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The apert and crouzon syndromes: general and dental aspects and management in orthodontics and dentofacial orthopaedics: A review article

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Abstract
Craniofacial malformations, as seen in Apert and Crouzon syndromes, may have an immense impact not only on function and esthetics, but also on the psychosocial well-being of the person affected. To provide insight on the social life aspects of persons with Crouzon syndrome, during the transition from childhood to adulthood and as young adults. Furthermore, to study the main facial and intraoral characteristics of persons with Apert or Crouzon syndrome, the clinical manifestations that may be present in addition to the main syndromic features, and the cranio-maxillofacial surgical treatment protocols. Finally, to investigate dental agenesis dental agenesis patterns of permanent teeth in persons with these syndromes. The persons with Crouzon syndrome had to face different obstacles when developing their self-image during the transition from childhood to adulthood. Young adults with Crouzon syndrome tried to make the best of their situation. Already from childhood, they developed various strategies that helped them to cope with their lives. Mental disability, associated additional malformations, cleft palate, and extensive lateral palatal swellings were more common in children with Apert syndrome. In both syndromes, clinical findings included concave profile, negative overjet, posterior crossbites, anterior openbite, and dental midline deviation, A combined orthodontic and orthognathic surgical treatment planning.

Keywords: Apert syndrome, Crouzon syndrome, social life, clinical features, cranio-maxillofacial surgery, dental agenesis, dental agenesis patterns

Introduction
Apert and Crouzon syndromes are rare developmental deformity syndromes, which are included in the clinical entity of craniosynostoses. Both have an autosomal dominant mode of transmission, and a mutation in the gene encoding for the fibroblast growth factor receptor 2 (FGFR2) is the cause in most patients. This is a heterogeneous group of conditions, characterized by premature fusion of cranial sutures. A suture is a form of joint, in which the opposing bone margins in the craniofacial complex are joined with a thin layer of fibrous tissue. Sutures are important growth sites of the craniofacial skeleton. Premature fusion of one or more sutures in the growing face results in growth retardation and underdevelopment of the midface and the cranium. Even as early as described the craniofacial deformity in cases with premature craniosynostosis as a result of growth inhibition to the fused suture, with compensatory overexpansion of the cranium at open sutural sites in order to accommodate brain growth. This pathology gives rise to multiple anomalies of the craniofacial region, including the calvaria, the cartilaginous cranial base, the orbits and the maxillary. Apert syndrome or acrocephalosyndactyly was named after the French pediatrician Eugene Apert [1] in 1906, he described the condition that shows "tall skull, flat in the back and also at times on the side" and "syndactyly of the four limbs". However, craniosynostosis combined with syndactyly (bony and cutaneous fusion of fingers and toes) had already been described earlier, in 1886, by Troquart. Crouzon syndrome or craniofacial dysostosis, was named after the French neurologist Octave Crouzon. In 1912, he described the hereditary syndrome of craniofacial dysostosis in a mother and her son, presenting the characteristic triad of calvarial deformities, facial anomalies and exophthalmos [2]. Nevertheless, the condition had already been reported earlier, in 1898, by Swanzy as "a case of microcephalus and proptosis". In the English literature it was not reported under the name of craniofacial dysostosis or Crouzon

syndrome until 1939. Earlier investigations of this condition were presented under the term of oxycephaly. It appears that Apert thought that his cases represented the same condition as those reported by Crouzon, with the exception of the syndactyly of hands and feet; however, Crouzon argued that his cases and Apert's cases were separate conditions.

Materials and methods

The electronic databases PubMed, Google Scholar, Science Direct, Cochrane Library along with a complimentary manual search of all journal till the year 2017. No limits and language restriction were applied during the electronic search in order to include all the relevant articles pertaining to the topic of interest. The search in PubMed yielded 224 articles which were screened based on the relevance of the title and abstract to the topic of interest. 112 articles were excluded based on this criterion. The full texts of the 56 articles were analysed of which 28 were excluded based on the exclusion criteria of this systematic review. Only one relevant article could be extracted through hand search and no articles were retrieved from other databases. The inclusion criteria includes *in vitro* and *vivo* studies.

