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INTEGRATED STUDY MASTER'S THESIS

Ankylosed Teeth in Orthodontics: Interdisciplinary Treatment Approach

Dantų ankilozė ortodontijoje: galimi gydymo būdai

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TABLE OF CONTENT

Abstract

The decision-making in terms of accurate, thoughtful and clinically appropriate treatment of dentoalveolar ankylosis pose a challenge for practitioners all over the world for many years. Especially in the field of orthodontics, clinicians are facing the pathology which is characterized by the inability to move ankylosed teeth under the application of orthodontic forces, referred to as *"diagnostic orthodontic force"*. This clinical presentation is considered to be the most important as well as significant evidence of dentoalveolar ankylosis and is the reason why ankylosed teeth are represented and diagnosed disproportionately in Orthodontics in comparison to other dental specialties, in which they often remain undetected. Dentoalveolar ankylosis brings along numerous clinical issues and challenges and even though various treatment approaches are reported in the form of case studies, there is a lack of generalizing information and clinical guidelines regarding that topic. This literature review aims to present interdisciplinary treatment approaches, expand individual indications and contraindications, reveal limitations and risk factors, and finally purposes to draw conclusions from which this literature review can eventually function as a clinical guideline for the treatment of ankylosed teeth.

1 INTRODUCTION

Dentoalveolar ankylosis is a clinical condition characterized by the pathologic fusion of the cementum or dentin of the tooth root to the alveolar bone. This condition presents as a challenging and relatively common clinical issue encountered in orthodontic practice, affecting both children and adults. Ankylosed teeth pose significant clinical implications as they can negatively impact and disrupt normal dental development, occlusion and aesthetics. The appropriate treatment approach has emerged as a crucial aspect in the management of ankylosed teeth in order to establish the restoration of function and aesthetics. The etiology of dentoalveolar ankylosis is various and often considered polyetiological, influenced by numerous factors and clinical conditions including trauma, genetic predisposition, local metabolic anomalies and disturbances in tooth eruption, as well as deficiency in alveolar bone growth (1). The ankylosed teeth present with limited physiologic mobility, while its clinical consequences extend beyond the ankylosed tooth itself, but instead may affect eruption patterns and cause compensatory mechanisms influencing function and aesthetics in multiple adjacent teeth as well. Moreover, ankylosed teeth may interfere with orthodontic treatment significantly by hindering tooth movement and causing malalignment hence frequently calling for an interdisciplinary treatment approach combining prosthodontic, orthodontic and/or surgical treatment (2,3). Those interdisciplinary treatment approaches encompass a variety of techniques and methods intended to disengage the tooth root from osseous attachment and allow it to move properly within the dental arch, including simple approaches like extraction as well as complex treatment approaches like distraction osteogenesis or segmental osteotomy with additional bone grafting (1,3). Upon the choice of treatment, the practitioner needs to take various factors into consideration such as patients age, skeletal and dental maturity, degree of ankylosis and the presence of any accompanying dental defects to determine the best treatment approach and tailor it towards each individual clinical case (1). These treatment approaches aim to create a harmonic occlusion and improve long-term dental health while restoring function and aesthetics. Ankylosed teeth that underwent successful handling can be relocated and integrated into the dental arch, enabling proper distribution of forces and occlusal stability leading to the ultimate goal of proper dental arch integrity. Furthermore, successful treatment of ankylosed teeth will have a positive impact on patient's psychological health as well as general quality of life by restoring function and aesthetics (4). Despite considerable knowledge about the pathogenesis of dentoalveolar ankylosis, there is up to now little and insufficient scientific data available to support management strategies and rehabilitation approaches that can be generalized and present certain long-term benefits (2). Nevertheless, it is a field of high interest for orthodontists and oral surgeons to overcome clinical challenges and provide proper treatment to their patients affected

by dentoalveolar ankylosis. Therefore, this thesis aims to explore and evaluate various and different interdisciplinary treatment approaches in order to contribute to the existing body of knowledge and establish an orientational guideline approach for the treatment of ankylosed teeth.

2 DEFINITION AND INCIDENCE OF DENTOALVEOLAR ANKYLOSIS IN PRIMARY AND PERMANENT DENTITION

The term ankylosis has its origin in the Greek language meaning *"lack of mobility",* even though clinically speaking ankylosed teeth may still retain some degree of movement based on clinical findings. Upon literature the term *Ankylosis* and other terms, utilized to explain its consequences such as *submergence*, *infraocclusion*, *incomplete eruption* or *impaction* are easily confused with each other (5). In general, dentoalveolar ankylosis is defined as an eruption anomaly, which presents histologically as a pathologic fusion and union of direct mineralized root surface that might be either cementum or dentin, with the surrounding bone of the alveolus, including the local elimination of the periodontal ligament (1,5). This process might occur during all stages of emergence as well as after eruption of teeth into the oral cavity. The etiology of the condition is various and highlighted in detail the later on, revealing that trauma is upon the most significant reasons for the onset of ankylosis' pathogenesis. Consequently, it is stated that ankylosis is most probably to affect avulsed and replanted teeth as well as teeth that are severely intruded (1). Regarding deciduous teeth, the overall prevalence varies from 1.3% to 14.3% upon population, in which Caucasians and Hispanics are proportionally overrepresented in comparison to Blacks and Orientals. The Female-to-Male ratio is reported to be 6:5 and therefore of no significant difference. Additionally, the disorder is strongly linked to a family tendency, as the incidence among siblings presents to be significantly higher (1,5). These findings are substantiated by several scientific reports regarding a more frequent occurrence of ankylosed molars in primary as well as ankylosed first molars in permanent dentition in siblings and twins, concluding genetic factor involvement (5–8). In general, literature coincides about the fact that primary dentition is about 10 times more affected by ankylosis than permanent dentition and the mandibular arch twice as likely affected as the maxillary one. Moreover, maxillary primary molars ankylose earlier compared to mandibular molars upon statistics and normally present with a worse prognosis (1,5,9). But when differentiating between the incidence of particular primary teeth affected by ankylosis, scientific evidence tends to differ among investigators for explainable reasons. Whereas some sources claim the primary first mandibular molar to be the most affected, others state that the primary second mandibular molar is even more affected (1,5,10). This might be explained by the theory that ankylosis of first primary mandibular molars occurs earlier, produces less infraocclusion and mostly exfoliates on time in the presence of a permanent successor and might therefore remain

undetected as the effect on the development of occlusion is only temporary. In comparison to that, ankylosis of the second primary mandibular molars usually presents with a more severe infraocclusion and an additional slight delay in eruption of its permanent successor. At this point it has to be stated that in general, deciduous teeth in the absence of a permanent successor have a higher prevalence, do neither resorb nor exfoliate as usual in a spontaneous manner and are thereby causing progressive infraocclusion that is more frequently detected by practitioners (1). Regarding the permanent dentition, it needs to be mentioned that the preponderance of confirmed cases of ankylosis are observed in primary rather than permanent molars. Consequently, those clinical findings are more frequently documented in literature compared to ankylosis in permanent teeth. The occurrence of ankylosis in permanent dentition is considered to be a multifactorial event and cannot be ascribed solely to a single causative factor, excluding trauma-induced ankylosed permanent teeth. Hence, the investigation of ankylosis incidence should be presented in correlation with the underlying causes of its manifestation. To the best of our knowledge, there is no accurate quantification of the incidence of tooth ankylosis in the permanent dentition. This could potentially be attributed to the challenges in diagnosing the pathology, due to a significant number of asymptomatic and thus undiagnosed cases of ankylosed teeth, particularly in the posterior teeth of non-growing individuals. However, studies reported incidences of dentoalveolar ankylosis in permanent dentition to be around ten times less common than in primary dentition and twice as prevalent in the mandibular arch compared to the maxillary arch. The most frequently affected permanent tooth was identified as the first molar. As a result, it can be corroborated that this pathologic phenomenon is rather underreported than rarely existing, and therefore not considered an uncommon phenomenon. Given the absence of precise estimates, it can also be hypothesized that the incidence of tooth ankylosis may be correlated with the prevalence of its etiological factors, which will be addressed in the following (5).

3 PATHOGENESIS AND ETIOLOGY OF ANKYLOSIS

Our current understanding of the pathogenesis of dentoalveolar ankylosis primarily stems from the result of animal and in vitro studies, as well as research findings gained from studies on human teeth that have been replanted. In individuals with a normal health status, abundant fibroblasts in the periodontal ligament obstruct osteogenesis within the periodontium. This is achieved through the release of locally acting regulators such as cytokines and growth factors, which maintain the separation of the tooth root from the alveolar bone. However, necrosis of the cellular elements of the periodontal ligament due to desiccation, crushing, or mechanical damage, as seen in severe luxation injuries, interferes with this normal homeostatic process. Finally, ankylosis is established by both

inflammatory-mediated and mechanical alterations in the periodontal ligament, as well as the survival of insufficient functional cellular elements that inhibit osteogenic activity (2). In general, the root surface devoid of cementum becomes susceptible to migration and recolonization by the more rapid bone forming cells as opposed to the slower periodontal ligament fibroblasts or cementoblasts. This results in a root surface populated by cells of osteoblastic lineage, which deposit bone directly onto the root surface, establishing a direct link between the two tissues. At this stage, the root has undergone ankylosis, but replacement resorption has not yet occurred. The root subsequently becomes integrated into the bone tissue, and its tissues are replaced with bone by osteoclasts and osteoblasts in a progressive, non-inflammatory remodeling process known as replacement resorption. It is crucial to note that replacement resorption can occur either in vital teeth with normal pulp tissue as well as in pulpless teeth without any infectious stimulus (5). Consequently, it is the growth of bone across the periodontal ligament, ultimately leading to ankylosis, which is the fusion of the tooth root and the surrounding alveolar bone (2). As previously mentioned, the described pathogenesis is directly linked to the etiology of dentoalveolar ankylosis, as numerous researchers state the risk for ankylosis as the highest in events of traumatic dental injuries and claim luxation traumas to be “the primary reason” for the pathology (2,5,11). Especially in the subset of luxation injuries, which are the most common traumatic dental injuries (incidence ranging from 30 to 44% among all dental trauma cases) the damage to the root-side of the periodontal ligament is of such severe nature that pathogenesis of dentoalveolar ankylosis is likely to occur (2). Andersson stated in 1984 that dentoalveolar ankylosis is probable to occur in case the injured root surface area reaches a threshold of 20% (11). This finding implies that the periodontal ligament and surface cementum possess a regenerative capacity that can mitigate the injury and facilitate the reattachment of periodontal ligament fibers, provided the compromised area does not exceed 20% of the root surface proven by *Andreasen* study results (12). Post-luxation the root surface is susceptible to mechanical trauma-induced injuries, which can manifest in varying degrees, forms and distributions. When the diffuse damage encompasses more than 20% of the root surface area, it triggers a reactive inflammatory response that sets the repair and healing process in motion and allows the migration and population of endosteal progenitor cells as described before (5). Furthermore, avulsed teeth are prone to develop ankylosis due to desiccation, inappropriate storage and critical dry-time that increase the risk for cell necrosis before replantation (2,5). It is stated that the probability of ankylosis development for replanted teeth “approaches 100% as extraoral exposure time increases” (12). This theory is corroborated by several in vitro studies that illustrate the vulnerability of progenitor cells on the root side of ex-articulated human teeth to desiccation. These cells exhibit a marked fragility when exposed to extended periods of extraoral storage (13–15). While a subset of progenitor cells located in the root

side maintain their viability post-injury, their capacity to differentiate into operational fibroblasts is diminished. Instead, these cells exhibit a predilection for differentiation into cells proficient in osteogenesis and osteoclasis, thereby promoting ankylosis over the regeneration of the periodontal ligament. Another traumatic dental injury prone to cause dentoalveolar ankylosis is intrusion. As in the context of severely intruded teeth, the periodontal ligament undergoes significant deformation, leading to its compression within the alveolar bone of the socket. This forceful intrusion results in ischemia within the periodontal ligament, the apical vascular bundle and the alveolus due to the consequent compression. Concurrently, the cementum is detached from the root surface due to the shearing forces involved, causing massive cell death. In cases of extreme intrusion, the tooth exhibits no mobility, indicating that repositioning through orthodontic traction alone may not yield successful outcomes (2). It is stated that teeth that underwent intrusion exceeding 6mm or half of the clinical crown length following a traumatic event exhibit an increased propensity towards ankylosis (1). Generally speaking, the probability of intruded teeth to undergo ankylosis increases proportionally to the severity of the intrusion (2). Moreover, local viral infections present to have the potential of playing a role in the development of dentoalveolar ankylosis. It is believed that a local viral infection by varicella zoster virus is associated with harm and damage to tooth innervation and/or dental follicles (5). Ankylosis might also occur in cases of impacted teeth, observed in approximately 29.5% of patients entering their fourth decade of life or beyond with impacted canines (5). The inability of these canines to erupt can be attributed to the ankylosis of the impacted tooth with the adjacent bone, or in certain instances, to the observable replacement resorption of the tooth itself (5). Additionally, literature reports the evidence of dentoalveolar ankylosis secondary to orthodontics. There is an elevated occurrence of dental ankylosis that has been correlated with the wire position and the existence of a stainless-steel ligature situated at the cementoenamel junction. This way of attachment placement for the exertion of orthodontic forces is considered suboptimal and the least favorable due to its potential to irritate the periodontal ligament, leading to either injury or ankylosis (1). Ankylosis following orthodontics might also occur following the treatment of impacted teeth, especially impacted canines. A potential hypothesis for the observed phenomenon could be the inadvertent leakage of the etchant towards the cementoenamel junction during the surgical procedure of exposing an impacted tooth and bonding an attachment. Alternatively, the cause could be attributed to mechanical trauma inflicted on the cementoenamel junction or an inadvertent alteration in the tooth's orientation during the exposure process. Regardless of the scenario, the underlying etiology remains ambiguous, necessitating further scientific investigation (5). A more ubiquitous form of ankylosis secondary to orthodontics occurs in the event of primary failure of eruption as a consequence to the attempt of exerting orthodontic forces on infraoccluded teeth (3). More local reasons to be mentioned,

