CHAPTER 2

Literature Review

2.1 Maxillary growth

Previous studies have shown that postnatal maxillary growth occurs by apposition of bone at the sutures that connect the maxilla to the cranium and cranial base, which are collectively called circummaxillary sutures, and by surface remodeling.[4,5] The maxilla grows downward and forward relative to the cranium and cranial base by a push from cranial base growth and by growth at sutures. As growth of surrounding tissue translates the maxilla downward and forward, space is created at its superior and posterior sutural attachments. New bone is added on both sides of this space. Another growth site of the maxilla is the tuberosity region. Bone is added at the posterior surface of tuberosity, creating additional space which the teeth successfully erupt. It has been estimated that growth by sutural activity ceases after about the seventh postnatal year and then surface apposition comes to represent the dominant mechanism of growth.

The zygomatic process grows posteriorly by a combination of resorption from its anterior surface and deposition along its posterior surface. The face simultaneously enlarges by bone deposition on the lateral surface of the zygomatic process together with resorption from its medial surface. Therefore, in young patients, the infrazygomatic crest is located between the maxillary second premolar and first molar, but above the maxillary first molar in adults.[2]

In the palate, the mechanism of growth conforms to the “V” principle. The palate grows in a downward direction by deposition on the oral surface together with resorption on the opposite nasal surface as well as on the labial periosteal surface of the anterior maxillary arch. During maxillary growth, maxillary sinus enlargement occurs by resorption from the inside combined with deposition on the outer surface. Development of the dentition is an important contributor to craniofacial growth. The stages of dentition development include the primary dentition, mixed dentition, and permanent dentition.

The primary dentition begins in infancy with the eruption of the first tooth, usually at about six months of age, and is complete from approximately three to six years of age, when all primary teeth are erupted. The mixed dentition starts from approximately age six to 12, when both primary and permanent teeth are present in the mouth. The permanent dentition is when all primary teeth have exfoliated. Girls are more advanced in calcification of permanent teeth than are boys at each stage. The sequence of tooth eruption is shown in Figure 2.1.

