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Ankylosed permanent teeth: incidence, etiology and guidelines for clinical management

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Abstract

Ankylosis is a condition of direct root surface fusion with the encompassing alveolar bone. Depending on the patient's growth rate and bone metabolism, it is usually accompanied by progressive replacement resorption of the root and infraocclusion of the crown. Treatment options for ankylosed teeth depend on the development of the patient, severity of the malocclusion, and size of residual root. The prognosis of ankylosed teeth undergoing significant replacement resorption is hopeless, and should be replaced with an implant prosthesis. Treatment modalities include decoronation, direct or fixed build-up of the affected tooth, or various surgical interventions, when appropriately indicated.

Introduction

Ankylosis might be one of the most prevalent causes for infraocclusion in the permanent dentition. Ankylosis in Greek means "lack of mobility". The term can refer to joints as well as teeth. From a clinical point of view, and based on our experience and reports by others, ankylosed teeth may still have some degree of mobility in spite of the literal name [1]. By histological means, ankylosis of teeth is defined as the fusion of the root surface (either cementum or dentin) with the surrounding alveolar bone. There is some confusion between the term ankylosis and other terms used to describe its consequences, such as infraocclusion, meaning a tooth not reaching the occlusal plane [2], submergence, impaction, and incomplete eruption.

Replacement resorption is a process of physiological remodeling of bone and erroneously the adjacent root cementum and/or dentin, which results in replacement of the root with bone tissue. Replacement resorption usually accompanies ankylosis, therefore leading to the confusion of the two phenomena in terms of diagnosis. In order to differentiate between the two different terms, one should refer to ankylosis in diagnostic terms, so that when a tooth is proven as ankylosed, the clinician should anticipate and radiographically look for replacement resorption as a progressive process accompanying ankylosis and compromising the tooth prognosis.

Mechanism

In mechanistic terms, ankylosis and replacement resorption should not be interchanged with external root resorption, which is an inflammatory-mediated process that necessitates the continuous presence of infectious stimuli through the pulp and can be reversed by elimination of the stimuli [3,4]. Tronstad described the initiation of ankylosis following extensive necrosis of the periodontal ligament along with formation of bone that invades the denuded root surface area. Tronstad claimed that involvement of dental trauma (luxation) is the primary reason for this injury, particularly avulsion of teeth and their presence in a dry environment for a critical time, which causes cell death on the root surface. The minimum injured root surface area leading to ankylosis as reported by Andersson is 20% [1]. This suggests a healing capacity of the periodontal ligament and surface cementum that can overcome the injury and allow for reattachment of periodontal ligament fibers if the affected area is less than 20% of the root surface [5,6]. Following tooth luxation, injury to root surface due to mechanical trauma occurs in variable degrees, forms, and distribution. Diffuse damage involving more than 20% of the root surface area is followed by a reactive inflammatory response that initiates the healing process. The result is an area of cementum-devoid root surface that is now susceptible to migration and repopulation by the faster bone forming cells rather than by the slower periodontal ligament fibroblasts or cementoblasts. This leads to a root surface area lined with cells of the osteoblastic lineage, that deposit bone in direct contact with the root surface, resulting in direct connection between the two tissues [7]. At this point, the root has become ankylosed, but replacement resorption is yet to take place. The root now becomes part of the bone tissue and therefore osteoclasts and osteoblasts replace its tissues with bone in a progressive non-inflammatory remodeling process, thus named replacement resorption. It is important to emphasize that replacement resorption is observed in either vital teeth with normal pulp tissue or in pulpless teeth with no infectious stimulus through the root canal. The presence of infectious stimuli, such as bacterial endotoxins, that pass from the root canal to the external root surface through the dentinal tubuli and accessory canals induces inflammation-mediated resorption of the root tissues and probably adjacent bone, in attempt to eliminate infectious elements3. Another major difference between replacement

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resorption and external root resorption is that the latter can be ceased by eliminating the infection components from the root canal [8], while the former is a progressive process [9].

Incidence and etiology

The majority of proven ankylosis cases occur in deciduous molars [10]. Therefore, this clinical observation is reported in literature more frequently than ankylosis of permanent teeth. Ankylosis of permanent teeth seems to be a multifactorial phenomenon and cannot be attributed to only one cause. Thus, studying the incidence of ankylosis must be presented in conjunction with the reason for its development. To our knowledge, there is no precise estimation of tooth ankylosis incidence in permanent dentition. This might be due to difficult diagnosis of the condition, and many asymptomatic, and therefore undiagnosed ankylosed teeth, especially in posterior teeth of non-growers. There is no significant difference in the prevalence of affected dentition between males and females at any age [11]. Incidence of affected primary molars is greater in Caucasians and Hispanics than in Blacks and Orientals [12]. Deciduous tooth ankylosis is estimated by 1.5-9.9% [13]. Biederman reported that the incidence of deciduous tooth ankylosis is 10 times more likely than permanent teeth ankylosis, and is twice as likely in the mandibular arch than in the maxillary arch [10]. He also found that the most affected permanent tooth is the permanent first molar. Consequently, we believe that the phenomenon is not an uncommon one, but rather underestimated. Due to the lack of accurate estimations, we assume that the incidence of tooth ankylosis can be related to the incidence of its etiological factors. One of the major causes of tooth ankylosis is dental trauma that leads to luxation. As a group, luxation injuries are the most common of all dental injuries, with reported incidence ranging from 30% to 44% of all dental trauma cases, which affect 6% of the population [14].

Ankylosis of impacted canines is a condition that appears in 29.5% of adult patients in their fourth decade of life or older, in comparison to no ankylosis in young patients aged 12-16 years [15]. Failure of those canines to erupt is due to ankylosis of the impacted tooth to the surrounding bone or, occasionally, actual demonstrable replacement resorption of the tooth.

Tooth ankylosis has also been reported as secondary to orthodontic treatment of specific impacted teeth [16,17]. One possible explanation is leakage of etchant towards the cemento-enamel junction during surgical exposure of impacted tooth while bonding an attachment to it [18]. Another explanation could be mechanical damage to the cemento-enamel junction or tilting the tooth during the exposure procedure. In either case, the etiology is far from being clear and more research is required.

As to be discussed later, a more generalized form of ankylosis secondary to orthodontic treatment occurs in cases of primary failure of eruption [19]. In these rare cases, ankylosis is a result of applying an orthodontic force on infraoccluded teeth.

