CHAPTER 2

Literature Review

Angle's Class II molar malocclusion can be treated with either extraction or non-extraction treatment. Distalization of maxillary molars is often used in non-extraction treatment to move the maxillary first molars distally, relieve the crowding, and establish a Class I molar relationship. It is indicated for patients in Class II molar malocclusion with maxillary dento-alveolar protrusion, for minor skeletal discrepancies or for camouflage treatment in nongrowing patients with skeletal Class II malocclusion.[28, 29]

This review is focused on the appliances which have active components on the buccal side providing the distalizing force for maxillary molar distalization. The review is divided into four parts as follows:

2.1 Compliance appliances for maxillary molar distalization

2.2 Non-compliance appliances for maxillary molar distalization

2.2.1 Non-compliance appliances for maxillary molar distalization with conventional anchorage

2.2.2 Bone-supported appliances for maxillary molar distalization

2.3 Simultaneous first and second molar distalization

2.4 Finite element method

2.1 Compliance appliances for maxillary molar distalization

The traditional approach to distalizing maxillary molars is with extraoral headgear types[1, 2] or extraoral traction in combination with removable appliances. Bondemarkand Karlsson, in 2005, evaluated the treatment effects of an extraoral appliance (a Kloehn cervical headgear) for distal movement of maxillary first molars.[30] The mean amount of distal molar movement was 1.7±0.91 mm. The average molar distalization time was 6.4 months. However, the maxillary incisors retroclined and moved distally 1.0±0.99 mm and the overjet decreased by a mean of 0.9 mm. This decrease in overjet is, of course, desired when Class II division 1 occlusions are treated. Although headgears are effective in molar distalization, they are highly dependent on patient compliance, which is the most important factor in the effectiveness. The amount of distal movement of the maxillary first molars was significantly higher and more rapid with the intraoral appliance than the extraoral appliance.

Intermaxillary Class II elastics alone or in conjunction with sliding jigs[31] are widely used for maxillary molar distalization because of their simplicity and anteroposterior effectiveness. The side effects include forward movement and proclination of the mandibular dentition, along with distal movement and retroclination of the maxillary dentition.[32] Such elastics have the disadvantages of requiring patient compliance and unwanted tooth movement due to reactive forces. To overcome these problems, some researchers developed the miniscrew-supported sliding jig.[33]

The need for compliance, the difficulty of use and impediments in the daily life of patients led many researchers to develop noncompliance appliances for maxillary molar distalization.

2.2 Noncompliance appliances for maxillary molar distalization

2.2.1 Noncompliance appliances for maxillary molar distalization with conventional anchorage

Conventional anchorage refers to dental anchorage and palatal anchorage designed with a Nance acrylic button placed on the palatal mucosa and/or two or four occlusal rests on the other teeth without the use of bony or absolute anchorage. Several studies have reported on noncompliance appliances for maxillary molar distalization with the active unit placed on the buccal side (Table 2.1). Their design includes an active unit that distalizes the molars, and the anchorage unit (a combination of dental anchorage with a Nance acrylic button placed on the palatal mucosa) that diverts the mesially reciprocal forces.

The use of magnets for maxillary molar distalization was reported by Bondemark and Kurol in 1992.[5] The principle of force application relies on the force of repulsion found between two homopolar samarium/cobalt magnets. The magnets are attached buccally with ribbon arches, the distal magnet being fitted directly to the headgear tube of the first molar. A Nance acrylic button is attached to the lingual wires which are soldered lingually to the second premolar bands to provide the anchorage. Although the appliance is effective for distalization, the corrosion and cytotoxicity of the magnetic materials must be considered.[6]

Super-elastic nickel-titanium (NiTi) coil springs are used for distal movement of maxillary molars. The coil springs can be inserted in the buccal sectional arch like the magnets. Bondemark et al. (1994)[6], Bondemark and Kurol (1998)[7], and Bondemark (2000)[34] combined the Nance button with open nickel titanium (NiTi) springs. These coil springs are fitted to vestibular arch sections.