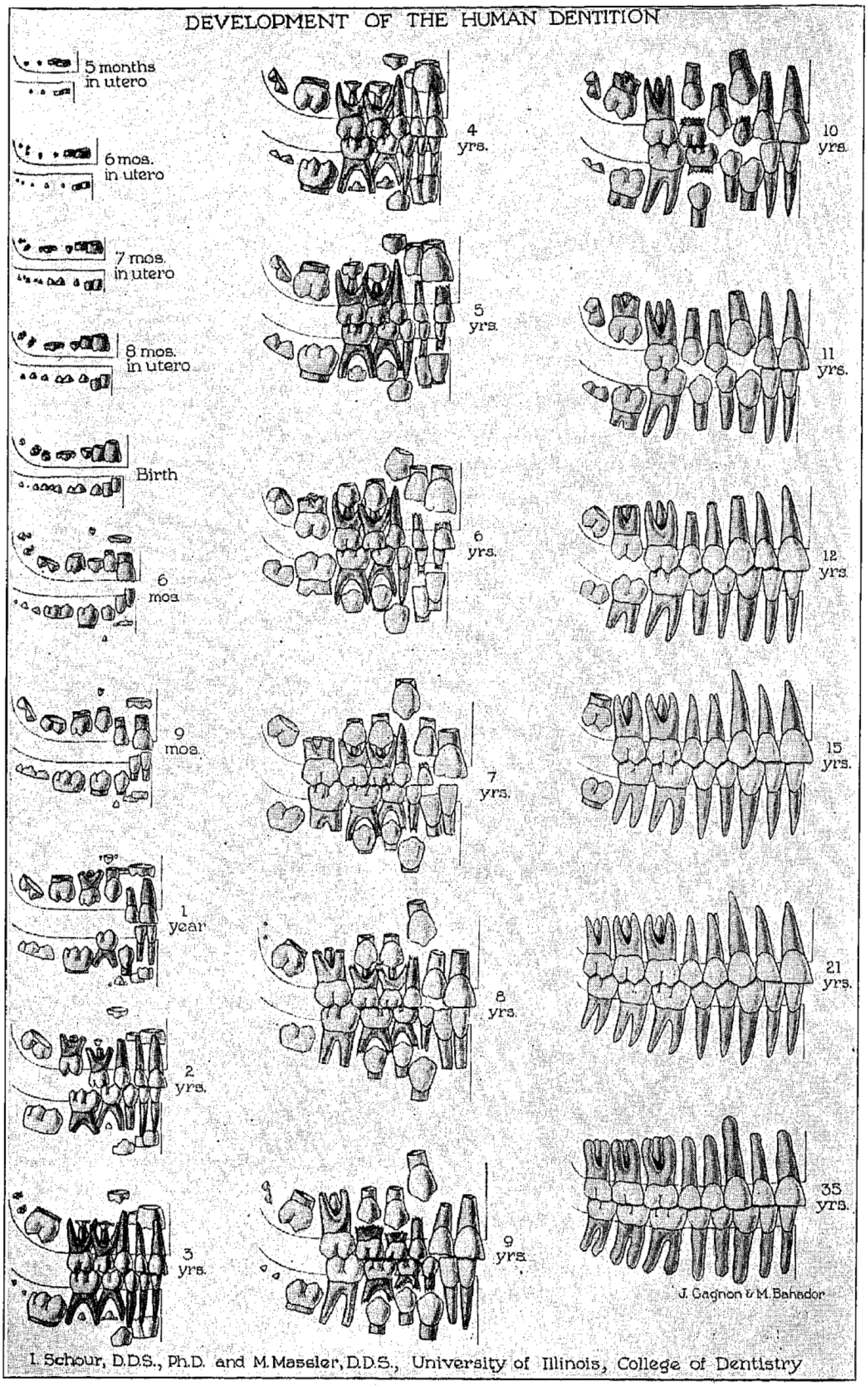

Figure 2.1 Chart showing of development of human dentition[6]

2.2 Maxillary deficiency in patients with cleft lip and palate

Treatment for maxillary deficiency

The incidence of Class III malocclusion varies according to the ethnic origin of the population. Many studies have found the greatest prevalence of Class III malocclusions in Asian populations. Several studies have recommended early treatment of developing Class III malocclusion by growth modification.[7] Growing patients with maxillary hypoplasia are usually treated by maxillary protraction using a facemask. [8,9] The aim of facemask therapy is to improve the relationship of the dental bases supporting the dentitions through growth adaptation. Previous studies have found that more favorable sagittal skeletal response was often found when protraction was started early in either late deciduous or early mixed dentition. The mechanism of maxillary growth modification is through mechanical separation of the maxilla from the cranial base. This separation occurs at the circummaxillary sutures, where appositional changes occur within the sutures to maintain their relationship. It is recommended that maxillary growth modification should begin before complete closure of the circummaxillary sutures. The peak in sutural growth has been reported at age six to seven years, then gradually decreased. Melsens[10] studied the maturation of the midpalatal suture at different developmental stages. In the ‘‘infantile’’ stage (up to 10 years of age), the suture is broad and smooth, whereas in the ‘‘juvenile’’ stage (from 10 to 13 years of age), it develops into a more typical squamous suture with overlapping sections. Finally, during the ‘‘adolescent’’ stage (13 and 14 years of age), the suture is wavy with increased interdigitation.

Conventional protraction facemask therapy, with indirect application of force to the circummaxillary sutures through tooth-borne anchorage, causes both skeletal and dental changes. The degree of orthopedic change is known to be affected by several factors, including patient age, growth pattern, amount of postsurgical scar tissue, type of cleft, compliance of subject, types of treatment devices, magnitude and direction of orthopedic force, and duration of protraction therapy.[11,12] The effects of maxillary protraction with a facemask are forward movement of the maxilla, downward and backward rotation of the mandible, proclination of the maxillary incisors and retroclination of the mandibular incisors.[7,8,12,13] Previous studies have shown that tooth-borne, protraction facemask therapy produces undesirable effects, such as the loss of anchorage of the posterior molars, extrusion of maxillary molars, proclination of the maxillary incisors and increase in lower face height.[7,8,14,15] These side effects increase as children grow older because ossification of the circummaxillary sutures progresses and the resistance to protraction increases.[16] Moreover, in tooth-borne anchorage, some of the protraction force is consumed by the tooth movement in the alveolar bone. In other words, the orthopedic effect is partly compromised by the orthodontic effect, which is against the goal of achieving the upmost skeletal alteration rather than dental compensation. Therefore, it would be reasonable to use skeletal anchorage for transferring orthopedic forces directly to the circummaxillary sutures.