that might cause dentoalveolar ankylosis are: deficiency of alveolar bone growth, periapical infections, abnormal pressure of the soft tissues as well as chemical or thermal irritation and previous surgical procedures (1,4,9). There are several other possible causes of dentoalveolar ankylosis, such as genetic predispositions or local metabolic changes. The accumulating body of evidence suggests a potential role of both genetic and epigenetic determinants in the manifestation of tooth ankylosis. It is postulated that a genetic or congenital anomaly in the periodontal ligament could act as a catalyst for this pathologic process. This hypothesis is further corroborated by multiple studies indicating a heightened prevalence of primary ankylosed molars and permanent first molars among siblings and twins, thereby implying a genetic predisposition (5–8). Additionally, there is a higher prevalence of bilateral cases of dentoalveolar ankylosis if induced genetically (10). Local metabolic changes and the concomitant metabolic disturbances associated with specific endocrine disorders and congenital anomalies, such as cleidocranial dysostosis and ectodermal dysplasia, have been scientifically linked with a heightened prevalence of tooth ankylosis and the submersion of implicated primary teeth. It is crucial to distinguish between systemic causes of delayed eruption and dentoalveolar ankylosis. The former encompasses conditions such as osteopetrosis, hypothyroidism, hypopituitarism, Fanconi's syndrome, avitaminosis A and D, vitamin D-resistant rickets, down syndrome, acrocephalosyndactyly and epidermolysis bullosa (1). Generally speaking, the etiology and corresponding pathogenesis of dentoalveolar ankylosis might be various and is often described as polyetiological, characterizing dentoalveolar ankylosis as an interplay of various reasons, influenced by numerous individual factors. The true etiology of ankylosis especially in primary dentition often remains unknown (10,16).

4 DIAGNOSIS AND DIFFERENTIAL DIAGNOSIS

A reliable and detailed diagnosis of ankylotic teeth is crucial and stated as "mandatory prior to therapy" as interdisciplinary treatment approaches present to be not only invasive but bring along serious potential risks (17). Throughout literature, practitioners strongly agree that the diagnosis of dentoalveolar ankylosis does not only appear to be truly challenging but often even highly difficult, thus frequently requiring various methods of investigation, time of monitoring and several steps until confirmation (5). In fact, especially the diagnostic value of different diagnostic criteria and tools present as controversial as well as highly dependent on the individual case, thereby making the draw for general diagnostic principles challenging. Nevertheless, an early and proper diagnosis is absolutely crucial in terms of treatment choice and success rates. Late diagnosis on the other hand might lead to severe clinical consequences and are proven to "impact the efficiency of orthodontic

therapy, even when it does not alter its effectiveness" (4). First and foremost, diagnosis of ankylosis needs to be strongly linked to dental and medical history, as events such as dental trauma can offer valuable clues to the potential etiology of ankylosis and might confirm a suspicious or ambiguous clinical finding associated with dentoalveolar ankylosis. In general, diagnosis of dentoalveolar ankylosis can be made from clinical, radiographical and/or computer tomography evaluation. The most characteristic clinical feature of ankylotic teeth, that raises attention upon clinical examination is infraocclusion of a tooth in comparison to the occlusal level of adjacent teeth (5). Infraocclusion of ankylotic teeth occurs due to the fusion of bone and tooth root that causes a vertical cessation of tooth eruption, leading to infraocclusion or potential impaction of the affected tooth (17). It is therefore known as a typical clinical feature of an ankylosed tooth and stated to be "one of the most powerful" findings regarding diagnostics of ankylosis (5). Therefore, the observation of gradual infraocclusion during adolescent growth serves as a further indication of late-stage ankylosis (2). Additionally, a regular dental examination should take into account the possibility of an infraoccluded tooth without an obvious cause, to be indicative of ankylosis. In terms of early diagnostics, it is further common practice to utilize mobility assessment, percussion sound evaluation and radiographic examination as a means of early detection of ankylosis (2,5). Although, the diagnostic and interpretive value of each of these modalities may be equivocal. It is widely spread upon literature, that an ankylosed tooth is identifiable by its characteristic and distinct high-pitched sound upon percussion, distinguishing it from adjacent unaffected teeth (2,11,18). A study-based analysis of digital sound waves has provided confirmation that an ankylosed incisor exhibits a notably greater concentration of sound energy in the higher frequency ranges when subjected to percussion, thus validating the distinctive sound pattern. Therefore, some practitioners believe, that the straightforward diagnostic method of subjectively evaluating the sound produced by tapping the tooth with a metal dental mirror handle has demonstrated high levels of both, specificity and sensitivity in diagnosing ankylosis (2,19). Controversially, other investigators claim the percussion test and basing diagnosis of ankylosis on a distinct metal sound as a non-reliable diagnostic tool, as studies prove that it can only be found in one-third of affected teeth (5,20). They argue, that if the extent of root surface ankylosis is less than 10%, no metallic sound will be detected upon percussion. To be more precise, only in case 10-20% of the root surface is ankylosed, just a portion of the teeth will elicit a metallic sound (5,11). In addition to this threshold finding, as reduction or lack of mobility in the buccolingual dimension appears to be a "popular" diagnostic finding suspecting ankylosis, it does in fact not always indicate a specific pathological condition, as a tooth may still exhibit mobility if less than 20% of its root surface is ankylosed (11). In terms of radiographic diagnostics, those areas in which ankylosis occurs are anticipated to exhibit the absence and/or interruption of the periodontal ligament space and likely

diminished ability to differentiate between the lamina dura and root dentin (5). Becker et al. propose examining the decreased vertical height of alveolar bone, the proximity of root apices to the lower border of the mandible, and the presence of hooked roots as indicators of tooth ankylosis in radiographic images. However, radiographic assessment is deemed to have limited efficacy in the early identification of ankylosis due to the two-dimensional nature of the imaging. The initial site of ankylosis is frequently found on the labial and lingual root surfaces, presenting challenges for radiographic detection (2,21,22). This theory is supported by Andersson who discovered that the use of two-dimensional radiography is insufficient for accurate diagnosis, as the presence of ankylotic areas may not be apparent if the affected area is not precisely aligned perpendicular to the x-ray beam. Hence, when ankylosis occurs in the buccal, lingual or inter-radicular regions of the root surface, and additionally more apically in young individuals whereas more coronally in older children, it becomes challenging to detect (1,16). Moreover, the presence of overlapping trabecular bone structure may lead to inaccurate positive diagnoses, whereas, the fact that even rather small areas of ankylosis situated on buccal or lingual root surface can already impede the process of tooth eruption is often overlooked (5,11,17). For all these reasons, radiographs regardless if in the form of intraoral or panoramic images are “considered insufficient for proper diagnosis of ankylosis” (11,17,20). Cone beam computer tomography (CBCT) shows promising potential as a valuable diagnostic tool for identifying dentoalveolar ankylosis due to its ability to offer a three-dimensional high-resolution imaging field. CBCT is a very valuable tool for assessing the position and dimensions of ankylosed areas and should be employed judiciously. It is recommended to conduct segmental or single tooth CBCT scans of suspected ankylosis sites in thin sections and to meticulously evaluate the relationship between the root and lamina dura. An absence of differentiation between the lamina dura and the root surface, as well as complete obliteration of the periodontal ligament space, should raise suspicion of ankylosis. Additionally, CBCT offers the advantage of providing diagnostic information prior to a luxation procedure, as the ankylosed bridge may be penetrating the root dentin, rendering the tooth vulnerable to root fracture during the procedure. Accurate diagnosis may significantly impact the treatment plan in such cases (5). A study by Ducommun et al. concluded that to identify an ankylosed tooth, the use of CBCT images can serve as a valuable supplementary diagnostic tool to complement clinical observations, dental and treatment history and potentially genetic data. However, it is not advisable to rely solely on CBCT for diagnosing ankylosis, as the study revealed instances of false positive results. Additionally, it has to be mentioned that further investigation needs to be carried out. Nevertheless, there are clinical procedures with the ability to provide a conclusive and definitive diagnosis regarding dentoalveolar ankylosis. The absence of tooth movement following the application of orthodontic force is considered to be the definitive diagnostic test. This clinical

procedure is called *Diagnostic Orthodontic Force* and is the reason why dentoalveolar ankylosis is disproportionally overrepresented in the dental field of orthodontics (5,23). It is advisable to apply a gentle diagnostic orthodontic force to the teeth in question for a duration of 7 to 10 days, for example by the use of separation modules. Subsequently, an assessment should be conducted to determine whether there have been any changes in tooth mobility or if the tooth has developed sensitivity to percussion. An alternative force system involves attempting to extrude the tooth against a fixed anchorage as in the form of an orthodontic mini-implant or even dental implant. Thereby the displacement of anchorage during diagnostic orthodontic force application, such as the intrusion of an anchorage unit, marks another indication for the diagnosis of dentoalveolar ankylosis. However, this consequence is for obvious reasons undesired. Another diagnostic aspect of crucial importance lies in differential diagnostics. As mentioned previously, certain terms with reference to diagnostics of dentoalveolar ankylosis are easily mixed and confused with each other. As replacement resorption commonly accompanies ankylosis, it might potentially complicate the differentiation between the two phenomena upon diagnosis. Replacement resorption is a physiological remodeling process of bone, that might lead to the substitution of the tooth root with bone tissue. In order to distinguish between ankylosis and replacement resorption, it is advisable to consider ankylosis as a diagnostic term. Consequently, when a tooth is diagnosed as ankylosed, clinicians should anticipate and use radiographic imaging to identify areas affected by replacement resorption as a progressive process that accompanies ankylosis and can impact the prognosis of the affected tooth (5). Furthermore, dentoalveolar ankylosis must be distinguished from other conditions, such as mechanical disturbances caused by parafunctional habits like tongue thrusting or finger sucking. Additionally, it needs to be considered that the infraoccluded tooth may also be blocked mechanically due to crowding. First and foremost, the most essential and important differential diagnosis needs to be done between ankylosis and *Primary Failure of Eruption* (PFE). Various factors might lead to a disruption in the process of tooth eruption. However, distinguishing between PFE and ankylosis can be clinically challenging without prior knowledge of trauma, dental history or further genetic information. PFE was initially defined by Profitt et al. as a rare disorder depicted by typical alveolar bone resorption without concomitant tooth eruption (5,24). In comparison to ankylosis, teeth affected by PFE do not exhibit fusion of bone and cementum. Instead, there is a disruption in the eruption mechanism, leading to the failure of a non-ankylosed tooth to fully erupt (17). Commonly, PFE is characterized by an unerupted or not fully erupted tooth situated at the bottom within a substantial vertical bony defect, resulting from the resorption of the occlusal alveolar bone (5). Further characteristics are that PFE predominantly impacts back teeth, particularly the first molars, and all teeth positioned distally from the most anterior affected tooth. Furthermore, teeth affected by PFE do not react if exposed to

orthodontic forces and are even prone to undergo ankylosis secondary to orthodontic force application (5,25,26). For those reasons, the differential diagnosis between PFE and ankylosis appears to be difficult and clinically challenging, as clinical presentation seems to resemble each other. The distinction between PFE and ankylosis can be drawn from the following: in both conditions, a suspected tooth may deviate from its normal vertical position and not react if exposed to orthodontic forces. In the case of an ankylosed molar, the adjacent teeth will demonstrate a normal response to orthodontic force and could potentially be repositioned to replace the ankylosed tooth following its extraction (5). Additionally, in some cases of ankylosis, the application of orthodontic force subsequent to the surgical luxation of the ankylosed tooth has been demonstrated to effectively disrupt the ankylotic bridge and restore the tooth to occlusion (27). Conversely, in case of PFE, the affected molar can only be repositioned occlusally through segmental osteotomy due to its incapacity to respond to the application of orthodontic forces at all (5). In fact, all patients suspected of PFE are constrained to undergo a genetic test, as a mutation of the *PTH1R* gene is linked to the occurrence of PFE discovered by Decker et al. and would definitively assert clear evidence of PFE to distinguish from ankylosis. (28) In the latest scientific literature, 51 total mutations of the PTH1R gene are proven to be linked to PFE, therefore, even though not all individuals with PFE present a *PTH1R* mutation, genetic testing is highly recommended prior to any orthodontic interventions in order to avoid subsequent ankylosis occurrence. (29)

In some cases, dentoalveolar ankylosis might remain undetected for several years, but as ankylosis can have a serious impact on occlusal development, especially in young patients, the importance of timely diagnostics to raise clinician's awareness for potential growth-related infraocclusion and eruption irregularities need to be clearly emphasized. Even though, early detection of ankylosis will not alter the ultimate outcome, accurate, proper and timely diagnostics of dentoalveolar ankylosis play a challenging as well as undeniably crucial role in choosing the appropriate treatment approach towards decreased morbidity and more promising long-term results (1).

