The Effect of Varied Positioning of Mini-screw, Anterior Retraction Hook, and Resultant Force Vector on Efficient En-Masse Retraction Using Finite Element Method: A Systematic Review

Ashish Agrawal¹ and P Subash¹

Abstract

Objective: The objective of this systematic review was to assess the available evidence to evaluate the effectiveness of en-masse retraction design with mini-screw with respect to the retraction hook and mini-implant position and height.

Methods: The following electronic databases were searched till July 31, 2020: Pro-Quest Dissertation Abstracts and Thesis database Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, Google Scholar, US National Library of Medicine, and National Research Register. En-masse retractions with anterior retraction hooks assisted by mini-implant three-dimensional finite element method (3D FEM) models were included in the study. The selected studies were assessed for the risk of bias using the Cochrane Collaboration risk of bias tool. The “traffic plot” and “weighted plot” risk of bias distribution were designed using the ROBVIS tool. The authors extracted and analyzed the data.

Results: Twelve studies fulfilled the inclusion criteria. The risks of biases were low for 9 studies and high for 3 studies. Data on mini-implant, retraction hook, and the center of resistance/force vectors were extracted. The outcomes of the included studies were heterogeneous.

Conclusions: According to the currently available literature review for successful bodily en-masse tooth movement, the force vector should pass through the center of resistance, which can be achieved by the clinical judgment of placing a mini-screw and an anterior retraction hook. The force from an implant placed at a higher level from the anterior retraction hook will cause intrusion; an implant placed at the medium level shows bodily movement; and an implant placed at a lower level shows tipping forces in consolidated arches.

Keyboards
Mini-screw, anterior retraction hook, FEM, en-masse retraction

Introduction

Anchorage is a crucial step in planning for orthodontic treatment. It can be provided by both intraoral and extraoral techniques and which can act as primary or reinforced anchorage. Newton’s third law states, for every action, there is an equal and opposite reaction, which is applicable in orthodontics. With recent advances in the specialty of orthodontics, it is established that skeletal anchorage provides absolute stability to the segments by providing resistance toward undesirable reactionary tooth movements. Bone screws, Y-shaped plates, and onplants¹ are used as means of achieving absolute anchorage. Intraoral anchorage using appliances such as transpalatal arch and nance holding arch does not require patient cooperation, whereas extraoral anchorage using appliances such as headgear demands patient’s cooperation for successful treatment outcome. The first successful orthodontic implant was placed by Creekmore and Eklund² in 1983, but it was Kanomi³ in 1997 who described a mini-implant specifically designed for orthodontic use. In anterior en-masse retraction, anchorage planning is critical

¹ Department of Orthodontics, IMS, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Corresponding author:
P Subash, Department of Orthodontics, Banaras Hindu University (BHU), ROOM No. 3, Post-graduate Section, Varanasi, Uttar Pradesh 221005, India.
E-mail: Subash.kathir123@gmail.com
for successful orthodontic treatment. Conditions such as skeletal open bite\(^4\) and skeletal class III malocclusion may require absolute anchorage. Planning anchorage, especially in extraction cases, is critical in determining both the treatment outcome and the selection of appropriate mechanisms\(^5\).

The photoelasticity method, the strain gauge method, laser holography, and the finite element method (FEM) are some of the advanced technologies used to analyze the biological and biomechanical properties of orthodontic tooth movement. FEM is a tool used to gauge stress and strain by simulating a biological entity to a computer-generated model\(^6\). FEM evaluates the stress distributions and three-dimensional (3D) displacements in different organic/inorganic models with irregular geometry and nonhomogeneous physical properties\(^7\).

In 1943, R. Courant\(^8\) first formulated mathematical techniques to analyze the biomechanical properties of the object. It was Weinstein\(^9\) in 1976, who first applied FEM to dentistry to measure the various occlusion loads on implants. Since then, the FEM method has been used in the field of orthodontics to decipher the physiologic responses of dentoalveolar complex to orthodontic forces by exhibiting quantitative data.