Using of skeletal anchorage for facemask therapy

Orthopedic anchorage for maxillary protraction is a new area of research and has been used increasingly in recent years. Facemask with miniplate or miniscrew therapy has been reported to maximize skeletal effects while minimizing dental changes.[11,17] Cevidanes et al.[18] introduced bone-anchored maxillary protraction, which induced a significantly greater maxillary advancement than did rapid palatal expansion in conjunction with facemask therapy. Mandibular sagittal changes are similar, whereas vertical changes are better controlled by bone-anchored maxillary protraction. Another favorable aspect of bone-anchored maxillary protraction is the lack of clockwise rotation of the mandible and retroclination of the mandibular incisors. It has been recommended that it would be more advantageous to perform maxillary protraction with a miniplate or miniscrew placed in the infrazygomatic crest area in patients with severe Class III malocclusions who need more advancement in the middle part of the zygomaticomaxillary complex.[19] Since miniplates or miniscrews are independent of the maxillary dentition, it is expected that facemask with miniscrew therapy would minimally influence the maxillary dentition. Moreover, miniscrew implants are used as rigid skeletal anchors to directly transfer forces to the sutural sides of the maxilla by bypassing the periodontal ligament area of the dentition, so that relatively low loading forces are applied, and seem adequate to achieve clinical improvements.[11] In addition, facemasks with various bone-borne anchors have been reported as successful active treatment for 10-12-year-old patients with moderate or even severe maxillary deficiency, gaining significant anterior displacement ranging from 2.0 mm to 4.8 mm, meanwhile reducing or avoiding dento-alveolar compensations.[11,19-23]

2.3 Miniscrew implants

Miniscrew implants are temporarily placed miniscrews which usually use as orthodontic anchorage reinforcement. Compared with other skeletal anchorage systems, miniscrew implants have the advantages of operational convenience, patient comfort, and low cost. Additionally, immediate loading can be achieved because these devices do not require osseointegration but rely on mechanical lock. Long-term stabilization is also possible using miniscrew implants as rigid anchors.[11]

Minicrews can be placed in many anatomic sites. They should be inserted into a region with high bone quantity, high bone quality and thin keratinized tissue. The placement location should be the optimal one for both patient safety and biomechanical tooth movement. Bone quality and soft-tissue health are key determinants that affect stationary anchorage and miniscrew success, depending on the indication and the biomechanics used. Popular placement sites appear to be the palate, the palatal aspect of the maxillary alveolar process, the retromolar area in the mandible, and the buccal cortical plate in the maxilla and the mandible. Stationary anchorage failure often occurs when miniscrew is placed in a region of low bone density with inadequate cortical bone thickness. Misch et al.[24] classified bone density into four groups; D1, D2, D3 and D4 (as shown in Figure 2.2), based on the number of Hounsfield units (HU), which are units of measurement used in computed tomographic scanning to characterize tissue density. D1 bone has the highest density. D4 bone has the lowest density and is not recommended for the miniscrew placement. Miniscrews can be placed in D1 to D3 bone with a 70% to 90% success rate.[24]

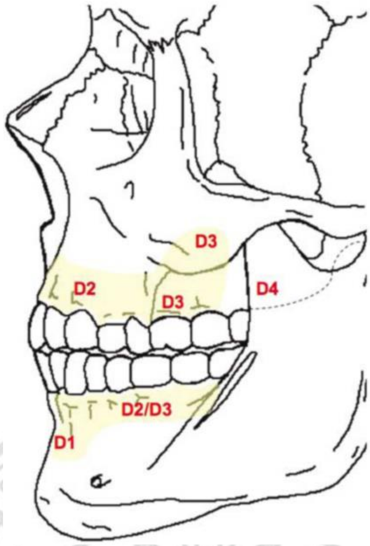

Figure 2.2 Regions of bone density [24]

Miniscrew implant placement locations can be varied.[25] In the maxilla, the placement locations include area below the nasal spine, midpalatal or paramedian area of palate, buccal or palatal of interradicular area, infrazygomatic crest site, tuberosity and maxillary edentulous alveolar ridge. Although the stability of miniscrew implant depends on several factors, proper placement location is key factor for the success of miniscrew implant placement. Cortical bone quality and quantity are also major factors associated with the primary stability of miniscrew implant placement.[26-28] The primary stability is derived from mechanical retention between the miniscrew implant and the bone site. Bone quantity refers to the amount of bone present at the placement site and depends on the thickness. Motoyoshi et al.[29] suggested that the miniscrew implant placement position should have a cortical bone thickness at least 1.0 mm that can be found in the posterior teeth area.