Secondary retention due to ankylosis has also been associated with local viral infection by a varicella zoster virus which damages either the tooth innervation and/or the dental follicle [20].

There is growing evidence that genetic and epigenetic factors might be involved in tooth ankylosis occurrence. A genetic or congenital factor in the periodontal ligament might be the process initiator [10]. There are several reports supporting the involvement of genetic factors by higher occurrence of primary ankylosed molars [21,22] and permanent first molars [23] in siblings and twins.

Clinical features

The clinical presentation and symptoms of ankylosis are highly dependent on whether dentoalveolar growth is still taking place. Growing subjects present significantly different from non-growing ones.

Ankylosed teeth in non-growing subjects might be completely asymptomatic. As long as progressive replacement resorption takes place, the root will be resorbed, and consequently, the alveolar support of the tooth will decrease until the root fractures and the crown sheds. Some changes may be noticed in the dentition by clinical examination, especially in the anterior teeth. In this way, an ankylosed tooth resembles an osseointegrated implant. For this reason, infraocclusion and asymmetry in the smile arc might develop; adjacent teeth still undergo true (but slow) vertical eruption as part of the adult occlusal equilibrium, while both ankylosed and osseointegrated implants do not, resulting in a vertical discrepancy with time as seen in Figures 1b, 1d-1h, 2a and 2e-2g [19,24,25]. Ankylosis in posterior teeth may be completely unnoticed, either by the patient or the clinician due to the slow change in vertical height of the teeth and the negligible discrepancy compared to adjacent marginal ridges.

Clinical features in children and growing adolescents are affected by the vertical, sagittal, and transverse growth taking place. Therefore symptoms are influenced mainly by the onset of ankylosis in relation to growth spurt [26]. The earlier tooth ankylosis occurs, the more severe are the expected symptoms. As mentioned earlier in this text, dental trauma is the major reason for tooth ankyloses [14], affecting mostly children between 8 to 12 years of age [27], i.e. before or coincident with growth spurt. This implies that most trauma-induced ankylosis will lead to significant malposition of the affected teeth relative to the adjacent healthy dentition, as seen in Figures 1b,1d-1h, 2a and 2e-2g.

Moderate to severe vertical discrepancy in both the crown and alveolar bone height is most likely to develop following onset of ankylosis in the developing subjects due to the post-emergent spurt and the subsequent juvenile occlusal equilibrium [19]. Reduced vertical distance of ankylosed teeth apices from the inferior border of the mandible compared to the contralateral unaffected teeth has also been observed [20] Some functional impairment due to loss of occlusal contacts is probable.

A shift in dental midline is very likely to develop [28] in conjunction with tipping of adjacent teeth towards the ankylotic site 29-31]. In his study of ankylosed primary molars, Becker attributed the midline shift and exaggerated tipping of adjacent teeth to stretching of the transseptal fibers connecting teeth in the dental arch in a mesh-like form. Open bite might also be observed as the ankylosed tooth and adjacent tilted teeth become infraoccluded, and as the opposing teeth fail to compensate, probably due to tongue thrusting [23]. Alternatively, supra-eruption of opposing teeth might occur.

Diagnosis

Overall, the diagnosis of ankylosed permanent teeth might be challenging, and therefore it may require several steps until it can be confirmed. Questioning of the patient and/or parents concerning history of dental trauma might be helpful to the diagnosis. Routine examination should consider any infraoccluded tooth with no apparent cause as possibly ankylotic such as in Figure 3b-3l. This finding might be one of the most powerful in this context. Further examination of mobility, percussion, and periapical radiographs should be performed, although the diagnostic value of each of these might be confusing, as described below.

Figure 1a-h. May 23, 2012. Initial photographs. 34 year old female with chief complaint about different level of central incisors. Typical ankylotic sound on percussion clinically observed. The patient went through comprehensive orthodontic treatment with fixed appliances

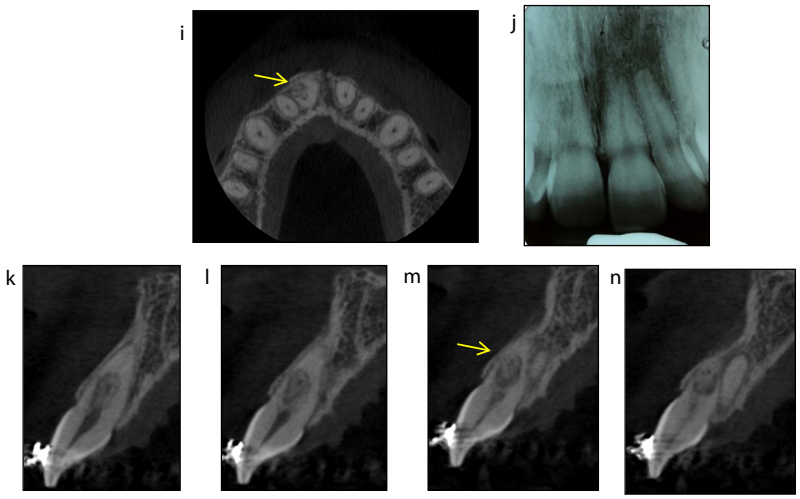

Figure 1i-n. CBCT and periapical radiograph demonstrating site of ankylosis and replacement resorption. It was decided not to tilt the tooth in order not to fracture the thin walls of the root. Therefore, a composite resin restoration was planned to be placed after completion of orthodontic treatment

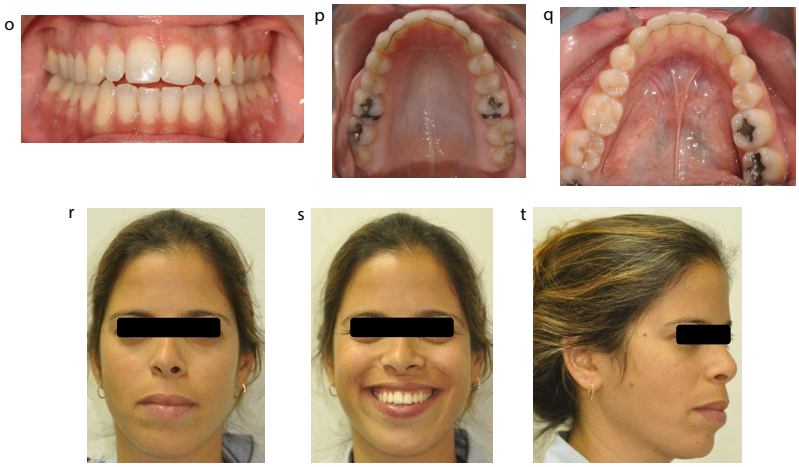

Figure 1o-t. September 10th, 2013.Completion of orthodontic treatment and composite resin restoration on tooth 11. Upper and lower fixed retainers were placed

