REVIEW ARTICLE

Displacement of Mini-implants under Orthodontic Force Loading: A Systematic Review

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Abstract

Aim and objective: To critically evaluate the displacement of orthodontic mini-implants (MIs) under orthodontic force loading.

Materials and methods: This trial has been registered to PROSPERO and the registration number is CRD42020150084. An electronic search was done and two independent authors (SS and AKS) screened the initial titles and abstracts to find all the eligible studies in PubMed, Cochrane library, Google Scholar Beta, LILACS from 1950 until June 26, 2020, using the terms orthodontic treatment, temporary anchorage devices, loading behavior, reactive force, stability, primary displacement, migration, dislodgement, loss of anchorage drift, primary stability, loosening, drift characteristics, movement, deflections, biomechanical effect, and randomized controlled trial. The assessment of articles was done using selection criteria. According to the PICOS (population, intervention, comparison, outcome, study design) criteria, the inclusion criteria were worked out. This review took into consideration only randomized and non-randomized trials, and prospective clinical studies were included. We used standard methodological procedures for selecting studies, collecting data. The risk of bias was evaluated and findings were synthesized.

Results: Of the 28 initial records identified, a total of 12 studies were included in this review. One study had a poor risk of bias and the remaining 11 studies had moderate to good overall risk. Of the parameters evaluated for displacement, mobility, root approximation of the MIs, the results showed that there was a displacement of MIs but clinically not often relevant to cause failure or complication in treatment.

Conclusion: From this review, it can be concluded that there is a displacement of the MI under orthodontic force loading. The primary displacement of the MIs did not appear to be clinically relevant to failure and mobility.

Clinical significance: There is a primary displacement that occurs during the loading of MIs and even in some cases secondary displacement. The position and direction of insertion of the MIs should be planned to keep in mind the migration in such a way that it does not interfere with the orthodontic tooth movement and vital structures.

Keywords: Displacement, Failure, Migration, Mini-implant, Mobility, Orthodontic force.

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Introduction

Anchorage planning is a priority when orthodontic treatment is being done. Skeletal anchorages have drawn the orthodontists' attention for the same. Mini-implants (MIs) are easier to place than mini-plate[1] which require a surgical procedure for placement and removal.[1] Their small size allows them to be placed almost anywhere, with only minimal surgery for placement and the surgical procedure is minor enough for evasion of inflammation.[2,3] Mini-implants thus provide maximal anchorage control and requires minimal patient compliance.[4,5]

The success rate of MIs is often called survival rate or stability. MIs are stabilized by mechanical interlocking of the cortical bone around the MI. Mini-implants offer the advantage of low cost and the placement of MI can be done in a single chairside clinical procedure. Mini-implants can be loaded immediately as there is no waiting period to allow for osseointegration.[6]

When an anchorage is adequately planned against orthodontic forces, teeth can be moved sufficiently. When anchorage planning is not done adequately then there will be reciprocal movement of the anchorage unit.[7] There is evidence that suggests that when the orthodontic forces are applied onto MIs they drift and migrate under loading.[8] Shorter MIs might be expected to subject the patient to less risk and discomfort during placement, but their stability remains to be established.[2] Primary stability is defined as implant stability immediately after insertion in the bone and is due to the mechanical contact between implant and bone, and also is dependent on factors like implant design, insertion angle, and bone density.[9–13]

In orthodontic treatment, the MIs when used as an anchorage unit are under constant load over a long period. Creep is a time-dependent viscoelastic displacement of bone under a constant load. Thus, it is likely that the viscoelastic creep following the elastic static displacement is an active form of displacement that occurs in the bone surrounding a MI under the functional orthodontic constant loading in the clinic.[14] Secondary displacement occurs over a treatment time and this can attribute

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to clinical scenarios where the MIs are in close root proximity and can even root resorption.[15]

Various pieces of evidence in the literature have reported a progressive migration of the implants upon orthodontic loading.[16] The main objective is to assess the clinical trials and prospective studies that evaluate the displacement, migration, or mobility of orthodontic MIs on the application of orthodontic force. The secondary outcomes that are assessed in this study are the mobility and failure of MIs.

