CHAPTER 2

Literature review

2.1 Anterior open bite

Anterior open bite is defined as no contact and vertical overlap of maxillary and mandibular incisors (11). Incidence of anterior open bite ranges from 1.5 to 11.0%, and varies between races and dental ages (12). Anterior open bite is attributed by several factors, including genetic, anatomical, and environmental factors (1). Genetic factors are primarily related to unfavorable vertical craniofacial growth. Anatomical conditions, such as tongue size, tongue position, pathological mandibular condylar resorption, enlarged adenoid or tonsil, deviated nasal septum, and other anatomical conditions that cause a mouth-breathing, can bring anterior open bite. Environmental factors are mostly associated with abnormal habits, such as finger sucking, forward tongue posture or tongue thrust, and neuromuscular deficiencies.

According to its etiologies, anterior open bite is generally classified in to two major types: 1) dental open bite; 2) skeletal open bite. Dental open bite malocclusion is caused by abnormal position of teeth with a normal craniofacial or skeletal pattern, such as proclination of incisors, under eruption of anterior teeth, or over eruption of posterior teeth (1, 13). Treatment planning for the dental anterior open bite is aimed to eliminate factors, impeding normal eruption of the anterior teeth, including patient instruction, oral appliances, abnormal oral habit reminders, and myofunctional exercise. In some cases, orthodontic treatmentmay be necessary to correct tooth position. For correcting the anterior open bite, Sarver and Weissma (14) have suggested criteria for orthodontic treatment in combination with tooth extraction as follows: 1) proclined maxillary or mandibular incisors; 2) little or no gingival display of smile; 3) normal craniofacial pattern; and 4) less than 2 to 3 mm of upper incisor exposure at rest.

Skeletal open bite is associated with unfavorable craniofacial growth patterns, including hyperdivergent growth pattern, posterior or clockwise rotation of the mandible, reduced posterior facial height, and excessive vertical growth of craniofacial skeleton, characterizing a long face pattern (1). Most skeletal open bite cases are related to Class II malocclusion and Class II sagittal skeletal relationship because the maxilla grows more downward and backward than forward, especially in the maxillary posterior region, that also causes downward and backward rotation of the mandible (11). The craniofacial characteristics of skeletal open bite are increase of the mandibular plane angle and the gonial angle, anterior rotation of the palatal plane, retrognathic mandible, and long lower anterior facial height(1, 13). Therefore, the ratio of the upper to lower anterior facial height is reduced (15). Some studies (15, 16) have reported that the posterior facial height of patients with anterior open bite was shorter than that of patients with normal bite. But Nanda (17) suggested that there was little or no difference in the posterior facial height among them. Nevertheless, the ratio of the posterior to anterior facial height in patients with anterior open bite is less than that in patients with normal bite.

In growing patients exhibiting skeletal open bite, a principle of treatment is to control and to restrict subsequent vertical growth of the posterior dento-alveolar regions of the maxilla (11). A result is preferable in patients who have adequate mandibular ramus growth, allowing normal growth of the mandible and rotation of the mandible in upward and forward direction. Several appliances are used to control the vertical craniofacial growth, including extraoral and intraoral appliances (13). Highpull headgear is a common extraoral appliance that restricts vertical position of the maxilla and reduces eruption of the upper molars. It is recommended to be worn 14 hours a day with a force greater than 12 ounces per side. The headgear can be worn in combination with the maxillary splint to reduce forward growth of the maxilla, to reduce upper anterior dento-alveolar protrusion and to intrude upper molars, leading to anterior rotation of the mandible. The effect is favorable in Class II skeletal open bite cases. A vertical pull chin cap in combination with fixed appliances is recommended in patients who have posterior rotation of the mandibular growth. Passive posterior biteblocks are intraoral appliances that impede the vertical growth of posterior dento-alveolar regions with intrusive force from the stretched muscle.The results of posterior biteblocks are forward and upward mandibular growth, or anterior rotation of the mandible, as a result of posterior tooth intrusion, and anterior tooth eruption. Functional appliances, such as open bite bionator, and Frankel's functional regulator type 4 (FR-4), effect dento-alveolar regions and make postural balance of orofacial musculature. According to Frankel *et al.* (18), it is believed that FR-4 acts asan exercise device causing postural balance between forward and backward muscles. Changes of vertical components are from lip-seal training. But Haydar *et al.* (19) reported that the effects of FR-4 were from dento-alveolar changes, including vertical eruption of upper and lower incisors, and retraction of maxillary incisors with no significant skeletal change. Nevertheless, patient's remaining growth and cooperation is the key of treatment success in growing patients with skeletal open bite.