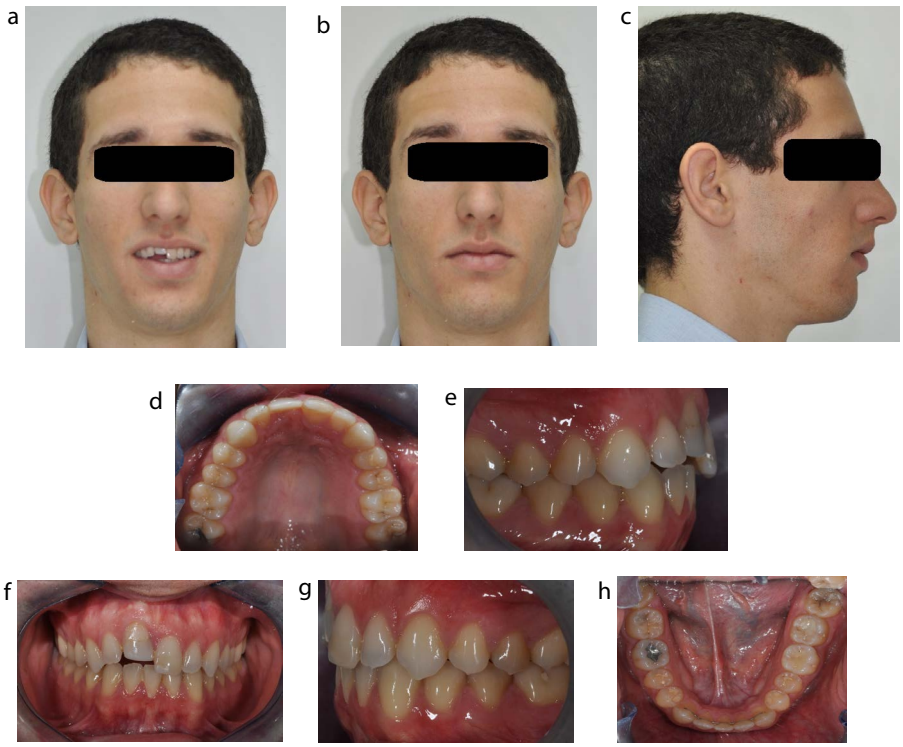

Figure 2a-h. April 6th, 2011. 24 year-old male. Clinical photos. Tooth 11 was traumatized when he was 12 years old, followed by comprehensive orthodontic treatment. The patient reported that at the end of orthodontic treatment, the tooth was at the same level as the adjacent tooth

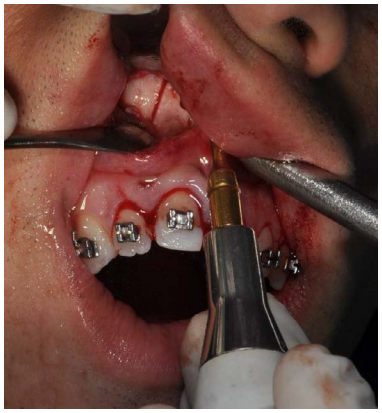

Figure 2i. March 5th 2012. Clinical photo of surgical osteotomy: a trapezoidal incision was made around tooth 11 along with surrounding alveolar bone, followed by orthodontic forced eruption of the tooth + bone segment

Figure 2j. June 24th, 2012. 3 month post-operative clinical photo with central incisors in occlusion, with orthodontic retention and in periodontal health

Figure 3a. March 15th, 2000. Before onset of Phase I orthodontic treatment due to lateral cross-bite. Full occlusion of permanent molars noted

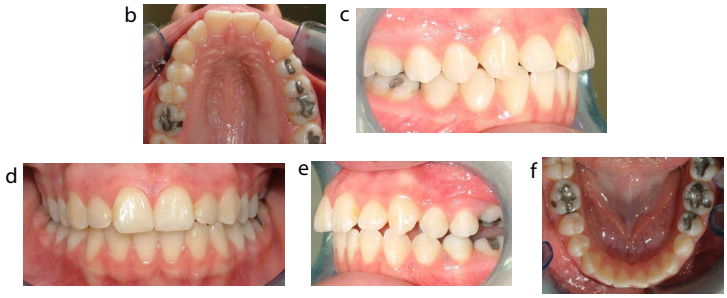

Figure 3b-f. May 19, 2005. Onset of phase II orthodontic treatment. Teeth 26 and 36 are infraoccluded and Angle Class II occlusal relationship noted

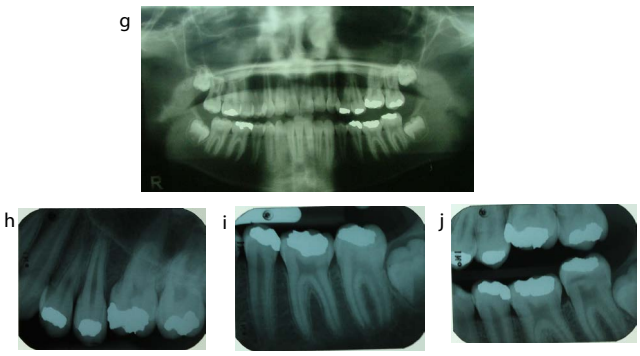

Figure 3g-f. May 19, 2005. Radiographs showing infraoccluded #26 and 36

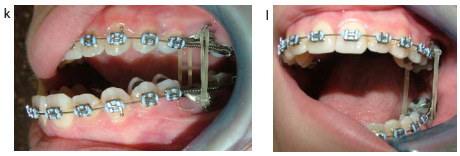

Figure 3k-l. During orthodontic treatment, infraocclusion increased significantly. Orthodontic force was applied with no response, therefore it was concluded that #26 and 36 were ankylosed. On July 9th, 2007, these teeth were surgically tilted to break ankylotic bridges then immediate strong orthodontic force with inter-arch elastics was applied. Prior to these procedures, space was created using coil springs

