Chapter

Alternative Craniofacial Orthodontics Treatment Approaches for Differential Severity in Patients with Unilateral Cleft Lip with/without Palate

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Abstract

The treatment of patients with cleft lip with/without cleft palate is still a challenge for its correct team management. The fact that not all clefts are alike, based on anatomical findings and ortho/surgical alternatives used in their correction, requires that clinicians -working in interdisciplinary or multidisciplinary teams- direct efforts not only to repair the facial and oral characteristics of the cleft, but also to work in the context of the patient's craniofacial growth and development, tri-dimensionally affected by this type of craniofacial difference. The first part of this chapter is focused on the diagnostic approach for patients with unilateral cleft lip and palate (UCLP), using a modified version of the GOSLON yardstick (GOSLON+) that considers not only dental components but also 3D facial aspects of a complex malocclusion originated from this congenital malformation. Second, current treatment alternatives based on patient's stages of dental development and cleft width, using either straight-wire or passive self-ligation appliances are presented, directed to avoid dental prosthetic replacements if possible. Finally, our treatment algorithms summarized in a step-by-step fashion the treatment of such differences with approaches that will focus on these two key aspects, essential for a successful, patient-based, interdisciplinary treatment protocol.

Keywords: Cleft lip, Cleft palate, Surgical Orthodontics, Craniofacial Surgery

1. Introduction

The correct management of craniofacial differences (CFD's) -including cleft lip with/without cleft palate (CL ± CP)- is still a challenge for clinicians treating such conditions, due to its treatment length and the different aspects that have to be holistically addressed in accordance with overall and craniofacial growth and development, speech and hearing, facial esthetics, and psychological self-perception of patients with such characteristics.

Although a universal treatment protocol has not been agreed among craniofacial teams worldwide [1], several parameters of evaluation and treatment have been set and reviewed periodically, following the recommended practices for the care of patients with craniofacial differences made by the ACPA (American Cleft-Palate

Craniofacial Association) [2] (revised in 2018), based on the call of the Surgeon General of the United States on the needs for children with special health care [3]. A summary of such parameters appears below:

(a) The interdisciplinary team management of patients with craniofacial differences is essential; (b) Clinical expertise in diagnosis and treatment and optimal care for these patients is provided by teams with enough exposure to these patients each year; (c) The first evaluation is within the first few days or weeks of life (ideal), but referral for team evaluation and management is appropriate at any age; (d) Since the beginning, the family of a child with a craniofacial difference must be assisted in adjusting to the birth and consequent demands and stress of having a child with CFD; (e) Responsible adults must receive information about treatment procedures, options, risk factors, benefits, and costs to take informed decisions on the child's behalf, and to prepare the whole family for all recommended procedures. The family (and patient, when is mature enough) participation and collaboration in treatment planning should be actively asked; (f) Team recommendations are basic to develop and implement treatment plans; (g) Complex diagnostic and surgical procedures should be restricted to centers with experienced health professionals; (h) Each team must be sensitive to linguistic, cultural, ethnic, psychosocial, economic, and physical factors affecting the relationships among the team, the patient and family; (i) Longitudinal follow-up of patients, including appropriate documentation and record-keeping is essential to monitor both short-term and long-term outcomes and falls under the responsibility of each team; (j) The effects on growth, function, appearance satisfaction and psychosocial well-being of the patient should be considered when performing evaluation of treatment outcomes.

Following these parameters, this chapter explain in detail our craniofacial orthodontics treatment algorithms for the patient with unilateral cleft lip and palate (UCLP) from mixed dentition onwards, which addressed all topics related with diagnosis and treatment planning for adolescents and young adults affected with this craniofacial difference.