5 CLINICAL FEATURES, CONSEQUENCES AND SUBSEQUENT CHALLENGES IN MANAGEMENT OF ANKYLOSED TEETH

On one hand, some clinical features of ankylosed teeth can present as equally common and on the other hand be of various and different natures decidedly depending on the patient's individual dentoalveolar growth status. Especially, the severity of symptoms and their accompanying consequences among growing and non-growing patients significantly vary from each other (5).

A clinical feature that all ankylotic teeth have in common regardless of the patients age and growth status, is the lack of mobility that was already referred to as a diagnostic symptom of ankylosis.

Thereby, it needs to be mentioned, that the lack of mobility might vary in its intensity, as studies verify that at least 20% of a tooth needs to be affected by ankylosis to detect a distinctive lack of mobility. Whether a tooth is specifically immobile in terms of ankylosis can only be assessed by using diagnostic orthodontic force (1). Another clinical feature in common refers to the radiographic presentation of infraocclusion secondary to ankylosis. Whereas radiological examination is seldomly suitable as an initial diagnostic tool due to its two-dimensional nature, it may clearly reveal clinical features of progressing ankylosis. Hence, infraocclusion as a clinical sign of dentoalveolar ankylosis is, depending on the progression, well visible and the radiographic presentation aids in determining the class and severity of ankylosis. On radiographs ankylosed teeth that became infraoccluded appear as an occlusal step and interfere with arch integrity, presenting teeth to be on different occlusal levels. Furthermore, the accompanying vertical bone discrepancy and the presence of a potential angular alveolar bone defect angled towards the site of ankylosis are further clinical features, that can be clearly detected upon radiographic examination and present the progression and evolution upon monitoring of ankylosed teeth over a period of time in the best possible way (10).

GROWING PATIENTS

The clinical features in growing pediatric and adolescent patients affected by ankylosis are influenced by vertical, sagittal and transverse growth processes. In particular, taking into account phases of rapid growth, as symptoms are foremost influenced “by the onset of ankylosis in relation to growth spurt” (5,30). As a rule of thumb, it can be stated that, the earlier the occurrence of dentoalveolar ankylosis, the more profound and severe the anticipated symptoms will be. To illustrate, Kennedy et al. stated that potential consequences are significantly reduced for a twelve-year-old female in comparison to a nine-year-old male in case of a similar clinical ankylotic primary molar, as the boy has not yet experienced his adolescent growth spurt (10). This clinical observation may be explained with reference to the etiology of dentoalveolar ankylosis. As previously presented, dental trauma marks the primary cause of tooth ankylosis, which predominantly impacts children between the age of eight to twelve. This stage is typically termed as a time before or during a rapid growth period. Dental traumas are usually accompanied by the pathologic process of replacement resorption, subsequently and in accordance with vertical eruption cessation, leading to infraocclusion. Due to an increased bone turnover rate in growing individuals, replacement resorption occurs at a more accelerated pace in comparison to individuals with a non-growing dentoalveolar status. Thus, in root resorption affecting 7 till 16 years old patients, teeth are common to be lost within three to seven years after the onset, whereas in adult patient affected teeth may endure for more than 20 years (30). Therefore, infraocclusion and vertical alveolar bone discrepancy present as more severe and advance more

rapidly in growing individuals due to teeth eruption and ongoing vertical bone growth. It concludes, that replacement resorption as well as infraocclusion are both "growth dependent" processes (5). As a result, growing individuals with ankylotic teeth, face the risk that most of these teeth are greatly prone to develop substantial malposition and misalignment in perspective to the adjacent unaffected dentition (1). Infraoccluded ankylotic teeth are often clinically described as submerged, as marginal ridges of the particular dental arch are located on different occlusal levels (10,16,31). It is stated, that "the severity of submersion is proportional to the rate of facial growth" (1). Therefore, infraposition is presenting more severe in the age group of 6.5-10 year-olds, in comparison to presenting as less severe in the age group of 12-16 year-olds (30). To categorize the severity of ankylosis it has been classified according to the degree of submergence and amount of infraocclusion, from *slight*, *moderate* to *severe* (10,32,33). Slight ankylosis is defined as submergence which is less than 2 mm, moderate ankylosis is defined as infraocclusion up to the contact point, while severe ankylosis manifests as significant clinical submergence well below the contact area of adjacent teeth, illustrated by radiographic images (Figure 1-3) of ankylosed second primary molars (10).

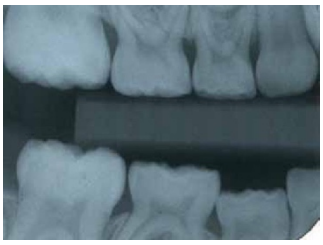

Fig.1: Slight ankylosis

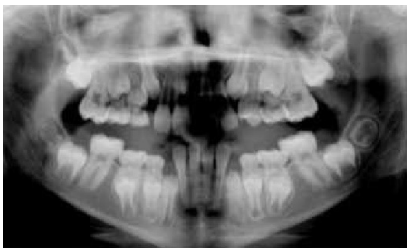

Fig.2: Moderate ankylosis

Fig.3: Severe ankylosis

Infraocclusion as the most prominent clinical feature of ankylotic teeth leads to further consequences, that potentially complicate the clinical situation and treatment approaches over time. Firstly, due to the inclination and tipping of adjacent teeth towards the infraoccluded ankylosed tooth, a localized or generalized loss of arch length with significant space loss greater than commonly lost by the Leeway space can develop (10). Especially, in unilateral cases of ankylosis, the dental midline is highly probable to shift towards the side of ankylosis in association with the compensatory tipping mechanism of adjacent teeth towards the infraoccluded tooth (1). In a study of Becker et al. dealing with primary ankylotic molars and its clinical consequences, the midline shift and the excessive tilting of adjacent teeth in a compensatory vertical eruption manner is ascribed to "the stretching of the transseptal fibers connecting teeth in the dental arch in a mesh-like form" (5,34–36). The risk for these serious clinical consequences to develop is highest in clinical cases of severe ankylosis of a second primary molar in the late primary or early mixed dentition (10,32). Therefore, ankylosed second primary molars are described as a "potential periodontal threat" to the neighboring first permanent molar, which is of significant importance for lifetime arch stability and integrity (3,10). Furthermore, the manifestation of a posterior open bite presents another serious clinical issue

secondary to infraoccluded ankylotic and tilted adjacent teeth, thus, the antagonistic teeth are failing to compensate, potentially promoted by subsequent parafunctional habits such as tongue thrusting (1,8). In detail, research conducted by Kula et al. revealed a notable prevalence of crossbites and dental aplasia in cephalometric and occlusal analysis. The majority of crossbites observed primarily affected the buccal and/or anterior segments. Such conditions could potentially contribute to the development of a posterior open bite (1,37). Another clinical consequence that refers to the antagonists of infraoccluded teeth can be the compensatory mechanism of supraeruption as antagonistic teeth seek contact point with a submerged ankylosed tooth (1). For all of these presented clinical findings as a consequence of dentoalveolar ankylosis, it can be "described as a local factor for malocclusion" (4). Moreover, adjacent teeth and the submerged ankylosed tooth itself may experience an increased susceptibility to caries and periodontal diseases (1). It has to be explicitly pointed out, that the presence of permanent successors plays a crucial role in the development of clinical features of ankylosis and needs to be expressively addressed.

In instances where a permanent successor is in place, the ankylosed primary molar typically undergoes normal resorption and any impact on occlusal development is transient, often remaining unnoticed. However, research has indicated that this may result in a minor delay in eruption of the permanent successors. Proffit et al explain that especially ankylosed primary molars with a permanent successor present a potential malalignment risk for the permanent dentition. Due to the fact that in some instances, those primary molars fail to resorb or remain attached to bone in the cervical region, thereby leading to a potential impaction of the primary molar. This retention might cause a delay in the eruption of the permanent successor and potentially source deviation from the ordinary eruption path and ectopic eruption (3,33). Additionally, the permanent successor can as well be affected by hypoplasia or impaction (1).

Primary teeth that lack a successor exhibited a higher prevalence of ankylosis, did not shed spontaneously, and demonstrated progressive infraocclusion. In fact, it can submerge to such an extent that the ankylosed tooth becomes covered by gingiva over again, as adjacent teeth erupt and carry alveolar bone with them. In those clinical situations, there is a significant risk for long-term periodontal problems and extensive vertical alveolar bone discrepancies. Proffit et al state that "the longer the ankylosed primary tooth is in place, the greater the chance of a long-term defect, because alveolar bone has not formed in that area"(3). It corroborates the principle, that management of primary ankylosed teeth strongly depends on the clinical situation whether a permanent successor is present or not and will be highlighted in the later on. By fact, if the ankylosed tooth is staying in place for too long, it might also take up too much space if remaining unreduced and thereby causing malocclusion among segments of dentition (10). In case of tipping and shifting of adjacent teeth,

those teeth will require repositioning in order to re-establish the lost space for future prosthetic replacement. It has to be mentioned, that with time, progressive infraocclusion of an ankylosed tooth becomes more challenging to surgically extract. In case of the presence of a permanent successor, any vertical bone discrepancies will be eliminated as the permanent successor brings bone tissue along with it during the eruption process (3).

NON-GROWING PATIENTS

Ankylosis concerning non-growing individuals might clinically present as entirely asymptomatic, especially regarding posterior ankylotic teeth, due to the slow alteration in the teeth's vertical height and the insignificant discrepancy in comparison to neighboring marginal ridges. Upon routine clinical examinations, those teeth might remain unsuspicious until the potential occurrence of shedding crowns or root fractures due to the undetected ongoing replacement resorption, causing resorption of the tooth root and subsequent loss of alveolar support. Those changes that are potentially noticed by the clinician primarily pertain to the anterior teeth. In this manner, ankylotic teeth bear an apparent resemblance to osseointegrated implants. Since, as part of the non-growing individual occlusal equilibrium, adjacent non-ankylosed teeth continue to experience true (whereas slow) vertical eruption. The resulting vertical discrepancy might ultimately lead to detectable and evident asymmetry and infraocclusion, interrupting the occlusal arch and its integrity. Ankylosis is considered to be the most common cause of infraocclusion regarding the permanent dentition (5). Obvious clinical malalignment or displacement of anterior teeth after dental trauma should always raise suspicion of potential ankylosis development. In some instances, dental trauma affecting the anterior permanent dentition can lead to an anterior open bite development, for example subsequently to intrusion, luxation or after reimplantation following avulsion at a younger age (33). As previously expressed, progressive dentoalveolar ankylosis has the potential to cause serious clinical consequences for the permanent dentition, its function and aesthetics. As clinical cases present as highly individual regarding their etiology or age of onset, as well as timely diagnostics playing a significant role, treatment plans to prevent any harm to primary or permanent dentition need to be specifically tailored toward the individual. Therefore, treatment approaches for dentoalveolar ankylosis are various, differing in their complexity and are often calling for interdisciplinary approaches, designed to restore and establish occlusal arch stability, integrity as well as proper function and aesthetics. Those treatment approaches are presented in detail in the following.

6 MANAGEMENT AND INTERDISCIPLINARY TREATMENT APPROACHES OF DENTOALVEOLAR ANKYLOSIS

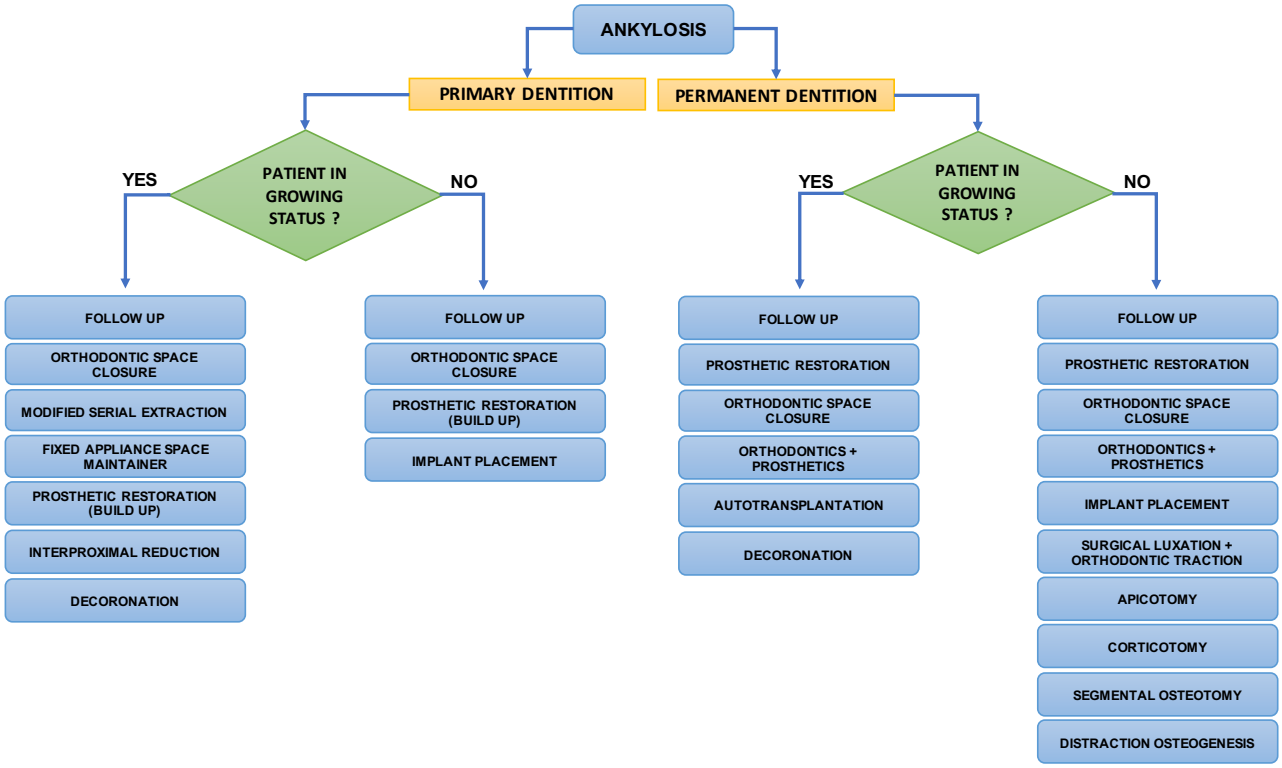

Fig.4: Flowchart presenting potential treatment approaches in relation to affected dentition and growth status