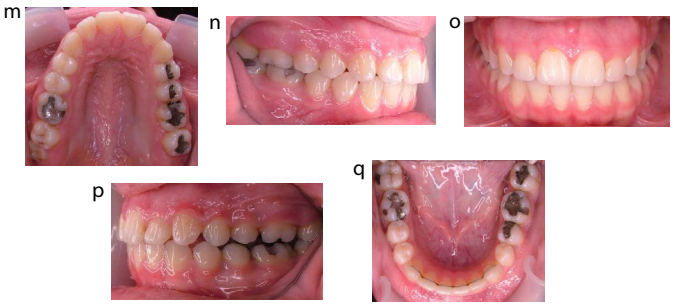

Figure 3m-q. July 7th, 2008. Clinical photos at conclusion of orthodontic treatment. Angle Class I occlusion with #26 and 36 in full occlusion with mandibular fixed retainer

Figure 3r. Panoramic image at conclusion of treatment. #26 and 36 in full occlusion at normal alveolar level as well.

A metal sound on percussion test is not a reliable diagnostic tool of ankylosis as it is found in only one third of affected subjects [32]. If less than 10% of the root surface is ankylosed, no metal sound is heard upon percussion, and if 10-20% of the root surface is ankylosed, only part of the teeth will produce a metal sound [1].

Decreased or lack of mobility in the buccolingual dimension is not an absolute pathognomonic sign, since the tooth may be mobile if less than 20% of the root surface is ankylosed [1].

Sites of ankylosis are expected to demonstrate obliteration of the PDL space and probably impaired discrimination between the lamina dura and root dentin in radiographs. Becker and colleagues suggest looking for reduced vertical height of alveolar bone, relative proximity of root apices to the lower border of the mandible, and hooked roots as clues for tooth ankylosis in radiographs [20]. Andersson found that two-dimensional radiography is not adequate for diagnosis since the ankylotic areas will not be evident if the affected area is not exactly perpendicular to the x-ray beam. Thus, in cases of ankylosis in the buccal, lingual or inter-radicular aspect of the root surface, it will be impossible to identify. In addition, overlapping trabecular bone structure might result in false positive diagnosis [1,33]. Cone beam computerized tomography (CBCT) is a promising tool for diagnosis of tooth ankylosis, since it provides a three-dimensional high resolution inspection field.

CBCT is useful when looking for position and size of the ankylotic area and it should be used appropriately. We recommend performing segmental or single tooth CBCT of suspected ankylotic sites in as thin sections as possible, and carefully examining the root-to-lamina dura relationship. Sites with no distinction between the lamina dura and the root surface and totally obliterated PDL space should be suspected for ankylosis. Another advantage of using CBCT is the diagnostic value before a luxation procedure, as the ankylotic bridge might be invaginating the root dentin, which makes the tooth susceptible to root fracture during the procedure. Correct diagnosis may have an influence on the treatment plan in these cases.

There are clinical procedures that provide definitive diagnosis. Failure of the tooth to move after application of orthodontic force is believed to be the definitive diagnostic test [34]. We recommend applying a light diagnostic orthodontic force on suspected teeth for 7-10 days, such as caused by separation modules, and examining if tooth mobility is altered or if the tooth becomes sensitive to percussion after that period. Another possible force system is trying to extrude the tooth against an absolute anchorage such as an orthodontic mini-implant or a dental implant. An additional diagnostic sign is loss of anchorage during orthodontic treatment such as intrusion of an anchorage unit during an attempt to extrude an infraoccluded tooth, but this side effect is obviously undesired.

Differential diagnosis

Ankylosis should be differentially diagnosed from other phenomena such as mechanical disturbances, for example due to tongue thrusting or finger sucking habits. The infraoccluded tooth might also be mechanically blocked out as a result of crowding. Ankylosis should also be distinguished from primary failure of eruption (PFE).

PFE, originally described by Proffit and Vig, is a rare condition characterized by normal alveolar bone resorption, not accompanied by underlying tooth eruption [35]. This is a nonsyndromic phenomenon in which eruption failure is not caused by a mechanical obstruction or by ankylosis.

When attempting to understand this rare phenomenon, we should emphasize the important findings by Cahill [36] who first demonstrated the fact that bone resorption is not dependent on tooth eruption. A common PFE can be described as a non-erupted tooth at the bottom of a large vertical bony defect, created by resorption of the occlusal alveolar bone. PFE characteristics were described by Proffit and Vig as follows [37]:

1. The posterior dentition is affected more than the anterior, and usually all teeth distal to the most mesial tooth will be affected.
2. Teeth may first erupt into occlusion and then stop erupting, or may not erupt at all.
3. Trying to orthodontically erupt the affected tooth will result in ankylosis.
4. Recent genetic research discovered that mutated PTH1R gene is strongly associated with failure of orthodontically assisted eruption or tooth movement [38-40]

The differentiation between ankylosis and PFE is as follows: in both conditions a suspected tooth might lose its normal vertical position and not respond to orthodontic force applied to it. If the molar is ankylosed, the teeth distal to it will have a normal response to orthodontic force and could be brought to substitute the ankylosed tooth in case of its extraction. Moreover, sometimes a surgical luxation of the ankylosed tooth followed by orthodontic force application was proven to be efficient in breaking the ankylotic bridge and bringing the tooth back to occlusion [28]. On the other hand, in a case of PFE, the affected molar can be brought occlusally only by means of segmental osteotomy because of its inability to respond to applied orthodontic force.

Clinical management of permanent ankylosed teeth

As previously mentioned in this article, ankylosis of traumatized teeth is usually associated with replacement resorption and infraocclusion. Both of these processes are growth dependent. Replacement resorption is much faster in growing than non-growing subjects due to higher rate of bone turnover [41]. Infraocclusion and vertical discrepancy of alveolar bone is more intense and progresses faster in growing subjects due to vertical bone growth and teeth eruption [42]. The hopeless prognosis of the ankylosed tooth calls for future replacement planning. Dental implant is a good choice if the residual ridge is of adequate dimensions. Removal of ankylosed tooth by extraction might damage the bone and surrounding tissues [43] and in growing subjects the resulting edentulous ridge will be of deficient vertical height at the age of implantation (i.e. the completion of jaws growth).