2. Craniofacial diagnosis of patients with UCLP

Mars et al. in 1987 introduced the GOSLON yardstick [4], which has become the standard diagnostic tool for patients with UCLP worldwide. Ozawa et al. in 2011 expanded the same classification for bilateral clefts [5]. This classification, based on dental casts, has proven to be a good and simple option to grade the malocclusion present and to give some hints on the level of difficulty in its correction. Other broader approaches -such as the original Huddart-Bodenham classification (used in deciduous dentition only) [6], or its modification used in both deciduous and permanent dentitions (proposed by Mossey et al. [7])-, are also other interesting approaches to classify all dental components present in UCLP and BCLP malocclusions. However, those indexes missed a common aspect that cannot be forgotten in a craniofacial orthodontic evaluation: the facial pattern in three dimensions that could worsen (or improve) the existing CL ± CP condition. The GOSLON does not consider frontal and lateral facial photographs or cephalometric radiographs, which are regular diagnostic records in orthodontics (taken digitally for these patients in the XXI century). These records are important to detect left-to-right bone vertical discrepancies that could make some UCLP cases more difficult to correct properly than previously thought. This is the reason why the orthodontic diagnosis (and its indicated treatment) cannot be established solely from study dental models. The GOSLON yardstick can be used as a classification system, but not as a determiner of treatment complexity without considering the 3D facial aspects of a complex malocclusion.

Having as a start point the GOSLON yardstick, our unit has developed a modified GOSLON yardstick (named GOSLON+), based not only on dental casts but also on frontal and facial digital photographs and radiographs. These records can be used to accurately determine the involvement of craniofacial orthodontics and craniofacial surgery in the resolution of unilateral (and bilateral) cases, depending on the degree of asymmetry associated with the cleft, following all aspects involved in a complete orthodontic diagnosis. The following diagram and the accompanying patients' photographs (with full records) demonstrate our current diagnosis

Group	Characteristics	Treatment	Prognosis
1±	• Positive overjet. • Retro-inclined or average inclined incisors. • No crossbite or openbite. • With or without mandibular deviation	Surgical orthodontics and surgical treatment for class II malocclusion.	Good/Fair (Depending of Degree of Facial Asymmetry [+])
2±	• Positive overjet • Average incisors inclination or retro-inclination • Unilateral or tendency to crossbite • May have open bite around cleft site. • No or minimal mandibular deviation	Surgical orthodontics and surgical treatment for moderate or complex class I malocclusion.	Excellent (None [−] to some Degree of Facial Asymmetry [+])
3±	• Edge to edge malocclusion with average or proclined incisors, or reverse overbite with retroclined incisors. • Unilateral crossbite • May have open bite around cleft site • No or minimal mandibular deviation	Surgical orthodontics and surgical treatment for mild class III malocclusion.	Good/Fair (Depending of Degree of Facial Asymmetry [+])
4±	• Inverted overjet • Average or proclined Incisors • Unilateral or bilateral crossbite • May have open bite around cleft site • With or without mandibular deviation	Surgical orthodontics and surgical treatment for severe class III malocclusion.	Fair (Depending of Degree of Facial Asymmetry [+])
5±	• Inverted overjet • Proclined incisors • Bilateral crossbite • Affected shape of maxillary arch and palatal vault • With or without mandibular deviation	Surgical orthodontics and step-wise surgical treatment for extreme class III malocclusion. (Maxillary Osteogenic Distraction and Orthognathic Surgery).	Fair (Depending of Degree of Facial Asymmetry [+])

Table 1.
Modified GOSLON yardstick (GOSLON+) for patients with UCLP. A similar table apply to patients with BCLP.