This systematic review aims at the displacement of MIs by evaluating how strong is the mechanical interlocking of the MIs with the cortical bone and dislodgement or the drift characteristics of the MIs on the application of orthodontic force. The null hypothesis of this systematic review is that there is no displacement of MI when loaded for orthodontic treatment and the alternate hypothesis is there is a displacement of MI when being loaded for orthodontic treatment. The objective of the study was to assess the displacement, mobility, and root approximation of the MIs which were used as skeletal anchorage and were loaded during orthodontic treatment.

Materials and Methods

This trial has been registered to PROSPERO (International Prospective Register of Systematic Reviews) and the registration number is CRD42020150084 in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist of systematic reviews and meta-analyses.

Two independent authors (SS and AKS) screened the initial titles and abstracts to find all the eligible studies from 1950 until June 26, 2020, from PubMed, Cochrane library, Google Scholar Beta, and LILACS using the terms Malocclusion, orthodontic treatment, orthodontic tooth movement, orthodontic therapy, orthodontic appliance, orthodontic patients, temporary anchorage devices, Screw, mini-screw, mini-implant, skeletal anchorage, orthodontic anchorage, anchor loss, loading behavior, reactive force, stability, primary displacement, migration, dislodgement, loss of anchorage drift, primary stability, loosening, drift characteristics, movement, deflections, biomechanical effect, randomized controlled trial, NOT functional appliance, corticotomy, and microosteoperforation. The full texts were retrieved according to their inclusion and exclusion criteria. All differences of opinions were discussed and resolved. If necessary, the third author (NR) was consulted. The results were screened with title and abstract screening to select which studies will be included in this review. The references used in these studies were hand-searched to see if there were any clinical trials included.

The data were collected that were included based on the author's name, publication year, study type, subjects, interventions, age group, treatment time, method of measurements, and outcomes assessed. The data of studies that assessed MI displacement, mobility, and failure rates in MIs placed in subjects at various locations for skeletal anchorage were considered.[5,8,15–24] Two independent authors assessed the studies included for the studies and were discussed with the third author.

The eligibility criteria were defined based on the PICO research strategy for clinical practice based on scientific evidence. The inclusion criteria for this review included participants undergoing fixed orthodontic treatment and that use MI, the types of study designs included were randomized controlled trials, prospective and retrospective clinical trial; and the outcome measures taken into consideration were displacement and mobility of MIs under orthodontic force loading. The exclusion criteria for this systematic review were studies that were done *in vitro* or using FEM analysis or in animals, studies that used other modes of skeletal anchorage other than MIs, and studies that were conducted on patients below 14 years and older than 50 years.

Based on the exclusion criteria, we have excluded the studies that assessed the displacement of MIs but were not performed as clinical trials and did not assess these results in patients and were tested in artificial environment or simulation studies.[1,2,7,9,14,25–33]

Two independent authors assessed the risk of bias for all the studies included. A fourth author was asked for advice and the final decision was made.

The PRISMA flow diagram of the selection of studies is represented (Flowchart 1). The search strategy helped us retrieve the following number of records from databases: PubMed ($n = 81$), Google scholar ($n = 48$), and Cochrane ($n = 3$) totalling 132 studies. After deletion of duplicates, there were 79 records for the title and abstract reading of which a total of 45 were eliminated as they were not relevant to the topic or did not meet the inclusion criteria. After reading the full article, 12 articles were chosen for qualitative analysis (Table 1). Articles could not be considered for a quantitative meta-analysis given the heterogeneity of the included studies.