Treatment modalities in growing patients

A promising approach for ridge preservation at an ankylosed tooth site was suggested by Malmgren in 1984 as an alternative for extraction [44], namely decoronation. This surgical procedure aims to utilize the process of root replacement by bone tissue for maintaining adequate growth of the alveolar bone to allow optimal implant insertion. This procedure is performed by elevation of a mucoperiosteal flap, followed by removal of the crown. Root tissue is removed 2 mm under the level of the alveolar crest. Then, removing pulp tissue or any root canal filling, followed by thoroughly rinsing the canal with saline and inducing bleeding, is necessary to enhance root replacement. The flap is then repositioned and sutured to completely cover the alveolar ridge with attached gingiva. If adequately intact, the residual crown can be used as a pontic that can be attached to adjacent teeth using

composite given that canines are fully erupted. A lingual/palatal bar attached to posterior teeth can be used if canines have not yet erupted. It is important to reduce the gingival aspect of the pontic for allowing growth of the underlying alveolar ridge [45]

The deficient alveolar bone growth and tipping of adjacent teeth usually seen with ankylosed teeth is related to a complex collagen fibers system including transseptal fibers, alveologingival fibers, and periodontal ligament fibers at the coronal part of the root. These fibers prevent the coronal growth of alveolar bone along with the erupting adjacent teeth when they are attached to ankylosed teeth. Decoronation seems to abolish this effect of collagen fibers [43], therefore, the advantages of the procedure are two-fold. First, it may relieve tipping of adjacent teeth. Second, it enables preservation of the horizontal (labio-lingual) thickness along with vertical growth of the alveolar ridge due to the action of interdental fibers and dentoperiosteal fibers linked to adjacent teeth. These fibers form a new periosteum on top of the alveolar crest. The ongoing eruption of the teeth induces bone apposition through traction from the fibers on the periosteum, although some bone augmentation might be necessary [46].

Decoronation requires a significant vertical bone growth and turnover, and therefore it is not indicated for non-growing adults. Decoronation timing in growing subjects is important. Sapir and Shapira generally claim for decoronation 2 years prior to implant insertion [26]. Chronological age may be used as a guide but it is not the only indicator. The extent of infraposition and its progress rate are also major indicators. According to Malmgren, decoronation is indicated when the infraposition of the ankylosed tooth is one-eighth to a quarter of the homologous tooth crown [44,47]. Growth spurt has a major impact on the timing of performing decoronation. If the patient is too young and is still a long way from his/her growth spurt, decoronation may be postponed, and infraocclusion should be well-monitored. In such cases, provisional crown build-up may be performed in order to enhance esthetics. Whenever infraocclusion starts to speed up, decoronation should be carried out. Patients that are far after the growth spurt might not be good candidates for decoronation, as replacement resorption might not be effective, and other alternatives should be considered [26].

In the vast majority of cases, decoronation is performed in single rooted and anterior teeth, as depicted in Figures 4a-4i. There are few reported cases of coronectomy performed in ankylosed permanent molars in order to correct a lateral open bite caused by the ankylosed molar, and achieve adequate vertical bone height for a future dental implant [48].

We believe that decoronation should also be carried out on ankylosed deciduous teeth with no permanent successor, where a significant vertical discrepancy has been developed. Effectiveness of decoronation in such teeth should be investigated.

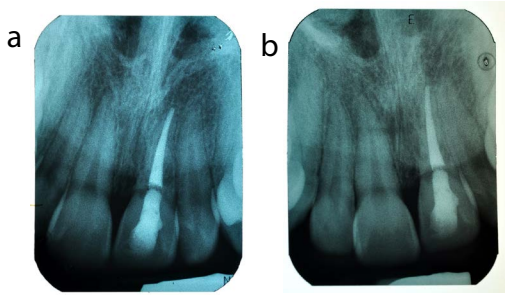

Figure 4a,b. May 12, 2012. 13 year-old female at the beginning of orthodontic treatment. The tooth was previously avulsed and implanted back in the socket after a few hours

Figure 4c. 6/10/13. Periapical radiograph. No changes noted

Figure 4d. August 8th, 2013. Periapical radiograph. Replacement resorption noted

Figure 4e. December 10th, 2013. Periapical radiograph. Resorption has progressed

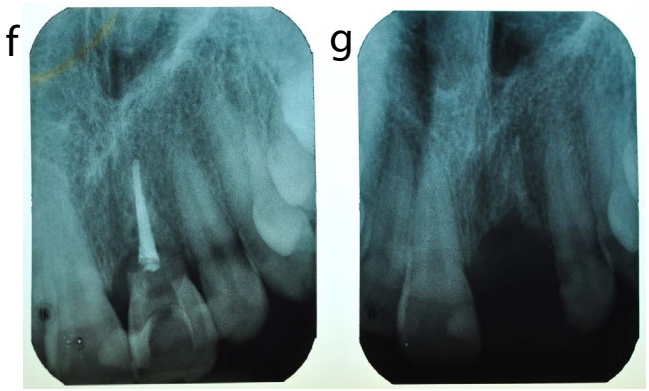

Figure 4f,g. December 17, 2013. Decoronation of tooth- pre-op and post-op radiographs prior to commencing orthodontic treatment

Figure 4h. July 23rd, 2014. Alveolar bone regeneration during orthodontic treatment

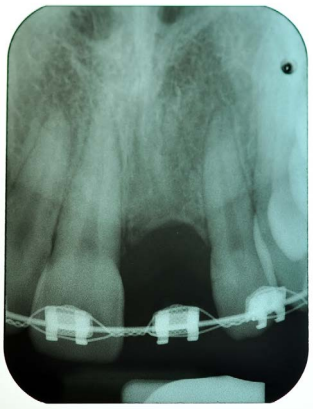

Figure 4i. June 4th, 2015. About 1 year later still continuing orthodontic treatment and maintaining space and bone volume for implant placement when age and growth stage appropriate

Briefly, decoronation might be indicated in infraoccluded permanent teeth undergoing replacement resorption of their roots, whenever considerable alveolar bone growth is expected soon, and alveolar ridge preservation is desired for future implantation.