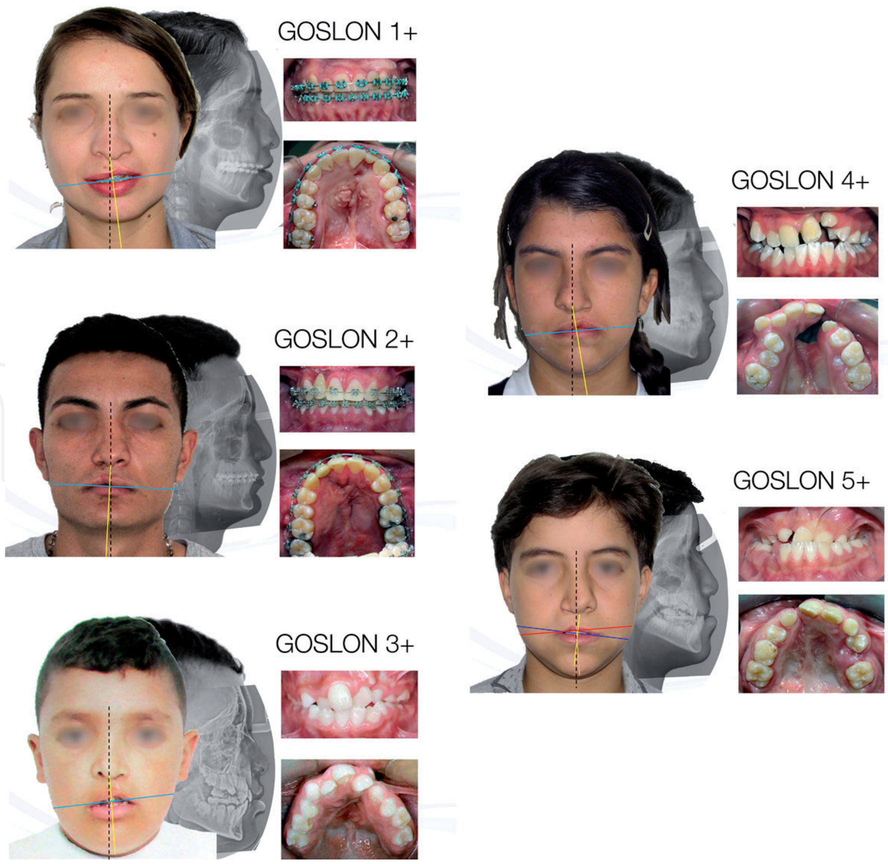

Figure 1.
Facial and intraoral characteristics of patients presenting the five different degrees of GOSLON+ yardstick. Observe that treatment prognosis further decreases when frontal and lateral facial photographs are included in the treatment algorithm to manage successfully the existing alveolar clefts.

categories and changes in the treatment of patients with UCLP (modified from the original GOSLON) (**Table 1**, **Figure 1**), [4] Our modified classification considers the influence of facial and occlusal 3D aspects in the craniofacial overall diagnosis and the need for additional treatment created by the existing frontal asymmetry.

It is well known that not all clefts are similar [6, 8–11]. Moreover, patients affected by UCLP have some degree of facial asymmetry that affects the prognosis (**Figure 1**). This fact must be considered within the orthodontic-surgical diagnosis. Accordingly, their ortho-surgical treatment plan should not be the same either, due to the type and extension of cleft, the timing for the initiation of those treatments, and the individual needs for surgical treatment influencing the selection of surgical techniques. In addition to these factors that have a negative influence on facial growth, the expertise of the ortho-surgical team and the interdisciplinary management given to the patient is the last -but not the least- item to be considered for obtaining a satisfactory treatment outcome [12].

Based on this improved GOSLON classification, a description of the surgical orthodontic management for average and wide clefts will be addressed. After that, two different surgical orthodontics algorithms will be presented, with clinical cases to summarize the decision-making process applied in the surgical orthodontic care of patients with UCLP with different degrees of sagittal and transversal maxillary-mandibular involvement in the Clínica Noel Foundation at Medellin, Colombia, S.A.

3. Current management of alveolar clefts in patients with UCLP

The alveolar cleft -the space between the maxillary segments anterior to the incisor foramen- represents a lack of continuity of both maxillary dental arch and basal bone. Spatially, it can be represented as a pyramid placed on its side, with its base towards the labial side and its apex located in a posterior and superior position inside the cleft maxilla [13]. This gap should be ideally filled by a cancellous bone graft to restore its basal and alveolar normal architecture. This defect gives origin to a particular kind of critical-size segmental defect that creates a significant challenge for craniofacial surgeons, maxillofacial surgeons and craniofacial orthodontists [14].