**Objectives**

The aim of this study was therefore to compare and evaluate the effectiveness of en-masse retraction design with mini-screw with respect to the retraction hook and mini-implant position and height.

**Material and Methods**

**Protocol and Registrations**

The systematic review was performed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis\(^10\) guidelines and the main research question was formatted according to the patient, problem or population intervention comparison, control or comparator outcome (PICO). The protocol for a systematic review of mini-screw-enabled en-masse retraction was registered on the National Institute of Health Research Database (PROSPERO https://www.crd.york.ac.uk/prospero/registration ID-CRD42020194373).

**Eligibility Criteria**

The following selection criteria were applied for the review.

1. **Study design**: Only original research articles were included.
2. **Participants**: Either patient 3D CT scanned model or ideal dental cast 3D model was considered. Sliding mechanics with first premolar extraction was the treatment protocol to be simulated.
3. **Interventions**: En-masse retraction with anterior retraction hooks (ARH) and assisted anchorage from mini-screw.
4. **Exclusion criteria**: Studies related to retraction performed with frictionless mechanisms and studies without FEM simulation were omitted from the review.
5. **Outcome measures**: The primary outcome of this review is to find the optimum height and position of ARH and mini-implant during en-masse retraction.

**Information Sources, Search Strategy, and Study Selection**

A comprehensive electronic database search was conducted with no limit of date of publication. Search engines such as Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, and Google Scholar were included (Table 1). In addition to this, unpublished research studies were electronically searched using electronic databases such as the US National Library of Medicine (https://clinicaltrials.gov/) and National Research Register (ISRCTN Registry http://www.isrctn.com/), using the terms “En-masse retraction” and “FEM.” The Pro-Quest Dissertation Abstracts and Thesis database were searched (https://about.proquest.com/libraries/academic/dissertations-theses/) using the terms “orthodontic*” and “En-masse retraction*.” The gray literature (http://www.opengrey.eu/) was also searched. The search strategy and terms used for the PubMed search engine are presented in Table 1. An e-mail alert was set for the PubMed search that allowed updates of results during the process of developing the review. Only studies included in English literature were selected for this systematic review. Hand searches were done on the list of references in the selected article.

**Table 1.** List of Search Engines and the Result Obtained Using MeSH Terms With Sample of PubMed Search Terms.

| S. No | Search Engine                                      | Results |
|-------|---------------------------------------------------|---------|
| 1     | PubMed                                            | 64      |
| 2     | Cochrane                                          | 32      |
| 3     | Google Scholar                                    | 104     |
| 4     | US National library of medicine (https://clinicaltrials.gov/) | 10 |

MeSH terms

\[ (((((extraction) OR (space clos*)) OR (retraction))) AND (((((((maxilla*) OR (mandible*)) OR (upper jaw*)) OR (lower jaw))) OR (dental)) AND (((((3-dimensional modeling)) OR (3-dimensional analysis)) OR (3 dimensional analysis)) OR (fe)) OR (fem)) OR (finite element analysis)) OR (finite element method)) OR (three-dimension*)) OR (three dimension*)) AND (orthodont*) AND ((stress on the cortical bone) OR (stress on dentition)) NOT (lingual) NOT (surgery) OR (orthognathic surgery)) \]

(Table 1 Continued)
The study selection was done in 2 phases. In the first phase, the title and abstract were screened independently by 2 reviewers (AA, PS). The short-listed studies are selected for full-text reading. Strict inclusion criteria scrutinizing was done. Any disagreements between the 2 reviewers were sorted by a discussion with third and fourth reviewers.

Data Items and Collection

The data extraction was performed by 2 reviewers (AA, PS) independently to record the general information such as author, year of publication, and study setting, study method, FEM software used, a technique used (En-masse retraction method, friction mechanics), the primary outcome, that is, position of ARH and mini-screw and secondary outcome, that is, force vector considerations, and inference/recommendations.