For the effect of age on the success rate of the miniscrew, this is still controversial. Nikolaos Topouzelis et al.[30] have found that patient age did not seem to correlate with the success rate of miniscrews. Park[31] have found that patients over the age of 20 years presented lower success rates than those below 20 years of age. Conversely, Miyawaki et al.[32] have found lower success rates for patients under the age of 20 years (80%) as compared to patients over 20 years (85%–88%), but these results were not statistically significant. Chen et al.[33] concluded that placing miniscrew implant in younger patients was a primary risk factor associated with their failure. Some other studies have reported a significantly greater rate of success in older patients that relative to thicker cortical bone thickness in adult except the infrazygomatic crest, the mandibular buccal first-second molar site, and the posterior palatal site.[26] Meanwhile, other authors have reported that a patient age showed no statistically significant difference regarding the success or failure of miniscrews. Age-related differences in cortical bone thickness and density might also be explained by changes in functional capacity, because maximum bite forces, masticatory muscle size, and muscle activity all tend to increase with age. Moreover, as the age of patients increased, much better oral hygiene is achieved because they become more conscientious, have more mature attitude and look after their teeth more throughly.[34]

Biting depth of miniscrew is the bone thickness where the thread of miniscrew implant is inserted through. The miniscrew biting depth also affects the stability of miniscrew implant. A thicker bone allows greater miniscrew biting depth and greater bone contact, and also improves the miniscrew implant stability. Liou et al.[2] reported that the 6.0 mm of miniscrew biting depth at the infrazygomatic crest is sufficient for stability throughout treatment.

The miniscrew insertion position also varied with miniscrew insertion angles.[2] The greater the postulated miniscrew insertion angle, the thicker the biting depth would be. The crucial complication during miniscrew insertion is an injury to the dental roots or the developing tooth germ in mixed dentition. Therefore, it is recommended to insert miniscrews in higher rather than lower positions, such as midroot, or beyond the root apex where interseptal bone is thicker and there is less chance of root injury. Vertically, miniscrew implant insertion position should be 5.0 to 6.0 mm above the buccal cemento-enamel junction of the maxillary first molar.

Many studies agreed that there is a relationship between miniscrew implant failure and soft tissue inflammation.[35,36] Park et al.[37] reported that the overall success rate of four miniscrew implant types were 91.6%, and suggested that, in order to reduce miniscrew implant failure, inflammation around miniscrew implant head should be prevented. There are many studies recommending to place a miniscrew implant at the keratinized or the mucogingival junction instead of non-keratinized mucosa in order to reduce gingival inflammation. Viwattanatipa et al.[35] reported that a success rate for miniscrew implant placed at high levels in the movable nonkeratinized mucosa was relatively low.

2.4 Infrazygomatic crest site

The infrazygomatic (IZ) crest or zygomatic buttress is a pillar of cortical bone on the zygomatic process of the maxilla that runs along the curvature between the alveolar and zygomatic process of the maxilla.[2] This site consists of two cortical plates: the buccal cortical plate and the floor or lateral wall of the maxillary sinus with cancellous bone between the plates. This anatomical advantage allows for bicortical fixation and possibly contributes to better primary stability of the miniscrew.

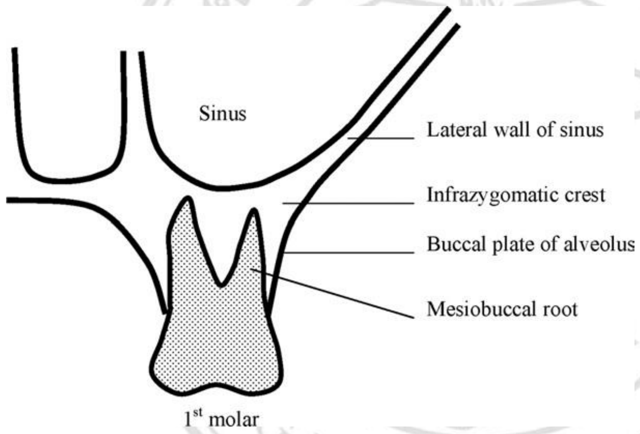

Figure 2.3 Illustration of IZ crest above MB root of maxillary first molar.[2]