From all the alternatives to fill completely the maxillary cleft, the secondary (intermediate or late) alveolar bone grafting (SABG) is still the gold standard treatment to restore the alveolar anatomy, either in mixed dentition or early permanent dentition [15]. The objectives of SABG include (1) to restore and stabilize the normal architecture of the maxilla; (2) to allow eruption of permanent lateral incisor and canine; (3) to provide support and elevation of the affected wing base; (4) to close present oronasal fistulas and (5) to provide "adequate" bone support to be restored later with prostodontics with/without dental implants, in case that a closure of the gap with dental eruption cannot be achieved [16, 17]. It has been our approach to limit its objectives to the first three in mixed dentition patients, due to the uncertain nature in time of this type of autografts and the impediment for free dental movement created by cortical grafts at early ages. However, two controversies proposed by Vig still remained valid today: which is the best bone graft type and the best donor site for harvesting? and what is the best timing for maxillary (dento-alveolar) expansion in patients requiring SABG [17]? A third controversy refers to whether the alveolar cleft can be repaired by a combination of bio-engineering alternatives currently available nowadays. Our treatment rationale tries to solve the first two questions as follows:

3.1 Average alveolar clefts (GOSLON 1 to 3 -without or with minimal mandibular asymmetry-): the appropriate use of alveolar bone grafts

Several aspects have to be considered for obtaining a successful bone graft in such patients:

3.1.1 Correct alignment of maxillary segments with normal transversal maxillary molar width

During mixed dentition stage, orthodontic treatment can be used previous to surgical treatment to increase maxillary dental arch width and length using the Quad-Helix [18–21] (**Figure 2**). This appliance -developed by Ricketts while he was part of the Cleft Palate Clinic at UIC (currently the UIC Craniofacial Center) [22] and improved by Wilson and Wilson in the 80's [20] and others- is currently applied to correct the collapse of the lateral maxillary segment behind the protruding premaxillary process [23]. In patients with UCLP, the bony palate anatomy presents a primary unilateral deficiency worsen by contraction of scar tissue, as a result of the neonatal surgical palatal closure [19, 23]. In addition to the dento-alveolar effect obtained in patients without clefts, the main bony effect of the Quad-Helix in UCLP cases is the expansion of the lateral maxillary shelves when the de-rotation of the maxillary molars is achieved [19, 23]. In such cases, dento-alveolar expansion before surgery results in similar treatment outcomes than in patients with maxillary expansion [24], with the benefit of working with minimum risk of creating secondary maxillary fistulas. Dento-alveolar expansion could also be obtained by other orthodontic appliances such as the reverse Quad-Helix (with poor correction of the molar rotation) [25], conventional or modified jointed fan (or butterfly) expander [26–28], NiTi palatal expander [29], or self-ligation appliances [30].

Figure 2.
Recovery of normal transversal maxillary width with correct maxillary alignment after the use of Quad-Helix. a. Before Quad-Helix, b. At removal time. Notice the change in the cleft architecture and the creation of alveolar spacing for the alignment of the right maxillary canine.

3.1.2 Correct alignment of teeth inside the segments

Dento-alveolar maxillary expansion is usually followed by maxillary dentition segmental leveling and alignment (using an anterior [3*2] utility arch) [21, 31–34]. In order to obtain similar results than those achieved using an inverse treatment protocol (alveolar grafting followed by orthodontics with maxillary expansion) [24], an orthodontic approximation of maxillary segments using a sectional arch approach -after obtaining proper maxillary width but before surgery- should be considered. In older patients, a mini-screws based molar distalization plus orthodontic dental retraction -by controlling the mesial inclination of the canine for greater bone approximation- is often required to create an alveolar defect with parallel walls to minimize the alveolar gap size when a segmental surgery is planned (**Figure 3**) [35, 36].

The suggested order of orthopedic-orthodontic procedures would be as follows: 1. Dento-alveolar maxillary expansion; 2. Maxillary segmental dental leveling and alignment; 3. Mini-screw based molar distalization (if needed in patients that have passed the appropriate timing for grafting) and 4. Orthodontic approximation of maxillary segments.

