CHAPTER 2

Literature Review

The literature review is divided into four parts as follows:

2.1 Deep overbite malocclusion

2.2 Suitable locations for mini-screw placement for maxillary anterior tooth intrusion

2.3 Finite element method

2.1 Deep overbite malocclusion

The term "overbite" refers to the overlapping in the vertical dimension of maxillary and mandibular incisors. Normal overbite can be considered as about 2-3 mm or 30% of the clinical crown height of the mandibular incisors, and "deep overbite" or "deep bite" are terms applied to greater amounts of overbite.[1]

Deep overbite is a common malocclusion trait. It has high prevalence in the studies in United states[18] and Singapore[19]. It is also prevalent in Thai people, with approximately 10% of boys and 6% of girls having overbites with more than two thirds overlap.[20]

The etiologies of deep overbite can be hereditary, dental, skeletal or muscular. Genetic patterns or familial conditions are hereditary causes.[1] Dental causes include infra-occlusion of the posterior segments or overeruption of the anterior teeth due to many causes, and can result in increased overlap of incisors. Growth of the alveolar segments is the principal skeletal cause. The impact of masticatory forces is a muscular cause that can alter the dentition.

Deep overbite can harm periodontal support, occlusion and the TMJ.[1] Possible complications of deep overbite include, TMJ disorders, unacceptable facial aesthetics, attrition of incisors, spacing of maxillary incisors, clenching of teeth, jaw stiffness, head ache and ringing in ears.[2]

There are three ways to manage deep overbite: intrusion of anterior teeth, extrusion of molars or a combination of both.[1, 3, 4] In growing patients, relative intrusion of incisors by extrusion of molars is a good method, but absolute intrusion of incisors is needed in non-growing patients because extrusion of the molars increases the lower anterior facial height and causes clockwise rotation of the mandible, resulting in the destruction of esthetics.[3, 21] True intrusion of incisors is primarily indicated in deep overbite cases with a large vertical dimension, in patients with excessive incision stomion distance and a large inter-labial gap. Advantages of true intrusion of anterior teeth include the achievement of lip competency and reduced incisal exposure without any increase in lower anterior facial height.

Many types of mechanics can produce intrusion of the anterior teeth, e.g., J-hook headgear, Rickett's Utility arch, Burstone's intrusion arch and reverse curve of Spee arch.[5] Each type of mechanics is designed to create the lowest force because the intrusion needs just a little load, and increased load means increased risk of root resorption.[22] Sifakakis et al.[23] reported that the intrusion arch of Burstone provided less force than did the Utility with the same size wire (0.017x0.025" TMA), whereas the reverse curve of Spee NiTi applied the highest force with a smaller wire (0.016x0.022"). Another report by the same authors[24] focused on the reactive load on the posterior teeth that was subjected to the same amount of force as the anterior teeth, but extruded the posterior teeth. They found that the Utility arch exerted a higher force level on molars than did the intrusion arch, but both exerted some load on the molars, as all teeth comprise one system.

The major disadvantages of those types of mechanics are extrusion and tipping of posterior teeth and complex wire bending. The J-hook headgear is an extra-oral appliance; so, the anchorage control is better than with intraoral devices, but patient co-operation determines the success of treatment.[5]

The emergence of implant technology revolutionized the biomechanics of orthodontic therapy. Bone anchorage eliminates the adverse side effects, there is no need for patient co-operation and many new types of mechanics are designed for various types of tooth movement.[25] On the other hand, mini-screw placement is more invasive than conventional mechanics and has some risk, such as infection and pain. The other disadvantages of mini-screws are fracture, failure, and damage to hard and soft tissue.[26]

2.2 Suitable locations for mini-screw placement for maxillary anterior tooth intrusion

The true intrusion of maxillary anterior teeth can be archived by mini-screw anchorage without side effects on posterior teeth. The location of mini-screw placement determines the success rate and force design. However, many factors affect the suitability/applicability of mini-screws and their location/site of placement.

Treatment considerations

Patient selection. Patient factors that can contribute to mini-screw failure are young age, a smoking habit, poor oral hygiene and bone metabolic disorders.[27-29] Immature bone is very soft.[29] This softness can lead to mini-screw failure. Thus, miniscrews are recommended for use in patients aged 12 and older, and are contraindicated in heavy smokers and patients with bone metabolic disorders.[29]

Proper location for mini-screw insertion. The balance between the bone quality and the proper location for the intended force system is crucial for the success rate of the treatment. Although high bone density is preferred, areas with high bone density are not necessarily the best location for controlling force direction.