PRIMARY ANKYLOSED TEETH

GROWING AND NON-GROWING PATIENTS

6.1 TREATMENT PRINCIPLES AND FOLLOW UP

6.1.1 PRIMARY ANKYLOSED TEETH WITH SUCCESSOR

In general, in the presence of permanent successors to ankylosed primary teeth, it is of major importance to monitor on a regular basis the development of successors and potential eruption paths by the use of radiographic examination (10). Studies by Kurol and Thilander presented that in 92.5% of clinical cases, exfoliation of primary ankylosed molar and normal eruption of permanent premolar successor occurs without any clinical intervention. Additionally mentioning, that an allowed temporary delay in eruption of 6 months was included in studies results (33,38). Therefore, ankylosis of primary teeth with permanent successors often remains unnoticed and undiagnosed, as its clinical presentation is asymptomatic. Nevertheless, it has to be noted that according to Proffit et al. there is a potential risk of delay in eruption and malalignment of the permanent successor as well as non-

resorption or impaction of the primary ankylosed tooth (3). Thus, in some instances, extraction of the ankylosed primary tooth and space management procedures will be indicated to prevent subsequent periodontal problems, ectopia or compensatory eruption mechanisms of adjacent teeth. Especially the antagonistic premolar needs to be monitored thoroughly in its eruption time and manner, as key parameters like the timing of eruption can lead to revealing information for the clinician regarding a potential delayed eruption of permanent successors below ankylosed molars. Furthermore, its eruption manner should be carefully noted to prevent any potential supraeruption. (10) Typically, clinical cases of slight and moderate ankylosis tend to resolve on their own, while severe cases often require intervention. Certainly, clinicians have to take into consideration that timing of extraction is crucial, as early extraction may promote a potential delay in eruption and subsequent space loss (39). Thus, calling for prolonged space management through transitional dentition. Late extraction of primary ankylosed teeth, on the other hand, is known to accelerate permanent tooth eruption and reduce the time of space management (10). In summary, it can be stated that the time of onset of ankylosis is the first crucial key factor to determine. As late onset cases focus on exfoliation of primary ankylosed teeth whereas early onset cases need to be differentiated into early diagnosis and late diagnosis of early ankylosis onset. Those cases with a late diagnosis typically present with more severe clinical consequences and therefore call for orthodontic intervention and/or extraction (33).

6.1.2 PRIMARY ANKYLOSED TEETH WITHOUT SUCCESSOR

In terms of primary ankylosed teeth without a permanent successor, the clinical preconditions for choosing the appropriate treatment approach are quite different and generally more challenging. The crucial decision for the long-term prognosis is whether to preserve the primary ankylosed tooth or to extract it (and if so when), demanding subsequent space and restorative management (10). Even though extraction will potentially lead to some degree of alveolar bone loss, it is often the preferred treatment option in order to avoid any long-term periodontal issues because of the diminished attachment and cementum exposure of neighboring teeth. Therefore, in the majority of clinical cases, it is mostly recommended to consider early extraction as a prophylactic extraction following a previous evaluation of root resorption, loss of periodontal support and the age of onset (33). Furthermore, it is recommended to have a skilled clinician extract ankylosed teeth, due to the fact that if extraction is not carried out carefully, it could lead to even severe periodontal issues (3). Only in those clinical cases presenting with very slow progression of infraocclusion and root resorption, apparently describing the ankylosed primary tooth as useful, it is advised to keep it in the dental arch

as a natural space maintainer and follow up with careful monitoring of the ankylosed site to make timely decisions about potential future restorations (33).
Overall, the condition of the primary tooth crown, roots, restorations and alveolar bone support, along with its position relative to the occlusal plane, must be taken into consideration. Choices and treatments affecting the mixed dentition stage might have a significant influence on the management of occlusion in general (10,40). Therefore, attentive monitoring as early as possible is mandatory, additionally turning attention towards a potential delay in eruption of six months. This delay in eruption is officially described as acceptable "with the degree of infraocclusion to the extent of the delay"(33).

To conclude, the general management principle of an ankylosed primary molar in an appropriate manner is defined as "maintaining it until an interference with eruption or drift of other teeth begins to occur." Subsequently, it is advised to extract the ankylosed tooth (3). The appropriate treatment approaches to maintain and/or regain space, as well as finally implement a modality for a long-term solution are presented in detail in the following.

6.2 EXTRACTION

6.2.1 EXTRACTION AND ORTHODONTIC SPACE CLOSURE

If a primary ankylosed tooth is indicated for extraction there are several treatment approaches how to follow up subsequently. One treatment approach regarding ankylosed second primary molars without successors is to extract as early as ankylosis diagnosis is confirmed and the absence of a permanent successor is reassured by dental age assessment and the evidenced non-formation of a dental follicle between ages 6 and 7, seldomly forming after 8 years of age. Therefore, it is advantageous to extract these ankylosed teeth at ages 7 to 9, depending on the timing of eruption of the first permanent molar. The main goal of this approach is to extract the ankylosed molar before any potential vertical deficiency development develops too far and subsequently to consciously resign from placing any space maintainer intervention. Thereby, it is desired to allow the first permanent molar to drift mesially and close the gap either fully or partially varying upon the amount and direction of the spontaneously erupting first molar. This mesial drifting is worthwhile as it might reduce the future size of the implant closer to the natural size of a second premolar and for the fact that drifting and forward motion of the first permanent molar inevitably brings some amount of bone with it, being especially beneficial regarding the periodontal attachment. If the spontaneous natural manner of space closing is limited due to late extraction or larger dimensions of defects, it is recommended to implement orthodontic space closure interventions to control partial space closure more precisely or

to achieve full space closure if desired. Whether to close the created gap partially or fully depends on various factors, such as occlusion, space availability and dental age of the patient in relation to the individual's growth status. For the fact, that clinicians are often facing the risk of alveolar bone defect on the ankylosed tooth site, it is generally advisable to guide teeth by orthodontic force application at least partially into the edentulous space after extraction, as this movement will just like in natural eruption, bring some alveolar bone along. Furthermore, this approach helps to stimulate the formation of new bone in the edentulous region. Orthodontic space closure is applicable not only in the growing but also in non-growing individuals, certainly limited by molar and canine occlusal relationships, as well as contraindicated in clinical cases of unsupported posterior teeth, retrusion of incisors or other not further differentiated spacing in the arch. In unilateral cases of ankylosed second primary molars without a successor, the extraction of opposing second premolar might be beneficial in terms of space closure treatment, in order to achieve a Class I occlusion. Elsewise, unilateral space closure is prone to result in Class II / III molar relationship as well as in midline shift especially in mixed dentition. Therefore, it is advised to reserve unilateral space closure treatment approach for a later time, when the individual turns at least 12, so that temporary anchorage devices (TADs) can be implemented. Another treatment modality is the combination of hemi-sectioning an ankylosed primary molar and pulp therapy, in order to letting adjacent teeth erupt partially into open spaces to control the size of the gap in perspective to the future size of a premolar restorative replacement as well as limit the risk of alveolar bone loss subsequent to extraction over time (3).

6.2.2 EXTRACTION AND MODIFIED SERIAL EXTRACTION

In clinical cases of patients presenting with significant crowding, infraocclusion due to primary ankylosed molars and no permanent successors, a modified serial extraction treatment approach may be deemed suitable under the supervision of an orthodontist in the nature of an orthodontic camouflage treatment. This approach addresses the clinical issues of crowding, infraocclusion and absence of permanent successor concurrently, with the long-term objective aim of resolving infraocclusion and closing the edentulous space left by the missing permanent tooth. The primary treatment goal is to relieve constriction of the particularly constricted jaw(s) and subsequent crowding by performing a sequential extraction to manage molar positions and align the dental midline. The procedure as such is highly individual and therefore called modified serial extraction. It is illustrated best by a clinical example of Kennedy et al. In this particular clinical case, the patient in the mixed dentition stage initially presented with Class I crowded malocclusion with missing maxillary right second premolar and ankylosis of primary molar, showing significant infraocclusion (Figure 5). The

treatment approach of modified serial extraction was chosen in order to correct maxillary constriction, crowding, deep bite and missing tooth space as well as control of dental midline. In the following, the maxillary right primary molars were extracted and a nance button space maintainer was placed in order to avoid shifting of dental midline and mesial drift of maxillary right first permanent molar. Additionally, all first premolars of the other three quadrants were extracted, leading to a period of "spontaneous dental drifting", throughout which the formerly crowded maxillary right canine, as well as the first premolar, moved distally into primary molar extraction site. Meanwhile, the maxillary dental midline was kept (Figure 6). Finally, full fixed orthodontic appliances with additional maxillary expansion were placed to finish the treatment (Figure 7) (10).

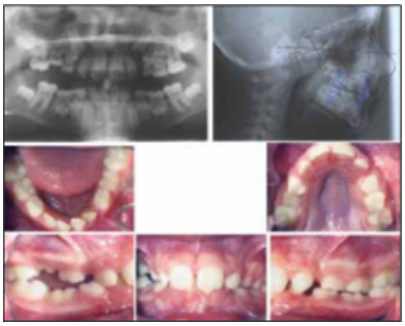

Fig.5: Pre-treatment

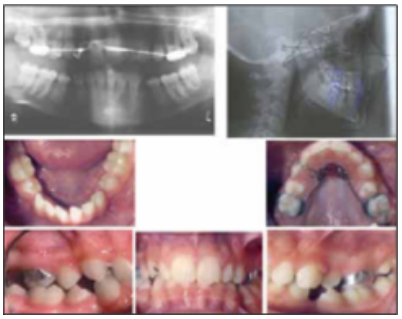

Fig.6: After modified serial extraction

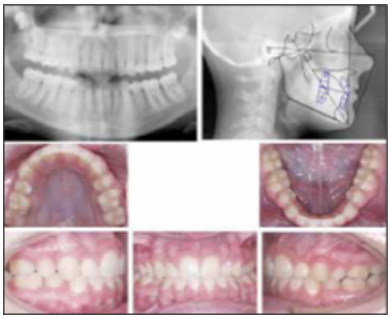

Fig.7: Final result

This treatment approach is highly promising, especially if performed on time during growth spurt in late mixed dentition to benefit from spontaneous drifting of teeth. The risk is in the potential misalignment of especially canines, calling for more extensive repositioning approaches and potentially prolonging the treatment (10).

6.2.3 EXTRACTION AND FIXED APPLIANCE SPACE MAINTENANCE

In those clinical cases of primary ankylosed teeth with a permanent successor that is calling for extraction either due to a severe degree of infraocclusion and subsequent progressing compensatory eruption mechanisms of adjacent teeth, the delayed and/or ectopic eruption of the permanent successor as well as the evidence of crowding in anterior dentition, it is recommended to extract the primary ankylosed molar and proceed with a fixed appliance for space maintenance. In addition, space regain in order to allow eruption of permanent successors or keep the dental arch space for future prosthetic restorations is often needed. Generally speaking, radiographic assessment is crucial for the observation of eruption paths and early detection of potential ectopic eruption that are raising attention towards timely extraction of primary ankylosed teeth. It is stated that when infraocclusion causes the occlusal surface of the primary ankylosed molar to descend below the highest point of the adjacent permanent teeth, it becomes unfeasible to maintain space by restoring the tooth by build-up

procedures, but instead necessitating the consideration of extraction. After extraction, it is recommended to place a fixed space maintenance appliance, such as a lingual bar in the mandibular arch or a nance button space maintainer in the maxillary arch. Those appliances are capable of stabilizing the first permanent molar while maintaining the space in order to prevent ectopic eruption of premolar successors and/or preserve the alveolar ridge for future prosthetic restorations. They also having a beneficial influence on potential mild crowding of the anterior dentition (10). The beneficial influence of fixed appliance space maintainers can be illustrated by the following clinical example of a patient presenting with bilateral ankylosed second primary molars, mild mandibular incisor crowding and bilateral ectopic eruption of mandibular second premolars (Figure 8-9). The extraction of both ankylosed second primary molars and placement of a lingual arch bar space maintainer led to an improvement in incisor alignment and normal eruption of second mandibular premolars upon follow-ups. In case of ankylosed primary teeth without a permanent successor, it needs to be mentioned that space maintenance is contraindicated due to the potential risk of alveolar bone development disturbances and deficiency, excluding cases with planned future implant restorations in which space maintenance with fixed appliances might be considered (3).