3.1.3 Timing of the graft

At the time of bone grafting, many craniofacial centers around the world use SABG during mixed dentition (5 to 12 years of age) before or during permanent canine eruption, taking advantage of the growth potential of the maxilla at this stage [37]. In our center, we use Intermediate or late SABG during mixed or early permanent dentition for GOSLON1–3 patients only. We usually perform such procedure in agreement with dental age characteristics of teeth around the cleft (permanent canine and lateral incisor when present). The ideal age range for surgical procedure

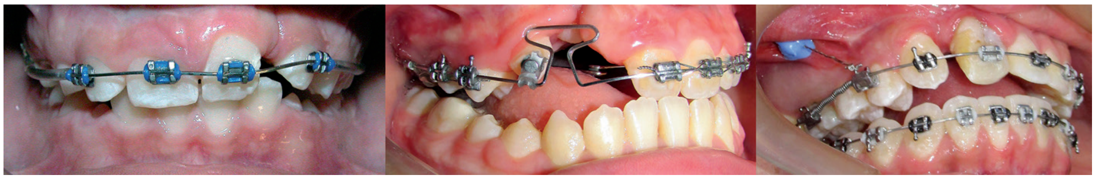

Figure 3.
Modified First-Phase Orthodontic Strategies. In addition to the a. maxillary utility arch, two other strategies have been useful in the correct alignment of the maxilla prior to surgery: b. sectional approximation of maxillary segments; and c. mini-screw based distalization.

should be when the canine on the cleft side is from less than 5 mm of its eruption place to a partially erupted canine (1/3 to ½ of crown visible). Late SABG cases with narrow alveolar clefts at the right age allows to work with bone graft stimulation (either with compression osteogenesis or RPE) to obtain excellent results in both cases (**Figure 4**) [24, 37]. Using SABG as an alveolar bone matrix, we achieve high degree of success in correcting the canine eruption and migration pathway [38]. The bone graft would give temporary bone support for the eruption of lateral incisor and/or canine without affecting the growth of the midface, with good outcomes similar to other centers in the world when compared with gingivoperiosteoplasty [21, 39]. Ideally, a complete closure of the space with no need for lateral incisor prosthesis is achieved when the migration of the canine occurs.

3.1.4 Bone harvesting site

In chosen candidates, cancellous iliac crest bone from the inner anterior portion of the crest is usually required to close mild-to-moderate type of fistulas (patients with UCLP GOSLON1 to 3 at the appropriate age) (**Figure 4**). This approach is used to restore momentarily alveolar bone continuity needed for dental movement [40, 41]. **Figure 4** shows a case with such approach, with an excellent outcome. However, other harvesting sites such as tibia, mandibular symphysis or retromolar area can be successfully used for this purpose [23, 42, 43].

3.1.5 Type of bone graft

Of all types of bone graft (cortical, cancellous, or mixed), the fresh autogenous cancellous bone is the "ideal" source for reconstruction of bone integrity, due to the fact that it provides living bone cells and is immune-compatible enough to allow osteogenesis and full integration with the maxilla [40]. Autografts have as its main characteristic osteoproduction [44] -bone growth obtained from combined