Risk of Bias/Quality Assessment in Individual Studies

The quality of the selected studies was evaluated by a pair of observers (AA, PS) on ROBVIS11 (Covidence) using the Cochrane Collaboration risk of bias tool, as described in the Cochrane Handbook for Systematic Reviews of Interventions12. A total of 6 domains of bias were assessed: (a) random sequence generation, (b) allocation concealment, (c) blinding of outcome assessment, (d) incomplete outcome data assessment, (e) selective reporting, and (f) another source of bias. The binding of participants and operators was not included. The sequence generation was not explained, as the included studies did not report it. The use of sequence generation is questionable for in vitro studies or perhaps impossible, particularly for FEM study. Evaluation of allocation concealment of in vitro studies was not appropriate.

Results

Study Selection and Characteristics

A total of 210 articles were identified after electronic search (PubMed, CENTRAL, Google Scholar, and US National Library of Medicine) and 8 articles were included by hand search. After removing the duplicates, 104 articles were short-listed, out of which 40 articles were included for abstract reading for Phase I screening. Totally, 18 articles selected for Phase II full-text reading (Figure 1). Finally, 12 articles were selected for qualitative review. Six articles were excluded, and the reasons for their exclusion are presented in Table 2. All the 12 articles were original research articles, and basic characteristics and inference were tabulated separately.

![PRISMA Flow Diagram](image-url)
Table 2. List of the Excluded Studies and Their Respective Reasons for Exclusion.

| Article            | Reason for Rejection |
|--------------------|----------------------|
| Tominago et al     | Outcome              |
| Kim et al          | Different technique  |
| Kojima et al       | Outcome              |
| Ozaki et al        | Comparison done on different technique |
| Yan et al          | Outcome              |
| Othaman et al      | Outcome              |

Risk of Bias Within Studies

All the included studies were assessed for risk of bias through the Cochrane Collaboration risk of bias tool, as described in the Cochrane Handbook for Systematic Reviews of Interventions (Figures 2 and 3). The overall assessment of bias was done under high, low, unclear, and not applicable as per Cochrane Handbook for Systematic Review. Three articles were having a high risk of bias, whereas 9 articles were having a low risk of bias. Tests for the risk of bias across studies were not undertaken.

Figure 2. “Traffic Light” Plot of Risk of Bias of Individual Studies. 
Source: Risk-of-bias ViSualization (ROBVIS).

Figure 3. “Weighted Plot” Distribution of Risk of Bias Among the Studies.
Source: Risk-of-bias ViSualization (ROBVIS).

Synthesis of Results

Meta-analysis was not possible due to sizeable heterogeneity in various methodological, clinical, and statistical variations. Solid heterogeneity is present in the various methods of outcome measurement, the different landmarks used for positioning the mini-implant and ARH, and application of force via elastics versus coil. Hence, only a qualitative report was obtained.

Results of Individual Studies

The summary of the included variables is outlined in Tables 3 and 4.

Position of Mini-screw

The position of mini-screw was described in 10 studies (Table 5), where the height varied from 4 mm to 13.5 mm. In 8 studies, the position of mini-implant placement is determined from the level of the archwire. Zhang et al.13 considered the height of placement from molar hook whereas Jain et al.22 measured it from the alveolar bone. Six studies have used 150 g of force for the retraction. Namburi et al.20 and Bohara et al.23 used intrusion force (60 g) from the anterior region in addition to the retraction force. Chetan et al.17 showed retraction component of force reduces by around 1% and the intrusion component of force increases by around 0.3% for each millimeter apical placement of the screw. Ashekar et al.16 proved that low mini-implant placement (6 mm) causes anterior teeth to tip, mid-implant placement (8 mm) causes bodily movement, and high implant placement (10 mm) shows intrusion in the FEM model. The ideal height for the bilateral implant position for the retraction of the anterior teeth is 10 mm29. But on the contrary, Chetan et al.17 suggested that the position of the implant in the vertical plane will have very little effect on the type of tooth movement. Bohara et al.23 showed force vector passing away from the center of resistance (CR) will show tipping movement independent of implant position.
Table 3. Basic Characteristics of the Included Studies.