Randomized trials were assessed using the Cochrane Risk of Bias (RoB 2.0) tool, Higgins JPT 2016 which involves judgment on seven headings as formulated by the Cochrane Group.[34] The risk of bias for each of the domains and overall risk of bias was made as per the recommendations of the RoB 2.0 tool. Trials were classified overall as having a low risk of bias, some concerns of bias, or a high risk of bias as described in the RoB 2.0 tool. Non-randomized trials were assessed on Newcastle–Ottawa quality assessment scale.[35] The risk of bias for each of the headings and overall risk of bias was made as per the recommendations of the ROBINS-I tool.[36] Trials were classified overall as having no information, low risk, moderate risk, serious risk, or critical risk of bias (Fig. 1).

The possible influence of small study publication biases on review findings was considered and formed a part of the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) level of evidence (GRADEpro Guideline Development Tool, available online at gradepro.org).[37] The influence of small study biases was addressed by the risk of bias criterion "study size". Assessment of the quality of the body of evidence-based on Oxford's CEBM table.[38]

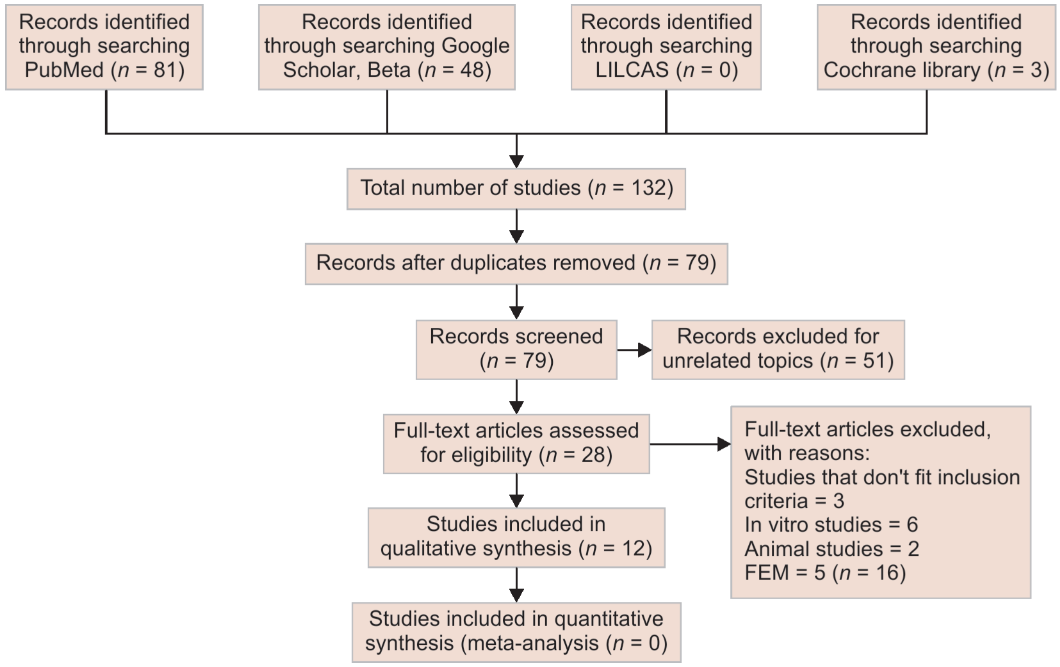
Results

Selection and Characteristics of Studies

The patients' age ranges from 11.5 to 48 years. The sample size ranges from 8 to 87 patients. The various methods of assessing displacement and primary stability in these studies included measurement of mobility using lateral cephalogram, periapical radiographs, computed tomography (CT), cone-beam CT (CBCT), and tweezers. Most of the articles assessed used the following techniques of checking the movement, mobility, extrusion, tipping of MIs, and assessing for root proximity (Table 1). All the studies assessed MIs for the duration of 1 month, 4 to 9 months, and/or during the full-time retraction.