Treatment modalities after growth spurt

a. Follow up: In cases of late-onset ankylosis, when no more significant growth will take place, a follow up will suffice as long as there is no significant vertical discrepancy between the ankylosed tooth and the adjacent teeth. It should be mentioned that some vertical growth is also taking place through adulthood. Thus, a vertical discrepancy of 0.1 mm/year will slowly develop even in adults [49,50].

b. Build up: If some vertical discrepancy already exists in the late-onset ankylosis cases, it is recommended to build-up that tooth crown, using composite materials, such as in Figures 1a-1t, or fixed prosthodontics [51]: occlusal and proximal contacts will be restored, and further tipping of neighboring teeth is prevented.

c. Surgical luxation: Another possible treatment option is surgical luxation of the ankylosed tooth, thereby breaking the bony bridge of ankylosis. This method as depicted in Figures 3a-3r was first mentioned in 1953 [52], and further described by Biederman as grasping the tooth firmly with dental forceps and rocking it bucco-lingually and mesio-distally, the axis of the movement being the tooth apex, so as not to impair the apical nutrient vessels. Vanarsdall claims that a vertical mobility of the tooth should also be generated [18], The consequence of this procedure is a new fibrous inflammation tissue which becomes co-extensive with the PDL, effectively restoring its continuity and enabling further tooth eruption. There is no definition in the literature concerning the amount of preferred force level. Forces must be continuous and kept at an appropriately high level for a prolonged period to maintain the distraction momentum and prevent reankylosis [28] Luxated teeth should be reactivated every 7 days, i.e. they should not be given the opportunity to re-ankylose [18]. If no change is seen within 6 months, the procedure should be repeated. If failed again, another treatment alternative should be considered. An immediate orthodontic force should follow luxation to promote formation of fibrous tissue [10,53]. Luxating the tooth may rarely end up in loss of its vitality in case nutrient vessels are torn [18], or in breaking of its root, especially when molars are luxated. Root resorption, primarily external, is late complication of surgical luxation. The prognosis of the procedure is excellent in adults who have single-root tooth with spot ankylosis. Molars are usually ankylosed in the furcation area, and luxation might lead to furcation involvement [18].

d. Segmental osteotomy: this treatment should be considered after repeated failure of surgical luxation, or as an alternative treatment option. In this procedure, as depicted in Figure 2i, an alveolar bone segment containing one or more ankylosed teeth is coronally repositioned. The alveolar segment is sectioned mesially, distally and subapically. The osteotomised segment might be repositioned with the help of an acrylic splint, prepared prior to the surgery. Segment stabilization is performed with mini-plates and screws in most cases, but the segment may also be orthodontically stabilized if the inter-osseous gap is not too wide, such as in Figure 2j. You et al. described segmental osteotomy of ankylosed maxillary central incisors (filling the gap with autogenous bone graft), with satisfactory periodontal results [54].

The disadvantage of this technique lies in its possible side effects, such as loss of tooth vitality, avascular necrosis in the bone segment, gingival recession, loss of crestal bone and pocket formation, delay in movement of the segment due to bone interferences, traumatic occlusion, and the typical risks of general anesthesia and hospitalization [55,56]. In severely crowded cases, the risk of damage to the tooth root and complications regarding insufficient blood supply due to reduction in the surrounding bone area were reported to contraindicate the application of this technique.

e. Distraction osteogenesis: Another treatment alternative that might be combined with segmental osteotomy is distraction osteogenesis, a 60 year-old technique. It was developed by Ilizarov, and is used primarily for bone lengthening [57]. It can also be utilized for treatment of an infraoccluded segment. The principles of this technique include an osteotomy procedure followed by a 7 day latency period during which the inflammatory phase of fracture healing will subside, and the reparative phase (with early osteogenesis) will begin. After the latency period, the distraction of newly formed callus is initiated, along with a 1 mm/day separation rate of the 2 bony parts. Slower rates such as 0.5 mm/day may lead to premature consolidation, while faster rates such as 2 mm/day may cause poor bone formation. During distraction, regenerated bone arises between the entire cross-sections of each distracted bone surface with a central radiolucent fibrous interzone comprising of type I collagen. New bone trabeculae forms directly from this central collagen zone, extending to both bone surfaces [58]. It is orientated parallel to the distraction force and surrounded by blood vessels. Following distraction, these microcolumns consolidate and rapidly remodel to form a structure similar in composition to that of the host bone, a process called consolidation.

Chang and Chen describe performing such a procedure to correct anterior open bite by a single tooth osteotomy [59]. The distraction procedure was followed by a six weeks retention period, during which results were maintained using a 0.017x0.025 stainless steel archwire and interdental elastics. A similar procedure was described, in which the ankylosed anterior tooth was first used as an anchorage in order to distalize the maxillary dentition and to correct the Class II malocclusion, and then a single tooth osteotomy was performed [60]. The distraction device (a regular expansion screw in this case) was bonded to the ankylosed incisor, and after a 4 days latency period the distraction of the dento-osseous block was initiated with a rate of 0.9 mm/day. The position of the tooth was overcorrected by 1 mm.

f. Extraction: Extraction of the ankylosed tooth can be taken into consideration at any stage. Extraction during the patient's growth spurt, when no implant can be performed immediately, will result in a severe bone loss due to a possible traumatic extraction, and in an impaired vertical alveolar dimension. Another scenario leading to extraction is in the non-growing patient, after a failure of surgical luxation of the tooth, or after a failure of segmental osteotomy or distraction osteogenesis.

Conclusions and clinical recommendations for treatment of permanent ankylosed teeth:

1. Ankylosis results from a mechanical damage to the root, primarily due to dental trauma, leading to a root surface area lined with osteoblasts that deposit bone in direct contact with the root surface. Replacement resorption then takes place. Therefore, special care should be taken so as not to harm the CEJ or the root surface during

surgical exposure of impacted teeth. Etching the tooth enamel should be done with gel and not with liquid etchant, in order to avoid leakage to the CEJ area. The surgeon should avoid any contact with the CEJ, and must not try to tilt the impacted tooth.

2. Ankylosis of permanent teeth is not an uncommon phenomenon, but exact rate in the population is not clear.

3. Diagnosis of ankylosed teeth might be obscure if less than 20% of the root surface is ankylosed, since no pathognomonic percussion sound, reduced mobility, nor radiographic appearance will necessarily accompany the situation. We recommend performing a local CBCT with thin slices in order to attempt locating the ankylotic area and its size, thus helping to determine prognosis of the tooth, and deciding whether to tilt it or not. To achieve definite diagnosis, we recommend applying a light diagnostic orthodontic force on suspected teeth for 7-10 days, such as force caused by separation modules, or applying a force using absolute anchorage, followed by clinical assessment for altered mobility or tenderness upon percussion.