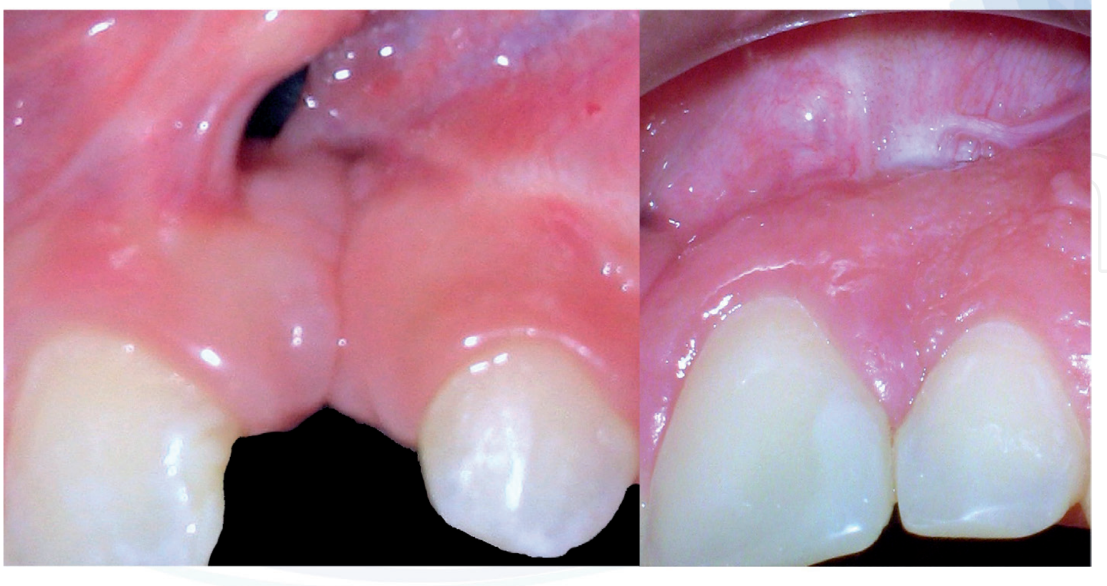

Figure 4.
Intraoral Results of Iliac Crest Late Secondary Alveolar Bone performed at the Correct Time. a. Despite the fact that all teeth around the cleft were erupted at the initial evaluation, the patient still had intermediate mixed dentition and remaining eruption potential in the lateral incisor adjacent to the alveolar cleft; b. After late SABG and finishing restorative dentistry procedures. Note the closure of the alveolar cleft and the normal gingival architecture obtained by the application of orthodontic compression osteogenesis after cancellous iliac bone grafting.

properties of osteoinduction (recruitment, proliferation, and transformation of osteoprogenitor MSC's into osteoblasts) [45], osteopromotion (process of secondary support of bone healing and tissue regeneration, without capability of initiate bone formation) [46], osteoconduction (process of osseous and vascular cell ingrowth inside the 3D matrix scaffolding) [47], and "relative" osteogenesis (process of deposition of newly formed bone by osteoblasts at the fracture site)- that enhance osteoprogenitor MSC's response according with autologous graft type. Allografts also share other advantages such as biocompatibility, and mechanical resistance vs. orthodontic remodeling depending on the graft source [48]. Iliac crest site morbidity, accessibility, and availability of areas of graft harvesting of other donor places create a supposedly difficulty that could be overcome with sufficient surgeon's exposure to this approach [49] in a capabilities-based curriculum [50]. When a successful incorporation (or modeling) of a graft is achieved, the term osseointegration can be used under this definition (**Figure 4**) [51]. An optional surgical procedure for treating wide alveolar clefts will be described later.

3.1.6 Missing tooth substitution

At the Pre-surgical Planning Time of Post-Surgical Procedures. In cases where lateral incisor in the cleft area is partially missing, split in two by the cleft (creating two "real" supernumerary teeth), or absent, all options involved in the dental restoration of the patient must be considered:

When the lateral (and central incisor or canine, depending on the location of the cleft) present a missing portion, a composite restoration could be required either during or once the orthodontic treatment is finished to improve esthetic appearance (**Figure 4**).

Lateral incisor supernumeraries present additional difficulties to be addressed: their crowns usually are of decreased size, and the roots are short and with many irregularities and dehiscenses along the root length. Performing restorative procedures, such as extensive composite restauration on the wider tooth, are in order if the chosen supernumerary has its root firmly embedded in bone and the final orthodontic placement of the tooth leaves the root with enough alveolar bone on both sides.

If the lateral incisor is missing, an option would be to take advantage of performing an intermediate SABG followed by the mesial eruption of the canine. Later on, restorative procedures in conjunction with orthodontics will convert the canine anatomy in lateral anatomy, although some differences between normal and converted teeth remain regarding color and crown emergent profile from gingiva (**Figure 5**).