Liu et al. assessed the movement of MIs in lateral cephalogram.[21] One prospective clinical trial followed up for 6 months used 3-dimensional (3D) analysis using CT scans. Alves et al.[17] and Son et al. assessed CBCT for analysis. The MI follow-up was started immediately, 1–2 weeks after the initial MI placement.[23] Among

Flowchart 1: PRISMA flow diagram



the various outcomes assessed from this review the method of retraction force application was done using NiTi coil springs and e chains to load the MIs. An adequate period of follow-up was observed in studies ranging from 1 month to up to 9 months in most studies whereas certain studies did not mention the period of follow-up.

Table 2 shows the evidence level selected studies and most of the studies had level 3 evidence and two studies had level 2 evidence.

Risk of Bias in the Studies–Newcastle–Ottawa Quality Assessment Scale

Liu et al. had a poor overall assessment.[21] The Newcastle–Ottawa scale as shown in Table 3, four articles had a good overall assessment, three articles had a moderate overall scale based on selection, comparability, and outcome (Table 4).

Risk of Bias in the Studies–Cochrane RoB 2.0 Tool

In the study (Fig. 1) by Hedayati et al., there was low risk.[5] The other included studies had an unclear risk due to missing outcome data. Quality score was a risk of uncertain bias.

In terms of displacement observed from these trials, it can be assessed as horizontal displacement and vertical displacement. Horizontal displacement has been assessed either as the entire screw or according to the region as head, body, and the tail and was observed from 0.1 to up to >1 mm. The vertical displacement was assessed as extrusion of the MI was recorded from 0.1 to 0.8 mm. Hedayati et al. and Wang et al. studies showed an increased extrusion of 0.5 to 0.8 mm. Certain studies such as that of Kinzinger et al. had assessed the angular displacement as tipping off the MI up to 6° from its original insertion. The secondary parameters assessed were mobility and root approximation.

Assessment of Quality of Evidence

The GRADE evidence profile table is shown in Table 3. The evidence for the outcomes evaluated ranged from low to moderate quality suggesting that the report can differ from the measures evaluated.

Discussion

Absolute anchorage is when there is no movement of the placed MI due to the reactionary force that is applied to move the teeth.[39] Skeletal anchorage aims at achieving an absolute anchorage. In this review, we aim at assessing if the MIs or screws used as skeletal anchorage in orthodontics migrated or displaced as a reciprocal reaction to the force applied. According to Newton's law which states that for every action in nature there is an equal and opposite reaction. It is nature's action to have a reactionary force on the MI when another force is applied to the implant in the opposite direction of its mechanical engagement to the bone.

Many factors are the cause for MI displacement. Mini-implants require some kind of surgical intervention and no implant can be directly placed and force applied through elastics.[40]

The implant factors that affect the rate of stability of an implant can be numerous. Implants can be self-drilling or self-tapping MIs and in the maxilla, there has been reported more successful use of self-tapping, as there are higher failure rates and more chance of mobility in self-drilling.[41] In orthodontic MIs, there have been attempts made to modify the implant surface like sandblasting, etching to improve their stability throughout the treatment period.[18] This is also based on the fact that this anchorage influences the orthodontic treatment and tooth movement.[42] Motoyoshi et al. stated that abutment was effective in raising initial implant stability.[43] Hedayati et al. extensively studied the MIs and stated that titanium screws are better for anchorage as in orthodontic treatment the MIs are loaded for 6–7 months and continuously loaded to 150–200 g.[5]

The next set of factors to be taken into consideration about the stability of implant is its placement-related factors. Liu et al. suggested that a mesial site for MI placement will be a better choice for its long-term stability.[21] Łyczek et al. conducted a study that tested antibiotic prophylaxis for MI success but they did not report any statistically significant success.[22] El-Beialy et al. reported that the vertical placement angle and the length of the MI did not determine its success.[19] If a drill needs to be used to place MIs, it is