| S.NO | Author          | Model  | Mesh Design                  | Technique Used          | Number of nodes | Number of Element |
|------|-----------------|--------|------------------------------|-------------------------|-----------------|-------------------|
| 1.   | Zhang et al     | 3D FEM | Not mentioned                | ANSYS 8.1               | 186322          | 130616            |
| 2.   | Sung et al      | 3D FEM | 4-node tetrahedron element   | ANSYS (solid45)         | Model I-49039   | Model 2-449796    |
|      |                 |        |                              |                         | Model 2-48429   | Model 2-246646    |
|      |                 |        |                              |                         | Model 3-49039   | Model 3-449796    |
| 3.   | Kojima et al    | 3D FEM | Not mentioned                | ANSYS software          | Not mentioned   | Not mentioned     |
| 4.   | Ashekar et al   | 3D FEM | Not mentioned                | ANSYS version 13        | 249796          | 49039             |
| 5.   | Chetan S et al  | 3D FEM | Not mentioned                | ANSYS 11                | 187937          | 41802             |
| 6.   | Parashar et al  | 3D FEM | Not mentioned                | MIMICS                  | Not mentioned   | Not mentioned     |
| 7.   | Hedayati et al  | 3D FEM | Not mentioned                | ANSYS Software          | 371100          | Not mentioned     |
| 8.   | Namburi et al   | 3D FEM | Not mentioned                | ANSYS 12.1 version      | 43887           | 209807            |
| 9.   | Shreevats et al | 3D FEM | Not mentioned                | MIMICS and ANSYS        | Not mentioned   | Not mentioned     |
| 10.  | Abhishek Jain et al | 3D FEM | tetrahedron shape          | Not mentioned           | 294124          | 66448             |
| 11.  | Bohara et al    | 3D FEM | Not mentioned                | software-MIMICS         | Model A 98972   | Model A 335781    |
|      |                 |        |                              | (version 8.11)          | Model B 313944  | Model B 93622     |
|      |                 |        |                              | ANSYS (version 12.1)    | Model C 335781  | Model C 98972     |
|      |                 |        |                              |                         | Model D 313944  | Model D 93622     |
| 12.  | Suzuki et al    | 3 D FEM| Not mentioned                | ANSYS 11.0              | 222391          | 136459            |

Table 4. Characteristics of the Included Studies.