Bone density is calculated from the thickness of cortical bone and the quality of bone trabeculae. Misch[30] classified bone density into five groups. D1 is the best for implant placement with dense cortical bone. D2 and D3 are less desirable, but still acceptable for placement, whereas D4 usually leads to failure. D5 is an incompletely mineralized bone, such as the immature bone of child patients, and is not recommended for mini-screw placement (Table 1).

Table 2.1 Bone density classification scheme (adapted from Misch[30]).

Bone density	Description	Typical anatomical location	CT number (Hounsfield units)
D1	Dense cortical	Anterior mandible	>1,250
D2	Porous cortical and coarse trabecular	Anterior mandible Posterior mandible Anterior maxilla	850-1250
D3	Porous cortical (thin) and fine trabecular	Anterior maxilla Posterior maxilla Posterior mandible	350-850
D4	Fine trabecular	Posterior maxilla	150-350
D5	Incomplete mineralization	Immature bone	<350

Most bones in the anterior maxilla have densities of D2 (25%) and D3 (65%). Although these areas do not have the best bone density, they are acceptable for placement of mini-screws.[30]

Soft tissue health. Placing mini-screws through non-keratinized gingiva or movable gingiva can evoke peri-implantitis and cause failure of the screw[12] and the mini-screw head may become covered by the mucosa, causing pain. Mini-screw insertion through attached or keratinized gingiva is usually recommended.[26]

Bone availability. The success of mini-screw placement is determined mainly by cortical bone thickness.[28] Other factors for avoiding failure or damage to teeth are the labio-palatal thickness of the alveolar bone and the interdental root distance. Choi et al.[13] reported that cortical bone is significantly thicker between the central incisors than between the lateral incisor and canine, and tends to increase in thickness from the CEJ to the apex. The labio-palatal bone is thinnest between the central incisors and tends to decrease from the CEJ toward the apex. On the other hand, the interdental root distance is shortest between the central and lateral incisors and longest between the lateral incisor and canine, and tends to increase from the CEJ toward the apex. Choi et al.[13] suggested that the region between the maxillary lateral incisor and the canine should be the first choice for mini-screw implantation, but this area requires two mini-screws, left and right. The second best site suggested is the region between the maxillary central incisors as intrusion of the maxillary anterior teeth is possible with just one mini-screw implant.[13]

A review of the literature shows various techniques for maxillary anterior tooth intrusion. Differences in the number and size of mini-screws, location of placement, magnitude of force and number of teeth intruded are found (Table 2.2).

Nanda and Tosun[14] suggested two designs of mechanics using mini-screws as anchorage for the intrusion of six anterior teeth. The first design involves placing one mini-screw between the roots of the central incisors with force applied to the main arch wire that connects the six maxillary anterior teeth together (Figure 2.1). With this method, the authors expected some protrusion of the incisors and they cinched the back of the arch wire to prevent this side effect. Many case reposts described intrusion of incisors by one mini-screw[7, 8] for both maxillary and mandibular teeth. Ohnishi et al.[7] loaded a very light force of 15-25 g to the whole maxillary arch and intruded the incisors 4 mm with 5° of lingual root torque. Kim et al.[8] used these techniques with Class II Division 2 cases, where proclination of incisors was necessary. When one mini-screw is used for intrusion of the incisors, the incisors are always proclined.

Table 2.2 Summary of literature review

A. Case reports

Study	Number and size of mini-screw			Location	Force magnitude	Number of teeth
	Number (Piece)	Diameter (mm)	Length (mm)			
Onishi et al. 2004.[7]	1	1.2	6	Between central incisors	20 g per side	Whole maxillary arch
Kim et al. 2006.[8]	1	1.6	6	Between central incisors	Not shown	Central incisors intruded to the level of lateral incisors, followed by intrusion of the 4 incisors together
Upadhyay et al. 2008.[9]	2	1.2	8	Distal to lateral incisor	50 g per side	6