Apert syndrome

In 1906, Apert defined a syndrome characterized by skull and mid facial malformations and syndactyly of the hands and feet of a special type (complete distal fusion with a tendency to fusion also of the bony structures). The hand, when all the fingers are webbed, has been compared with a spoon and, when the thumb is free, to an obstetric hand[3] distinguished two clinical categories: (1) ‘‘typical’’ acrocephalosyndactyly, to which the Apert name is appropriately applied, and (2) other forms, lumped together as ‘‘atypical’’ acrocephalosyndactyly. The feature distinguishing the 2 types is a middigital hand mass with a single nail common to digits 2–4, found in Apert syndrome and lacking in the others. Acrobrachycephaly is present, and bulging at the bregma may be noted in some cases. The anterior cranial fossa is very short with consequent shallow orbits and orbital hypertelorism. The middle third of the face is retruded and hypoplastic, resulting in relative mandibular prognatism. The nasal bridge is depressed, and hypertelorism, proptosis, and downslanting palpebral fissures are observed. The lips frequently assume a trapezoid configuration. The palate is highly arched, and cleft of the soft palate is observed in 30% of the cases. Class III malocclusion is present with an anterior open bite, as well as anterior and posterior crossbite. Varying degrees of mental deficiency are associated with this syndrome. Fusion of cervical vertebrae [3] in 68% of patients with Apert syndrome: single fusion in 37% and multiple fusions in 31%. C5–C6 fusion was most common. In contrast, cervical fusion occurs in 25% of patients with Crouzon syndrome and most commonly involves C2–C3 only. The authors concluded that when fusions are present, C5–C6 involvement in the Apert syndrome and C2–C3 involvement in Crouzon syndrome separate the two conditions in most cases. Cohen and Kreiborg [4] commented on the cutaneous manifestations in a series of 136 cases of Apert syndrome. Hyperhidrosis was found in all patients. At adolescence and thereafter the skin was oily. Acneform lesions were particularly prevalent on the face, chest, back, and upper arms. In 1933 Vogt [5] described cases presenting the hand and foot malformations characteristic of Apert syndrome, together with the facial characteristics of Crouzon syndrome, caused by a very hypoplastic maxilla. The syndactyly was less severe than in Apert syndrome and the thumbs and little fingers were usually free. Later, Nager and de Reynier [6] gave this deformity the name of Vogt cephalodactyly, while other authors called it Apert-Crouzon disease, indicating the similarity in both abnormalities.

Syndactyly

All acrocephalosyndactyly syndromes show some level of limb anomalies, so it can be hard to tell them apart. However, the typical hand deformities in patients with Apert syndrome distinguish it from the other syndromes [6]. The hands in patients with Apert syndrome always show four common features: [7] A short thumb with radial deviation complex syndactyly of the index, long and ring finger symbrachyphalangism simple syndactyly of the fourth webspace. The deformity of the space between the index finger and the thumb may be variable. Based on this first webspace, we can differentiate three different types of hand deformation:

Type I: Also called a "spade hand". The most common and least severe type of deformation. The thumb shows radial deviation and clinodactyly but is separated from the index finger table.1. The index, long and ring finger are fused together in the distal interphalangeal joints and form a flat palm. During the embryonic stage, the fusion has no effect on the longitudinal growth of these fingers, so they have a normal length. In the fourth webspace, we always see a simple syndactyly, either complete or incomplete.

Type II: Also called a "spoon" or "mitten" hand. This is a more serious anomaly since the thumb is fused to the index finger by simple complete or incomplete syndactyly. Only the distal phalanx of the thumb is not joined in the osseous union with the index finger and has a separate nail. Because the fusion of the digits is at the level of the distal interphalangeal joints, a concave palm is formed. Most of the time, we see complete syndactyly of the fourth webspace.

Type III: Also called the "hoof" or "rosebud" hand. This is the most uncommon but also most severe form of hand deformity in Apert syndrome. There is a solid osseous or cartilaginous fusion of all digits with one long, conjoined nail. The thumb is turned inwards and it is often impossible to tell the fingers apart. Usually proper imaging of the hand is very difficult, due to overlap of bones, but physical examination alone is not enough to measure the severity of deformation.

Table 1: Three different types of hand deformation

Types	Type I ("spade")	Type II ("mitten")	Type III ("rosebud")
First webspace	Simple syndactyly	Simple syndactyly	Complex syndactyly
Middle three fingers	Side-to-side fusion with flat palm	Fusion of fingertops forming a concave palm	Tight fusion of all digits with one conjoined nail
Fourth webspace	Simple and incomplete syndactyly	Simple and complete syndactyly	Simple and complete syndactyly

Epidemiology

Findings for the incidence of the syndrome in the population have varied with estimates as low as 1 birth in 200,000 provided [8] and 160,000 given as an average by older studies. A study conducted in 1997, however, by the California Birth Defects Monitoring Program found an incidence rate of 1 in 80,645 out of almost 2.5 million live births [9]. Another study conducted in 2002 by the Craniofacial Center, North Texas Hospital for Children, found a higher incidence of about 1 in 65,000 live births [10].

Genes associated with apert syndrome

Mutations in a gene known FGFR2 cause Apert syndrome. This gene provides instructions for making a protein called fibroblast growth factor receptor 2 (FGFR2). Among its multiple functions, the FGFR2 protein plays a key role in development before birth by signaling immature cells to become bone cells. A mutation in a specific part of the FGFR2 gene alters the protein, increasing its signaling. The abnormal signaling causes the cell to mature too quickly and promotes the premature fusion of bones in the skull, hands, and feet. The FGFR2 gene provides instructions for making a protein called fibroblast growth factor receptor 2 (FGFR2). Fibroblast growth factor receptors are related proteins that are involved in important processes such as cell growth and division (proliferation), cell maturation (differentiation), formation of blood vessels (angiogenesis), wound healing, and embryonic development table 2. The FGFR2 protein spans the outer membrane surrounding cells, so that one end of the protein remains inside the cell and the other end projects from the outer surface of the cell. This positioning allows the FGFR2 protein to interact with specific growth factors outside the cell and to receive signals that help the cell respond to its environment. When growth factors attach to the FGFR2 protein, the receptor triggers a series of chemical reactions inside the cell that instruct the cell to undergo certain changes, such as maturing to take on specialized functions. The FGFR2 protein plays an important role in bone growth, particularly during development before birth (embryonic development Fig. 1. For example, this protein signals certain immature cells in the developing embryo to become bone cells and form the head, hands, feet, and other tissues. There are several slightly different versions (isoforms) of the FGFR2 protein. Specific patterns of these isoforms are found in the body's tissues, and these patterns may change throughout growth and development.