The Jones Jig appliance is one of the most commonly used in noncompliance Class II orthodontic treatment developed by Jones and White in 1992.[10] The appliance consists of an active arm incorporating nickel-titanium open coil springs fitted to the buccal tube of the molars and an anchorage unit consisting of a palatal Nance button combined with a wire soldered lingually to the second premolar bands.

Table 2.1 Studies using the noncompliance appliances for maxillary molar distalization with conventional anchorage: appliances, number of treatment cases, the location of distalizing force, the amount of force application, treatment duration (m=month, w=week), and intra-anchorage designs, NB= Nance acrylic button, B= wire soldered to band, OR= wires bonded on occlusal rests, BP= anterior bite plane, PM1= first premolar, PM2= second premolar.

Authors	Appliances	n	Force/ Quadrant (g)	Tx time	Anchorage	
					Soft tissue	Dental
Bondemark & Kurol (1992)[5]	Magnets	10/ 10	215	16.6 w	NB	2 B PM2
Bondemark et al.(1994)[6]	Magnets/ supercoils	18/ 18	225/225	6 m	NB+BP	2 B PM2
Bondemark & Kurol (1998)[7]	Magnets/ supercoils	18/ 18	Not available	6 m	NB+BP	2 B PM2
Bondemark (2000)[34]	Magnets/ NiTi coils	21/ 21	225/180-200	5.8±0.97/ 6.5±1.36 m	NB	2 B PM2
Brickman et al. (2000)[35]	Jones Jig	72	70-75	6.35±2.75 m	NB	2 B PM2
Gulati et al. (1998)[36]	Jones Jig	10	150	12 w	NB	4 B
Papadopoulos et al. (2004)[37]	Modified Jig	14		16.5 w	NB	2 B PM2

Effects on the molars

The maxillary molars moved distally with distal tipping and vertical changes (Table 2.2). The most distal movement was reported by Bondemark & Kurol (1992). The minimum distal movement was reported by Papadopoulos et al. (2004) using a modified jig.

Table 2.2 Effects on the molars after distalization: appliance, amount of distalization (mm.), distal tipping (degrees), intrusion and extrusion (mm.), intrusion(-)/extrusion(+)

Authors	Appliances	Measurements of the molar		
		Distal movement (mm)	Distal tipping (°)	Intrusion/ extrusion (mm)
Bondemark & Kurol (1992)	Magnets	4.20±0.92	8.00±3.53	Not available
Bondemark et al.(1994)	Magnets/ supercoils	2.02 ±0.94 3.20 ±1.09	1.00 ±1.39 1.00 ±1.38	0.80 ±0.66 0.80 ±0.66
Bondemark & Kurol (1998)	Magnets/ supercoils	2.20±1.05 2.60±1.17	Not available Not available	1.10±0.61 1.10±0.61
Bondemark(2000)	Magnets/ NiTi coils	2.60±0.51 2.50±0.69	2.20±2.53 8.80±2.82	Not available Not available
Brickman et al.(2000)	Jones Jig	2.51±1.35	7.53±4.57	0.14±1.39
Gulati et al.(1998)	Jones Jig	2.95±0.76	3.50±1.85	1.60±1.25
Papadopoulos et al. (2004)	Modified Jig	1.4-0±2.06	6.80±5.91	-0.40±1.27

Effects on the premolars and incisors

The amounts of premolar and incisor movement in horizontal and vertical direction are shown in Tables 2.3 and 2.4. Anchorage loss resulting from reactive force occurred with mesial movement and tipping of premolars, incisor protrusion and increased overjet.