4. Ankylosed teeth in the pubertal growing patient are treated by decoronation. In this manner, the alveolar ridge dimensions are kept ideal for future implantation. If the onset of ankylosis is too early, follow up until the pubertal growth spurt should be conducted. The feasibility of primary teeth and permanent molars decoronation might be an interesting subject for future investigation.

5. Follow up and estimation of infraocclusion and residual root should be adequate in non-growers. Build-up of the tooth crown can prevent expected occlusal disturbances. Alternately, surgical luxation of the ankylosed tooth followed by immediate orthodontic force application can be performed. Less conservative methods such as segmental osteotomy or distraction osteogenesis might also be considered.

References

1. Andersson L, Blomlöf L, Lindskog S, Feiglin B, Hammarström L (1984) Tooth ankylosis. Clinical, radiographic and histological assessments. *Int J Oral Surg* 13: 423-431. [Crossref]

2. Douglass J, Tinanoff N (1991) The etiology, prevalence, and sequelae of infraclusion of primary molars. *ASDC J Dent Child* 58: 481-483. [Crossref]

3. Tronstad L (1988) Root resorption--etiology, terminology and clinical manifestations. *Endod Dent Traumatol* 4: 241-252. [Crossref]

4. Hargreaves K, Berman L (2011) Cohen's Pathways of the Pulp. (10th edtn). Mosby Inc., Missouri, United States

5. Andreasen J (1975) Periodontal healing after replantation of traumatically avulsed human teeth: assessment by mobility testing and radiography. *Acta Odontologica* 33: 325-335.

6. Andreasen J (1981) Effect of extra-alveolar period and storage media upon periodontal and pulpal healing after replantation of mature permanent incisors in monkeys. *Int J Oral Surg* 10: 43-53. [Crossref]

7. Lindskog S, Pierce AM, Blomlof L, Hammarstrom L (1985) The role of the necrotic periodontal membrane in cementum resorption and ankylosis. *Dent Traumatol* 1: 96-101. [Crossref]

8. Chen H, Teixeira F, Ritter A, Levin L, Trope M (2008) The effect of intracanal anti-inflammatory medicaments on external root resorption of replanted dog teeth after extended extra-oral dry time. *Dent Traumatol* 24: 74-78. [Crossref]

9. Andreasen J, Andreasen F (1993) Textbook and color atlas of traumatic injuries to the teeth. Munksgaar, Copenhagen. Pp: 368-372.

10. Biederman W (1968) The problem of the ankylosed tooth. *Dent Clin North Am* . [Crossref]

11. Brown ID (1981) Some further observations on submerging deciduous molars. *Br J Orthod* 8: 99-107. [Crossref]

12. Mueller CT, Gellin ME, Kaplan AL, Bohannan HM (1983) Prevalence of ankylosis of primary molars in different regions of the United States. *ASDC J Dent Child* 50: 213-218. [Crossref]

13. Mullally B, Blakely D, Burden D (1995) Ankylosis: an orthodontic problem with a restorative solution. *Br Dent J* 179: 426-429. [Crossref]

14. Da Silva AC, Passeri LA, Mazzonetto R, De Moraes M, Moreira RW (2004) Incidence of dental trauma associated with facial trauma in Brazil: a 1-year evaluation. *Dent Traumatol* 20: 6-11. [Crossref]

15. Becker A, Chaushu S (2003) Success rate and duration of orthodontic treatment for adult patients with palatally impacted maxillary canines. *Am J Orthod Dentofacial Orthop* 124: 509-514. [Crossref]

16. Becker A (2012) Orthodontic treatment of impacted teeth. Wiley-Blackwell, New Jersey, United States.

17. Becker A, Abramovitz I, Chaushu S (2013) Failure of treatment of impacted canines associated with invasive cervical root resorption. *Angle Orthod* 83: 870-876. [Crossref]

18. Vanarsdall RL (1985) Correction of periodontal problems through orthodontic treatment. Orthodontics and periodontics. Quintessence, Chicago. Pp: 127-167.

19. Proffit WR, Fields Jr HW, Sarver DM (2012) Contemporary orthodontics. (5th edtn). Mosby Inc., Missouri, United States.

20. Becktor KB, Bangstrup MI, Rølling S, Kjaer I (2002) Unilateral primary or secondary retention of permanent teeth, and dental malformations. *Eur J Orthod* 24: 205-214. [Crossref]

21. Cozza P, Gatto R, Ballanti F, De Toffol L, Mucedero M (2004) Case report: severe infraocclusion ankylosis occurring in siblings. *Eur J Paediatr Dent* 5: 174-178. [Crossref]

22. Dewhurst S, Harris J, Bedi R (1997) Infraocclusion of primary molars in monozygotic twins: report of two cases. *Int J Paediatr Dent* 7: 25-30. [Crossref]

23. Cohen-Levy J (2011) Ankylosis of permanent first molars: genetics or environment? A case report of a discordant twin pair. *Int Orthod* 9: 76-91. [Crossref]

24. Rosa M, Zachrisson BU (2010) The space-closure alternative for missing maxillary lateral incisors: an update. *J Clin Orthod* 44: 540. [Crossref]

25. Thilander B, Odman J, Lekholm U (2001) Orthodontic aspects of the use of oral implants in adolescents: a 10-year follow-up study. *Eur J Orthod* 23: 715-731. [Crossref]

26. Sapir S, Shapira J (2008) Decoronation for the management of an ankylosed young permanent tooth. *Dent Traumatol* 24: 131-135. [Crossref]

27. Glendor U, Halling A, Andersson L, Eilert-Petersson E (1996) Incidence of traumatic tooth injuries in children and adolescents in the county of Västmanland, Sweden. *Swed Dent J* 20: 15-28. [Crossref]

28. Rosner D, Becker A, Casap N, Chaushu S (2010) Orthosurgical treatment including anchorage from a palatal implant to correct an infraoccluded maxillary first molar in a young adult. *Am J Orthod Dentofacial Orthop* 138: 804-809. [Crossref]