Table 2: Clinical signs and symptoms of Apert syndrome

Signs And Symptoms
Head and skull
• Sunken appearance of the face (midface hypoplasia) • Broad skull • Abnormally pointed head at the top with prominent forehead • Widely spaced eyes (hypertelorism) • Abnormally bulging eyes (exophthalmos) • Flat face with right and left asymmetry • Flat nose with a low bridge • Narrowed opening between nose and throat affecting swallowing and breathing • Narrow roof of mouth or palate • Cleft palate with a bifid uvula • Protruding lower jaw • Crowding of teeth • Bad bite due to malocclusion of teeth
Upper and lower limbs
• Unusually broad thumbs and big toes • Short digits of hands and feet with partial or complete fusion (syndactyly) • Mitten-like syndactyly due to complete fusion of 2-4th fingers with a single common nail • Fusion of bones of the wrist
Other organs
Chronic ear infections and hearing loss • Hole in the wall of the ventricle • Tracheal cartilage defects affecting breathing and swallowing • Narrow gastric outlet with potential for obstruction • Obstruction of the food pipe • Malposition of the anal opening • Failure of descent of testes into the scrotum in males • Obstruction of the vagina in females • Enlarged kidneys • Fusion of the vertebral bones of the neck • Moderate-to-severe acne • Varying degrees of mental retardation

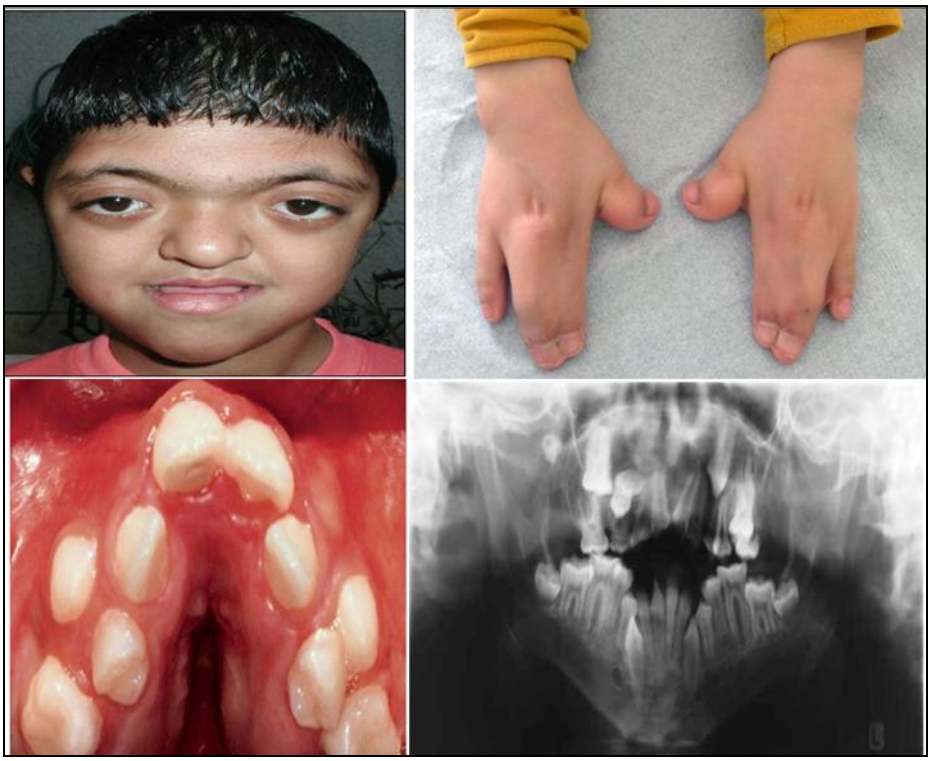

Fig 1: Classical signs and symptoms of Apert syndrome (google scholar)

Crouzon syndrome

In 1912, Crouzon defined a syndrome characterized by cranial synostosis, hypertelorism, exophthalmos, parrot-beaked nose, short upper lip, hypoplastic maxilla, and a relative mandibular prognathism [11]. Cranial malformation depends on the order and rate or progression of sutural synostosis. Brachycephaly is the most commonly observed, but scaphocephaly and trigonocephaly also are described Shallow orbits is an essential diagnostic feature. Ocular proptosis is a consequence and results in a high frequency of conjunctivitis. Because of maxillary hypoplasia, the anteroposterior dimension of the dental arch is shortened and crowding teeth is common, as well as anterior open bite and mandibular overjet [12]. There is marked variability in both cranial and facial manifestations of the syndrome. Dodge *et al.* [13] reported five patients, three with typical Crouzon syndrome. The other two patients had syndactylism of both hands and feet, and are more correctly said to have Vogt cephalodactyly. Vulliamy and Normandaless [14] identified 14 cases of Crouzon disease in four generations of a family with several instances of male-to-male transmission. Juberg and Chambers [15] suggested, on the basis of an affected brother and sister with unaffected non consanguineous parents, that a recessive form of Crouzon disease exists. It seems more likely that they were dealing with a recessive form of craniosynostosis. Under the designation cranial dysostosis with pronounced digital impressions, or pseudo-Crouzon disease, Franceschetti [16] described a seemingly distinct disorder. There is not a general agreement if the pseudo-Crouzon syndrome is a separate entity.

