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REVIEW

Systematic review of mini-implant displacement under orthodontic loading

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A growing number of studies have reported that mini-implants do not remain in exactly the same position during treatment, although they remain stable. The aim of this review was to collect data regarding primary displacement immediately straight after loading and secondary displacement over time. A systematic review was performed to investigate primary and secondary displacement. The amount and type of displacement were recorded. A total of 27 studies were included. Sixteen *in vitro* studies or studies using finite element analysis addressed primary displacement, and nine clinical studies and two animal studies addressed secondary displacement. Significant primary displacement was detected (6.4–24.4 μm) for relevant orthodontic forces (0.5–2.5 N). The mean secondary displacement ranged from 0 to 2.7 mm for entire mini-implants. The maximum values for each clinical study ranged from 1.0 to 4.1 mm for the head, 1.0 to 1.5 for the body and 1.0 to 1.92 mm for the tail part. The most frequent type of movement was controlled tipping or bodily movement. Primary displacement did not reach a clinically significant level. However, clinicians can expect relevant secondary displacement in the direction of force. Consequently, decentralized insertion within the inter-radicular space, away from force direction, might be favourable. More evidence is needed to provide quantitative recommendations.

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INTRODUCTION

To withstand the reactive forces that occurred during tooth movement and prevent negative side effects, a stable anchorage unit is necessary.[1–2] New solutions to provide sufficient anchorage have become feasible with the use of skeletal anchorage.[3–6] In the last few years, mini-implants in particular have become increasingly popular for anchorage reinforcement.[7–9] Mini-implants have proved to provide reliable anchorage in various clinical situations.[10–11] Their versatility has made new types of mechanics and treatment options possible.[12–13] Regarding orthodontic mini-implants, current meta-analyses have reported a success rate of 83.6%.[14–15]

A basic requirement for success is sufficient primary stability.[16] Different factors affecting primary stability have been reported in the literature:

First, a region with high bone quality should be chosen.[17] The bone should be covered with a thin, attached mucosa to allow for sufficient insertion depth.[18] Additionally, different aspects concerning insertion protocol should be considered.[18–20] Regarding the implant design, increased diameter[21–22] and length[23–24] have resulted in longer survival rates and greater stability.[25] In these studies, success rate has been defined as ‘survival rate’ or ‘remaining stable’.

Being integrated into the surrounding bone, endosseous implants remain absolutely stationary when orthodontic force is applied.[26–27] Correspondingly, mini-implants are also often considered to offer absolute anchorage. This assumption applies that they do not move in the direction of force and therefore prevent movement of the anchorage unit.[28–29]

However, Liou *et al.*[30] suggested that orthodontic mini-implants did not remain in their positions under orthodontic loading although they remained stable. Regarding mini-implant displacement, it can be differentiated between direct, primary displacement, due to elastic characteristics of the bone and periodontal structures and migration or secondary displacement under loading over the treatment time caused by remodelling processes. These phenomena can cause clinical problems:

The alveolar ridge is the most common insertion site for orthodontic mini-implants.[14–15] Root contact and close proximity to the roots are well-known risk factors for mini-implant failure.[31–32] Direct root contact or even a proximity of less than 0.6 mm between the mini-implant and root surface can also cause root resorption.[33–34] These complications may also occur when mini-implants are displaced during treatment.

The question that arises is whether orthodontic mini-implants are really displaced by orthodontic force. What are the dimensions of primary displacement, due to elastic characteristics of the implant supporting structures, and of secondary displacement, caused by bone remodelling under loading? Which of the aforementioned factors regarding primary stability can affect mini-implant displacement? Are there new suggestions regarding the required space for insertion?

To answer these questions, a systematic review was performed.

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MATERIALS AND METHODS

A search was performed using PubMed and Scopus up to the end of July 2013. The aim was to identify all papers dealing with orthodontic mini-implants and primary and/or secondary displacement. Primary or direct displacement was defined as follows: immediate displacement of a mini-implant loaded with force due to the elastic and plastic properties of the bone. Secondary displacement, i.e., migration was defined as follows: long-term displacement of a mini-implant loaded with force due to the remodelling processes of the bone. The search strategy is shown in Figure 1.

