection or fracture depending on specific material characteristics, mini-implant design (shape, length, diameter), or simulated clinical scenarios (e.g., sterilization or reinsertion after root contact). Twenty-one studies include class V titanium mini-implants in the test sample, whereas three studies also include stainless steel mini-implants for comparison, and one study includes only steel mini-implants.

The mechanical strength of miniscrews in relation to the alloy was explored in five reviewed articles. Barros et al. concluded that in general, SS-MSs had higher torsional and flexural strength than TiA-MSs [16]. However, in the total sample, variation in torsional and flexural strength was more influenced by the diameter (90.3% and 83.5%) than by the type of metal alloy (2.2% and 3.8%). The authors of the study cited have further suggested that the miniscrew's design is of higher importance than the alloy with regard to fracture resistance. Quite similar conclusions could be drawn from the study by Lopes et al. [9]. The comparison of SS-MSs and TiA-MSs conceded the advantage of mechanical properties for SS; however, the study had proven that larger-diameter (2.0 mm) MSs performed better than those of a smaller diameter (1.5 mm) regardless of alloy type. Further consistency with these results can also be found in the study by Scribante et al. as MSs of ø2 mm showed higher bending and fracture resistance than ø1.5 mm diameter MSs, but no significant differences between TiA-MSs and SS-MSs of the same diameters were found [4]. The discordance between studies comparing different alloys regarding fracture resistance might be due to different alloy compositions and treatments during the manufacture.

A slightly different approach to the mini-implant alloy was adopted in the studies by Serra et al. and Kang et al. [20,24]. Serra et al. attempted to modify the properties of a titanium alloy and combine the biocompatibility of commercially pure titanium MSs and the mechanical resistance of the Ti-6Al-4V mini-implants by nanostructured titanium processing. As a result, nTi mini-implants showed torsion resistance compatible with Ti-6Al-4 V mini-implants and better than cpTi mini-implants. Similar surface finishing and fracture processes among the three types of mini-implants were found [24].

Kang et al. aimed to improve bone–implant contact by roughening the surface of SS mini-implants with a Nd-YAG laser. The laser surface treatment did increase surface roughness without compromising fracture resistance; however, it did not improve bone–implant contact [20].

Studies by Sfondini et al. proved a positive correlation between forces required to deflect the miniscrew and its diameter—the highest forces required for bending were reported with 1.7, 1.8, 1.9, and 2.0 mm MSs, whereas the lowest values were reported with 1.6, 1.5, and 1.3 mm MSs [25].

In their study, Pithon et al. investigated the influence of MS length on the insertion torque and fracture torque values in various cortical bone thicknesses [21]. As a result, an increase in insertion torque was associated with an increase in bone thickness; however, the length of MSs did not influence fracture strength on insertion, flexural strength, or fracture strength on flexion.

As for aspects that depend on the operating technique, Cho et al. proved the significance of insertion angle [7]. Regardless of the MS design (dual or single thread), an increase in insertion angle increased insertion torque, and partial insertion of the MS was associated with increased fracture risk upon flexural loading [6]. In turn, Fabi et al. described the deformation of MSs upon root contact: dimensional changes (blunting) of the MS tip and threads, decreased cutting ability on reinsertion, and an increase in the maximum torque insertion value [18].

3.2. Risk of Bias Assessment

The quality of the included studies differed; most of them were of low and moderate quality, while only one presented a high quality. The most common methodological flaws among the studies were lack of sample size calculation, lack of randomization, lack of description of who prepared the test samples and how the outcomes were assessed, and objectivity of the assessor was not present due to a lack of blinding in different steps of the study. Some studies did not provide a proper description of the statistical analysis that was applied or presented the methods too briefly, raising some doubts. Table 2 contains the risk of bias of in vitro studies and Table 3 contains the animal study by Kang et al., 2016 [20].

Table 2. The risk of bias of in vitro studies.

Criteria No.	**Criteria**	**Alavi S., 2020 [14]**	**Assad-Loss T.F, 2017 [15]**	**Barros S.E, 2021 [16]**	**Barros S.E, Janson G, 2011 [17]**	**Cho I-S., 2013 [7]**	**Chung CJ, 2014 [8]**	**Fabi B.A.J, 2022 [18]**	**Franciloli D., 2010 [1]**	**Hosein Y.K., 2016 [19]**	**Kang H-K, 2016 [20]**
1	Clearly stated aims/objectives	2	2	2	2	2	2	2	2	2	2
2	Detailed explanation of sample size calculation	0	0	0	0	0	0	0	0	0	0
3	Detailed explanation of sampling technique	2	2	2	2	1	1	2	1	2	2
4	Details of comparison group	2	2	2	2	2	2	2	2	2	2
5	Detailed explanation of methodology	2	2	2	2	1	1	2	1	2	2
6	Operator details	0	2	0	2	0	0	0	0	2	2
7	Randomization	0	1	0	0	0	0	0	0	0	2
8	Method of measurement of outcome	2	2	2	2	2	2	2	2	2	2
9	Outcome assessor details	0	1	0	0	0	0	0	0	2	0
10	Blinding	0	0	0	0	0	0	0	0	0	0
11	Statistical analysis	0	2	2	2	2	2	2	2	2	2
12	Presentation of results	2	2	2	2	2	2	2	2	2	2
13	Overall	high	low	medium	medium	high	medium	medium	high	medium	low