Table 3: Signs and Symptoms of crouzon syndrome

• Abnormal face shape
• Shallow mid-face, which may lead to breathing difficulties
• High forehead
• Wide-set, bulging eyes
• Shallow eye socket, which may lead to vision problems eyes that point in different directions (strabismus)
• A small beak-like nose underdevelopment of the upper jaw which may lead to trouble eating
• dental problems
• low-set ears hearing loss with possible narrow ear canals
• A less common sign is an opening in the roof of the mouth (cleft palate) or lip (cleft lip).
• For some children symptoms are severe, for others they are milder. The condition affects each person differently.

Epidemiology

Crouzon syndrome is a fairly rare entity and is estimated to occur in 1 in 60,000 new borns; however, it is the second most common craniosynostosis syndrome behind only the more recently described Muenke syndrome [17].

Genes associated with crouzon syndrome

The current research indicates fibroblast growth factor receptors (FGFR) FGFR2 and FGFR3 as the leading factors in causing the autosomal dominant Crouzon syndrome [18]. These two transmembrane proteins are two of four fibroblast growth factor receptors involved in osteoblast differentiation during embryonic development; mutations amongst these receptors are involved in several genetic disorders. There are 40 known mutations, most of which are caused by a missense mutation. FGFR2 is the most commonly mutated gene, a missense at cysteine 342 in exon 9, which creates a gain-of-function. The FGFR2lllc isoform, created via alternative splicing of exon 3 of the FGFR2 gene, uses exon 9 and is used in mesenchymal stem cells to control ossification. However,

the mutation constitutively activates the transmembrane protein via a disulfide bond formed incorrectly due to the loss of cysteine 342. FGFR3 is expressed more in the frontal bones during embryonic development, guiding cranial bone development. A point mutation causes constitutive activation of tyrosine in the activation loop, located in the cytosolic region of the protein, leading to accelerated differentiation of frontal osteoblasts, resulting in premature fusion of frontal cranial bones.

Dental management

- Treatment objectives for the dental management of patients with craniofacial dysostosis include improving oral hygiene and periodontal status, maintaining or restoring the health of the dentition, and alleviating dental crowding. All are important elements in preparing for surgical orthodontics.
- Oral hygiene and periodontal status Children with craniofacial synostosis typically are evaluated by a team in the first few months of life and followed closely during the early years. At that time oral health preventive practices can be established and reinforced by multiple team member

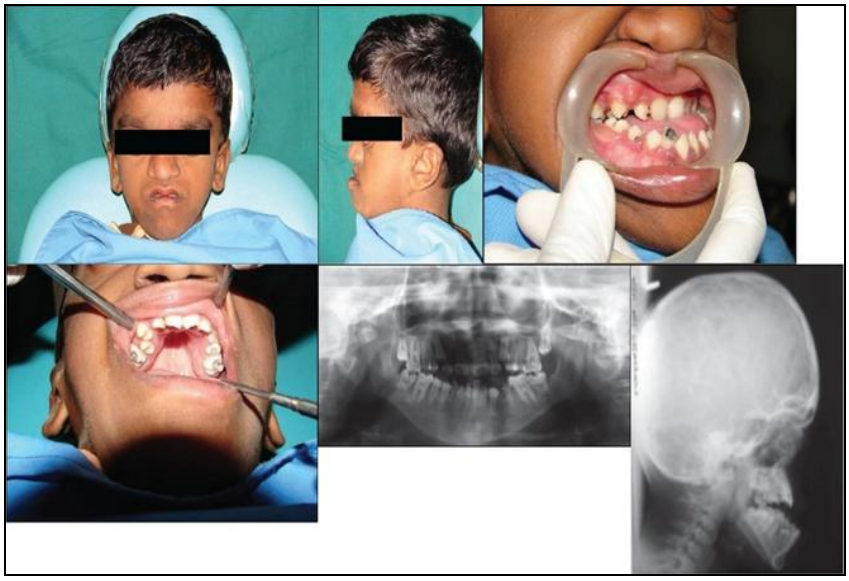

Fig 2: (a) Frontal view showing concave profile, ocular proptosis and hypertelorism.(b) Lateral profile showing maxillary deficiency with relative mandibular prognathism, (c) Intraoral photograph showing a negative overjet in the anterior region, (d) Photograph showing high arched palate with lateral palatal swellings, (e) Orthopantomograph showing impacted 17, 13, 23, and 27 (case details from google scholar)