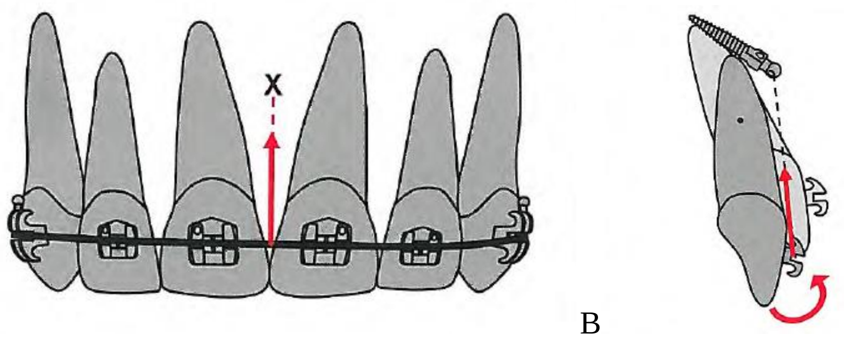
B. Other type of studies

Study	Number and size of mini-screw			Location	Force magnitude	Number of teeth
	Number (Piece)	Diameter (mm)	Length (mm)			
Deguchi et al. 2008.[31] (Clinical trial)	2	1.5	6	Mesial to lateral incisor	80-120 g per side	Whole maxillary arch
Polat-Ozsoy et al. 2009.[6] (Clinical trial)	2	1.2	6	Distal to lateral incisor	80 g per side	4

Table 2.2 Summary of literature review (continued)

B. Other type of studies (continued)

Study	Number and size of mini-screw			Location	Force magnitude	Number of teeth
	Number (Piece)	Diameter (mm)	Length (mm)			
Polat-Ozsoy et al., 2011.[32] (Descriptive)	2	Not shown	Not shown	Distal to lateral incisor	Not shown	4
Senisik and Turkkahraman, 2012.[33] (Clinical trial)	2	1.3	5	Distal to lateral incisor	90 g per side	4
Jain *et al.* 2014[5] (Clinical trial)	2	1.4	6	Mesial to lateral incisor	42.52 g (1.5 ounces) per side	4
Aras and Tuncer, 2015.[34] (Clinical trial)	2	1.4	6	Distal to lateral incisor	40 g per side	4



A B

Figure 2.1 A) One mini-screw placed between the roots of the central incisors for intrusion of the six maxillary anterior teeth. B) Protrusion is expected with this technique.[14]

The second design involves placing two mini-screws either between the roots of the central and lateral incisors or between the roots of the lateral incisor and the canine (Figure 2.2). Nanda and Tosun[14] recommended these methods for severe deep overbite cases, but did not comment on inclination of the incisors. Many studies reported placing mini-screws between the roots of the lateral incisor and canine[6, 9, 32-34], while others placed mini-screw between roots of central and lateral incisor.[5, 31] Although no study has compared the results of these two methods, considering the sites of mini-screw placement discussed earlier, the location between roots of the lateral incisor and canine is more suitable[13] and potentially better than between the roots of the central incisors, because of the risk of soft tissue irritation at the latter site.[9] Park et al.[15] explored many designs of mechanics for mini-screw placement and point of force application for the intrusion of the six-tooth mandibular anterior segment using the finite element method. Designs placing mini-screws distally to the canine and applying force in an oblique direction showed less flaring than others. The authors suggested that the results probably depended on the location of the center of resistance.[15]

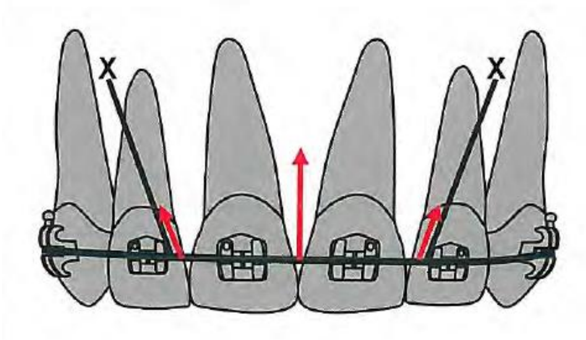


Figure 2.2 Two mini-screws placed between the roots of the lateral incisor and canine for intrusion of the six maxillary anterior teeth.(14)

2.3 Finite element method

The key of orthodontic treatment is the periodontal ligament response to force from devices.(21) Based on "Pressure-tension theory", stress in a periodontal ligament is the initiating factor in tooth movement which is transmitted to alveolar bone through periodontal ligament and the reaction cause changing in cellular level.(22)

The response of periodontal tissue is affected by several factor such as types and durations of force.(22) Types of tooth movement is also one factor that makes the different in result of mechanical stresses distribution at varying locations within the roots.(35) Many studies examined the mechanism of orthodontic tooth movement through various methods: histological, histo-chemical, biochemical, physiologic, bioelectrical and biomechanical aspects.(36)

Limitations of those conventional methods are that they cannot measure the internal stress level of the periodontal ligament.(36) Strain gauge techniques could measure tooth displacement but the gauge cannot be placed directly on the periodontal ligament without causing tissue damage. The photo-elastic techniques are also limited in determining the internal stress levels due to the crudeness of modeling and interpretation. At this point, the finite element method (FEM) seems to have many advantages over other methods. It can construct complex three-dimensional shapes of tissues with heterogeneous biomechanical properties and is easier to apply load at different directions and magnitudes compared to other methods.