In non-growing patients, skeletal open bite can be corrected by orthodontic treatment alone or in combination with orthognathic surgical approach, depending on the severity. The greater severity of skeletal open bite, the higher necessity of orthognathic surgery is required. Some studies (20, 21) were carried out to evaluate patients with anterior open bite who require either orthodontic treatment, or orthodontic treatment in combination with orthognathic surgery. Nahoum *et al.* (20) recommended to use cephalometric measurement to distinguish pure dental open bite from skeletal open bite. The crucial cephalometric measurement is the ratio of upper anterior facial height and lower anterior facial height (UAFH-LAFH). Patients with UAFH-LAFH ratio, that is less than 0.65, are considered to be poor prognosis and cannot be corrected by conventional orthodontic treatment. Kim *et al.* (21) has attempted to identify the patients with anterior open bite who had poor prognosis in orthodontic correction. The indicator has been developed, so called overbite depth indicator that combines two angular measurements: the A-B plane to the mandibular plane and the palatal plane to the Frankfurt horizontal plane. The regular mean of the overbite depth indicator is 74.5 deg. The open bite type isidentified when the overbite depth indicator is less than 65.0 deg. In mild skeletal open bite cases, the principle of conventional orthodontic treatment is to create tooth movement modalities in order to camouflage the vertical skeletal discrepancy by intruding posterior teeth as well as preventing molar eruption, or extruding anterior teeth, or extracting molar and forward movement of terminal molars to allow upward and forward mandibular rotation, or combination of all modalities (13).

2.2 Posterior tooth intrusion

Posterior tooth intrusion is aimed to rotate mandible forward and upward. Kuhn (22) postulated that 1.0 mm of vertical molar intrusion provides approximately 3.0 mm of anterior bite closure due to forward and upward rotation of the mandible. Posterior tooth intrusion is indicated to anterior open bite cases when conventional orthodontic mechanics do not exceed the limitation of skeletal discrepancy, or to adolescent patients who develop dento-alveolar compensation and have to wait for surgical correction while cessation of facial growth (23). There are several considerations during treatment planning prior to commencing posterior tooth intrusion (24). The first aspect is the skeletal relationships. The good candidate in this technique should be the patient who show long face types with Class I or mild Class II skeletal relationships. Sugawara *et al.* (25) have reported the results of posterior tooth intrusion, including the reduction of lower anterior facial height, mandibular plane angle, ANB angle, and the increase of overbite and Wits appraisal. Therefore, counterclockwise rotation of the mandible is worsen the Class III skeletal relationship. The second aspect is the facial esthetics (24). The patient who does not show sufficient incisor exposure should be treated by incisor extrusion rather than molar intrusion. Thirdly, the angulation and inclination of molars should be carefully monitored, especially torque control, because pure intrusion cannot be done. This problem can be prevented by implantation of miniscrew implants on both buccal and palatal sides or by using cross-arch stabilizing appliance. The fourth aspect is the healthy periodontal status before orthodontic treatment.

Several appliances is introduced to intrude maxillary posterior teeth, such as high pull headgear, passive posterior bite blocks, functional appliance, active vertical corrector. But patient compliance is required during using those appliances (13). In addition, some techniques, that result in intrusion of posterior teeth simultaneously with extrusion of incisors, are limited in the patients who have adequate or excessive anterior dento-alveolar height prior to orthodontic treatment. Therefore, posterior tooth intrusion with TADs is an effective way to accomplish pure posterior tooth intrusion without undesirable tooth movement and does not require patient compliance.