- In pre dentate patients, using a cloth to wipe the gingival tissues can help introduce routines that become critically important when the dentition is present. As teeth emerge, the transition to tooth brushing becomes necessary
- Delay in tooth emergence among patients with craniofacial dysostosis has been observed. Kaloust *et al*. [19] reported that patients with Apert syndrome have a mean delay of 0.96 years (range, 0.5 – 2.9 years), with a trend of increasing delay with increasing age. Kreiborg and Cohen [20] reported similar findings of dental delays more than than 1 and 2 years for the primary and permanent dentition, respectively. The crowded dentition reduces the ability to maintain good oral hygiene, as evidenced by greater dental plaque and gingivitis among patients with craniofacial dysostosis [21].
- Retention of food is common for patients with npronounced palatal bulbous swelling that produces a pseudocleft appearance.
- In patients with Apert syndrome, limited dexterity because of syndactyly of the fingers inhibits adequate hygiene practices [22]. Supervised oral hygiene practices and dental aids for these patients, including floss holders and electric toothbrushes, can help address the increased dental plaque and gingivitis.
- Localized anterior inflammation of the gingiva also can result from mouth breathing related to growth disturbance of the midface.
- Lip incompetence and trapezoidal mouth shape can exacerbate this condition further. Clinical practice suggests that placement of petroleum jelly on the gingiva can ameliorate the dryness that causes inflammation secondary to mouth breathing.
- Poor oral hygiene is a risk factor for dental caries [23]. Findings are limited and equivocal, however, as they relate to the incidence of disease in patients with craniosynostosis.
- For children who experience dental caries or require recontouring of existing shovel-shaped teeth for functional, developmental, and esthetic reasons, it is important to consider the risks or benefits of treatment options.
- Childrens who are unable to cooperate in a dental chair or in whom treatment needs are too complex or involve multiple quadrants, sedation and general anesthesia in an operating room setting are reasonable treatment options [24]. One specific consideration when planning treatment under general anesthesia that requires placement of an endotracheal tube is the potential presence of cervical spine anomalies in a subgroup of these patients, because intraoperative airway management and intubation may be compromised.
- The presence of these anomalies and the relatively high incidence of a compromised upper/ nasal airway must be incorporated into the decision making process, and it frequently means that sedation in a nonsurgical dental office setting is not a favourable option. When the management of dental treatment requires the use of general anesthesia, the opportunity to coordinate multiple

procedures and subspecialties should be assessed.

- Other dental anomalies found as part of the craniofacial dysostosis syndromes include enamel defects and supernumerary teeth. The cause of disturbance to the tooth structure is complex and often developmental in origin.
- Iatrogenic causes should be minimized when at all possible, however. For example, distraction osteogenesis can be a successful treatment option for craniofacial abnormalities. The technique can be associated with long-term dental sequelae, including damage to developing teeth or the genesis of dentigerous cysts secondary to placement of pins in unerupted tooth follicle spaces [25].
- To minimize effects on teeth and peridontium, careful planning using tomograms, radiographs, and three dimensional imaging techniques is necessary. The use of periapical radiographs can provide valuable information to assess the presence, absence, or quality of individual crown and root development.
- Dental crowding is common in children affected with craniofacial dysostosis syndromes (Fig. 3). Regardless of the variation in crowding found in this population, comprehensive orthodontic intervention is required to maximize optimal alignment and esthetic result of the dentition.

Orthodontic management in coordination with surgical treatment

- Orthodontic treatment by itself cannot achieve a satisfactory esthetic result for the craniofacial dysmorphology produced by Apert and Crouzon syndrome.
- Coordinating orthodontic treatment with surgical management of the dysmorphology is an integral component of the comprehensive management of these problems.
- The general guideline for contemporary orthognathic surgery treatment is that every patient requires a variable period of orthodontic preparation for surgery (presurgical orthodontics) and a relatively constant period of postsurgical orthodontic treatment.
- Before the initiation of orthodontic treatment, control of systemic disease, periodontal treatment (at least to the extent of bringing periodontal disease under control), and restoration of carious lesions are required. The orthodontic management of patients with Crouzon and Apert syndromes in preparation for surgery can be divided into two stages:

a) Orthodontic treatment during childhood
b) Orthodontic treatment during adolescence.

- Depending on the facial alteration associated with Crouzon and Apert syndromes, surgical correction of the anomaly can have up to three sequences of reconstruction in three age groups:

a) Release of the craniosynostosis (usually bilateral coronal) for initial decompression and reshaping of the cranial vault during infancy,
b) Correction of the total midface deficiency during childhood, and
c) Definitive orthognathic procedures to finalize the position of the lower face and occlusion.

- Orthodontic preparation is performed in combination with surgical correction in childhood and in the late teens. During childhood, surgical treatment often involves midface advancement at the Le Fort III level, and coordinated orthodontic treatment is needed to correct the characteristic dental problems and allow the placement of an acrylic occlusal splint to stabilize the monobloc segment at the time of the surgery.
- Orthognathic treatment during adolescence almost always involves maxillary advancement at the Le Fort I level. At that stage, more extensive, comprehensive orthodontic treatment is recommended to finalize the position of the teeth and facilitate correct placement of the jaws at surgery.

Orthodontic treatment during childhood

- Orthodontic treatment at this phase is performed during the mixed dentition. Common dental presentations for patients with Crouzon and Apert syndromes in this stage of development include ectopic eruption, crowding, posterior crossbite, and delayed tooth emergence.
- Comprehensive care by a pediatric dentist and an orthodontist during childhood (ranging from ages 5 – 8 years) provides an opportunity to evaluate patients during the early mixed dentition and identify patients for whom treatment is required regardless of whether surgical intervention is planned. Ectopic eruption of permanent first molars occurs in 50% of patients with Apert syndrome and 40% of patients with Crouzon syndrome.
- This is nearly 20 times more prevalent than in the general population and occurs twice as often as in patients with cleft lip and palate. This eruption pattern may result in resorption of the distal root of the adjacent primary tooth and often creates space loss that further exacerbates the already severe dental crowding (Fig. 3A, B).