| S.No | Name of the Author | Year | Objectives                                                                 | Model Design | Retraction Hook | Mini-screw | Consideration of CR (En-masse Retraction) | Conclusion | Retraction Hook | Mini-screw | Recommendations                  |
|------|--------------------|------|----------------------------------------------------------------------------|--------------|-----------------|------------|-------------------------------------------|------------|-----------------|------------|-----------------------------------|
| 1.   | Zhang et al        | 2008 | To investigate the stress and displacement of maxillary anterior teeth during retraction by FEM. | Ideal model NISSIN B3-305 | Molar hook | Case 1-2 mm | Case 24 mm | Apical to molar tube 10 mm | 150 gm | Mentioned about CR but not specified the position | Re traction force passing near the center of resistance of 6 anterior teeth makes their displacement uniform. |
| 2.   | Sung et al         | 2010 | To examine effective en-masse retraction with mini-implant anchorage with varying height and position of mini-implant and retraction hooks by FEM. | Ideal model NISSIN (21D-400G) | From arch wire | 1.0 mm 2.2 mm 3.5 mm 4.8 mm | From arch wire level 1.10 mm 2.12 mm | 200 gm | Yes, and center of resistance was 9 mm superiorly and 13.5 mm posteriorly from the midpoint of the labial splinting wire | As the height of the ARH increased, lingual tipping of the central and lateral incisors was reduced. | For bodily retraction of 6 anterior teeth, the line of action of the force passing through the CR is desirable. |
| 3.   | Kojima et al       | 2012 | To evaluate the length and position of the anterior retraction hook and placement of mini-implant by FEM. | Patient CT scan to 3D model---FEM model | From arch wire | 1.1 mm 2.4 mm 4.8 mm | From arch wire | 1.4 mm 2.8 mm | 1.5 N | No and the position of CR is not specified | The high-position (8 mm) mini-screw, bodily tooth movement was almost achieved | When the power arm was lengthened, rotation of the entire dentition decreased. | For bodily retraction force passing near the center of resistance of 6 anterior teeth makes their displacement uniform. |
| No. | Name of the Author | Year | Objectives | Model Design | Reference Position | Reference Position | Force | Consideration of CR (En-masse Retraction) | Conclusion | Recommendations |
|-----|-------------------|------|------------|--------------|-------------------|-------------------|-------|---------------------------------------|------------|------------------|
| 4.  | Ashekar et al 2013 | To evaluate the proper position of anterior retraction hook and mini-implant position for retraction by FEM Study. | Retraction Hook | 0 mm | 2. 5 mm | 3. 8 mm | 150 gm | Yes, and center of resistance was 9 mm superiority and 13.5 mm posteriorly from the midpoint of the labial splinting wire | 1. (6 mm) mini-implant shows tipping movements. 2. Mini-implant (8 mm) shows bodily movement. 3. High implant condition (10 mm) shows intrusion and retraction. | To produce more amount of retraction, the force vector must pass through or near the center of resistance of all anterior teeth. |
| 5.  | Chetan et al 2014 | To evaluate the proper position of mini-implant for en-masse retraction by FEM study. | Retraction Hook | 2 mm | 13.5 mm | 2.9 mm | 4.3 mm | Yes, and center of resistance was 9 mm superiority and 13.5 mm posteriorly from the midpoint of the labial splinting wire | For every mm of apical displacement of implant, the retraction component of force reduces approximately by around 1% and intrusion component of force increases approximately by around 0.3%. | Not specified. The position of implant in vertical plane will have very little effect on the type of tooth movement. |
| 6.  | Abhishek Parasher et al 2014 | To evaluate anterior en-masse retraction with force vectors from 2 different levels of mini-implants by FEM. | Retraction Hook | 0 mm | 2.3 mm | 4.9 mm | 200 gm | Yes, and center of resistance was 9 mm superiority and 13.5 mm posteriorly from the midpoint of the labial splinting wire | Bodily movement with very minimal torque loss was observed in high implant position to low retraction hook. | Not specified. The force vector passing close to the center of resistance produced bodily movement. |
| 7.  | Hedayati et al 2016 | To evaluate the proper anterior position of mini-implant and anterior retraction hook size for retraction by FEM Study. | Retraction Hook | 1.0 mm | 2.3 mm | 3.6 mm | 150 gm | Yes, and center of resistance was 9 mm superiority and 13.5 mm posteriorly from the midpoint of the labial splinting wire | Body movement occurred with the 9-mm height of the power arm in both mini-screw positions. | Rotation of anterior dentition was decreased with a longer anterior power arm and the mesial placement of the mini-screw. |
| 8.  | Namburi et al 2017 | To compare the 2 mini-screw vs 3 mini-screw with different heights of mini-implant for the en-masse retraction by FEM study. | Retraction Hook | 1.7 mm | 1.19 mm | 120 gm | Yes, center of resistance for the present study model might be located at 10 mm | 1. Low mini-implant—tipping movements. 2. Mid-implant—bodily movement. 3. High implant condition shows intrusion and retraction. | In 3-implant system, more intrusion and less stress are seen in PDL than 2-implant system. |
Agrawal and Subash