Table 1: Individual study characteristics

Study	*Study design*	*Sample size*	*Age*	*Intervention*	*Force application*	*Time of loading*	*Time interval*	*Outcome assessed*	*Displacement*	*Measuring method*	*Statistical analysis*
Liou et al. 2004[8]	Retrospective study	16 patients	22–29 years	32 mini-screws	NiTi coil spring–150 g	Immediately	9 months	Movement of mini-implants	Horizontal head: 0.4 ± 0.5; Body: 0.1 ± 0.3; Tail: −0.1 ± 0.5; Extrusion 0.1–0.2	Lateral cephalogram	Paired *t*-test; error analysis
Park et al. 2006[23]	Retrospective study	87 patients	15.5 years	227 screws of 4 types	Power chain or super thread or NiTi coil spring-200 g	Not specified	Not mentioned	Mobility	3.203 odd ratio	Cotton tweezers	Student *t*-test; Chi-square test; logical regression test
Hedayati et al. 2007[5]	Prospective randomized control trial	19 patients (2 groups)	15.5–19 years	9 maxilla; 18 mandible	NiTi coil spring −180 g	7–11 days after insertion	Start to end of retraction	Movement of screw	Horizontal: 0–0.25; extrusion–0.5–0.8	Lateral cephalogram	Paired *t*-test; Chi-square test
Wang et al. 2008[16]	Retrospective study	32 patients	18-48 patients	64 mini-screws	NiTi closed coil spring–200–400 g	2 weeks after placement	5 Months	Displacement of mini-screw tail, body, and head	Head: 0.7–0.8; Body: 0.4–0.5; Tail: 0.2–0.3; Extrusion–0.5–0.8	Lateral cephalogram	Paired *t*-test; Student's *t*-test; Correlation coefficient
Kinzinger et al. 2008[20]	Retrospective study	8 patients	12.2 years	16 mini-screws	Not specified–200–240 cN	1 week after placement	6.5 months	Movement, tipping, and extrusion of mini-implant	Head: 0.95 ± 0.82; Tipping: 2.65 ± 6.23°; Extrusion: 0.21± 0.28	Lateral cephalogram	Paired *t*-test
El-Beialy et al. 2009[19]	Prospective trial	12 patients	Not specified	22–maxilla; 18–mandible	Not specified–150–250 g	2 weeks after placement	6 months	Movement of mini-implants, implant head, and tail, extrusion of mini-implant	Head: 1.08; Tail: 0.828; Extrusion 0.548	3D volumetric analysis of CT scans	Paired *t*-test; Correlation coefficient
Türköz et al. 2010[44]	Prospective randomized clinical trial	62 patients	11.5–19.9 years	112 titanium mini-implants (3 groups)	Not specified–200 g	2 weeks after placement	1 month and till the end of treatment	Root approximation	Not specified	Periapical radiograph	*Z* tests
Calderón et al. 2011[18]	Prospective clinical trial	13 patients	Age not specified	24 Mini-screws	NiTi closed coil spring–150 g	4 weeks after placement	4 months	Angular displacement	More than 1° tipping in 65% mini-screws	Occlusal radiographs	Non-parametric ANOVA
Alves et al. 2011[17]	Prospective clinical trial	15 Patients	29.7–31.4 years	41 mini-implants	Not specified–200 g	Next day after insertion	5 months	Displacement, mobility	Head: 0.29–0.78; Tail-0.27–0.6; Extrusion not mentioned	3D Reconstruction of CBCT scans	Descriptive statistics
Liu et al. 2011[21]	Retrospective study	60 patients	19–27 years	No	Elastic chain–150 g	Not specified	Start to end of space closure	Drift displacement of mini-screw head and tail	Head: 0.23 ± 0.08; Tail: 0.23± 0.07; Extrusion–not mentioned	FEM analysis using whole skull CT	Descriptive statistics
Son et al. 2014[24]	Prospective study	70 patients	16–31 years	140 Screws (2 groups) Self drilling and self-tapping	Not specified–2 newton's	Immediately after placement	Not specified	Mini-screws mobility; root contact	17.9–22.9	Periotest values CBCT	Descriptive statistics
Łyczek et al. 2018[22]	2 Arm parallel pilot RCT	38 Patients	Not specified	76 Screws	Not specific–200 g	1 week after placement	Not specified	Stability of mini-implants	4% failure	Cotton tweezers	Descriptive statistics