Criteria No.	Criteria	Lopes G.B., 2023 [9]	Pithon M.M., 2013 [21]	Quraishi E., 2014 [5]	Reichenender C., 2008 [6]	Reimann S., 2016 [22]	Santos R., 2014 [23]	Scribante A., 2018 [4]	Serra G., 2013 [24]	Sfondrini M.F., 2018 [25]	Smith A., 2015 [3]
1	Clearly stated aims/objectives	2	2	2	2	2	2	2	2	2	2
2	Detailed explanation of sample size calculation	0	0	0	0	0	2	0	0	0	0
3	Detailed explanation of sampling technique	1	2	2	1	2	2	1	1	1	2
4	Details of comparison group	2	2	-	2	2	2	2	2	2	2
5	Detailed explanation of methodology	1	2	2	1	2	1	1	1	1	2
6	Operator details	0	0	0	0	0	0	0	0	0	0
7	Randomization	0	0	0	0	0	0	0	0	0	0
8	Method of measurement of outcome	2	2	2	2	2	2	2	2	2	2
9	Outcome assessor details	0	0	0	0	0	0	0	0	0	0
10	Blinding	0	0	0	0	0	0	0	0	0	0
11	Statistical analysis	2	2	2	2	2	2	2	2	2	2
12	Presentation of results	2	2	2	2	2	2	2	2	2	2
13	Overall	high	medium	medium	high	medium	medium	medium	high	medium	medium

Criteria No.	Criteria	Walter A., 2013 [26]	Wilmes B., Panayotidis A., 2011 [27]
1	Clearly stated aims/objectives	2	2
2	Detailed explanation of sample size calculation	2	0
3	Detailed explanation of sampling technique	2	2
4	Details of comparison group	2	2
5	Detailed explanation of methodology	2	2

6	Operator details	0	0
7	Randomization	0	0
8	Method of measurement of outcome	2	2
9	Outcome assessor details	0	0
10	Blinding	0	0
11	Statistical analysis	2	0
12	Presentation of results	2	2
13	Overall	medium	high

Table 3. The risk of bias in the animal study.

Author and Year	**Kang H-K, 2016 [20]**
Selection bias	Not present.
Performance bias	Not present.
Detection bias	There was no sample size calculation or blinding.
Attrition bias	There was no description of who performed the measurements and whether they were repeated.
Reporting bias	Not present.
Other biases	Not present.

4. Discussion

Many terms have been used for orthodontic temporary anchorage devices in the included studies. Although ‘temporary anchorage device’ (TAD) is a broad term that could also cover appliances other than screws, such as mini plates, the present study opts for the use of the term ‘miniscrew’ (MS) as it properly describes the proprieties of the auxiliaries concerned.

The main factors influencing MS plastic deformation and fracture include specific material characteristics, mini-implant design (shape), and miniscrew length and diameter. The two main metal alloys used for the production of MSs are stainless steel (SS) and medical titanium alloy (Ti-6Al-4V) [2]. Considering the properties of the compared miniscrew materials, it is not possible to unequivocally state the mechanical superiority of a particular alloy [16]. Taking into account the higher torsional and flexural strength of stainless steel MSs, it could be an indication for clinical application in more demanding sites such as the mandibular buccal shelf and infrazygomatic crest or when orthodontic screws are used to anchor high orthopedic forces as in miniscrew-assisted rapid palatal expansion (MARPE) [27]. However, currently, the majority of temporary anchorage devices are manufactured from either commercially pure titanium or grade V titanium alloy (Ti-6Al-4V) [16]. The latter is favored due to its mechanical resistance surpassing pure titanium [28]. The reason behind the widespread use of titanium alloy and its being the preferred choice over stainless steel arises from the exceptional biocompatibility of this material. It has been proven that grade V titanium alloy is neither cytotoxic nor genotoxic [29], while featuring high strength, corrosion resistance, and low weight.