| No. | Name of the Author | Year | Objectives | Model Design | Retraction Hook | Mini-screw | Consideration of CR (En-masse Retraction) | Conclusion | Recommendations |
|-----|-------------------|------|------------|--------------|---------------|-----------|--------------------------------------|------------|-----------------|
| 9.  | Ruchira Shreevats et al | 2017 | To evaluate the effective en-masse design with varying heights of mini-screw and alveolar bone by FEM method. | CT-scan to 3D model—FEM model | From arch wire 1. 1 mm 2. 2 mm ... 10. 10 mm | From alveolar crest 8 mm | Yes, and it varies according to the alveolar bone height. 100%—8 mm apically 75% bone height—10 mm apically 50% bone height—14 mm apically | Not specified | Not specified | In cases where the bone loss is 50% or more, bodily movement is not feasible. |

10. Abhishek Jain et al 2017 | Comparison of varying height of mini-implant with force application from NiTi coil vs E-chain for en-masse retraction by FEM method. | Not mentioned | Not mentioned | From arch wire | From alveolar crest | 1. 3 mm 2. 5 mm | 150 gm | Mentioned about CR but not specified the position | Increasing the height of mini-screw placement encouraged the transitory movement of anterior teeth | Not specified |

11. Bohara et al 2017 | To understand the nature of stresses and displacement patterns of anterior teeth during en-masse intrusion and retraction on force application with different combinations of mini-implants and retraction hooks height by FEM method. | Not mentioned | From arch wire | From arch wire 1. 6 mm gingivally 2. 2 mm incisally | 1. 6 mm Or 2. 6 mm + in the incisor region | 150 gm | Mentioned about CR but not specified the position | Not specified | The retraction hook height could be the most easily modifiable clinical factor in determining and achieving the most desirable direction of anterior teeth displacement during intrusion and retraction of anterior teeth. The teeth showed almost bodily movement and controlled lingual crown tipping when a 6-mm gingival retraction hook was used. | The force passing near the center of resistance exhibits bodily movement. |

12. Suzuki et al 2019 | To evaluate the height of the retraction hook and implant anchorage effect on the tooth movement during en-masse retraction of anterior teeth by FEM method. | Dried adult skull CT-scan to 3D model—FEM model | From arch wire | From arch wire | 1. 0 mm 2. 5 mm 3. 10 mm | 1. 0 mm 2. 5 mm 3. 10 mm | 150 g | Yes, and it is located 5 mm above the alveolar crest | Not specified | 1. The traction at 0 mm height hook, all teeth move distally 2. With traction of hook at 0 mm, with higher the implant position extrusion of central decreased. Force should pass through or near the center of resistance to avoid tipping of the teeth. * |

Note: * All the included articles studied via FEM and sliding mechanics.

Table 5. Results of Individual Studies on Vertical Position of Mini-screw and Height of Anterior Retraction Hook.

| Study          | Height of the Mini-implant | Height Measured Level | Force     |
|----------------|----------------------------|----------------------|-----------|
| Sung et al     | 10 mm (low)                | Arch-wire level      | 200 g     |
|                | 12 mm (high)               |                      |           |
| Kojima et al   | 4 mm                       | Arch-wire level      | 1.5 N (150 gf) |
|                | 8 mm                       |                      |           |
| Ashekar et al  | 6 mm (low)                 | Arch-wire level      | 150 g     |
|                | 8 mm (medium)              |                      |           |
|                | 10 mm (high)               |                      |           |

(Table 5 Continued)
Position of Anterior Retraction Hooks

A total of 9 articles have considered the varying height of the ARH for en-masse retraction (Table 5). Hedayati et al 19 suggested that placing an ARH size of 9 mm exhibits bodily movement independent of mini-screw position, mesial or distal to premolar. The rotation of anterior dentition was also decreased with a longer anterior power arm. On the contrary, Zhang et al 13 found that when an ARH of 2 mm is used, the lateral incisor showed controlled lingual crown tipping; on the other hand, when an ARH of 4 mm is used, the central and canine teeth showed lingual crown tipping and laterals shows bodily retraction and intrusion.