Fig. 8: Pre-treatment radiographs and intraoral photographs

Fig. 9: Lingual arch bar in place, erupting second premolars visible

PRESERVATION OF THE PRIMARY ANKYLOSED TOOTH

A nearly contrastive approach to treating primary ankylosed teeth lays in the preservation of it. It provides to be clinically beneficial for several reasons and in particular applicable for clinical cases with signs of only mild infraocclusion. Its main goal is to maintain as much alveolar bone as possible and prevent bone loss secondary to extraction for further prosthetic restorations, as well as to avoid compensating eruption mechanisms. Another objective is to ensure the most favourable maintenance of lower incisor position in order to evade any negative effect on the facial profile. Patients exhibiting minimal crowding, deep overbites, retrusive incisors, reduced anterior lower facial height and flat mandibular plane angles are typically recommended for a non-extraction treatment approach. Therefore, in clinical cases presenting with these characteristics, it is advised to retain primary ankylosed teeth for as long as possible, requiring that there is adequate root structure and only mild

infraocclusion. Upon preservation of ankylosed teeth, the basic principle to follow is “disk and build up as needed” (10). Consequently, a study by Scurrin et al. reported that an ankylosed primary second molar lasted up to 15 years beyond commonly expected exfoliation timing (41). Another investigation by Sletten et al. asserted that adults aged 36 to 48 years with retained secondary primary molars with full aplasia of permanent successors presented only with a minimal degree of root resorption (42). Additionally, mandibular primary molars appeared to be more durable in comparison to their maxillary counterparts (40). Those research-based findings provide clinicians with the reassurance and confidence that preservation of primary ankylosed teeth without a significant amount of infraocclusion or root resorption is likely to endure for several years and retaining those teeth is a reasonable treatment approach (43).

6.3 PROSTHETIC BUILD UP

In those clinical cases characterized by only a slight degree of infraocclusion secondary to ankylosis of a primary tooth and the patient is either in a growing stage of limited anticipated future growth or non-growing stage, restoring the occlusal surface by a restorative build up marks an appropriate treatment approach. Thereby, it is possible to maintain proximal contact integrity and achieve the prevention of compensatory eruption mechanism such as supraeruption of antagonists and tilting of adjacent teeth. The short-term build up can either be done by the use of composite resin, or alternatively by more durable restorations in the form of crowns and onlays (10). Through the application of a stainless-steel crown / *Paediatric Metal Crown* (PMC) or the addition of posterior composite material to restore proper occlusion, potential vertical extension of the crown is achievable and preserves the mesiodistal dimension (33). Those restorative interventions are considered expressively beneficial until a long-term prognosis of a retained primary tooth has been established. However, as soon as infraocclusion transitions to a moderate or even severe form, causing the occlusal surface of the primary molar to descend below the greatest convexity of the adjacent permanent teeth, the restorative intervention becomes unfeasible and consequently extraction needs to be considered. One possible drawback of a PMC is the chance of over-sizing the retained primary molar in a way that might lead to a reduction of free Leeway space. In cases characterized by severe infraocclusion, attempting to increase and raise the occlusal level is absolutely contraindicated as the ongoing vertical growth will make the ankylosed tooth interfere with occlusion. A clinical example for the successful implementation of a ceramic onlay in terms of prosthetic build up can be seen in the following Figure 10-13 (10).

Fig. 10,11: Bilateral Ankylosed second primary mandibular molar, bilateral absent second premolars
Fig. 12,13: Ceramic onlays on both ankylosed primary molars to close mesial gaps

ONLY IN GROWING PATIENTS

6.4 INTERPROXIMAL REDUCTION OF PRIMARY ANKYLOSED TOOTH

In treatment approaches dealing with the preservation of primary ankylosed teeth, one of the main objectives is to maintain as much alveolar bone as possible and keep sufficient space within the dental arch for future restoration of the missing tooth. Thus, interproximal reduction of the primary ankylosed molar for space maintenance is a treatment approach indicated for growing individuals exhibiting ankylosed posterior dentition without permanent premolars. The reason why this treatment approach emphasizes the importance of interproximal reduction refers to the mentionable risk of keeping the ankylosed primary molar without any intervention in place for too long, subsequently causing malocclusion. This clinical consequence affecting the occlusion might occur, due to the fact that the primary molar, especially in the mandible is wider in mesio-distal dimension as a potential premolar successor. The Leeway space, in cases of normal eruption sequences, resulting, commonly provides adequate space to resolve potential crowding in the mixed dentition. As ankylosed primary molars that are retained beyond their common exfoliation time, are wider in mesio-distal dimension compared to their designated successor, malocclusion can develop as the permanent molar fails to drift into Class I occlusion. This phenomenon is best illustrated by the following clinical example of retained primary second mandibular molar. Due to its preservation beyond common exfoliation time, the first permanent molar exhibits a cusp-to-cusp or half Class II molar relationship, whereas the canines are in a Class I relationship (Figure 14) (10).

Fig.14 Unreduced retained ankylosed second primary molar

Therefore, figures 15 and 16 give a perfect clinical example for the beneficial outcome according to the principle “disk and build up as needed” of the preservation treatment approach.

Fig.15 Mild infraocclusion, interproximal reduction of retained secondary molar
Fig.16 Composite restoration

Nevertheless, it has to be explicitly addressed that this treatment approach has several limitations and bears risks. The dimensions of the pulp, the curvature of the root of the primary second molar, its proximity to the neighboring first permanent molar and premolar appear as limiting factors for the interproximal reduction (44). Thus, upon interproximal reduction of the second primary molar, it is advised to operate with special caution in order to avoid excessive reduction near the pulp horns, potentially leading to pulpal inflammation and triggering premature root resorption. Regarding the curvature of the roots as another limiting factor, it has to be pointed out that excessive reduction might lead to the proximity of roots between the retained second primary molar and adjacent permanent teeth once more bearing the potential to trigger root resorption. Although these hypotheses appear plausible from a physiological point of view, there is a lack of empirical evidence to substantiate these assertions, especially regarding long-term outcomes (10,44).

6.5 DECORONATION

The treatment approach of decoronation is primarily known, approved and investigated for the treatment of permanent ankylosed teeth. However, throughout literature clinicians agree that besides a lack of clinical investigation and examples, decoronation can also be carried out on primary ankylosed teeth without a permanent successor that developed a significant vertical discrepancy (3,5,45,46). Malmgreen et al proposed an alternative approach to the extraction of ankylosed incisors in pre-adolescent children in 1984. Their main principle involves the removal of the crown while leaving the root in place in order to maintain the alveolar bone height and width (45,46). As mentioned previously, this method is typically utilized for ankylosed permanent incisors after traumatic luxation to prevent it the decline of alveolar bone properties subsequent to extraction. The decoronation treatment approach is recommended to be performed before the major growth spurt of the patient in order to preserve alveolar bone and potentially eliminate the necessity for an alveolar ridge augmentation procedure prior to future implant placement. While primarily recommended for permanent ankylosed teeth, the same concept should be considered for managing primary ankylosed second molars without a successor, as long as the patient is in his/her ongoing growth period before a future implant placement (3,10). Nevertheless, it needs to be emphasized that there is a lack of scientific research on the efficacy of this approach for primary ankylosed teeth and further investigations need to be carried out.

6.6 AUTOTRANSPLANTATION

Autotransplantation following extraction of an ankylosed primary molar predominantly refers to the attempt of treating the posterior dentition and replace a missing permanent premolar. In detail, autotransplantation is indicated in those cases presenting with an uneven distribution of absent premolar teeth (10,47). For instance, in those clinical situations characterized by crowding in one arch or quadrant in concurrence with congenitally missing teeth in other parts of the dentition. In this clinical example taking the treatment approach of autotransplantation proposed by Jonsson and Sigurdson in 2004 into consideration, extraction of teeth in the crowded arch and autogenous transplantation towards the opposing arch, in which teeth are congenitally absent can be implemented (48). This principle can be illustrated by the following clinical case, in which the growing patient was considered for autogenous transplant of one first premolar towards the right maxilla with missing second premolar. The patient presented as well with crowding in the mandible. Therefore, the treatment plan implemented to extract both first premolars in the lower jaw and autotransplant the left one, whose root development of approximately 2/3 of root length was more suitable to autotransplant towards the side of the right missing maxillary second premolar (Figure 17-19). By this approach, the clinician resolved the crowding in the lower jaw and replaced the missing second premolar for an equal distribution of teeth in relation to space availability in both jaws. In the following, fixed appliances were placed in order to finish the treatment (10).

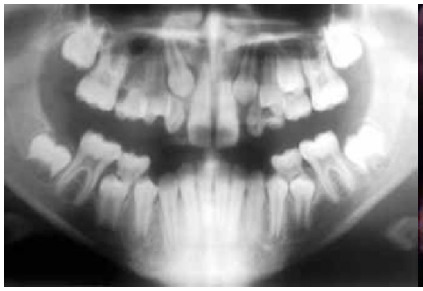

Fig.17: pre-treatment

Fig.18: 5-year post transplant

Fig.19: 5-year post transplant

Following the transplantation procedure, observations revealed the presence of calcification in the pulp canal, alongside apical development (Figure 18) (10). Research by Jonsson and Sigurdsson proves that autogenous premolar transplants exhibit a success rate of 92,5% over a decade of time. However, it is important to point out that those procedures are associated with potential risks of pulp calcification and secondary ankylosis (48).

Another clinical situation that is potentially applicable to the treatment approach of autotransplantation refers to children exhibiting Class II malocclusion as well as a good facial balance and congenitally missing mandibular second premolars (47). The according treatment plan implicates extraction of maxillary premolars and autotransplantation of these into the mandibular arch, with

subsequent application of fixed appliances in order to achieve a more favorable canine Class I and molar Class II relationship (10). For the sake of completeness, it should be mentioned that in some instances of missing premolars and non-extraction of any present premolars, even third molar transplants have been described in the literature to substitute a missing premolar (44). As already mentioned, this treatment approach might be very beneficial with a good long-term prognosis in suitable and particular clinical cases performed in consideration of the correct timing. The greatest benefit is the preservation and stimulation of continuous bone growth in growing individuals (49). The root development of the transplanted tooth as well as its pulpal status needs to be monitored on a regular basis (10).

ONLY IN NON-GROWING PATIENTS

6.7 EXTRACTION AND IMPLANT PLACEMENT

In clinical cases of non-growing individuals with ankylosed primary teeth without a successor and a low decay rate, an implant-supported crown restoration is considered to be the best restorative option. (10). Implant placement is contraindicated in patients who are still experiencing growth as it may impede proper growth patterns, similar to an ankylosed tooth, subsequently leading to infraocclusion. However, it is imperative to include this treatment option in the overall treatment plan as a definitive solution once growth has ceased (50). The crucial key aspect predominately influencing successful long-term implant placement regarding satisfying function and aesthetics is the preservation of the alveolus to support and ensure proper osseointegration of the implant (10). Ostler and Kokich conducted a study indicating that subsequent to the extraction of a second primary molar, a reduction of 25% in buccal lingual dimension occurs within the first three years and thus, may dictate the future implant placement in the buccal lingual orientation. Afterward, a decrease of only 4% is observed, with the majority of the reduction taking place on the buccal surface (10,51). It implies that precise timing of extraction of the primary ankylosed tooth is essential in the treatment planning for future implant placement and is highly individual strongly depending on the time of onset and time of diagnosis. When the extraction is performed early during the ongoing growth of the individual, the progressive eruption of adjacent teeth leads to a passive eruption mechanism, as the expansion of the periosteum across the alveolar ridge triggers the osteoblastic activity, eventually carrying bone along occlusally so that the extraction site that can be associated with normal growth entailing a seldom occurrence of vertical bone discrepancy. Therefore, in the absence of a permanent successor and early extraction followed by the placement of a suitable space maintainer, the alveolar ridge is rarely compromised for future implant placements. In order to establish the best alveolar and periodontal

conditions while the patient is still growing, active pre-surgical interventions such as placement of coral granules, decoronation or autotransplantation can be incorporated into the treatment plan. Those interventions promote the alveolar bone and surrounding tissue development and ordinarily prevent the need for bone grafting measures in order to restore appropriate alveolar height and width (10,11,52). On the other hand, late removal of the primary ankylosed tooth until the completion of growth is expected to lead to significant vertical bone deficiency. In the following, positioning of the implant would be rather deep in such a way, that the clinical crown length would need to be extended, ultimately resulting in a less favorable crown-root-ratio as illustrated in Figure 20-25 (15,45).

Fig.20,21: Ankylosed second primary molar, pre-extraction, space maintainer in place

Fig 22,23: Severe vertical bone defect due to late extraction

Fig 24,25: Single tooth Implant placement, poor crown-root ratio, long clinical crown

Under those clinical circumstances of severe bone defects after extraction, other potential interventions including treatment approaches such as bone grafting or the so called “implant-site development” by relocating the first premolar into the position of the second premolar or vice versa in order to place an implant into the newly generated bone site, need to be considered. As a matter of course, the process of implant-site development requires an extended period of time, disproportionate to the time of space maintenance upon early extraction. Therefore, in order to prevent significant vertical bone defects, it is recommended to extract primary ankylosed molars as soon as infraocclusion is detected, while there is still a substantial amount of growth potential left. Consequently, delayed implant placement after early extraction poses no clinical concern as the alveolar ridge typically stabilizes after an initial narrowing to the size of the first premolar. The decision to extract a primary ankylosed tooth in the absence of a permanent successor will be contingent upon the extent of the patients ongoing facial development at the point of diagnosis (44).

6.8 FOLLOW UP

In those clinical cases of permanent teeth undergoing ankylosis with a late-onset where substantial growth has ceased, a follow up treatment approach may be appropriate provided that there is no evidence of considerable vertical discrepancy of the ankylosed tooth in relation to the adjacent dentition, that is in need for any clinical intervention. At this point, it has to be pointed out that certain vertical growth continues as well in adulthood within the concept of occlusal equilibrium. More precisely, a vertical discrepancy of 0.1mm per year will gradually emerge even in mature individuals (5). The process of replacement resorption which should in any case be monitored by radiographic examination is considered as rather slow and gradual in comparison with the pace of resorption in growing objects. Therefore, retained permanent ankylosed teeth that do not cause any clinical consequences might last for numerous decades up to potentially throughout a whole life regardless of its ankylotic status without calling for any clinical intervention (50).