2.3 Miniscrew implant placement sites, suitable for maxillary posterior tooth intrusion

Recently, miniscrew implant is a common skeletal anchorage because of several advantages over other skeletal anchorage devices. The advantages of miniscrew implant are easy placement, the absence of trauma during placement, low cost, immediate loading and small size (5). The miniscrew implant placement sites are varied and depend on the appliance design, biomechanics, important anatomical structures, and quality and quantity of surrounding bone. Miniscrew implant placement in tooth-bearing areas, such as interradicular area, may increase risk of dental root damage and miniscrew implant fracture due to the limited dimension of miniscrew implant (26). Moreover, single miniscrew implant placement in buccal dento-alveolar area produces intrusive force that does not pass through center of resistance of the posterior teeth, causing buccal crown torque of the molars. Therefore, additional interradicular miniscrew implant in palatal dento-alveolar area or transpalatal arch may be necessary to prevent buccal crown torque of the molars. Nevertheless, miniscrew implant in the palatal dento-alveolar area may increase the risk of miniscrew implant tipping and failure due to low bone density, covered with thick palatal soft tissue (7). Moreover, there are critical anatomical structures, including greater palatine foramen and maxillary sinus. The infrazygomatic area is one of non-tooth-bearing areas for miniscrew implant placement for maxillary molar intrusion. The risk of root damage decreases, and miniscrew implant stability increases because of sufficient cortical bone thickness (27). However, mucosal irritation and tissue inflammation occur in patients who have insufficient attached gingiva and cannot maintain optimal oral hygiene, resulting in miniscrew implant failure. In addition, buccal crown tipping cannot be avoided in single miniscrew implant placement in infrazygomatic area. Therefore, the palatal area is considered to be a common alternative implantation site for providing a skeletal anchorage. Previous studies (28, 29) have been reported about the stability of palatal miniscrew implant placement due to its dense bone, sufficient cortical bone thickness and few vital anatomical structures. Furthermore, the thickness of palatal mucosa is claimed to be suitable for biomechanical stability for placement of miniscrew implant. Success rate of palatal miniscrew implant is 90.8-95.6% in the midpalatal area (28, 30) and 79.2% in the paramedian area (28).

Palatal miniscrew implants have been successfully used as a skeletal anchorage for intrusion of posterior teeth in anterior open bite treatment, for distalization of maxillary molars, and for retraction of anterior teeth (26, 31-34). Fliegel *et al. (*32) has reported success of molar intrusion, using two palatal miniscrew implants, that was located in the paramedian area of the anterior palate. The x-ray images and digitized models have shown favorable molar intrusion without complication. Kang *et al.* (26) have introduced two midpalatal miniscrew implants, connecting to each other with wire. The intrusive force was provided by springs or elastomers between the hooks at miniscrew implants and the lingual sheaths of molar bands. They have suggested that two miniscrew implants with connectors provided good stability for posterior tooth intrusion in various force directions. Palatal swelling occurred around palatal miniscrew implants in few patients, but all miniscrew implants still remained until treatment was complete. Xun *et al.* (34) have reported that the maxillary first molars were intruded for average 1.8 mm without miniscrew implant failure. Although there are various appliance designs for posterior tooth intrusion, the transpalatal arch is still required to prevent lingual crown torque of molars. In some appliance designs, the posterior teeth are simultaneously intruded with the transpalatal arch. In addition, a mediator device or extension arm is necessary in posterior tooth intrusion, using palatal miniscrew implants because palatal miniscrew implants are far from the moving teeth. Some design of devices may be complex and bulky, causing imprinting tongue (35).