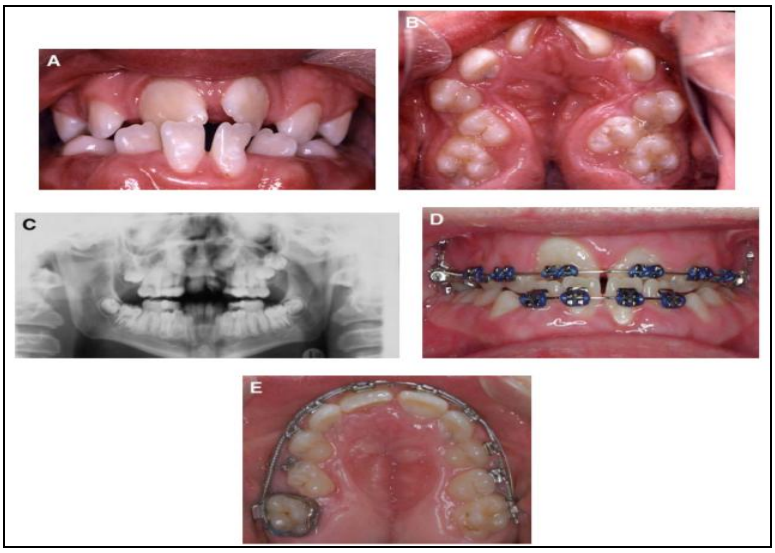

Fig 3: Dental crowding in a patient with Apert syndrome. (A) Occlusion before any orthodontic intervention. (B) View of maxillary arch with extensive crowding, which has resulted in inadequate space for eruption of the maxillary canines. Also note the bulbous contour of the posterior maxilla. (C) Panoramic radiograph reveals superiorly positioned impacted maxillary canines. (D and E) Occlusal and maxillary arch views during presurgical orthodontic treatment in preparation for orthognathic surgery. In this patient's case, treatment consisted of extraction of permanent canines, orthodontic alignment, and removal of dental compensations before surgical correction.

- The cause of this pattern of tooth emergence includes a discrepancy between the needed space to accommodate the maxillary teeth and the affected hypoplastic maxilla and an abnormal angulation of the permanent molars during eruption.
- In non-syndromic patients, few ectopically positioned permanent molars require treatment, because most (66%) eventually self-correct. No definitive data yet exist on the prevalence of self-correction in patients with Apert and Crouzon syndromes; however, it seems likely that the prevalence may be more similar to that seen in the patients with clefts in which only 20% will self-correct
- For ectopic molars that do not self-correct, intervention is frequently required. Considering the common crowding present in these patients that translates to the potential need for extractions of permanent teeth in the maxilla (usually advocated in class III patients being prepared for surgery), however, space regaining is not performed.
- The second primary molar is extracted, which allows the first permanent molar to erupt mesially. The space loss is expressed during the eruption of the subsequent permanent teeth and is resolved definitively with subsequent premolar extraction.
- In patients with Apert syndrome, the second permanent premolars usually erupt palatally, and the permanent canines erupt more toward the facial aspect of the alveolus. In some cases, there is a risk of maxillary canine impaction, which reflects the severe lack of space (Fig. 3).

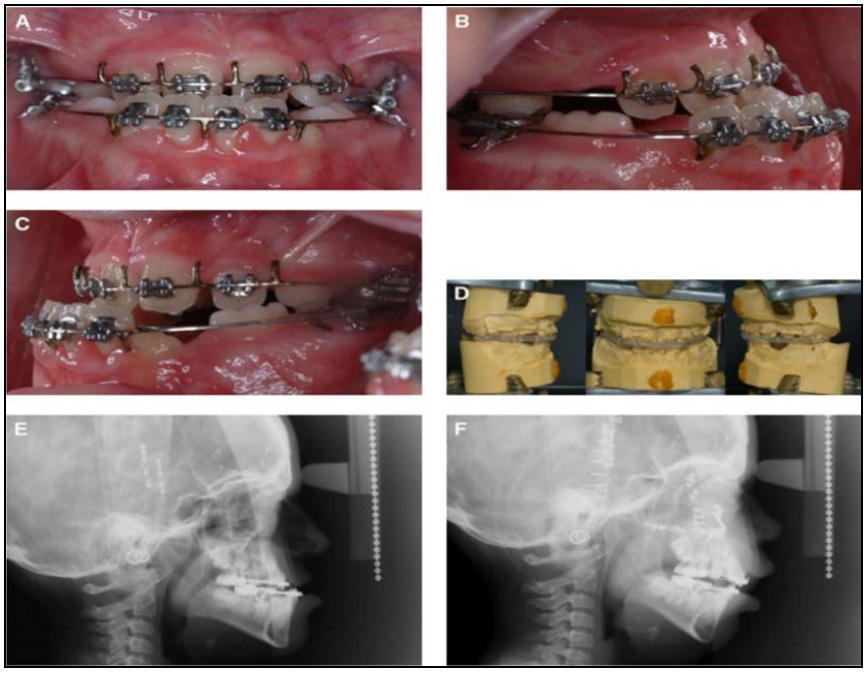

Fig 4: The same patient seen after initial phase of orthodontic treatment. (A, B, C) Patient with Crouzon syndrome after preparation for early midface advancement, with fixed orthodontic appliances, full size wires, and surgical lugs in place. (D) The surgical models show the acrylic splint for use at surgery fabricated in the desired advancement position. (E and F) Cephalometric radiographs before and after monobloc midface advancement. (Photographs courtesy of Dr. Ramon L. Ruiz, DMD, MD, Chapel Hill, NC [27]