From the articles found using the keyword search, those articles meeting the inclusion criteria were included. One additional study was found by hand searching.

The inclusion criteria were

- published in either the German or English language;
- measurement of mini-implant displacement;
- a clear description of study design; and
- reproducible measuring methods.

All of the articles were selected independently by each author regarding their content. Only studies quantifying displacement were included. These papers were divided into articles dealing with primary displacement and those dealing with secondary displacement.

In the primary displacement group, *in vitro* studies using both human jaws and animal bone were included. Additionally, studies using finite element analysis for the simulation of primary displacement were evaluated and compared with the *in vitro* results.

In addition to the range of displacement, the insertion site, size and design of the mini-implants were considered.

In the secondary displacement group, only clinical and animal studies were included. Regarding clinical trials, prospective, as well as retrospective, studies were selected, whereas case reports and review articles were excluded.

Clinical and animal studies were judged according to their study designs. Data were collected regarding the accuracy of the measurement method, adequacy of the method error analysis, statistical analysis and sample size.

For the analysis of secondary displacement, the mean and maximum horizontal and vertical displacements were measured. Whenever possible, the type of mini-implant movement was assessed.

Insertion site and technique, as well as the size and design of the mini-implants, were considered. Articles were also evaluated regarding healing period, level of force, loading time and rate of mini-implant failure. Concerning orthodontic treatment, anchorage modes and indications for skeletal anchorage were recorded.

RESULTS

The systematic search by keywords resulted in 68 hits (Figure 1). A total of 63 articles were published in English or German. Application of the inclusion and exclusion criteria led to 26 relevant articles. One additional clinical study was identified by hand searching, so a total of 27 articles were included.

Sixteen papers were found dealing with primary displacement; these papers included *in vitro* studies with different types of bone (n=9) and studies using finite element analysis for the simulation of mini-implants in bone (n=7). The 11 articles regarding secondary displacement were divided into clinical studies (n=9) and animal studies (n=2).

Primary displacement

In vitro studies[35–36] reported a primary displacement of less than 0.5 mm using forces of up to 20 N (Table 1). Akyalcin *et al.*[37] reported of force levels of 56–98 N to achieve a displacement of 1 mm. Focusing on forces relevant for orthodontic treatment (0.5–2.5 N), displacement ranged from 6.4 to 24.4 μm.[38–43] Holst *et al.*[39] observed significant displacement beyond elastic recovery of the surrounding bone. Consistently, Pittman *et al.*[43] reported residual displacement after 2 h of loading after being unloaded again. Bicortical placement reduced displacement.[36] Within the results of *in vitro* studies, different insertion angles did not affect the level of deflection.[38] Regarding mini-implant design, Su *et al.*[40] found no differences between self-tapping and self-drilling screws. Size and shape seemed to play roles in general, with less displacement for larger and conical designs.[39] In contrast, Chatzigianni *et al.* observed no differences regarding size for low forces (<0.5 N). These authors also compared