In young patients it is located between the maxillary second premolar and the maxillary first molar, whereas it situates above the maxillary first molar in adults. The thickness of the infrazygomatic crest ranges from 5.5 to 8.8 mm in adult. However, the thickness varies on the pneumatization of the maxillary sinus. The thickest area of the infrazygomatic crest is located above the turning point between the alveolar process and the zygomatic process. From computed tomographic image study of Liou et al.[2] suggested that the proper miniscrew implant insertion position at the infrazygomatic crest in adult patients should be 14.0 to 16.0 mm above the maxillary occlusal plane, and that the insertion direction should be 55 to 70 degrees to the maxillary occlusal plane.

Miniscrews achieve their retention purely mechanically,[38] so a thicker bone allows greater miniscrew biting depth, more osseous contact and subsequently better primary stability of the miniscrew. Various types of instrument were reported to be used at infrazygomatic crest site for providing absolute anchorage. The infrazygomatic crest has been used successfully to place skeletal anchorage for maxillary protraction, anterior retraction, maxillary retraction, distal movement of the whole maxillary dentition, and intrusion of the maxillary posterior teeth.[2,26]

According to Misch and Kircos,[24] bone density of the infrazygomatic crest is greater than that of the maxillary alveolar ridge. The infrazygomatic crest is chosen as an insertion site for orthodontic skeletal anchorage because of its absence of adjacent tooth structure, ease of surgical access, and subsequent ability to apply elastic traction in addition to its thicker bone.

Melsen et al.[3] suggested that, in extreme cases where no other solution could be found, zygomatic ligature at the infrazygomatic crest site might be useful for providing anchorage for retraction of maxillary incisors and intrusion maxillary molars. And also, Singer et al.[20] reported a successful case in which osseointegrated implants were placed at the zygomatic buttress, and were used as anchorage for facemask therapy. Several studies showed that, the maximum stresses were seen at frontonasal, frontomaxillary, zygomaticomaxillary, zygomaticotemporal, and pterygomaxillary suture. Some of the investigators claimed, that the infrazygomatic area could transfer the orthopedic force more effectively to the sutures.[39]

Cha et al.[40] showed a successful case of Class III malocclusion that was treated by face mask combined with miniplates and three miniscrew implants on both sides of the infrazygomatic crest site. The success rate in terms of stability of miniplate at infrazygomatic crest site is as high as 97%, but extensive surgical procedure for placement and removal is needed. Whatever, the cost of such procedure is high, and the surgical procedure is also painful for patient.[41]

Miniscrew implant has been introduced as alternative for absolute anchorage in orthodontic treatment. In comparison with other skeletal anchorage systems, miniscrew implants have the advantages of placement and removal operational convenience, comfort, and inexpensiveness. Additionally, immediate loading and long-term stabilization are possible using miniscrew implants as rigid anchors.[19]

In the previous studies, the infrazygomatic crest above the maxillary first molar was significantly thicker than the lateral wall of the maxillary sinus. As an insertion site for orthodontic skeletal anchorage, the infrazygomatic crest is usually used for a single miniscrew because of its thicker bone whereas the lateral wall of the maxillary sinus is used for miniplates with several miniscrews because of its thinner wall.[25,39,42-44] Farnsworth et al.[26] reported that infrazygomatic crest site has the thickest cortical bone in relation to other sites in the maxilla, and that there was no significant difference in cortical bone thickness at this site between adult and young patients. Baumgaertel and Hans[1] assessed the bone depth at the infrazygomatic crest from the level of root tip of the maxillary first molar to higher levels. They reported that the greatest bone depth was located 11.48 mm apical to the buccal cemento-enamel junction of the maxillary first molar. However, the infrazygomatic crest over the mesiobuccal root of the maxillary first molar is thinner than that over the mesiobuccal root of the maxillary second molar. Both patient CT image and dry skull studies confirmed this finding. For Clerck et al.,[39] They suggested that the position of these miniscrew implants should be located between the first and second molars to avoid the roots of the maxillary molars.