6.9 EXTRACTION

6.9.1 EXTRACTION AND PROSTHETIC RESTORATION

Extraction of an ankylosed permanent tooth may be considered at any point in time of treatment. Clinicians should exercise with special caution regarding the patient's individual growth and level of maturation, as an early extraction of a permanent tooth without the possibility to immediately place an implant might lead to severe bone loss and the vertical dimension of the alveolus will undergo atrophy over time. In non-growing patients primarily the failure of surgical interventions such as surgical luxation of the ankylosed tooth, or after failure of distraction osteogenesis or segmental osteotomy, are frequently calling for extraction of an ankylosed tooth and future prosthetic restoration in order to restore function and aesthetics (5). In adolescents and rather young adults with anticipated ongoing growth, it is recommended to refrain from the use of fixed prostheses whenever feasible, as they have the potential to impede the natural growth and maturation of tissues. It is rather advised to use removable prostheses as a temporary solution until the canines have fully erupted. Acid-etch bonded bridges can also serve as an interim solution subsequent to tooth extraction. In those clinical cases concerning individuals before the start of growth spurt, treatment approaches such as autotransplantation or orthodontic space closure should be considered as more suitable treatment options. At this point it has to be mentioned that a long-standing extraction site with prosthetic

restoration will inevitably lead to alveolar bone loss and in all probability require bone augmentation interventions, if implant placement is considered to be a future option (50).

6.9.2 EXTRACTION AND (ORTHODONTIC) SPACE CLOSURE

In clinical cases inevitably leading to extraction of permanent ankylosed teeth, especially in trauma cases of anterior teeth, orthodontists have the possibility to close the so occurring gaps within the dental arch by orthodontic space closure. Mostly, this treatment approach refers to the anterior dentition but is likewise applicable for the posterior dentition. Orthodontic space closure provides not only an aesthetic solution but also a rehabilitation of the alveolar bone ridge. The procedure can be performed for growing and non-growing individuals, but presents to be more advantageous for the growing individuals, as in these individuals with ongoing growth and progressive eruption, orthodontic managing of space appears to be more facile. For example, in the clinical case of a lost lateral incisor, it may be beneficial to allow the canine to erupt into the space of the lateral incisor lost in order to promote new bone growth and offer a temporary aesthetic solution, although orthodontic distalization and implant treatment are intended in the future (30). In certain, but rare instances, a lateral incisor may serve as a substitute for a central incisor and can be considered a "biologically correct alternative" as the replacing tooth has the ability to facilitate future vertical growth of the alveolar bone. Regrettably, the application of this treatment approach is restricted by constraints such as the presence of malocclusion, dental and skeletal maturity, particular teeth conditions in terms of its periodontal condition and tooth morphology, as well as the necessity for additional extractions or tooth reshaping, which in conclusion all contribute to higher financial costs and prolonged patient compliance. Thus, the number of suitable cases is limited to very distinct clinical cases. However, this treatment approach may offer a long-term beneficial treatment outcome and excellent preservation of alveolar bone (30,50). Especially, bilateral cases of orthodontic space closure present to be of higher patient satisfaction regarding facial aesthetics and symmetry in comparison to unilateral treatments (50). Regarding the posterior dentition, the institution of temporary anchorage devices enables the protraction of posterior teeth without causing lower incisor retraction, marking a recent major advance in technology and should therefore be taken into consideration (10).

6.10 ORTHODONTIC TREATMENT AND PROSTHETIC RESTORATIONS

In those clinical cases of late onset ankylosis when the growth of the individuals is completed or nearly completed and the permanent dentition is presenting with vertical discrepancy, it is generally

advised from an aesthetic treatment approach point of view, to take the prosthodontic build up into consideration. Procedures included are composite build ups or fixed prosthodontic restorations such as crowns. It is generally contraindicated in very young adults pre growth spurt as there is a potential risk for interference with normal alveolar process development. Those prosthodontic interventions aim to restore occlusal and interproximal contacts and prevent further compensatory mechanisms, for example, the tipping of adjacent teeth, that might potentially impair the dental arch balance and integrity. In many instances those mechanisms already took place, therefore previous orthodontic treatment is frequently indicated in order to upright tilted adjacent teeth or intrude supraerupted antagonists (5). Generally speaking, a prosthetic build up is feasible in those clinical cases not exceeding 5 mm of infraocclusion (53). This procedure can be nicely illustrated by a clinical case of Hadi et al., dealing with a 34-year-old female patient complaining about different levels of central incisors due to ankylosis of her maxillary right central incisor (Figure 26). After initial orthodontic treatment, the right maxillary incisor was build up using a composite resin restoration in order to avoid potential fracture of the buccal alveolar wall due to ankylosis-induced replacement resorption (Figure 27, 28). Upper and lower jaw fixed retainers were placed in order to gain more stabilization.

Fig.26: Ankylosed maxillary incisor; Fig. 27,28: CBCT revealing thin buccal wall, replacement resorption; Fig.28: Composite resin restoration

In conclusion, this treatment approach should rather be seen as a temporary modality until a permanent clinical solution can be stated, as the root of ankylosed teeth will progressively resorb. In terms of maintaining the alveolar bone dimensions and volume, it can be defined as very valuable, providing that only very little additional infraposition is anticipated (50).

ONLY IN GROWING PATIENTS

6.11 EXTRACTION AND AUTOTRANSPLANT

In contrast to autotransplantation in the context of ankylosed primary teeth, autotransplantation in terms of replacing ankylosed permanent teeth primarily deals with the anterior dentition, especially incisors of growing individuals. Autotransplantation is considered a viable treatment approach regarding the loss of permanent incisors in all cases of dental trauma (49). Therefore, permanent incisors affected by the clinical consequences of trauma-induced dentoalveolar ankylosis can present as applicable for the treatment modality of autotransplantation. In case an affected permanent incisor

is lost or needs to be extracted in the growing individual, the transplantation of a premolar, usually the second premolar of the lower jaw, should be taken into consideration. Thereby, the timing of extraction and transplantation needs to be carefully assessed and planned, preferably in an interdisciplinary approach involving oral surgeons and orthodontists (1,50). The donor site region typically closes on its own in young patients, although orthodontic intervention may be necessary in certain cases. The timing of the transplantation is crucial regarding optimal root development conditions. It is indicated to extract at 2/3 of root development in order to facilitate revascularization of the pulp as well as ensure successful periodontal healing. Transplanted teeth with fully developed roots do not undergo revascularization, but instead may require endodontic treatment post-transplantation as opposed to the risk of pulp calcification. By adhering to meticulous protocols and employing a delicate surgical approach, the prognosis for autotransplantation is favorable. Subsequent to a successful autotransplantation, the transplanted tooth will be aesthetically restored by the use of composite materials and shaped according to the form and function of natural incisors. Autotransplanted teeth exhibit normal periodontal ligament maintenance, allowing for continued eruption and the development of a common alveolar process with adjacent tissues. A successful impletion of the treatment approach can be illustrated by the following clinical example (Figure 29-31) of a lower second premolar transplanted to maxillary position 11 for an extracted former ankylosed right central incisor (50).

Fig. 29: Autotransplant second lower premolar

Fig. 30: 4-year post-transplantation, reshaped with composite

Fig. 31: Further root development

A substantial factor for the prognosis which makes up to 50% of the success rate, is the try-in of the donor tooth into the recipient site that has been prepared beforehand, prior to final transplantation. Thereby, the clinician needs to ensure the proper fit of the gingival tissues around the donor tooth. Not till then the transplanted tooth should be placed marginally below the occlusal plane, stabilized with sutures and potentially a composite wire. A physiological splint may be employed to restrict specific tooth movements in order to immobilize it sufficiently to promote healing of the pulp and periodontal tissues while reducing potential negative outcomes. It is essential to prescribe prophylactic antibiotics prior to the procedure and for a week post-surgery (1).

6.12 DECORONATION

The most promising, beneficial and frequently used treatment approach for permanent ankylosed teeth in growing individuals, close to pubertal growth spurt, is decoronation. Decoronation seems to be of major interest for clinicians all over the world as case reports are numerous and detailed information regarding principle and clinical outcome (except success rates) are disproportionately represented upon literature in comparison to alternative treatment approaches. In general, decoronation primarily deals with permanent ankylosed teeth of the anterior dentition, nevertheless, this treatment approach might be applicable for the posterior dentition too, as literature reports about clinical cases of coronectomy performed on permanent molars in order to treat a lateral open bite and precondition the alveolar process prior to implant placement (3,5,10). The procedure is generally indicated for pediatric or adolescent patients presenting with an ankylosed permanent incisor whose prospected root resorption will not take place within one year and who wish for future rehabilitative treatment in the form of dental implants or bridge restoration, who do not exhibit any medical, surgical and/or orthodontic contraindications (30). Malmgren et al. introduced the decoronation technique in 1984 originally as an extraction alternative aiming to preserve the alveolar bone, promote further growth of the alveolar process and prevent infraocclusion (1,45). This surgical intervention is drafted to leverage the mechanism of replacement resorption secondary to dentoalveolar ankylosis in order to support the proper development of the alveolar bone and eventually facilitate ideal conditions for future dental implant placement (3,5). The procedure as such involves the elevation of a full-thickness mucoperiosteal flap, followed by the removal of the dental crown, the so called decoronation, beneath the Cemento-Enamel-Junction (CEJ) only 1 to 2 mm beyond the margin of crestal bone. Any remaining pulp tissue or endodontic filling of the remaining root has to be removed and canal side is rinsed thoroughly with saline in order to induce initiated bleeding from the coronal and apical sides. Thus, leading to additional internal resorption while perpetuating external replacement resorption (1,5,30). The flap is completely repositioned and sutured to promote initial healing of the soft tissues and stimulate vertical bone apposition (5,30). In case the residual crown is sufficiently preserved, it may serve as a pontic that can be bonded to adjacent teeth by composite resin, provided that canines have fully emerged. Alternatively, a lingual or palatal bar can be placed under the circumstances that canines have not yet erupted. Otherwise, a restorative temporary space maintainer has to be implemented in order to provide a temporary aesthetically satisfying as well as comfortable solution. Factors to be considered upon the choice of space maintainer are the individual caries risk, supporting teeth status, eruption patterns and jaw growth. Potentially viable options are hawley retainers or maryland bridges (30). In any way, it is crucial to minimize the gingival portion of the pontic to facilitate the development of the underlying alveolar ridge (5). Thereby, decoronation provides

several advantages, such as its reliability in terms of preservation of the alveolar process in width and height in beneficial interplay with additional vertical bone apposition. Furthermore, it prevents the tipping mechanism of adjacent teeth and presents to be more economical and of a less invasive surgical nature in comparison to bone augmentation procedures (5,30). Even though, it has to be mentioned that the prolonged need for space maintenance can pose a disadvantage for the individual. Timing of the decoronation procedure is crucial as the process requires a substantial vertical bone growth and turnover rate and therefore describing it as contraindicated for non-growing adults. Sapir and Shapira define that the "optimal time for performing decoronation is two years prior to surgical implant insertion", taking the necessity for a complete remodeling process prior to implant insertion into consideration (30). Chronological age might serve as a reference point, however, it should not function as the sole indicator. Instead, the degree of infraocclusion and its rate of progression are considered significant factors. Malmgren suggests the indication of decoronation when ankylosed tooth's infraposition is "one-eighth to a quarter of the homologenous crown" (30,46,54). It can be generalized, that commonly the decoronation process is carried out two to three years after diagnosis (45). Furthermore, the timing of decoronation is significantly influenced by the individual onset of growth spurt. In moderately young patients who have yet to reach growth spurt in a rather long time, it is advised to postpone decoronation, monitor infraocclusion in the meantime and consider provisional crown build-ups for aesthetic reasons. Once infraocclusion accelerates and pubertal growth peaks, the process of decoronation should be performed. Additionally, in clinical cases of trauma-induced ankylosis of the anterior dentition that leads to an undesired discoloration or deep fractures, further investment is not justified and early decoronation with a subsequent aesthetic space maintainer placement is indicated. In the following Sapir et Shapira present a clinical example of successful decoronation prior to implant placement of a 12-year-old male patient (30).