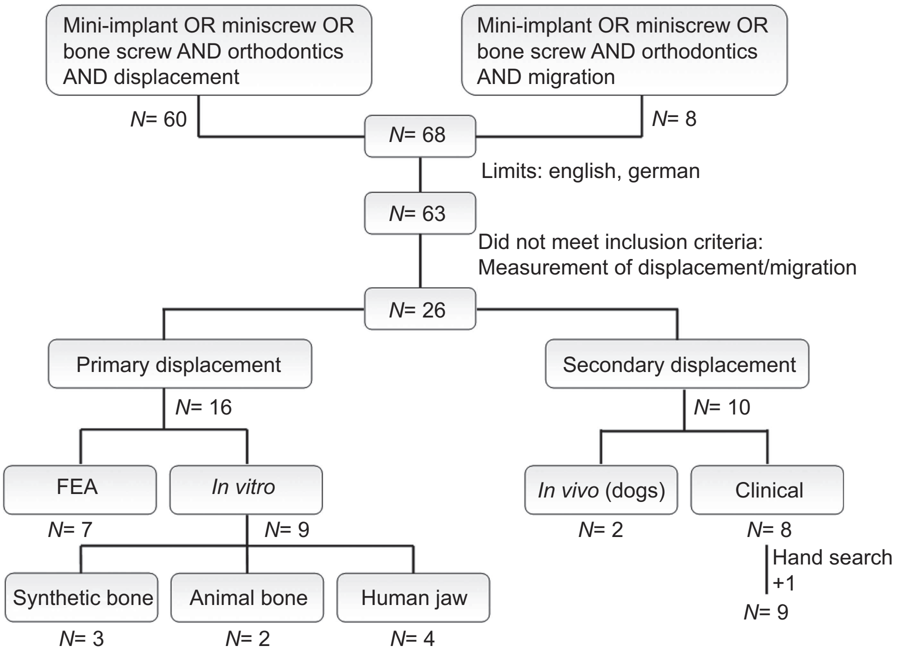

Figure 1 Search strategy and results. *N*, number of studies found.

Table 1 Results of the *in vitro* and finite element studies regarding primary displacement

Studies	Bone	Insertion region	*n*	Implant size/ (mm×mm)	Force/N	Primary displacement/mm
In vitro						
Holst *et al.* 2010	Human	Alveolar ridge; maxilla	39	n/a	2.5	0.02–0.25
Morarend *et al.* 2009	Human	Alveolar ridge; maxilla+mandible	96	2.5×17; 1.5×15	10	<0.3
Brettin *et al.* 2008	Human	Alveolar ridge; maxilla+mandible	44	1.5×15	20	<0.5
Pittman *et al.* 2013	Human	Basal part; mandible	26	1.5×6	0–2	<0.025
Su *et al.* 2009	Ilia of country pigs		54	1.6×8	2	0.024 4
Chatzigianni *et al.* 2011	Bovine rib		n/a	1.5×7; 1.5×9; 2×7	0.5	⩽0.006 4
Hong *et al.* 2010	Biosynthetic bone		20	1.5×6	>2	0.01
Hong *et al.* 2011	Biosynthetic bone		100	1.3×5.5; 1.9×6.1	>2	0.02
Akyalcin *et al.* 2013	Biosynthetic bone		120	1.4×8; 1.5×8	1.1–98.5	0.025–1.0
Finite element						
Jang *et al.* 2011				1.6×7	2	0.000 87–0.001 00
Motoyoshi *et al.* 2005				1.4×4	2	0.000 173–0.000 185
Chang *et al.* 2012				2×9.82	3	0.219–0.315
Singh *et al.* 2012				2.48× 6.86	0.35	⩽0.000 916
Liu *et al.* 2012				(1.2–2.0)×(7–15)	2–6	0.001–0.003
Lee *et al.* 2013				n/a	8	0.001 275–0.001 582

n/a, data was not available.

between *in vitro* and finite element analysis (FEA) studies. Their results indicated that FEA was feasible for the simulation of an *in vitro* situation.

Using FEA, most of the authors reported little displacement ranging from 0.173 to 0.919 µm.[44–47] Only Chang *et al.* observed displacement of up to 0.315 mm, although the level of force was comparable.[48] Comparing the results of different studies, the use of larger mini-implants did not seem to result in less displacement. However, within the same finite element model, size significantly affected the level of displacement, although a comparison of quantitative data between different finite element models could not be performed.[47] There was no effect of modifying the thread pitch,[45] whereas greater depth of the threads resulted in greater displacement.[48] Liu *et al.*[47] noted that the ratio between the inserted and external parts of the mini-implant was one of the most important factors affecting displacement. In contrast to the results of *in vitro* studies, insertion angle affected lateral displacement in a FEA study.[49]

Secondary displacement

The study design of the selected, mostly uncontrolled clinical trials appeared appropriate (Table 2). All of the studies used image-based radiographic techniques, with superimposition of pre- and post-treatment data, for the evaluation of mini-implant displacement. Superimposition was performed by means of stable structures. Three three-dimensional techniques were chosen. Five investigations were based on lateral cephalograms. Only one study used occlusal X-rays. Method error, according to Dahlberg,[50] was performed in four studies. The statistical analysis was adequate.