In orthodontics, the finite element analysis provides the orthodontist with quantitative data that can extend the understanding of physiologic reactions that occur within the dento-alveolar complex.[37, 38]

Steps in FEM

Finite element method uses computer program to build a mathematic model by dividing the problem domain into a number of sub-domains called each “element”, that are now finite units.[16] Each element has a function which is assumed to solve differential equations over the volume of the element. These models represent properties of the overall structure and the actual response when the force is loaded.

The steps involved in the finite element analysis are pre-processing, solution and post-processing.[37]

1. Pre-processing phase:

1.1 Construction of the geometric model

The purpose of the geometric modeling phase is to represent geometry in terms of points, lines, areas and volume.[37] This can be achieved by laser scanner or computed tomography (CT) scanner. Laser scanner is normally used when modeling inanimate objects such as brackets. On the other hand, CT scanner is normally used when modeling complex structures or living tissues.

Commercial maxillary model is also used as a prototype of the teeth and alveolar bone. The model is scanned using a 3-D scanner to produce digital tooth images.

1.2 Conversion of geometric model into solid model

SolidWorks program (Dassault Systèmes SolidWorks Corporation, Waltham, MA, USA) is used to produce the 3-D model of each tooth, bone, PDL or other compartments. This program provides an ability to create and make changes to the design of model. Digital tooth images or CT data can also be used in this process. CT data stored in DICOM format are converted to an STL (Standard Tessellation Language) format to allow data transferring between Computer-Aided Design (CAD) programs and stereolithographic machines.(37)

1.3 <u>Conversion of solid model into finite element model</u>

After a solid model is constructed, it is imported into the software that is used in finite element analysis such as Ansys, Abaqus, Hypermesh, Dytran, Femfat, etc

These programs will perform the “discretization”, the process of dividing the model into several small elements connected by nodes. The elements can be created in one, two or three-dimension and in various shapes.(37) (Figure 2.4) The accuracy of the model was determined by the complexity of the element, three dimensional element’s accuracy is better than two, but the process of analyzing is longer.

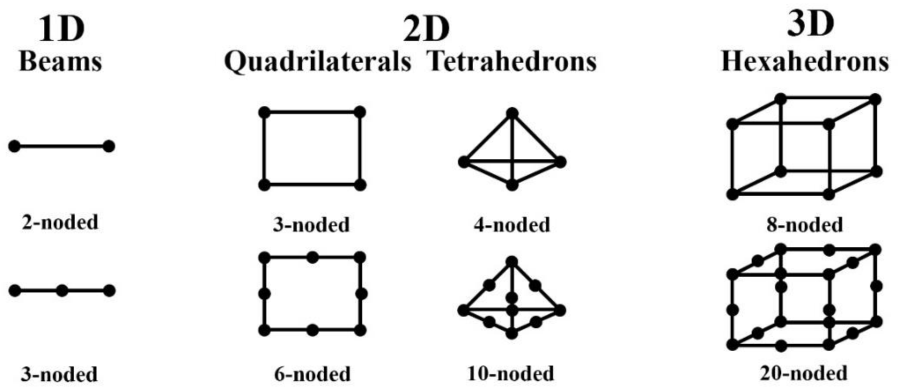


Figure 2.4 The solid model can be divided into several small elements. The elements could be displayed in one, two or three-dimension and in various shape.

1.4 <u>Defining the material properties</u>

The important material properties in finite element analysis that define an elasticity are a modulus of elasticity (Young’s modulus) and Poisson’s ratio.(39) Young’s modulus represents the inclination of the linear portion of the stress-strain diagram, while Poisson's ratio refers to the absolute value of the relationship between transverse and longitudinal deformations in an axial traction axis. Correct properties of the material let the finite element model predict correct mechanical behavior of each component.