- Early extraction of primary canines can help to control this problem and is another modality for relieving transient crowding in the mixed dentition. During the eruption of the permanent laterals, it is common to see a primary canine lost prematurely because of the eruption of the permanent lateral tooth (Fig. 4).
- The contralateral canine may be extracted to maintain a normal dental midline while allowing eruption of the permanent laterals. When mandibular primary canines are extracted, a lingual arch to maintain space usually is indicated (Fig. 4).
- This appliance prevents anterior movement of the posterior teeth and lingual tipping of the mandibular incisors while maintaining space to facilitate non-extraction treatment of the lower arch [26]. A non-extraction approach in the mandibular arch in combination with the commonly needed extractions in the maxillary arch increases reverse overjet temporarily, but usually this procedure is necessary in preparation for later orthognathic surgery.
- Unilateral or bilateral posterior crossbite is evident in two thirds of patients with Crouzon or Apert syndrome. Before orthodontic expansion, it is important to consider that posterior crossbites present in these patients are caused by a constricted and retropositioned maxilla. Repositioning the study casts in an anteroposterior position, which simulates planned surgical movement, can be performed to evaluate the severity of the true transverse problem. If a crossbite still is present, palatal expansion is warranted.
- For patients with Apert syndrome, the type of maxillary expander depends on the severity of the palatal swelling. A lingual arch rather than a jackscrew appliance may be necessary. For patients older than 12 years, in whom palatal expansion is more difficult to achieve because of the suture closure in the palate, orthodontic expansion is limited to 2 to 3 mm per side (4 – 5 mm total); that is, not more than a half-cusp crossbite correction.
- If orthodontic dental expansion is not sufficient, segmental surgery at the Le Fort I level becomes part of the future surgical movements to correct the transverse discrepancy in this phase, the use of fixed orthodontic appliances is indicated when alignment of the anterior permanent teeth is desired or when help is required to hold the acrylic surgical splint in place during surgery for midface advancement, which may be performed during middle to late childhood (6 – 10 years).
- To achieve the desired result, whenever possible, bands are placed on the first permanent molars and brackets are bonded to the incisors for alignment (2 X 4 appliance) (Fig. 5). Particular attention must be paid to bracket positions for the maxillary laterals to avoid distal root tipping toward the unerupted permanent canines. Because the degree of horizontal deficiency at the orbits rarely is uniform, the surgical goal at this stage is to normalize the fronto-orbital relationship, not necessarily to achieve a positive overbite and overjet at the incisor teeth.
- At the time of the midface advancement, the maxilla can be advanced into a near ideal anteroposterior relationship with the mandible. But the specific surgical movements are made primarily with the position of the orbits—not the occlusion—in mind. Waiting until the permanent maxillary first molars have erupted and the first premolars and canines have dropped from a high position in the maxilla decreases the chance of damaging these teeth during the total midface osteotomy.
- Extraction of the maxillary primary canines and first primary molars allows the permanent maxillary premolars to accelerate their eruption at the same time the canines come down from the high position [26]. In preparation for surgery, full-dimension rectangular arch wires are placed, at least 21 X 25 in a 22-slot appliance and 17 X25 in an 18-slot appliance. Lugs are soldered to the full dimension arch wires (Fig. 5) to be used to attach a surgical splint when used at the time of surgery.
- Orthodontic treatment time in preparation for surgery (eg, transcranial or subcranial Le Fort III osteotomy) to address the total midface deficiency in childhood ranges from 6 to 9 months. It is important to recognize that it is not possible to finalize the occlusion with this early operation. It is predictable that these patients will have continued normal mandibular growth combined with deficient maxillary development.
- A Le Fort I osteotomy is planned for a later time to correct the malocclusion and finalize the position of the lower face and occlusion (see later discussion). When a first phase of orthodontic treatment is completed during childhood (with or without early surgery), a removable retainer may be considered to maintain the dental alignment achieved and prevent dental relapse.
- Patients are then monitored for growth and eruption of the remaining permanent teeth to initiate the presurgical orthodontic stage in preparation for the orthognathic surgery.

Orthodontic treatment during adolescence in preparation for orthognathic surgery

- For patients with Crouzon or Apert syndrome, surgical treatment in adolescence almost always involves a Le Fort I osteotomy to allow for horizontal advancement, transverse widening, and vertical lengthening. Often this is combined with a genioplasty to further correct lower face deformity and occlusion.
- Bilateral split mandibular osteotomies may be required to normalize the lower face in relation to the rest of the face.
- Computer predictions are available to visualize planned orthodontic and surgical movements. They are particularly valuable as a treatment planning tool and to communicate with patients on anticipated surgical movements (Fig. 6).
- The presurgical orthodontic stage is initiated when all the permanent teeth are present and at the time of early skeletal maturity (approximately 13 – 15 years in girls and 15 – 17 years in boys).
- Presurgical orthodontics, the treatment performed in preparation for orthognathic surgery, must include removal of dental compensation for skeletal deformity that would limit the surgical correction. Patients with Crouzon and Apert syndromes commonly present with class III dental compensation: upright lower incisors that are crowded because they have tipped lingually during growth and upper incisors that are protrusive and crowded.
- Orthodontic preparation for surgery is just opposite to what would be performed in nonsurgical orthodontic treatment; the lower incisors are advanced and the upper incisors retracted, which increases the reverse overjet. The goal is to fit the upper and lower teeth to their own jaw without worrying about dental occlusion.