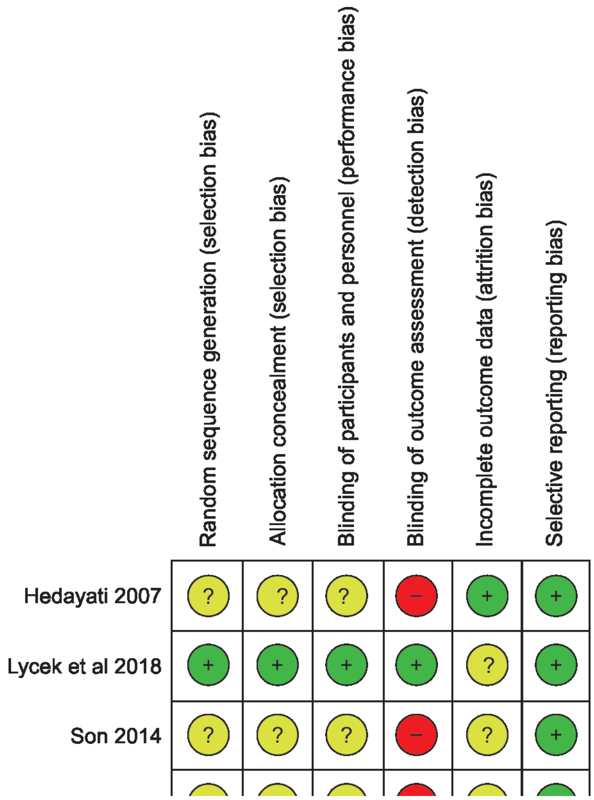


Fig. 1: Risk of bias graph for included RCT–COCHRANE RoB 2.0 Tool

Table 2: Evidence level of selected studies

No	*Author and year*	*Study design*	*Level of evidence*
1	Liou et al. 2004	Retrospective clinical trial	Level 3
2	Park et al. 2006	Retrospective clinical trial	Level 3
3	Hedayati et al. 2007	Prospective randomized control trial	Level 2
4	Wang et al. 2008	Retrospective clinical trial	Level 3
5	Kinzinger et al. 2008	Retrospective clinical trial	Level 3
6	El-Beialy et al. 2009	Prospective clinical trial	Level 3
7	Turkoz et al. 2010	Prospective randomized clinical trial	Level 2
8	Calderon et al. 2011	Prospective clinical trial	Level 3
9	Alves et al. 2011	Prospective Clinical trial	Level 3
10	Liu et al. 2011	Retrospective clinical trial	Level 3
11	Son et al. 2014	Prospective randomized clinical trial	Level 3
12	Lycek et al. 2018	2 arm parallel pilot RCT	Level 2

Table 3: Grade working group grades of evidence

Mini-implant dislodgement with [orthodontic loading] when used for [skeletal anchorage]			
Patient or population: [Orthodontic patient] who need [Maximum Anchorage]			
Settings: [Dental practice]			
Intervention: [Orthodontic mini-implant]			
Outcomes	No. of studies	Quality of the evidence (GRAD)	Comments
Mini-implant dislodgement Mobility of mini-implant	12	⊕⊕⊕⊖ moderate	Displacement or mobility did not appear to be clinically relevant. Most of the studies confirmed that significant secondary displacement occurred under orthodontic loading over time.