Material properties have 4 different types; isotropic, transversely isotropic, orthotropic, and anisotropic.(40) Properties of an isotropic material are the same when measured in different directions. An anisotropic material, however, has different properties when measured in different directions. The analysis is either performed as linear static analysis or non-linear analysis depending on the allocation of appropriate physical characteristics to different parts of the structure. In FEM studies, linear models are widely used, with an assumption that materials are homogeneous, linear and isotropic.(37, 41-44)

Many investigations measured mechanical properties.(37, 44, 45) For hard tissue such as bone, most studies(37, 46, 47) have modeled it as homogenous and isotropic, ignoring its trabecular structure which seems to have low impact to the result. On the other hand, periodontal ligament had an important role in supporting tooth by distributing the force applied to it. Compared to the linear static analysis, non-linear analysis provides more realistic results as they closely reflect the dynamic nature of the oral environment.(48) Many studied concluded that the PDL reacted to a load with non-linear elastic property.(39, 49-51) Hemanth et al.(52) reported the results of comparison between linear and non-linear analyses of the stress induced in the PDL under orthodontic loading had a dramatic difference which is in agreement with the study by Toms and Eberhardt.(53) While the levels of force applied to the tooth increase, the force-displacement curve is found to be non-linear. Non-linear analysis has become an increasingly powerful approach to predict stress and strain within structures in a realistic situation that cannot be solved by a linear statistic. Assuming that the linear elasticity is a constant material property of the periodontal ligament could lead to an erroneous solution.

Examples of non-linear elastic or hyper-elastic model are Neo-Hookean, Mooney-Rivlin, Fung, and Ogden models. Lin et al.(54) reported that for the biological tissues, the Fung and Ogden models achieved the best fits of the data. The Ogden models were reported capable of accurately representing the elastic response of the biological soft tissues liked the vocal fold(55), brain tissue(56), and dura mater from the brain and spinal cord(57). The Ogden models was also applied in the study of the PDL under orthodontics loading.(58)

2. Solution phase

The solution phase has two sub-processes which are defining the boundary conditions and loading configuration.(16) Without boundariry conditions, an object will act as a free-floating rigid body and will undergo a translator or rotary motion or a combination of the two without experiencing any deformation. To study its deformation, the degree of freedom must be restricted (movement of the node in each direction x, y and z) for some of the nodes. Loading configuration is an application of force at various points of geometry and its configuration.

Sequencing, the computer solves differential equations, assembles the process into matrices and computes the summation of the matrix equations. The stresses are determined from the strains by Hooke's law.(16)

3. Post-processing

In this final step, the output from the finite element analysis is measured in several forms.(16) The numerical form is the basic. It usually consists of nodal values of the field variables and its derivatives. For example, in solid mechanical problems, outputs are nodal displacement and element stresses. Graphic outputs and displays are usually more informative. (Figure 2.5) The curves and contours of the field variable can be plotted and displayed. Also, deformed shapes can be displayed and superimposed on unreformed shapes. The output is primarily in the form of color-coded maps. The quantitative analysis is determined by interpreting these maps. Animated output displays the result as animation.(16)

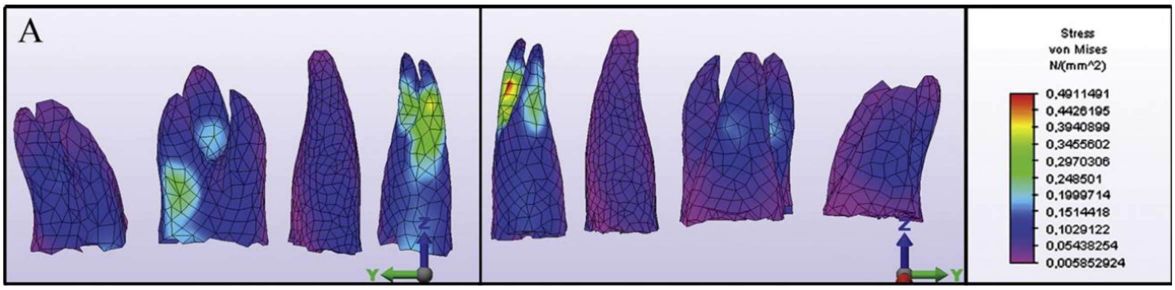


Figure 2.4 An example of graphic output, obtained from Cifter and Sarac.[59] The results of this study are shown as graphical outputs of stress distribution (N/mm^2) along the root surfaces.