Fig.32: Severely infrapositioned and discolored right maxillary incisor

Fig.33: Periapical radiograph upon initial examination

Fig.34: Decoronation process

Fig.35,36: Space maintainer: Palatal arch + resin tooth, orthodontic arch wire + elastomeric modules

Fig.37: Post-operative radiograph after 4 years, complete remodeling of root to bone and preservation of alveolar ridge, dental implantation planned 2 years later

ONLY IN NON-GROWING

6.13 EXTRACTION AND IMPLANT PLACEMENT

In modern dentistry, dental implant restoration is considered the most beneficial long-term restorative modality to replace missing teeth. Likewise in clinical cases of ankylosed permanent teeth, that are indicated for extraction due to reasons such as severe root resorption mechanisms, root fracture or infection leading to a poor prognosis (55). In order to close the occurring gap and restore function and aesthetics of the dental arch in anterior as well as posterior dentition, dental implant placement might represent one of the best treatment solutions. To place a dental implant successfully, clinical conditions like an adequate dimension of the residual ridge and alveolar bone height and width need to be provided. As extraction of an ankylosed permanent tooth will eventually result in surrounding bone and soft tissue injury, as well as some degree of bone loss and a deficient vertical height it is crucial to note that early extraction in growing patients might make dental implant placement unfeasible in the future (5). Furthermore, the implant placement itself is not possible if the patient is still undergoing growth and may impede proper growth patterns, just like clinical consequences caused by ankylosed teeth leading to infraocclusion and potential compensatory eruption mechanisms of adjacent teeth. Nevertheless, this treatment option should nowadays always be taken into consideration during treatment planning as the final restorative solution once individual growth is completed, especially in young adults. Soft tissues in normal developed conditions at the time of implant placement are considered advantageous in order to achieve aesthetically optimal outcomes. Therefore, proactive pre-surgical interventions concerning traumatized areas after extraction, which is for various reasons performed during active growth before implant placement is possible, are recommended. Those pre-surgical interventions involve decoronation or autotransplantation as previously presented, for their beneficial effect on the preservation of adequate alveolar bone dimensions and soft tissue conditions. In instances presenting with a deficiency of alveolar bone dimensions, additional clinical measures such as bone grafting or other osteopromotive techniques should be employed (50). Lastly, it should be emphasized that the growth of the patient should always be measured and determined individually to achieve the best timely implementation of treatment possible. Thus, factors like sexual dimorphism in general, can impact those treatment interventions, as there is a potential for earlier implant placement in girls due to earlier onset of puberty and facial maturation compared to boys by an average of two years (30).

6.14 SURGICAL LUXATION AND ORTHODONTIC TRACTION

A very promising and frequently applied orthosurgical treatment approach, recommended as a conservative modality for patients after growth spurt, is surgical luxation followed by orthodontic traction (27). Throughout literature there are various case reports of successful implementation of this treatment approach, especially regarding ankylosed molars of young adults clinically presenting with infraocclusion. The main principle of the treatment approach is to surgically luxate the ankylosed tooth and thereby mechanically break the ankylotic bony bridge between the tooth root and the surrounding alveolus in order to eventually bring the infraoccluded ankylotic tooth to an appropriate occlusal level. This technique was initially introduced in 1953 and subsequently elaborated by Biederman. He described to firmly grasp the ankylosed tooth with a dental forceps, gently rock it in a bucco-lingual and mesio-distal direction, with the tooth apex representing the axis without damaging the apical nutrient vessels. It is suggested that a vertical mobility of the tooth should as well be induced (5). Case-study-based principles state, that an "adequately aggressive surgical luxation to a class III mobility should be performed" (27). As a result of this treatment approach, a new fibrous inflammatory tissue forms in a reparative process, aligning with the periodontal ligament, thus restoring its integrity and facilitating continuous tooth eruption. Geiger and Bronsky (1994) recommended the application of orthodontic forces following the surgical luxation to maintain a functional tooth within the alveolar bone structure (56). Even though there is no distinct definition among existing literature regarding the specific magnitude of optimal force level, it is clearly stated and emphasized that orthodontic forces need to be applied immediately in a continuous extrusive manner and kept at a high level over an extended period of time in order to sustain the distraction process and mitigate the risk for re-ankylosis (1,5,27). Luxated ankylosed teeth should undergo reactivation every seven days, therefore, it is crucial to provide a reliable anchorage unit. It is advisable to repeat the procedure in case no changes are detectable within six months of observation, as well as to consider another treatment approach if failed once more. Besides the referred to risk of re-ankylosis, other potential risk factors such as root or alveolus fracture, as well as loss of tooth vitality potentially leading to endodontic treatment or even tooth loss, should be mentioned even though rarely occurring. Root resorption, predominantly of the external type, is a delayed complication secondary to surgical luxation. Furthermore, as molars typically exhibit ankylosis in the furcation area, luxation might lead to furcation involvement (5,27). As the key to success upon this treatment approach lies in the timely application of high continuous orthodontic forces, a reliable source of anchorage is a crucial key factor to consider carefully. The methods for delivery of orthodontic traction following surgical luxation are various reaching from solely inter-arch elastics

to temporary anchorage devices (TADs) as in the following clinical example in the form of a mid-palatal implant anchorage unit connected to an archwire system (Figure 38-40) (27).

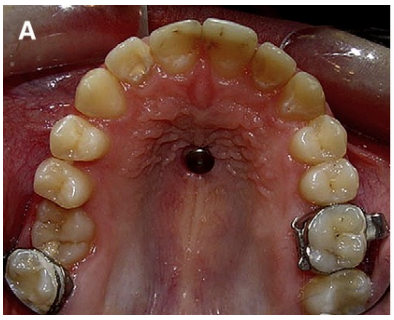

Fig.38: Midpalatal implant

Fig.39: Anchorage unit

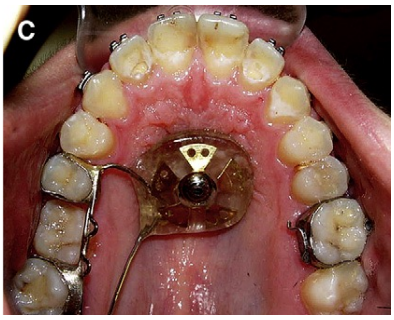

Fig.40: Intraoral occlusal view

6.15 APICOTOMY

A treatment approach that mainly refers to impacted canines with ankylosed roots in non-growing individuals is apicotomy. As previously mentioned, ankylosis might occur secondary to the attempt of orthodontic treatment of impacted teeth. In particular, impacted canines are prone to develop ankylosis due to their inability to erupt. According to Puricelli it was noted that ankylosis could potentially be associated with the anatomical positioning of the root apex of the canine in relation to adjacent anatomical structures (57,58). The mechanism of apicotomy involves a controlled fracture of the apex of a canine root, followed by orthodontic traction of the canine crown in order to integrate it into the dental arch. In detail, the apex of the canine becomes surgically exposed and a groove indicating the position for the chisel to separate the root apex is created using a small bur. Subsequently, immediate orthodontic traction forces are applied, in order to prevent re-ankylosis, however, it is complicated to fully avoid. In case the impacted canine will not move during the next six months, the procedure is indicated to be repeated. In case of recurrent failure, extraction of the ankylosed impacted canine is the treatment of choice.

This procedure serves as a more conservative surgical alternative for managing impacted canines affected by apical root ankylosis in comparison to other treatment approaches such as surgical luxation and repositioning. Several studies over the last 25 years have came across the conclusion that apicotomy is a viable and effective treatment for ankylosed maxillary canines (57).

6.16 CORTICOTOMY

An alternative treatment approach in terms of impacted ankylosed canines and the attempt to bring those teeth of non-growing individuals into occlusion is corticotomy. Corticotomy is a surgical procedure that involves performing a small osteotomy to reposition an ankylosed tooth and the surrounding alveolar bone (1,59). This technique entails cutting only the cortex of the bone and thereby preserving periosteal and endosteal layers, rather than the full thickness of the bone as in segmental osteotomy, which will be highlighted in the later on. Consequently, orthodontic appliances are installed to gradually shift the tooth in the weeks subsequent to the surgery. This way of moving an ankylosed tooth has been documented several times throughout scientific literature. Thus, claiming the advancement of corticotomy-assisted orthodontic therapy to be a promising method to facilitate movement of ankylosed teeth. In detail, the procedure includes a full-thickness mucoperiosteal flap reaching from the mesial to the distal surface of the particular ankylosed canine and is reflected beyond the apex. Afterward, two vertical and one horizontal corticotomy cuts are performed using a surgical blade and mallet as visible in Figure 41.

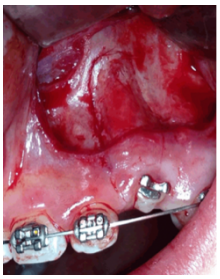

Fig.41: Corticotomy cuts

In summary, corticotomy is described as any deliberate surgical injury to the cortical bone, aimed at facilitating a tooth in conjunction with surrounding bone and soft tissues. Throughout the years, the corticotomy technique has undergone revision and adaptations to mitigate potential risk factors of the procedure, such as periodontal injury and the compromised vitality of teeth and bone segments due to insufficient blood supply. Further investigation, needs to be carried out regarding the force magnitude to apply as this still remains controversial and uncertain (59).

6.17 SEGMENTAL OSTEOTOMY (AND BONE GRAFTING)

A more invasive surgical treatment approach, that should be taken into consideration for non-growing patients presenting with adequate periodontal tissue surrounding the ankylosed and infrapositioned permanent tooth, is segmental osteotomy with or without additional bone grafting (60). Segmental osteotomy serves as an alternative treatment approach for repeated failure of surgical luxation or where orthodontic space closure is contraindicated (5,60). The main principle of this procedure is to section and reposition one or more ankylosed teeth together with the surrounding alveolar bone coronally to the desired occlusal level. Thereby, the alveolar segment is divided into mesial, distal and subapical sections. To reposition the osteotomic segment, an acrylic splint is typically created

before the surgery. In many instances, segment stabilization is achieved using mini-implants and screws, in other cases orthodontic stabilization might be sufficient if the inter-osseous gap is relatively narrow. You et al. documented a clinical case of segmental osteotomy followed by autogenous bone grafting in order to fill the gap created upon osteotomic sectioning of ankylosed maxillary central incisors, eventually leading to a beneficial periodontal outcome on a 16 years old female patient with trauma-induced ankylosed maxillary central incisors (Figure 42-45). They completed segmental osteotomy and autogenous bone grafting in a single-stage surgery and successfully moved the osteotomic segment to the predetermined position. Therefore, it was concluded that "segmental osteotomy with autogenous bone grafting is a viable surgical procedure in the treatment of ankylosed maxillary central incisors with sufficient periodontal tissue" (60).

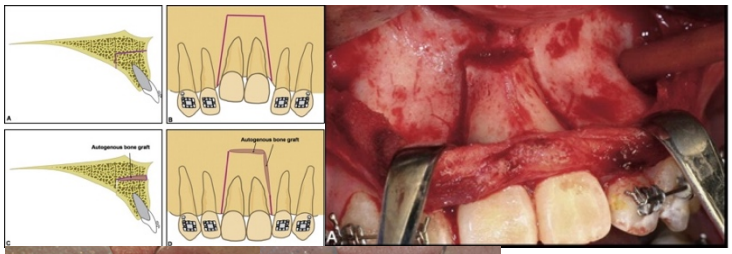

Fig.42: Schematic view of treatment procedure

Fig.43: Segmental Osteotomy of both maxillary incisors;

Fig.44: Preoperative clinical situation

Fig.45: Postoperative (20 months follow up) clinical situation

Another significant clinical factor for this treatment is the anticipated growth of the individual. It is recommended to perform this type of surgery only past the completion of facial growth to achieve optimal results. Otherwise, if growth is still ongoing, there is a possibility of recurrence of different vertical levels subsequent to the surgery. Furthermore, segmental osteotomy seems to be very feasible and beneficial for the treatment of maxillary ankylosed teeth as it provides an advantageous vascularity. The major advantage of segmental osteotomy is that the repositioning procedure to the desired occlusal level can be performed in a single-stage surgery, making it more predictable in comparison to distraction osteogenesis process, which will be referred to in the later (60). On the other hand, the disadvantages of this treatment are potential side effects of the surgery such as tooth vitality loss, avascular necrosis in the bone segment, gingival recession, crestal bone loss, pocket formation, delayed segment movement due to bone interferences, traumatic occlusion and the omnipresent risk of general anesthesia. In clinical cases dealing with severe crowding, application of the technique is contraindicated, as there is an additional risk for tooth damage and impairment of blood supply as a consequence of the decline in the surrounding alveolar bone (5). Another limiting factor for the ability to move and stabilize the segment is the soft tissue conditions, which often present as deficient due to a lack of vertical growth secondary to dentoalveolar ankylosis.

6.18 DISTRACTION OSTEOGENESIS

Another treatment approach that is frequently combined with Segmental osteotomy as previously described is distraction osteogenesis, also referred to as *Orthodontic Bone Stretching* upon literature. Distraction Osteogenesis, is in general a rather old treatment approach, primarily used in the lengthening or stretching of bone and firstly introduced by Ilizarov about 60 years ago (5,61). Alveolar bone remodeling is considered the "key component of orthodontic tooth movement" and the fact, that this bone remodeling is enhanced in the event of wound healing as described by Frost, led to the early arising of the idea to accelerate orthodontic tooth movement, subsequent to local injury of the alveolar process (3).

The primal principle of orthodontic bone stretching includes only partial osteotomies also referred to as corticotomies in combination with orthodontic force application, excluding the repositioning of bony segments as schematically shown in Figure 46 (55).