*The basis for the assumed risk (e.g., the median control group risk across studies) is provided in footnotes. The corresponding risk (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

GRADE Working group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

better to place with smaller diameter drills to contribute to better clinical stability.[24] Migliorati et al. noted that torque values play an important role in the stability of the MIs; early torque decrease after implant placement suggests relaxation phenomenon and the implant is stable for a longer period.[26] Higher values of torque may result in higher failure rates because of bone compression and microdamage and can also cause fracture of the MIs. Chatzigianni et al. stated that at higher force levels, longer and wider MIs are less displaced.[9] Brettin et al. suggested that bicortical MIs for better resistance when compared with monocortical skeletal anchorage.[31] Pickard et al. stated that even though the MI is only as small as 6 mm, there are chances that the lingual cortex is reached during placement, for maximum stability and resistance to failure the MI should be loaded along its long axis.[30]

Park et al. explained various factors such as the host and the environment that determine the stability of the MIs.[13] They reported more mobility and failure in the right side and the mandible when compared to the left side and maxilla. Lee et al. reported the effect of hygiene in the right and left side due to right-handedness and the better the hygiene there is less chance of inflammation which allows for a better chance of success of the orthodontic MIs.[12] Park et al. commented on the direction of loading as an important factor that influences if the implant gets displaced on loading.[13] Singh et al. found out that there is a winding movement of MI upon orthodontic loading.[33]

On assessing the displacement or the absoluteness of the anchorage, Moon et al. concluded that most displacements of orthodontic MIs happened in the initial 2 months and failure occurred within 4 months.[27] Alves et al. studied the migration of MIs by measuring the movement of the head and the tail of the

Table 4: Risk of bias: Newcastle–Ottawa quality assessment scale–cohort studies

Study	*Selection*	*Comparability*	*Outcome*	*Overall*
Liou et al. 2004	**	–	**	Poor
Park et al. 2006	**	*	***	Good
Wang et al. 2008	**	*	**	Moderate
Kinzinger et al. 2008	***	–	**	Moderate
El-Beialy et al. 2009	***	–	***	Good
Calderon et al. 2011	**	–	**	Moderate
Alves et al. 2011	***	*	***	Good
Liu et al. 2011	***	–	***	Good

MIs under orthodontic force loading and that the displacement was of less clinical relevance regarding its dimensions and the mechanics of movement.[17] Kinzinger et al. stated that titanium MIs did not provide a stable anchorage for molar distalization.[20] Park et al. stated that even slightly mobile MIs could withstand force application below 200 cN.[13] Wang et al. stated that there was movement in both the predrilling and self-drilling MIs on orthodontic force loading.[16] The pattern of the displacement or the movement of MI is extrusion, controlled or uncontrolled tipping or bodily movement, and also the displacement of the MI on the right and left side of the same patient need not be the same. The longer the loading period on the MI, the more horizontal displacement occurred, the MI should be placed with a 2 mm of clearance from the tooth roots and the surrounding vital structures.

The limitation of this study is that this review provides an insufficient explanation. From the evidence we assessed, on force application on MI causes dislodgement and drifting of mini-implants and hence it would be safer to evaluate the inter-radicular space before MI is being planned for skeletal anchorage, but no quantitative data can be given on the amount of displacement. Further reviews are needed to evaluate the individual factors that attribute to the displacement of MIs and the success of MIs. More well-planned clinical trials involving MIs success and its factors need to be assessed.

From this systematic review, we can conclude that the MIs provide adequate anchorage when an absolute anchorage is planned in orthodontics. There is primary displacement or mobility that occurs and from these included studies we can confirm that a significant level of secondary displacement and migration of the MI occurs on functional orthodontic loading. Considering that there is a reciprocal movement of the MI, the direction, and position of insertion of the MI should be planned.

Conclusion

From evaluating the articles included based on our inclusion criteria in this review, we conclude that there is a displacement of the MI under orthodontic loading and application of force. The studies that we assessed have different methods of evaluation and these warrants for randomized controlled trials with an adequate sample size by estimation of the power of the study, proper randomization technique, and a standard technique for assessing the displacement of the MI will improve the strength of evidence. We can conclude that MIs provide adequate anchorage during orthodontic treatment because the primary displacement of the MIs did not appear to be clinically relevant to failure and mobility.

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