In all of the clinical studies, the mini-implants were loaded with horizontal force and comparable force levels ranging from 1.5 to 2.5 N (Table 3). Except for one study, in all of the studies, a direct anchorage mode was used. The loading period ranged from 5 to 8.5 months. The healing period ranged from 0 to 28 days; whereas most authors waited

Table 2 Study designs of clinical trials

Studies	Study design	Type of study	Sample size calculation	Measuring method	Method error	Special analysis	Statistics
Clinical							
Liou *et al.* 2004	CT	Retrospective	No	Superimposition; cephalogramms	Yes	—	Adequate
El-Beialy *et al.* 2009	CT	Prospective	No	Superimposition; dental CT	No	Measured twice after 2 weeks	Adequate
Liu *et al.* 2011	CT	Retrospective	No	Superimposition; dental CT	Yes	Point registration three times; measured twice; mean	Adequate
Alves *et al.* 2011	CT	Prospective	No	Superimposition; CBCT	No	Measured twice; mean	Adequate
Wang *et al.* 2006	CT	Retrospective	No	Superimposition; cephalogramms	Yes	—	Adequate
Hedayati *et al.* 2007	RCT	Prospective	No	Superimposition; cephalogramms	No	Measured twice; mean	Adequate
Calderon *et al.* 2011	CT	Prospective	No	Superimposition; occlusal X-ray	No	Cone beam CT for calibration	Inadequate
Lifshits *et al.* 2010	CT	Prospective	No	Superimposition; cephalogramms	Yes	—	Adequate
Kinzinger *et al.* 2008	CT	Retrospective	No	Superimposition; cephalogramms	No	Measured twice; mean	Adequate
Animal							
Mortensen *et al.* 2009	CT	Prospective	No	Clinical measurement with digital calliper	No	Repeated measurements	Adequate
Ohmae *et al.* 2001	CT	Prospective	No	Superimposition of dental radiographs	No	—	Descriptive

CT, clinial trial (without control group); RCT, randomized controlled clinical trial.