Tooth Movement

Seven studies had discussed tipping, torque, and translation of incisor while retraction. Parashar et al 18 suggested positioning the mini-implant in a higher position (13.5 mm from the archwire plane) while retraction prevents torque loss and also positioning the mini-screws in a lower position (8 mm from the archwire plane) leads to maximum torque loss. Namburi et al 20 suggested placing mini-screw 10 mm from arch wire as a reference point. Chetan et al 17 suggested the more apical the placement of the mini-screw, the more is the intrusion achieved. Sung et al quoted increasing the length of ARH (<8 mm) reduces unwanted tipping of the central and lateral incisors. Shreevats et al 21 suggested that bodily movement during en-masse retraction is feasible only when 50% alveolar bone height is present in the anterior. In addition to the bilateral implants, an inter-radicular implant in the incisor region reduces the stresses in periodontal ligament (PDL) and achieves greater intrusion in comparison to the 2-implant system. Retraction with elastomeric chain produces lesser amount of von Mises stress on the bone as well as mini-implant and produces more displacement of anterior teeth in both vertical and sagittal directions as compared to that with nickel titanium wire (NiTi) coil spring.
Discussion

At the time of registration with PROSPERO, this systematic review was the first to specifically investigate the position of mini-screw, the height of ARH, and the CR of 6 anterior teeth for en-masse retraction. However, before writing this systematic review, several in-vitro FEM studies were published which have addressed various aspects of en-masse retraction as stated. Studies such as Zhang et al., Sung et al., Parashar et al., Namburi et al., Jain et al., Shreevats et al., and Suzuki et al. have not concluded either optimum position of mini-screw, size of ARH, reference plane to be considered, or the exact position of CR in their respective published articles. To elucidate the above aspects, it was imperative that a systematic review be conducted for discernment. A total of 218 articles were selected using medical subject headings (MeSH) terms, and few articles were handpicked. After regress scrutinization using inclusion and exclusion criteria, 12 articles were finally considered for a systematic review.

Summary of Evidence

The methodological heterogeneity was noted in all these studies. Parashar et al, Sreevats et al, and Bohara et al used MIMICS software for simulation. Zhang et al, Sung et al, Kojima et al, Ashekar et al, Hedayati et al, Namburi et al, Bohara et al, and Suzuki et al used ANSYS software for simulation, whereas Jain et al have not mentioned the software used for the study. Kojima et al, Suzuki et al, and Parashar et al designed an FEM model based on the CT scan and converted it into a 3D model, while other studies such as Ashekar et al, Chetan et al, and Hedayati et al designed a model based on Wheeler’s dental anatomy textbook. Jain et al and Bohara et al did not quote the model design.

Namburi et al compared the stresses on the 2-implant systems with 3-implant systems for retraction. He stated that the stresses on the hard bone, PDL, and implant showed less stress in 3-implant systems. Zhang et al found more displacement and stress in the cervix and root apex in teeth and also that lateral incisors experience more compressive stress on the labial and lingual surfaces with mini-screw assisted retraction. Jain et al used NiTi coil spring and elastomeric chain on mini-screws for retraction force. They inferred a higher level of Von Mises stresses in bone while using the NiTi coil spring and mini-screw.

The positioning of ARH differed inciso-gingivally and mesiodistally in included studies. Bohara et al compared the position of ARH incisally (inverted) and gingivally with respect to the arch wire. The positioning of ARH in between lateral incisors and canine was common, and this was specifically mentioned in the 12 studies. Zhang et al considered a molar hook for deciding the dimensions of ARH, whereas an arch wire was reported as the reference plane in studies by Sung et al, Kojima et al, Ashekar et al, Chetan et al, Parashar et al, Hedayati et al, Namburi et al, Shreevats et al, and Suzuki et al.