2.4 Quantitative and qualitative evaluations of palate for palatal miniscrew implant stability

Palate is a roof of oral cavity, separating oral cavity to nasal cavity. It is divided into immovable hard palate in anterior part and movable soft plate in posterior part. A hard palate is formed by two symmetrical palatal processes of maxilla and two horizontal plates of palatine bone. There is a wide anterroposterior gap between two palatal processes of maxilla prenatally, which is called a midpalatine suture. The continuing growth of the midpalatine suture has a major effect in the width of the palate until 17 years old, when it simultaneously increases interdigitation of sutural bone (36). There is an incisive canal that contains nasopalatine nerves extending superiorly and posteriorly in the anterior region of the palate. The greater palatine foramens are located on the palatal side of both maxillary alveolar processes, containing greater palatine nerves, greater palatine vessels, and dense vascular bundles. Lesser palatine foramens, containing lesser palatine nerves and vessels, are located behind greater palatine foramens. Therefore, there are higher density of blood vessels in the posterior than anterior region of the palate (10). Palatal bone means all fusing bones of the palate that are flat bone and consist of intervening cancellous bone between double palatal and nasal cortical layers. The palatal bones are covered by soft keratinized tissue, which becomes thicker in the posterior than anterior palate because it contains adipose tissue and salivary glands (10).

Several studies (10, 29, 37-39) have evaluated anatomical preconditions of the palate to locate suitable regions for successful palatal miniscrew implant placement. The soft-tissue anatomy, vital anatomical structure, quantity and quality of surrounding bone are considered before implantation. Quality and quantity of the supporting bone are very important for the initial stability of miniscrew implant. Tight contact of miniscrew implant and surrounding bone, not osseointegration, is a vital factor.

The palate is covered by keratinized tissue, and this is an important factor for the success of miniscrew implant that requires thin attached gingiva. Previous studies (38, 40) have reported that the midpalatal area is covered by thick palatal mucosa in the anterior region, and from 4.0-mm posteriorly to the incisive papilla a constant 1.0-mm-thick palatal mucosa. Moreover, the palatal mucosa increases from medial to lateral region and from posterior to anterior region. The keratinized gingival mucosa, covering the palate, reduces susceptibility of infection and inflammation of placement site. Therefore, the quality and quantity of the palatal soft tissue is one of the considerations in selection of placement sites and lengths of TADs.

The density of midpalatal bone in human cadavers has been reported by Stockmann *et al.* (39). The bone density, assessed as a ratio of bone volume to total volume, was 40-60% in all measured areas. The greatest bone density was found at the level of the first premolars. The least bone density was found at the level of the canines due to minimal density of the trabecular bone. Nonetheless, other studies (41) reported that there was no significant different bone density in anterior, middle and posterior regions in the midpalatal areas. The bone density of palate can also be measured, using

CBCT. Han *et al.* (42) indicated that the area located at 15.0 mm posteriorly to the incisive foramen and 6.0 mm laterally to the midline, approximately second premolar area, is the greatest bone density area of the palate.

The total palatal bone thickness and cortical bone thickness are important factors for successful palatal miniscrew implant placement. Palatal bone thickness is the thickness of all fusing bones of the palate, including palatal cortical bone layer, nasal cortical bone layer and intervening cancellous bone. Palatal bone thickness have been carried out, using various methods. Stockmann *et al.* (39) measured median palatal bone thickness by histologic analysis of 10 human cadavers. Mean palatal bone thickness was greater than 5.0 mm along the midsagittal plane. In 2.0-mm paramedian area of the midpalatal suture, the palatal bone thickness decreased from anterior to posterior region. The palatal bone thickness at first premolar level was measured on lateral cephalogram (43). The palatal bone thickness at first premolar level was 8.6±1.3 mm, but actual palatal bone thickness that was inferior to incisive canal was 4.3±1.6 mm.Wehrbein *et al.* (44) found the real palatal bone thickness in anterior midsagittal region was higher than that indicated in lateral cephalogram at least 2.0 mm. Due to distortion and superimposition of lateral cephalogram, CBCT is introduced to three-dimensional evaluation of implantation site. According to the investigations of total palatal bone thickness, using CBCT (10, 37), the palatal bone thickness was the greatest in the anterior region and decreased in the posterior region. In every antero-posterior position, the palatal bone thickness was the greatest in area closing to the suture and decreased laterally. Information pertaining to the palatal bone thickness supports the selection of ideal miniscrew implant placement sites and miniscrew implant lengths to secure adequate retention and to avoid damage to vital structures, such as nasal perforation. It was reported that increase in penetration depth of TADs results in greater retention of miniscrew implant (45). There is no conclusive evidence pertaining to adequate palatal bone thickness for the stability of miniscrew implant. Kang *et al.* (37) have suggested bony support that is less than 4.0 mm as a risky area because miniscrew implant length is longer than 5.0 mm. The placement of the 6.0-mm miniscrew implant or longer in the area, posterior to first molar, increases the risk of nasal perforation. Winsauer *et al.* (38) have suggested bony support of at least 5.0 mm to resist rotational forces and dynamic loads, contributing to the stability of miniscrew implants. Furthermore, perpendicular placement angle and complete insertion of the miniscrew implant also increase the risk of nasal perforation.