Table 2.3 Effects on the first premolars after distalization: appliance, amount of mesialization (mm.), mesial tipping (degrees), intrusion and extrusion (mm.), intrusion(-)/extrusion(+)

Authors	Appliances	Measurements of the premolar		
		Mesial movement (mm)	Mesial tipping (°)	Intrusion/ extrusion(mm)
Bondemark & Kurol (1992)	Magnets	Not available	Not available	Not available
Bondemark et al.(1994)	Magnets/ supercoils	Not available Not available	Not available Not available	Not available Not available
Bondemark & Kurol (1998)	Magnets/ supercoils	Not available Not available	Not available Not available	Not available Not available
Bondemark(2000)	Magnets/ NiTi coils	1.80±0.86 1.20±1.01	6.70±2.95 2.10±2.75	Not available Not available
Brickman et al.(2000)	Jones Jig	2.00±1.99	4.76±4.74	1.88±1.56
Gulati et al.(1998)	Jones Jig	1.05±0.83	2.60±1.17	Not available
Papadopoulos et al. (2004)	Modified Jig	2.60±1.70	8.10±5.14	0.60±1.57

Table 2.4 Effects on the incisors after distalization: appliance, amount of mesialization (mm.), protrusion/ mesial tipping (degrees), intrusion and extrusion (mm.), intrusion(-) /extrusion(+)

Authors	Appliances	Measurements of the incisor		
		Mesial movement (mm)	Protrusion (°)	Intrusion /extrusion(mm)
Bondemark & Kurol (1992)	Magnets	1.80±0.75	5.80±2.88	Not available
Bondemark et al.(1994)	Magnets/ supercoils	1.90 ±0.41 1.90 ±0.41	4.40 ±1.97 4.40 ±1.97	0.20 ±0.38 0.20 ±0.38
Bondemark & Kurol (1998)	Magnets/ supercoils	1.80±0.91 1.80±0.91	Not available Not available	0.20±0.4 0.20±0.4
Bondemark(2000)	Magnets/ NiTi coils	1.90±0.64 1.50±0.92	5.50±2.52 4.70±3.65	Not available Not available
Brickman et al.(2000)	Jones Jig	Not available	2.40±3.46	0.14±0.87
Gulati et al.(1998)	Jones Jig	Not available	Not available	Not available
Papadopoulos et al. (2004)	Modified Jig	2.30±2.25	4.80±3.23	0.35±0.56

Various noncompliance appliances with buccal force application can be effective for maxillary molar distalization. Even though the molars can be distalized, side effects occur with distal tipping and intrusion/extrusion of the molars, and anchorage loss occurs with mesialization of premolars and increased overjet. The influence of the side effects depends on the biomechanical forces derived from the design of the individual devices. Appliances which provide bodily movement of the maxillary molars with little/no anchorage loss still need further development.

2.2.2 Bone-supported appliances for maxillary molar distalization

To control unwanted movement and reinforce the anchorage unit, many researchers have developed appliances for maxillary molar distalization combined with skeletal anchorage. Skeletal anchorage refers to an anchorage design with dental implant, miniplate or miniscrew implant use for direct anchorage which is connected to the tooth or group of teeth to be moved in order to apply the force directly on them, or indirect anchorage which involves a tooth, group of teeth or Nance acrylic button that act as anchorage elements. Various studies have investigated maxillary molar distalization with buccal force application (Table 2.5).

Nowadays, miniscrew implants are commonly used for orthodontic anchorage. The safe zones for miniscrew implant placement in the maxillary buccal region are between the second premolar and the first molar.[38, 39] Several articles have reported on distalizing maxillary molars combined with miniscrew implants placed in the interradicular space.

Sliding mechanics with the aid of miniscrew implant anchorage and its application for the treatment of skeletal Class II malocclusions have been described. Park et al.[15] and Oh et al.,[40] who placed miniscrew implants in the buccal alveolar bone between the second premolars and the first molars when distalizing the posterior teeth using sliding mechanics. Two hundred grams of distalizing force were applied with nickel-titanium closing coil springs or elastic chains from miniscrew implants to the maxillary canines. The amounts of molar distalization were 0.60±1.37 mm and 1.51±1.59 mm, respectively, with distal tipping 0.31±4.13 degrees and 3.47±5.92 degrees, respectively. Yamada et al.[41] used interradicular miniscrew implant anchorage to distalize the whole maxillary arch. The miniscrew implants were placed between the second premolars and the first molars at an oblique angle of 20-30 degrees to the long axis of the proximal tooth. Elastic chains or nickel-titanium closed coil springs generated 200 g of force from the miniscrew implants to hooks placed distal to the maxillary canines.