- Patients are informed about the presurgical orthodontics will worsen the occlusion temporarily.
- Directly bonded stainless steel or titanium twin brackets and banded molars are used commonly and are compatible with surgical orthodontics Extractions in the maxillary arch are frequently contemplated to relieve severe crowding and increase the surgical advancement of the maxilla. In cases in which the permanent canines are severely impacted, extracting these teeth instead of first premolars can shorten considerably the presurgical orthodontic time
- A typical arch wire sequence for these cases is

1. Superelastic/Heat activated Niti round wires,
2. Stainless steel round wires,
3. Rectangular elastic, and
4. Rectangular stainless steel wires.

- The final step in presurgical orthodontics is to achieve arch compatibility so that the teeth fit together after surgery. Judging a patient's arch compatibility before surgery is not possible from clinical examination and requires repositioning study casts.
- Diagnostic dental casts are placed in the expected postsurgical position, and the occlusion is evaluated for interferences from lingual cusps in the molar area caused by lack of torque control, elongation of second maxillary molars, and incompatible canine widths.
- Properly preparing the dentition before surgery saves time long-term because it avoids months of additional postoperative orthodontic detailing and a compromised result. At the conclusion of presurgical orthodontics, the patient should be in full-dimension rectangular arch wires; that is, at least 21 X 25 in a 22-slot appliance and 17 X 25 in an 18-slot appliance. These arch wires help establish arch compatibility and torque and are used for stabilization at surgery.
- Soldered brass spurs on the arch wire are the preferred attachment for use with temporary, intraoperative maxillomandibular fixation, particularly when multiple dentoalveolar segments will be created.
- Records taken for the final surgical planning should include at least panoramic and lateral cephalometric radiographs, dental casts, and facial and intraoral photographs. In cases in which significant asymmetry is evident, a posteroanterior cephalometric radiograph is required.
- The panoramic radiograph is used to verify that root positions will not interfere with any planned osteotomy cuts. Four to 5 mm of root separation is recommended to surgically excise between them without undue risk and to assess any developing pathologic changes.
- The cephalometric radiograph is necessary so that cephalometric and computer image predictions can be repeated in preparation for model surgery.
- Dental casts are used to model the surgery, and they require the use of facebow transfer to replicate a patient's craniofacial relationships. Cast mounting is necessary in Le Fort I osteotomy cases and if the mandibular arch will be segmented or interrupted.
- Predictions, model surgery, and splint construction are completed so that both the orthodontist and the surgeon are satisfied with the position of the teeth and jaws as predicted by the tracings and model surgery. The use of an occlusal surgical splint provides positive indexing between the teeth in the operating room, which allows surgery to occur before orthodontic detailing of the occlusion is complete and ensures greater precision in the jaw placement.
- The surgical splint is used to control occlusal relationships during surgical maxillo-mandibular fixation while rigid internal fixation is being placed during the final stages of the operation.
- Postsurgical orthodontics begins after a healing phase, during which clinical stability of the segments is reached. With rigid fixation, it usually is possible to start the postsurgical orthodontics approximately 3 to 6 weeks after surgery. At that time, the splint and stabilizing arch wires are removed, the orthodontist makes any necessary repairs to the appliances, and working orthodontic arch wires are placed. The process of settling the teeth into the final occlusion is initiated. The arch wires used at this stage allow the necessary elongation and faciolingual tipping of teeth in at least one arch (usually the lower) as interdigitation of the teeth develops [28].
- The patient uses light vertical elastics along the posterior segments. The same may be done for anterior segments if an open bite is present, as may be seen in patients with Crouzon and Apert syndromes. Initially, these elastics should be worn all the time, even when eating, and removed only for oral hygiene activities.
- The elastics serve two purposes. First, they help bring the teeth into a solid occlusion, reinforcing the settling produced by the arch wires. Second, they prevent any tendency to shift into a relationship that is different from centric relation. When the desired occlusion is obtained, an additional 4 to 6 weeks of part-time elastics use is recommended to prevent relapse or shifts in the occlusion.
- The patient usually is ready for appliance removal and retainers within 6 months after returning from the surgeon's care, depending on the amount of orthodontic detailing of the occlusion needed.

Conclusion

Patients with Crouzon and Apert syndromes exhibit particular orofacial features in combination with the craniofacial skeletal discrepancy that requires reconstructive surgical maneuvers at various stages of development. To maximize positive surgical outcomes and patient satisfaction, an interdisciplinary approach that includes pediatric dentistry and orthodontics within a developmental context is needed. Routine dental care is provided in conjunction with ongoing surgical and orthodontic treatment during all phases of the reconstructive process. The goal of orthodontic treatment in the mixed dentition is to resolve issues related to the aberrant eruption of the permanent teeth and favorably influence the occlusion when early midface advancement is planned. Orthodontics during adolescence always is needed to prepare these patients for orthognathic surgery. This usually involves extraction orthodontics within the maxillary arch. Postsurgical orthodontic management is an important component of the definitive occlusal correction after orthognathic surgical procedures.

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