Palatal cortical bone is the cortical bone that lines in oral side of the palate. Palatal cortical bone thickness is measured from outer to inner border of the palatal cortical bone. The knowledge of the palatal cortical bone thickness is beneficial for selection of the palatal miniscrew placement site because the cortical bone thickness is a crucial factor for the primary stability of miniscrew implant (46-48). Primary stability prevents movement of the miniscrew implant, and allows an appropriate environment for healing. Finite element analysis has shown that most of the force applied to miniscrew implants was concentrated in the cortical bone (49, 50). Motoyoshi *et al.* (48) suggested that the cortical bone thickness should be at least 1.0 mm for adequate primary stability and clinical success because it correlates with torque upon miniscrew implant placement. According to Baumgaertel *et al.* (10), for overall palatal bone thickness and cortical bone thickness, the longer distance from the midsagittal plane and from the anterior region, the thinner palatal bone thicknesses were found. Even though total palatal bone thickness and the cortical bone thickness is reduced in the posterior midpalatal region, the posterior region should not be ruled out because it is compensated by the quality of bone, density of bone and thin keratinized tissue, which is considered to be biomechanically favorable area (10).

The midpalatal area is highly dense structure of the palate due to the additional height, provided by the nasal crest (37). The midpalatal area within 1.0 mm is the thickest part of the palate (28). The thickness of soft tissue is uniformly 1.0 mm posteriorly to incisive papilla. However, the midpalatal area is not recommended for TADs placement because of incomplete ossification in this area, especially in growing children and adolescents (37), leading to possible disturbance of normal transverse growth of the maxilla (39). In addition, the stability of TADs is affected by the interposition of connective tissue between the screws and bone (44, 51). Schlegel *et al.* (52) have shown that complete ossification of the midpalatal suture is rare before the age of 23 years. The sutural ossification progresses in posterior to anterior direction. So, favorable osseointegration is found posteriorly to the interconnecting line of first premolars.

2.5 Palatal bone thickness in different skeletal patterns

As mechanostat hypothesis of Frost (53, 54), the form and mass of bone is influenced by the range of strain. The strain above the range induces bone production. On the contrary, the bone lossoccurs when the strain is below the range. Therefore, the form of the maxilla and mandible, especially the density and thickness of the cortical bone, is affected by the functional load, and is adapted to different masticatory forces in various types of skeletal patterns. Several studies (55-58), including animal and human studies, have shown evidence of relationship between increased vertical skeletal configuration and decreased muscle function. The different bony structures in various skeletal patterns are explained by the association of masticatory force and bony adaptation.

Some studies (7, 8, 59) have evaluated the quality and quantity of alveolar bone in patient with different facial types. Ozdemir *et al.* (8) concluded that there was not statistically significant difference of the cortical bone thickness between patients with different sagittal facial types. But there was statistically significant difference in both the maxillary and mandibular alveolar bone thickness between different vertical skeletal patterns, including open, normal and deep vertical configurations (7, 59). In addition, the alveolar ridge and the alveolar cortical bone in patients with open vertical skeletal configuration were thinner and less dense than in those with deep vertical configuration, in both maxillary and mandibular alveolar processes (7, 8). But there was not significant difference in the trabecular bone thickness in different vertical skeletal patterns.