The studies showed 2.8±1.6 mm distal movement of maxillary molar crown with distal tipping of 4.8±4.5 degrees, and 0.6±1.0 mm of intrusion.

Goyal et al.[42] described a case report with miniscrew supported molar distalization. A nickel-titanium open coil spring was inserted between the second premolar and the first molar to provide the distalizing force. A miniscrew implant was inserted between the second premolar and first molar to prevent the loss of anterior anchorage. Stainless steel ligature wire (0.010" diameter) was tied to the first premolar brackets from the miniscrew implant to prevent their mesial movement.

Lim et al., 2011[33] used a miniscrew-anchored sliding jig for molar distalization. The distalizing force was applied by elastomeric chain connected from the miniscrew implant to the jig’s vertical leg. They reported about 2 mm of distal maxillary molar movement and suggested using this appliance for mandibular molar distalization when the miniscrew implant is placed in the retromolar area or buccally between the second premolar and first molar.

Although there are advantages when the miniscrew implant is placed in the buccal dento-alveolar area, such as the possibility of applying relatively simple force systems and simple surgical procedures, the amount of maxillary molar distalization is limited because the location of the miniscrew implant between the roots of the maxillary posterior teeth obstructs tooth movement when the adjacent teeth are moved in the antero-posterior direction. Therefore, some investigators have suggested relocation of the miniscrew implant in order to allow additional distal movement.

Table 2.5 Studies using noncompliance appliances for maxillary molar distalization with skeletal anchorage: appliances, type of study, number of treatment cases, treatment duration (m=month), anchorage placement and anchorage design (MI= miniscrew implant), the location of distalizing force, the amount of force application, and the distalized tooth (3=canine, 4= first premolar, 5= second premolar, 6= first molar and 7= second molar)

	Appliances	Type of study	n	Tx time (month)	Anchorage		Force/ Quadrant (g)	Distalized tooth
					Site	Design		
Park et al. (2005)[15]	Nickel-titanium coils	Retrospective	13 (max=4)	12.30±5.70	4 = Buccal alveolar bone (between 5 and 6)	2 MI	200	4,5,6,7
Sugawara et al. (2006)[43]	Skeletal anchorage system (SAS)	Retrospective	25	19.00	Zygomatic buttress	Miniplate	200 g or 500 g	7 or 4,5,6,7
Cornelis and De Clerck (2007)[44]	E-chain anchored with miniplate	Prospective	17	7.00±2.00	Zygomatic buttress	Miniplate	150	4,5,6,7
Yamada et al. (2009)[41]	Nickel-titanium coils	Retrospective	12	8.40±4.20	Buccal alveolar bone (between 5 and 6)	Titanium screw (1.3 x 8.0 mm, 1.5 x 9.0 mm)	200	Not reported

Authors	Appliances	Type of study	n	Tx time (month)	Anchorage		Force/ Quadrant (g)	Distalized tooth
					Site	Design		
Kaya et al. (2009)[45]	Zygoma anchorage system (ZAS)	Prospective	15	9.03±0.62	Zygomatico maxillary bone crest	Miniplate	450	4,5,6,7
Oh et al. (2011)[40]	Microimplant-aided sliding mechanic	Retrospective	23 max=19	20.00±4.90	n=16: buccal alveolar bone (between 5 and 6); n=3: palatal alveolar bone (between6 and 7)	1 micro implant	200	4,5,6,7
Nur et al. (2012)[46]	Zygomatic-Gear Appliance	Prospective	15	5.32	Zygomatic buttress of the maxilla	Zygomatic plate	300	4,5,6,7
Bechtold et al. (2013)[47]	Microimplant-aided sliding mechanic	Prospective	Gr.1= 12 Gr.2=13	Gr1: 8.2 Gr2: 10.2	Buccal alveolar bone(Gr.1: between 5 and 6; Gr.2 : between 4 and 5, 5 and 6)	Gr1: 1 screw Gr2: 2 screw (1.8x7.0 mm.)	200 400	3,4,5,6,7