29. Becker A, Karnei-R'em RM (1992) The effects of infraocclusion: Part 1. Tilting of the adjacent teeth and local space loss. *Am J Orthod Dentofacial Orthop* 102: 256-264. [Crossref]

30. Becker A, Karnei-Rem RM (1992) The effects of infraocclusion: part 2. The type of movement of the adjacent teeth and their vertical development. *Am J Orthod Dentofacial Orthop* 102: 302-309. [Crossref]

31. Becker A, Karnei-R'em RM, Steigman S (1992) The effects of infraocclusion: Part 3. Dental arch length and the midline. *Am J Orthod Dentofacial Orthop* 102: 427-433. [Crossref]

32. Raghoebar GM, Boering G, Vissink A, Stegenga B (1991) Eruption disturbances of permanent molars: a review. *J Oral Pathol Med* 20: 159-166. [Crossref]

33. Thornton M, Zimmermann E (1964) Ankylosis of primary teeth. *ASDC J Dent Child* 31: 120-126. [Crossref]

34. Phelan M, Moss Jr R, Powell R, Womble B (1990) Orthodontic management of ankylosed teeth. *J Clin Orthod* 24: 375. [Crossref]

35. Proffit W, Frazier-Bowers S (2009) Mechanism and Control of Tooth Eruption: Overview and Clinical Implications. *Orthod Craniofac Res* 12: 59-66. [Crossref]

36. Cahill DR (1969) Eruption pathway formation in the presence of experimental tooth impaction in puppies. *Anat Rec* 164: 67-77. [Crossref]

37. Proffit WR, Vig KW (1981) Primary failure of eruption: a possible cause of posterior open-bite. *Am J Orthod* 80: 173-190. [Crossref]

38. Frazier-Bowers S, Simmons D, Wright J, Proffit W, Ackerman J (2010) Primary failure of eruption and PTH1R: the importance of a genetic diagnosis for orthodontic treatment planning. *Am J Orthod Dentofacial Orthop* 137: 160.e1-7. [Crossref]

39. Frazier-Bowers S, Koehler K, Ackerman J, Proffit W (2007) Primary Failure of Eruption: Further Characterization of ar Rare Eruption Disorder. *Am J Orthod Dentofacial Orthop* 131: e1-11. [Crossref]

40. Frazier-Bowers S, Simmons D, Koehler K, Zhou J (2009) Genetic Analysis of Familial Non-Syndromic Primary Failure of Eruption. *Orthod Craniofac Res* 12: 74-81. [Crossref]

41. Andersson L, Bodin I, Sorensen S (1989) Progression of root resorption following replantation of human teeth after extended extraoral storage. *Dent Traumatol* 5: 38-47. [Crossref]

42. Malmgren B, Malmgren O (2002) Rate of infraposition of reimplanted ankylosed incisors related to age and growth in children and adolescents. *Dent Traumatol* 18: 28-36. [Crossref]

43. Malmgren B, Malmgren O, Andreasen JO (2006) Alveolar bone development after decoronation of ankylosed teeth. *Endodontic topics* 14: 35-40.

44. Malmgren B, Cvek M, Lundberg M, Frykholm A (1984) Surgical treatment of ankylosed and infrapositioned reimplanted incisors in adolescents. *Scand J Dent Res* 92: 391-399. [Crossref]

45. Malmgren B (2013) Ridge preservation/decoronation. *J Endod* 39: S67-72. [Crossref]

46. Cohenca N, Stabholz A (2007) Decoronation--a conservative method to treat ankylosed teeth for preservation of alveolar ridge prior to permanent prosthetic reconstruction: literature review and case presentation. Dent Traumatol 23: 87-94. [Crossref]

47. Malmgren B (2000) Decoronation: how, why, and when? *J Calif Dent Assoc* 28: 846-854. [Crossref]

48. Chalmers E, Goodall C, Gardner A (2012) Coronectomy for infraoccluded lower first permanent molars: a report of two cases. *J Orthod* 39: 117-121. [Crossref]

49. Bernard J, Schatz J, Christou P, Belser U, Kiliaridis S (2004) Long-term vertical changes of the anterior maxillary teeth adjacent to single implants in young and mature adults. *J Clin Periodontol* 31: 1024-1028. [Crossref]

50. Kawanami M, Andreasen J, Borum M, Schou S, Hjerting-Hansen E, et al. (1999) Infraposition of ankylosed permanent maxillary incisors after replantation related to age and sex. *Dent Traumatol* 15: 50-56. [Crossref]

51. Jacobs S (1989) Ankylosis of permanent teeth: a case report and literature review. *Aust Orthod J* 11: 38. [Crossref]

52. Hemley S (1953) Orthodontic theory and practice. Grune & Stratton, Philadelphia, USA.

53. Geiger AM, Bronsky MJ (1994) Orthodontic management of ankylosed permanent posterior teeth: A clinical report of three cases. *Am J Orthod Dentofacial Orthop* 106: 543-548. [Crossref]

54. You KH, Min YS, Baik HS (2012) Treatment of ankylosed maxillary central incisors by segmental osteotomy with autogenous bone graft. *Am J Orthod Dentofacial Orthop* 141: 495-503. [Crossref]

55. Epker BN, Paulus PJ (1978) Surgical-orthodontic correction of adult malocclusions: single-tooth dento-osseous osteotomies. *Am J Orthod Dentofacial Orthop* 74: 551-563.

56. Merrill R, Pedersen G (1965) Interdental osteotomy for immediate repositioning of dental-osseous elements. *J Oral Surg* 34: 118-125. [Crossref]

57. Ilizarov GA (1989) The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. *Clin Orthop Relat Res* 239: 263-285. [Crossref]

58. Vauhkonen M, Peltonen J, Karaharju E, Aalto K, Alitalo I (1990) Collagen synthesis and mineralization in the early phase of distraction bone healing. *Bone Miner* 10: 171-181. [Crossref]

59. Chang HY, Chang YL, Chen HL (2010) Treatment of a severely ankylosed central incisor and a missing lateral incisor by distraction osteogenesis and orthodontic treatment. *Am J Orthod Dentofacial Orthop* 138: 829-838. [Crossref]

60. Kofod T, Wurtz V, Melsen B (2005) Treatment of an ankylosed central incisor by single tooth dento-osseous osteotomy and a simple distraction device. *Am J Orthod Dentofacial Orthop* 127: 72-80. [Crossref]