Still, in consideration of MS fracture and deflection, the micro and macro designs of MSs are factors of higher importance. The most extensively researched variable with a well-proven impact on MS mechanical strength is screw diameter. All reviewed studies remain consistent in results: fracture torque value increases with increasing MS diameter [1,3,4,9,11,22,26,27]. This relation might lead to the conclusion that MSs of 2 mm diameter should be predominantly recommended for clinical use. However, the application of such considerable-diameter MSs may not be possible in many cases due to insertion site requirements. Most commonly, MSs are inserted into the inter-radicular space. The often-limited inter-radicular site creates an additional risk of root contact during insertion for thicker MSs. As such, attempts to avoid periodontal (root) contact by changing the insertion angle may hinder the stability of the MSs [7]. In some cases, the extra-radicular areas can be recommended as an alternative location for MSs, such as the buccal shelf in the mandible or the infrazygomatic crest in the maxilla [9,27].

As for the MS length, the studies did not confirm its influence on fracture or flexural strength [21]. Thus, the choice of longer MSs should be a matter of insertion site requirements rather than an aim to increase the mechanical strength of the implant, especially since length's overestimation, clinically resulting in the partial insertion of MSs, was proven to increase fracture risk upon MS loading [6].

The mechanical properties of the mini-implant are also attributed to the screw's shape. Higher values of fracture torque, and thus better mechanical resistance, can be attained by cylindrical or mixed designs as compared to tapered screws [5,6]. The mechanical inferiority of a tapered screw design could derive from the fact that the weakest part of an MS is the tip of the screw. The area of the tip presented in studies had significantly lower fracture torque values when compared to the MS neck [15]. Moreover, a deformation of the tip was the most commonly (84.5%) noted shape distortion in MSs retrieved from patients after clinical use [8]. The blunting of the tip results in its decreased cutting ability, which can strongly hinder the self-drilling efficacy of the screw.

An MS design that allows adequate self-drilling is clinically a highly desired feature as it simplifies the insertion procedure, removing the need for pre-drilling. However, in light of this review's findings, the safe placement of MSs without pre-drilling can only be attained at 1 mm or 2 mm thickness of the cortical bone. In the case of particularly dense bone or a cortical layer exceeding 3 mm, the increase in MS fracture risk leads to the recommendation of pre-drilling [17].

As in every surgical procedure for implant placement, the insertion of MSs must be preceded by microbiological control through proper sterilization processes. Despite the commercial availability of most MSs in single sterile packages, some require sterilization in the office. Steam sterilization proved to have no detrimental influence on insertion torque values, whereas dry heat sterilization affected mechanical resistance by lowering the fracture torque value [14].

Finally, amidst the articles included in this review, quite noteworthy are the publications exploring the possibility and limitations of reusing MSs. The aforementioned study by Chung et al. compared unused and retrieved MSs [8]. Besides tip deformation, surface composition analysis of used MSs found debris of carbon, calcium, and phosphorus. Thus, retrieved MSs exhibited decreased cutting ability due to deformation of the tip structure and surface contamination. MS reusability may also cause concern when tooth root contact occurs during the MS insertion and clinicians are advised to remove the screw and reinsert it in a better location. However, the analysis of retrieved MSs by scanning electron microscopy exhibited varying amounts of deformation and blunting at the MS tip and its threads on root contact [18]. Considering those results, the reusability of self-drilling MSs should be regarded with caution. The biomechanical risk associated with the increased insertion torque (MS fracture) and the biological consequences associated with the higher insertion torque (excessive insertion force may hinder soft tissue healing and may induce microcracks and bone damage) strongly advocates for the avoidance of the clinical use of retrieved mini-implants.

Limitations

A significant limitation of the articles included in this systematic review is the lack of clinical studies. Most experimental studies were performed in vitro, which streamlines the research process and allows researchers to fully control the study environment; however, it may not fully reflect the clinical conditions.

Also, the predominantly moderate and high risks of bias limit the quality of scientific evidence for application in clinical practice. Although a large number of keywords in different variations were used in as many as five databases, it could be possible that not all of the reports on the topic explored were found.

Moreover, a relatively small number of studies—twenty-two—met the highly specific inclusion criteria of this review. As more studies will be published in this field in the future, the conclusions made could be stated with more certainty.

5. Conclusions

Considering this study's limitations, the following conclusions could be drawn from the review:

- The most important factor influencing miniscrews' plastic deformation and fracture was screw diameter.
- The fracture and deflection resistance of MSs increased with diameter. The length did not influence MS properties significantly.
- Both length and diameter should be selected in accordance with the anatomical conditions of the clinical site.
- Partial insertion of the MS increases the fracture and deformation risk.
- The alloy used in MSs does not influence deformation or fracture significantly.
- If the cortical bone thickness of the insertion site exceeds 3 mm, pre-drilling is recommended.
- Orthodontic MSs should not be reused (tip deformation occurs and cutting ability is reduced, increasing the risk of fracture).
- High-quality clinical studies are needed for suitable scientific evidence on the subject of MS deformation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14135577/s1. Supplementary Material S1: Prisma 2020 Checklist, Supplementary Mate-rial S2: Prisma 2020 for Abstract Checklist [10].

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