All of these miniscrew-supported distalizers can provide suitable anchorage. The maxillary molars can be distalized but side effects can still occur, such as distal tipping and extrusion or intrusion of the molars. Some anchorage units move distally simultaneously with molar distalization, pulled by the trans-septal fibers. The incisors tip distally with extrusion or intrusion. However, anchorage loss occurs, resulting in increased overjet when miniscrew implants have some mobility.[48]

Use of a miniplate for maxillary molar distalization provides absolute anchorage. The ability to apply high distalization forces is an important advantage of the zygoma anchorage system. Sugawara et al.[43] used a force of 200 g for single molar distalization and 500 g for buccal segment distalization. They obtained 3.7 mm molar crown and 3.2 mm root distalization. According to Cornelis and De Clerck,[44] and Kaya et al.,[45] the amounts of molar distalization were 3.30±1.80 mm and 5.03±0.30 mm, respectively. No anchorage loss was reported. There were no effects on the incisors when using miniplates for anchorage. [43-46] Moreover, miniplates can be used for anchorage when retraction of the premolars and the anterior teeth is performed or when en-masse movement of the molars, the premolars, and the incisors is performed without a separation of the procedure into two stages.

Various distalizer designs are effective in distalization when skeletal anchorage is placed on the buccal side, but distal tipping of the molar has been an unwanted side effect. Appliances which provide bodily movement of the maxillary molars during distalization but with little/no anchorage loss still need further development.

2.3 Simultaneous first and second molar distalization

Maxillary molar distalization can be used to distalize only the first molar or to distalize both the first and second molars simultaneously. How the second impacts distalization of the first molar is still controversial. Several authors have agreed that the eruption stage of the second molar has an impact on the distalization of the first molar.[6, 8, 11] The presence of the second molar impacts tipping and distal movement of the first molar. Kinzinger et al. stated that the unerupted second molar acts as a fulcrum distal to the first molar, thereby increasing its tipping movement. When the second molar continues to erupt, the tipping tendency is reduced.[8] Some authors concluded that the position of the second molar during distal movement of the first molar is of little significance.[4, 49] In addition, they found that there is no relation between the second molar budding stage and duration of therapy and no statistical significance in horizontal molar distalization based on eruptive stage of the second molars. In contrast, Gianelly et al.[11] concluded that duration of treatment increases if the second molar has erupted. Kinzinger et al. stated that treatment time was longer, although not significantly, when first and second molars were distalized simultaneously.[8]

2.4 Finite element method

2.4.1 Introduction

The finite element method (FEM) is a mathematical method of calculating stresses and strains in all materials, including living tissues.[17] This method has become widely used to predict the biomechanical performance of various medical devices and biological tissues. One feature of the finite element method is a color-coded map related to stress values, allowing easy explanation and understanding of the results. The first FEM study in dentistry[50] appeared in 1973 and analyzed stresses and strains in the alveolar structures. Buranastidporn et al.[51] studied the relationship between biomechanical changes in the temporomandibular joint (TMJ) and the internal derangement (ID) symptoms in patients with vertical mandibular asymmetry. In orthodontics, the FEM can help orthodontists to understand the physiologic reactions in the dentoalveolar complex induced by orthodontic forces.

2.4.2 FEM studies in orthodontics

Orthodontic tooth movement is achieved by remodeling processes in alveolar bones, processes which are triggered by changes in the stress/strain distribution in the periodontium. The FEM has been a useful tool to simulate various force systems and to study biomechanical performance in tooth movement. Cattaneo et al., 2005 have illustrated FEM as a tool to study orthodontic tooth movement.[52]

FEM can be used to evalulate stress distribution in the dentofacial structures in order to understand the results of using extraoral appliances, such as face mask[53] and head gear.[54] Holberg et al., 2007 investigated the stresses in the midface and cranial base during surgically assisted rapid maxillary expansion with various surgical procedures, using the finite element method.[55, 56]