Table 3 Results of the clinical trials regarding secondary displacement

	Clinical studies									*In vivo* animal studies	
Studies	Liou *et al*., 2004	El-Beialy *et al*., 2009	Liu *et al*., 2011	Alves *et al*., 2011	Wang *et al*., 2006	Hedayati *et al*., 2007	Calderon *et al*., 2011	Lifshits *et al*., 2010	Kinzinger *et al*., 2008	Mortensen *et al*., 2009	Ohmae *et al*., 2001
Patients or animal	Age: 22–29 Gender: 16F	n/a	Age: 19–27	Age: 29–31 Gender: 10F; 5M	Age: 18–48 Gender: 32F	Mean age: 17.4	Gender: 7F; 6M	n/a	Mean age: 12.2 Gender: 2F; 6M	Male beagle dogs: 10–15 month	Male beagle dogs: 19–26 month
Patients number	16	12	60	15	32	9	13	6	8	5	3
Mini-implants/ (mm×mm)	2×17	1.2×8	1.6×11	1.4×8; 2×6	2×17; 2×(10–14)	2×11; 2×9	6; 8–10	1.6×6	1.6×(8–9)	1.3×6; 1.3×3	1×4
Mini-implants number	32	40	120	41	64	27	24	12	16	40	18
Insertion site	Zygomatic buttress	Buccal alveolar ridge; maxilla/ mandible	Buccal alveolar ridge; maxilla	Palatal/ buccal alveolar ridge; midpalatal	Infrazygomatic crest	Midpalatal; buccal alveolar ridge; mandible	Buccal alveolar ridge; maxilla/ mandible	Buccal alveolar ridge; maxilla	Anterior palate; paramedian	Alveolar ridge: buccal mandible; palatal maxilla	Alveolar ridge; mandible; palatal/buccal
Predrilling	1.5 mm diam.	Yes, n/a	n/a	Cortical bone perforation	1.5 mm diam. for 2 mm× 17 mm	2 mm diam.; cortical bone	n/a	n/a	No	No	1.5 mm diam. in cortical bone; 0.9 mm diam. in spongiosa
Healing period/d	14	14	n/a	1	14	7-11	28	No	7	Direct	42
Force	(1.5+2.5) N; NiTi spring	1.5–2.5 N; NiTi spring	1.5 N; elastics	2 N	NiTi, 'heavy force'	1.8 N; NiTi spring	⩽1.5 N; NiTi spring	2 N	2.0–2.4 N; NiTi spring	(6+9) N	1.5 N; NiTi spring
Anchorage mode	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Indirect	Direct	Direct
Indication	Retraction upper front	Upper/lower canine retraction	Retraction upper front	Upper molar intrusion	Retraction upper front	Upper/ lower canine retraction	n/a	Retraction upper front	Molar distalization	–	Premolar intrusion
Loading period/ month	8.5	6	6	5	5	6.4	6	6	6.4	1.5	0.75
Implant loss	0	7	n/a	6	0	5	4	1	n/a	10	n/a
Secondary displacement, horizontal; mean/ mm	Head: 0.4±0.5 (s); Body: 0.1±0.3; Tail: -0.1±0.5	Head: 1.08; Tail: 0.828	Head: 0.23±0.08; Tail: 0.23±0.07	Head: 0.29–0.78; Tail: 0.27–0.6	Head: 0.7–0.8; Body: 0.4–0.5; Tail: 0.2–0.3	Overall: 0–0.25	65%⩽1° tipping; 35%⩾2°	Overall: 2.7±2.1	Head: 0.95±0.82; Tipping: (2.65±6.23)°	1.8–2.2	No movement
Secondary displacement, horizontal; max/ mm	Head: 1.0; Body: 1.0; Tail: -1.0–1.0	Head: 4.1; Tail: 1.8	n/a	Head: 1.72; Tail: 1.92	Head: 2.0; Body: 1.5; Tail: -1.0–1.5	n/a	n/a	5.5	n/a	3.4–4.4	–
Secondary displacement, vertical/mm	Extrusion: 0.1–0.2	Extrusion: 0.548	n/a	n/a	Extrusion: 0.5–0.8	Intrusion/ extrusion: -0.5–0.25	–	Extrusion: 0.2±2.7	Extrusion: 0.21±0.28	n/a	–

F, female; M, male; diam., diameter; n/a, data was not available.

7–14 days until loading. The mean secondary displacement of the entire mini-implants ranged from 0 to 2.7 mm with maximum values of up to 5.5 mm.[51–52] Studies differentiating the movement of the mini-implants' parts observed mean displacements of 0.23–1.08 mm for the head part, 0.1–0.5 for the body and 0.1–0.828 mm for the tail. The maximum values ranged from 1.0 to 4.1 mm for the head, 1.0 to 1.5 for the body and 1.0 to 1.92 mm for the tail part. Two studies also investigated a tipping angle ranging from 1.0 to 2.65°.[53–54] The mean extrusion of the mini-implants ranged from 0.1 to 0.8 mm, with only one author reporting intrusion of up to 0.5 mm.

The two animal studies were performed using mature male beagle dogs. The first study confirmed that secondary displacement occurred.[55] Using small screws loaded with high forces up to 9.0 N, the mean movement was 2.2 mm within 6 weeks. In the second study, no movement beyond measurement inaccuracy was observed using superimposition of dental X-rays.[56]

DISCUSSION

Regarding primary displacement, the studies evaluated whether there was significant movement immediately after loading, even beyond elastic recovery of the surrounding bone.[39,43] With movement dimensions of less that 0.1 mm in most of the studies, no direct clinical consequences of primary displacement could be observed.[38–42] However, the factors possibly affecting primary displacement might be fundamental for further research regarding secondary displacement. Aspects such as corpus[39] or thread design,[57] which seem play important roles in this regard, might be interesting starting points for future investigations.