After the CT study and more clinical experiences, Lin et al.[45] suggested the new position about one molar width distal to the original infrazygomatic region, and called this region “modified” infrazygomatic crest region. They suggested that the safe zone for placing the modified IZC miniscrew is about 5-6 mm above the cervical line, on the buccal between the distobuccal root of the maxillary first molar and the mesiobuccal root of the maxillary second molar. However, young patients with mixed dentition could not use this miniscrew placement position due to calcifying of tooth bud in this area.

2.5 Cone beam computed tomographic (CBCT) image

Cone beam computed tomography (CBCT) or 'dental CT', is the x-ray equipment that produces three-dimensional high-resolution images with diagnostic reliability has resulted in a significant increase in CBCT examinations in areas such as orthodontics, endodontics, periodontics, implantology, restorative dentistry, and dental and maxillofacial surgery.[46,47] It provides more information than conventional two-dimensional (2D) radiograph. For CBCT, axial, sagittal and coronal images can be observed. In addition, 3D image reconstruction can be obtained.

CBCT image production

CBCT is an image acquisition technique based on a cone-shaped x-ray beam centered on a two dimensional detector.[48] It is accomplished using a rotation in which a cone-shaped x-ray beam is directed towards an area, and the x-ray detector is on the other side of the patient's head. During the rotation, multiple two dimensional projection images are acquired for a field of view selected according to the site of interest. Because CBCT exposure incorporates the entire field of view, only one rotational sequence is necessary to acquire enough data for image reconstruction. This procedure is different from that of conventional CT, which uses a fan-shaped x-ray beam in a helical progression to acquire individual image slices of the field of view and then stacks the slices to obtain a three dimensional reconstructions. Therefore, cone-beam geometry has inherent quickness in volumetric data acquisition, and uses a comparatively low cost radiation detector. The rapid scan time of CBCT is desirable because the artifact results from subject movement is reduced.

There are many advantages of CBCT such as rapid scan time (10.0 - 70.0 seconds), and reduced patient radiation dose compared with conventional CT.[49] Some studies reported that the dose of CBCT was up to four times less radiation than a conventional CT. There are studies that reported dose equivalent to that needed for four to 15 panoramic radiographs. In addition, the x-ray beam of CBCT can be limited only in the area of interest. An optimal field of view can be selected for each patient based on suspected disease area and the site of interest. This decreases radiation dose by limiting the irradiated field to fit the field of view. One of the most important advantage of CBCT is that it provides three dimensional image and its display mode are unique to maxillofacial imaging. CBCT units reconstruct the projection data to provide inter-relational images in three planes (axial, sagittal and coronal). Basic enhancements include zoom or magnification, window level and the capability to add annotation. Cursor driven measurement algorithms provide the clinician with an interactive capability for real-time dimensional assessment.

CBCT in Orthodontics

CBCT scan gives valuable information about all the images needed for orthodontic diagnosis and treatment planning.[48] Orthodontic assessment with CBCT should follow the "as low as reasonably achievable" principle, so the routine use of CBCT is not recommended in orthodontic procedures.[50] Because conventional images deliver lower doses to patients, CBCT is recommended in some cases of orthodontic practice such as impacted teeth evaluation, temporomandibular joint evaluations, and assessment of maxillofacial growth and development. With the widespread use of temporary anchorage devices (TADs), the determination of bone volume, bone quality, and the location of adjacent structures have become important in providing orthodontic treatment. A technique using high-resolution CBCT scans and rapid prototyping to fabricate surgical guides has also been described for placing TADs on the buccal aspect of the jaw.[51]

CBCT in growing patients

In comparison with conventional CT in which fan beam scanners are used, CBCT technology decreases radiation exposure dose and examination time. However, CBCT imaging is associated with a higher radiation dose to the patient than panoramic and intra-oral imaging. Although radiation dose from CBCT is low relative to conventional CT, the radiation risk to the patient should be assessed and quantified. The radiation risk can be estimated by calculating the effective dose, which is a radiation quantity proposed by the International Commission on Radiological Protection (ICRP). Children are more sensitive to radiation than adults because the number of dividing cells promoting DNA mutagenesis is higher and they have more time to express any radiation induced effects, such as cancer.[47] There is an order of magnitude increase in cancer risk between children and adults, and there is also a significant difference between boys and girls, with the latter being more radiosensitive. Furthermore, a substantial proportion of dental X-ray procedures are performed in the pediatric group notably in relation to orthodontic group.