Recently, the miniscrew implant has become very popular in clinical orthodontic approaches to obtaining absolute anchorage. Several studies have analyzed the stress distribution on miniscrew implants used for orthodontic anchorage, using the FEM. Motoyoshi et al.[57] were the first to report the application of the FEM in orthodontic miniscrew implant anchorage. They investigated the effects of primary factors, especially thread pitch and the presence of an abutment, on stress distribution, in an attempt to design a miniscrew implant that endures increased orthodontic force during treatment. Torut et al,[58] evaluated the influence of miniscrew implant size and orthodontic loading force on stress distribution in miniscrew implants and in surrounding bone. The results showed that increasing the diameter of miniscrew implant models resulted in decreased stress values in cortical and cancellous bone, and changing miniscrew implant length from 4 to 12 mm slightly increased stress values in the miniscrew implants and cortical bone. They recommended using miniscrew implants of 1.6 to 1.8 mm in diameter with lengths of more than 4.0 mm. Various articles have investigated the influence of miniscrew implants for orthodontic anchorage using several parameters, such as bone quality, loading condition, direction of force, screw length, diameter, thread depth, taper shape, and different materials.[20-22]

To evaluate the stress distribution in teeth in relation to different designs, FEM has been applied to the *in vitro* study of the biomechanics of tooth movement and to the assessment of the effects of appliance systems. Mo et al.[26] evaluated the factors affecting torque control during *en-masse* retraction design with orthodontic minicrew implant anchorage. The inclination and position of the incisors varied with the height of the anterior retraction hooks (1, 4, 7, 10 mm) and the amount of intrusion force (70, 80, 90 g). The results showed that greater intrusion forces and longer retraction hooks caused increased incisor intrusion and canine extrusion. Liang et al.[23] studied the biomechanical differences in incisor torque control in both lingual and labial orthodontic treatment. In the same year, Tominaga et al.[24] determined the optimal height of the power arm to apply retraction force, and its position on the archwire in sliding mechanics. The results showed that bodily anterior tooth movement occurred when using a power arm height of 5.5 mm placed mesial to the canine. Controlled lingual crown tipping of the incisor was shown at the level between 4 mm to 5 mm and lingual root tipping was carried out when the height of the power arm was raised above 5.5 mm. Kojima and Fukui[25] evaluated the effects of a transpalatal arch on periodontal stresses of molars when applying mesial force. The stress distributions in the periodontal ligament (PDL) with and without a transpalatal arch were almost the same. They found that in orthodontic movement, the transpalatal arch had almost no effects, preserving anchorage for mesial movement. However, the transpalatal arch prevented rotational and transverse movements of the anchor teeth.

Cifter and Sarac[27] compared and evaluated the effects of three types of maxillary posterior intrusion mechanics with miniscrew implant anchorage. The results, using a model, in which the miniscrew implants were placed between the roots of the first and second premolars and the first and second molars on both vestibular and palatal sides, showed balanced intrusion. The authors suggested that this type of mechanics was the best, but that the use of four miniscrew implants might be too much for patients for reasons of both discomfort and cost.

Yu et al.[59] used the FEM to evaluate distalization modalities, using a palatal plate and a buccal miniscrew implant for anchorage. They found that distalization with the palatal plate provided bodily molar movement without tipping or extrusion. Ueno et al.[60] clarified the asymmetric influence of the placement site of miniscrew implants when distalizing the maxillary molar. They found that when the location of the miniscrew implant was moved to the left of the midline, the amount of distal movement of the left molar increased.

2.4.3 Advantages of the FEM

The FEM is a tool in biomechanical orthodontic research. This method has several advantages. It can accurately assess the effect of new appliance systems and materials without the need to go to animal or other less representative models. It is a noninvasive technique. It does not require extensive instrumentation. It closely simulates natural conditions. The study can be repeated as many times as the operator wishes and reproducibility does not affect the physical properties involved.

2.4.4 Disadvantages of FEM

The limit of the FEM is that this method does not represent reality. The accuracy of the results relates to the accuracy of the FE model, including the anatomic accuracy of the morphology, and of the specifications of the material properties and the boundary conditions.

2.4.5 Conclusions

The finite element method becomes a valuable option for the evaluation of biomechanical factors in orthodontics. Although this method has improved over the past decades, the need for further development remains. In the future, FEM can be used increasingly for biomechanical research in dentistry.