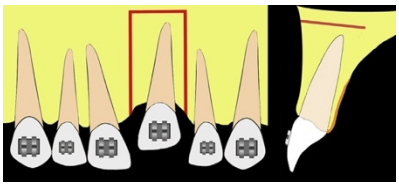

Fig.46: Schematic view of deep running corticotomy cuts with preservation of palatal cortical bone

Previous studies have indicated that distraction can be induced either through the use of an internal distraction device or orthodontic appliances in order to stimulate osteogenesis (62). To be more precise, the treatment involves a gradual, partial osteotomy procedure, followed by a seven-day latency period, during which the inflammatory phase will be replaced by the reparative phase of fracture healing, including the early start of osteogenesis. This latency period is followed by distraction initiation of newly formed callus, with a separation rate of approximately 1 mm per day between the two bony parts. Deviations from this rate, such as in slower cases of 0.5 mm per day or faster rates like 2 mm per day, may lead to unwanted effects such as premature consolidation or poor bone formation. The newly formed bone is aligned parallel to the distraction force and enclosed by blood vessels (5). Distraction osteogenesis is therefore called a "biologic process of new bone formation". The distraction techniques have the potential to effectively and reliably address alveolar and gingival deformities. Therefore, they are indicated in clinical cases characterized by severe infraposition of permanent ankylosed teeth with deficient alveolar bone dimensions, contraindicating orthodontic space closure or extraction, followed by prosthetic rehabilitation solutions. However, in some instances, infraocclusion might present as too severe to solely reposition the ankylosed tooth by distraction osteogenesis, as attached soft tissues will limit the distance to cover until reaching the desired occlusal level. This is when clinicians should take the combination of distraction osteogenesis and segmental osteotomy into consideration, thus osteotomies will potentially aid in redevelopment of soft tissues and the alveolar process, ultimately reaching the correct final occlusal position within

the dental arch. It should be mentioned that, in the surgical osteotomy process, a reduced size of the tooth block segment results in constrained blood supply, which plays a crucial role in maintaining the vitality of a segment consisting of a single tooth. Such a clinical case was presented by Chang and Chen dealing with an anterior open bite of 9 mm resulting from ankylosis subsequent to replantation after avulsion of a maxillary central and lost lateral incisor upon childhood, eventually leading to severe infraposition with significant alveolar and soft tissue deficiency. The ortho-surgical intervention using distraction osteogenesis and segmental osteotomy combined resulted in a successful and satisfying treatment outcome (Figure 47-50) (62).

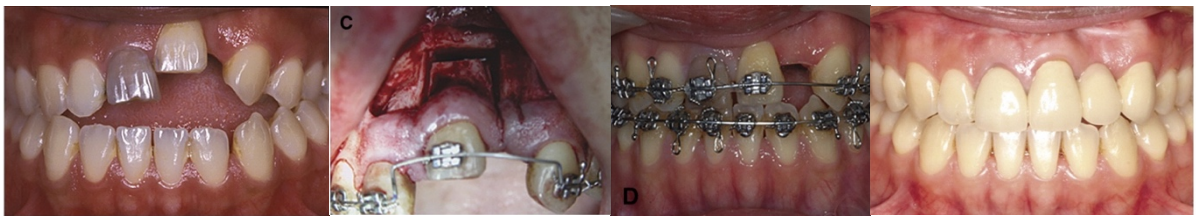

Fig.47.: Ankylosed left maxillary central incisor; Fig.48: Segmental osteotomy;
Fig.49: Archwire system was activated after 5-7 days, nearly in final position 3 weeks later;
Fig.50: Final result

By the use of vertical extrusion bends, coil springs, vertical elastics, a nickel-titanium wire or a simple distraction device, the traction of the single tooth osteotomy can be performed, aspiring immediate repositioning to the desired occlusal level position. Just like in all different treatment approaches presented, the level of maturation and stage of growth of the patient is of special concern. Thus, if this treatment approach is applied to a young adolescent, the clinicians need to express and be aware of the fact, that this approach is treating only the clinical consequences of ankylosis rather than the pathology itself. Therefore, continued vertical growth will inevitably lead to some degree of further vertical deficiency. Once healing achieved a bony union between segments, further distraction is impossible (62). A modern alteration of the original treatment approach of bone stretching is the use of piezoelectric devices. The bone micronization created by ultrasonic shock waves comes along with major advantages, such as thinner and more precise osteotomic cuts, less invasiveness, time efficiency and beneficial effect on bone healing compared to the conventional treatment procedure (63).

7 TREATMENT GUIDELINES

This literature review aimed to define and describe guidelines for the treatment of dentoalveolar ankylosis and emphasize the complexity, importance and necessity of interdisciplinary treatment approaches. Generally applicable guidelines are stated as the following:

1. In all cases of dentoalveolar ankylosis, whether primary or permanent teeth, time of onset, time of diagnosis and affected area location in relation to the patient's growth status, are the crucial factors defining the course of treatment planning.
2. When diagnostics are uncertain, thorough and regular monitoring upon follow up visits of all clinical cases suspicious of dentoalveolar ankylosis is mandatory, in order to ensure timely clinical intervention. In case of doubt, implementation of CBCT diagnostics and *Orthodontic Diagnostic Force* application for 7-10 days needs to be considered.
3. The extent of infraposition and its rate of progression is more clinically meaningful than the chronological age of the patient. Additionally, individual growth patterns are more accurate than chronological age, therefore, mean values of growth development curves are considered unreliable. Establishment of an individual growth curve, hand-wrist radiograph, periodic body height measurement, assessment of pubertal signs of growth and comparison to siblings of the same sex are essential aids in skeletal growth determination for each individual.
4. In case of primary ankylosed teeth, the general management principle is maintaining the tooth until clinical sequelae such as tipping of adjacent teeth or interference with eruption occur. Subsequently, those ankylotic teeth are indicated for extraction.
5. In all cases of preservation of ankylosed teeth, except when infraocclusion reaches below the greatest convexity point of adjacent teeth, clinicians are supposed to generally follow the treatment principle of "disk and build up as needed", in order to establish occlusal stability, arch integrity and to avoid any compensatory eruption mechanisms until a long-term solution is chosen.
6. In ankylosed primary molars with a successor, the timing of onset and diagnosis determines the appropriate treatment approach. In case of late onset, focus on exfoliation. In case of early, onset and early diagnosis, monitor thoroughly and eventually build up as needed. In case of early onset and late diagnosis, extract and apply orthodontic intervention (space maintainers).
7. In ankylosed primary molars without successor fixed appliance space maintainers are generally contraindicated, instead extraction and natural eruption, decoronation or, if possible in particular cases, autotransplantation are considered more beneficial in order to promote the development of alveolar bone.
8. Ankylosed teeth (primary or permanent) in close proximity to pubertal growth spurt, should be treated by decoronation in the first instance, as treatment outcome generally provides the best conditions for future implant placement, which is deemed to be the most beneficial long-term restoration for both clinical cases of primary or permanent ankylosed teeth.

9. In case an ankylosed tooth, regardless of the dentition stage, is lost and entails a gap, which is supposed to be filled by prosthetic restoration (especially in terms of intended implant placement), it is advised to guide adjacent teeth at least partially (by spontaneous natural eruption or orthodontic intervention) into the edentulous space in order to promote bone formation and if needed reduce the size for the future prosthetic crown restoration.
10. In the clinical presentation of crowding accompanying primary ankylosed teeth without successors or permanent ankylosed teeth, a modified serial extraction approach with or without additional orthodontic traction is considered beneficial, especially in unilateral cases of ankylosis.
11. When surgical approaches (Surgical luxation, segmental osteotomy or distraction osteogenesis) to treat permanent ankylosed teeth fail, subsequently leading to extraction, removable prosthesis for space maintenance and function/aesthetic reestablishment are preferable to fixed prosthesis until a long-term prosthetic restoration can be placed.
12. Surgical luxation should be carried out in all clinical cases of permanent teeth after growth completion applicable (especially posterior teeth) to the procedure, as its conservative surgical nature is considered highly beneficial in case or successful repositioning of the ankylosed teeth.
13. In cases of failed surgical luxation, segmental osteotomy with or without additional distraction osteogenesis is preferred over solely distraction osteogenesis, as its repositioning procedure is more predictable, less limited and more time efficient.
14. For clinical cases of impacted ankylosed permanent canines, clinicians should take treatment approaches like apicotomy or corticotomy in consideration as they present as less invasive in comparison to surgical luxation or segmental osteotomy.
15. Prevention manners in terms of trauma-induced dentoalveolar ankylosis involve the reduction of extraoral dry time in case of avulsion before replantation, as well as the implementation of flexible rather than rigid splints for stabilization.

As stated, time of onset and diagnosis, local occurrence and maturation of the individual patients are major key factors for the decision-making process of treating dentoalveolar ankylosis. In order to give orientation and guidance in choosing appropriate and applicable treatment methods, the following table (Figure 51), including the clinical factors of dentition, location and growth phase was developed. Additional indications and limiting factors regarding each treatment approach can be gleaned from the preceding context:

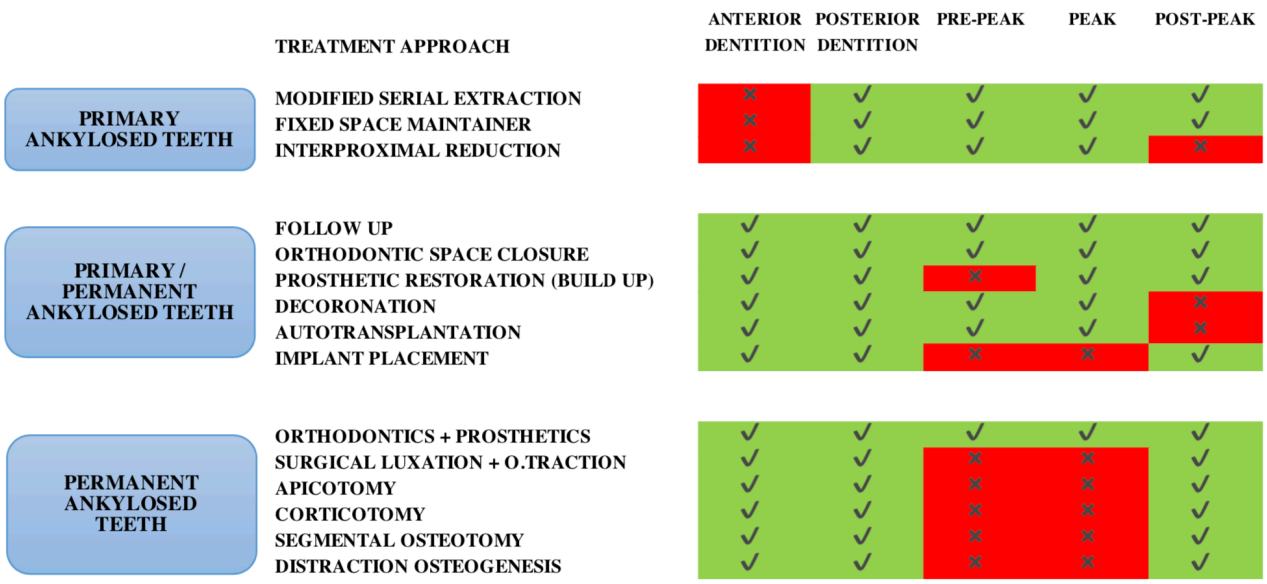

Fig.51: Summary of treatment approaches and orientational treatment guideline

8 CONCLUSION

In conclusion, this thesis investigated the intricate scientific landscape of interdisciplinary treatment approaches for dentoalveolar ankylosis providing a profound understanding of the pathogenesis, etiology and clinical consequences, leading to various clinical challenges in both diagnostics and management for clinicians. Throughout this comprehensive review of currently existing literature, the complexity of treatment approaches emphasizes the importance of collaboration among dental specialists in an inter-disciplinary treatment approach manner as treatment of dentoalveolar ankylosis is not possible by conventional orthodontics only, but instead calls for a combination of orthodontic, surgical and/or prosthodontic intervention. Furthermore, indications and contraindications as well as limiting factors, particularly regarding time of onset in conjunction with individual growth patterns and the diverse clinical manifestation and sequelae, are inevitably leading to tailored and highly individualized treatment plans, that need to be designed for long-term successful treatment outcomes. From the presented interdisciplinary treatment approaches we can draw the following conclusions: In general, primary ankylosed molars should be thoroughly monitored and maintained without any intervention as long as no clinical consequences (interference with eruption or compensatory eruption mechanism of adjacent teeth) are beginning to occur. In the presence of a permanent successor, clinicians should focus on exfoliation and eruption of antagonistic teeth. Therefore, recalling panoramic radiographic evaluation on a regular base is mandatory. In the absence of a permanent successor, intervention is indicated in early onset and late diagnostic cases commonly presenting with more severe clinical consequences and should be treated by extraction and subsequent space management. In case of preservation of primary ankylosed teeth, the clinician should follow the

principle of “disk and build up as needed”. In case of extraction of primary ankylosed teeth, the occurring gap can be closed by partial or full space closure with or without orthodontic intervention, as well as a modified serial extraction or in particular cases autotransplantation prior to growth peak. Space management in close proximity to pubertal growth spurt for future implant placements is most beneficially performed by decoronation procedure. This applies likewise for all cases of ankylosis in the permanent dentition. Implant placement is considered to be the best and most stable long-term restoration to replace an ankylosed tooth. Surgical treatment approaches toward permanent ankylosed teeth are carried out only after growth completion. In permanent dentition all posterior ankylosed teeth applicable should undergo surgical luxation followed by orthodontic traction prior to more invasive approaches, as it is considered a very promising approach of re-positioning, benefiting from modern orthodontic modalities such as TADs as a reliable anchorage source. Anterior permanent ankylosed teeth, due to their frequently occurring nature of being trauma-induced, are consequently calling for more invasive interdisciplinary treatment approaches, such as segmental osteotomy, which should be preferred over distraction osteogenesis. In case of failure of surgical interventions, extraction should be carried out and space management for future prosthetic restoration in the form of removable prosthesis applied.

Decision-making needs to be done only after thorough evaluation and identification of a patient’s individual clinical conditions and needs. Furthermore, this individuality of clinical cases and low prevalence rate regarding dentoalveolar ankylosis is the reason why no comparing and standardizing success rates can be found upon literature, that’s why there is need for future scientific research in order to gain more knowledge.

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