The clinicians should beware of miniscrew implant placement in both buccal maxillary and mandibular regions in patients with open vertical configuration. There is higher risk of interradicular miniscrew implant failure due to thinner and less dense of alveolar cortical bone. Moon *et al.* (6) have reported a significant reduction in interradicular miniscrew implant success in the buccal maxillary region with open vertical skeletal configurations, and suggested that the reduction was associated with high Frankfort-mandibular plane and low upper gonial angles. Ozdemir *et al.*(8) have suggested to use thick or more angulated miniscrew implant placement to keep more contact to bone, and to strictly monitor oral hygiene. Furthermore, the other alternative miniscrew implant placement sites are considered, such as an in frazygomatic bone and a palate. Previous studies try to investigate the palatal bone thickness to evaluate the most suitable miniscrew implant placement site. But no study has examined total palatal bone thickness and the cortical bone thickness in patients with open vertical skeletal configurations and difference of the palatal bone thickness in patients with different vertical skeletal patterns, especially in Thai patients.

2.6 Cone beam computed tomography (CBCT)

Radiographic imaging is an important diagnostic tool in orthodontics. Two-dimensional radiographic imaging, such as cephalogram, is a common technique due to its accessibility and low radiation dose. But they are limited in some purposes, that need accuracy because of low resolution, superimposition, magnification and distortion, leading to misrepresentation of images. Computed tomography (CT) is three-dimensional (3D) radiographic techniqueproposed by Hounsfield and Comark (60). This technique is involved fan-shaped x-ray beam with helical progression. Nevertheless, CT is limited in dentistry because of difficult access, high cost and high radiation dose. Cone-beam computed tomography (CBCT) is evoluted from the conventional CT. CBCT is introduced in dentistry to assess hard tissue and soft tissue in maxillofacial regions in three-dimensions. The cone beam technique is involved single 360° scan of cone-shaped x-ray beam through the middle of interested area, projecting to an opposite rotating detector. CBCT provides accurate 3D images with sub-millimetre resolution, especially highly contrasted structures, such as bone. Scanned regions can be adjusted to be small region for reduction of radiated area or entire maxillofacial regions. Rapid scan time (10-70 seconds) reduces motion artifacts from patient movement. Radiation dose (36.9-50.3 micosievert [µSv]) is significantly reduced up to 98% when comparing to conventional CT (1,320-3,324 µSv for mandible; 1,031-1,420 µSv for maxilla). Radiation dose of CBCT isapproximately equivalent to periapical films of full mouth (13-100 µSv) and 4-5 times of single panoramic radiograph (2.9-11 µSv). Gribel *et al.* (61) have reviewed accuracy and reliability of craniometric measurement on lateral cephalogram and CBCT. They found that there was statistically significant difference between lateral cephalometric and direct craniometric measurements. The mean difference was 5.0 mm. On the contrary, there was no statistically significant difference between CBCT measurements and direct craniometric measurements. The mean difference was only 0.1 mm.

Currently, CBCT imaging becomes a useful tool in dental treatment, such as assessment of bony and dental pathology, assessment in endodontic treatment, temporomandibular joint imaging, assessment of maxillofacial growth and development, and evaluation of available bone for implant planning (8, 59, 62-64). In orthodontic treatment, CBCT is recommended technique for preoperative evaluation of TADs placement area to investigate the most suitable TADs placement site because it provides precise images of bony structures and surrounding anatomical structures without superimposition and distortion. The quality and quantity of bone are evaluated precisely using CBCT. Several studies determined bone thickness and cortical bone thickness in various regions with CBCT to indicate safe TADs placement sites, including alveolar process (62, 63) and interradicular distance at different levels from the alveolar crest (64, 65), infrazygomatic bone (66, 67), and inferior level of maxillary sinus (68). In addition, CBCT has been widely used to investigate the palatal bone thickness, including total palatal bone and cortical bone thickness (10, 29, 37,69-71). Gahleitner *et al* .(72) have demonstrated that CBCT can determine accurate palatal and alveolar bone volume, and be a proper imaging method for selection of miniscrew implant size and placement site during orthodontic treatment planning.