The method of retraction and force used for retraction was discussed. Namburi et al and Bohara et al compared 2-mini-implant models versus 3-mini-implant models for an anterior retraction and showed that the 3-implant system has better biomechanical advantages for better intrusion and retraction and minimum stress on the periodontium. Hedayati et al studied the mesiodistal positioning of the mini-screws by comparing the bio-mechanical effects by placing one implant placed at the mesial and other at the distal of the second premolar. Shreevats et al and Jain et al considered the alveolar crest as a reference point for the mini-screw placement. Zhang et al considered apical to Molar tubes. Park et al took the bracket slot as a reference plane for placement of mini-screw. Studies such as Sung et al, Kojima et al, Ashekar et al, Chetan et al, Parashar et al, Hedayati et al, Namburi et al, Bohara et al, and Suzuki et al had taken arch-wire level as reference. Zhang et al and Shreevats et al placed the mini-implant at a fixed height from the respective reference planes and varied the ARH height. Ashekar et al, Chetan et al, Namburi et al, and Suzuki et al used 3 different implant positions for comparison. Sung et
al14 (10 mm, 12 mm), Kojima et al15 (4 mm, 8 mm), Parashar et al16 (13.5 mm, 8 mm), and Jain et al22 (3 mm, 5 mm) used 2 different implant positions.

The CR is critical for assessing the resultant direction of force for en-masse retraction when applied from mini-screw to ARH. The line of force vector passing through CR will bring about the bodily retraction. Melsen et al26 considered CR at a point 9 mm superiorly and 13.5 mm posteriorly from the center of the arch wire. The same point is considered in studies by Sung et al14, Ashekar et al,16 Chetan et al,17 Parashar et al,18 and Hedayati et al. 19 Namburi et al20 estimated the location to be at 10 mm from the alveolar bone in between lateral and canine. Suzuki et al24 considered CR to be at 5 mm above the alveolar crest apically above the central incisor. Zhang et al,13 Kojima et al,15 Bohara et al,23 and Jain et al22 have mentioned the importance of CR but not specified its location. Shreevats et al21 discussed CR in relation to periodontally compromised patients. He stated that as the alveolar bone loss increased, the CR moved apically.

Upadhayay et al27 suggested retraction force to be angulated when applied from mini-screw whereas in the conventional techniques force vector remains parallel to the occlusal plane. Antoszewska-Smith et al28 stated retraction with mini-screw is more efficient with minimum undesirable effects. Koyama et al29 and Rizk et al30 laid stress on en-masse retraction using mini-screw, as it reduces the treatment time period and augments anchorage. Kim et al31 corroborate the above results by retracting 6 anterior teeth using mini-screws without bonding posterior segments.

Limitations

The FEM model is an emerging diagnostic and investigating method in the engineering and biomedical fields, but the simulation and original result may vary due to clinical and biological factors such as bone level, bone density, age/gender of the patient, and periodontal integrity. The studies included in this systematic review were in English, although few studies in different languages were published but not included, suggesting incomplete data collection and probably publication bias. The 12 articles discussed in the systematic review used FEM as an investigating tool however, the results of these studies were not corroborated with clinical studies under the same orientation of mini-screw and ARH.

Conclusions

According to the currently available literature review for successful bodily en-masse tooth movement, the force vector should pass through CR, which can be achieved by the clinical judgment of placing a mini-screw in the right position and assessing the height of ARH.

1. The retraction force should pass through the CR, to achieve the bodily movement and controlled lingual crown tipping.
2. The force from an implant placed at a higher level from the ARH will cause intrusion; an implant placed at a medium level shows bodily movement, and an implant placed at a lower level shows tipping forces in consolidated arches.
3. The use of an extra implant in the incisor region improves intrusion and reduces stress in the periodontal ligament.

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ORCID iD

P Subash https://orcid.org/0000-0003-2146-6689

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