Clinical studies have varied in many factors, such as implant dimension, insertion protocol, insertion site or types of patients, making it very difficult to compare the influence of one parameter regarding secondary displacement between studies. Within the studies, only one or two parameters were used as variables.

The current results of clinical investigations suggest that the size of the mini-implant and the insertion site play important roles.[53] The most important factor seems to be loading duration, whereas the amount of force seems to be less important, as long as it does not exceed normal orthodontic levels.[58] Moreover, there was no significant difference between self-tapping and self-drilling mini-implants.[58]

Liu reported that movement of stable mini-implants could not be explained by a periodontal pressure-tension concept.[59] He discussed the mechanostat theory of Frost,[60–61] which is based on peak strain of dynamic loading controlling the remodelling processes. Therefore, he recommended finite element analysis to evaluate the stress and strain distributions in the surrounding bone. Nevertheless, the exact mechanism remains ambiguous. In this context, further investigations regarding the influence of different healing periods would be desirable. Liou *et al.*[30] discussed whether a healing period of 2 weeks was too short to obtain sufficient osseointegration. Perhaps a treatment of the mini-implants' surface might affect the process of osseointegration and therefore the displacement behaviour, as suggested by Calderon *et al.*[53]

However, all authors have affirmed that mini-implants provide good anchorage quality regarding orthodontic treatment. Nevertheless, all of the studies except one confirmed that significant secondary displacement occurred. The level of displacement is clinically relevant regarding interference with anatomical structures. The mean values for the displacement of the whole mini-implant ranged from a mean displacement of 0 to 2.7 mm.[51–52] However, in every study that quoted the maximum displacement, the values were at least 1.0 mm ranging up to 5.5 mm.[30,51,58,62–63] Therefore, the clinician must expect significant displacement.

Regarding the type of movement Wang *et al.*[58] stated that 71.9% of mini-implants showed a controlled tipping or bodily movement, only 15.6% showed uncontrolled tipping, and 12.5% showed no movement. Additionally, results of studies differentiating the movement of mini-implants' parts have suggested that controlled tipping and bodily movement are the most common types of movement. Whereas maximum movement of the head mostly ranged between 1.0 and 2.0 mm in the force direction, the movement of the tail ranged up to 2.0 mm in the same direction and was no more than −1.0 mm in the opposite direction.

Poggio *et al.*[64] recommended a distance of 1 mm between the mini-implant and the root surface, whereas Liou *et al.*[30] advised 2 mm for safe clearance. Due to missing evidence and the lack of data from well-designed clinical studies, no quantitative recommendations regarding safe distances have been offered. However, there is consensus regarding the appearance of clinically significant secondary replacement. The current results regarding the type of movement suggest it might be favourable not to insert implants in the middle of the inter-radicular space but instead to insert them slightly nearer to the root, away from the force direction. Insertion sites with good bone quality and thin mucosa should be preferred. If possible, insertion close to anatomical structures, such as dental roots, should be avoided, both to prevent any damage and to reduce the risk of implant loosening. Alves *et al.*[63] recommended monitoring implant position during treatment to prevent contact with anatomical structures. El-Beialy *et al.* proposed that patients should be informed before insertion that the mini-implants' position might need to be redirected because of displacement. The aim of planning should be to provide a maximum range of action for the mini-implant, especially when long loading periods are necessary.[62]

CONCLUSION

The authors have affirmed that mini-implants provide good anchorage quality regarding orthodontic treatment. Primary displacement did not appear to be clinically relevant. Most of the studies confirmed that significant secondary displacement occurred under orthodontic loading over time. The level of displacement was clinically relevant, considering possible interference with anatomical structures, such as dental roots. Based on the given data concerning the amount and type of displacement, decentralized insertion within the inter-radicular space, away from force direction, might be favourable. Following this advice might help to minimize the risk of damaging anatomical structures and to reduce the failure rates of mini-implants. No quantitative recommendations have been given to date due to a lack of evidence. Further research regarding the amount of and factors affecting secondary displacement should be performed for better prediction of the space required needed in individual situations.

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