3.1.7 Need of additional procedures

Orthodontic procedures (regarding bracket type and bracket positioning -proper height and buccal-lingual crown inclination of canine and first bicuspid on the cleft side), periodontal procedures (to maintain or recover -partial or totally- the periodontal anatomy affected by decreased gingival thickness as a consequence of mesenchymal deficiency in patients GOSLON3+, 4, 4+, 5 and 5+) (**Figure 6**) and/or additional cosmetic dentistry/prosthodontic procedures (to transform with such strategies the maxillary canine in lateral incisor and the maxillary bicuspid in canine, and perform additional restorative work if needed) are necessary after SABG surgical procedure for an adequate dental characterization with good-to-fair periodontal condition (**Figures 7** and **8**). Optional plastic surgery procedures could be needed as well.

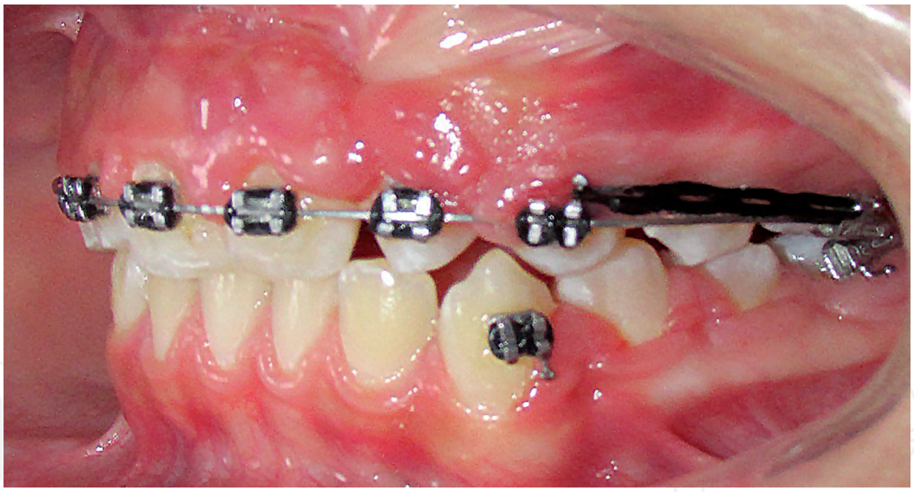

Figure 5.
Intraoral Results of Guided Migration of Permanent Canine through SABG performed at the Correct Time. After successful SABG, the left maxillary canine was directed to erupt in a mesial position from its initial site. Note the hypertrophic gingiva surrounding the teeth on the repaired cleft site. The patient will require cosmetic dentistry procedures in addition to the correct bucco-lingual root torques delivered by the use of lower first bicuspid brackets on the maxillary canine (to act as lateral incisor) and first bicuspid (to act as canine). Protraction of the upper first molar to obtain a well-established class II relationship is under way.

Figure 6.
Periodontal Results of Connective Tissue Graft and Enamel Matrix Protein Application after Ortho-Surgical Procedures. This experimental procedure in cleft patients allow the clinicians working in poor anatomic conditions -due to the negative influence of a mesenchymal deficiency- to partially recover gingival architecture at the short-term follow-up. Long-term follow-up will give us answers regarding the success of the obtained periodontal stabilization. a. Initial intraoral left close-up photo. The patient has a wide left alveolar cleft with dental inclination of left permanent central incisor (moderate), and left permanent canine (severe); b. Intermediate intraoral left close-up photo. After a segmental maxillary advancement, moderate loss of periodontal attachment and apical migration of gingival margins was observed; c. After connective tissue graft plus enamel matrix protein infiltration. Notice the gain on gingival margins and periodontal thickness as a result of this approach; Surgical sequence: d. Harvesting of palatal connective tissue graft; e. graft waiting to be inserted below gingiva; f. Graft placement under keratinized gingiva; g. Emdogain® syringe used in this case.

3.1.8 Retention

Our retention protocol for patients with normal skeletal relationships (GOSLON2 and 2+) or with mild skeletal discrepancies (GOSLON1, 1+ and 3) use Essix-type retainers. As our treatment approach is directed to obtain a maxillary arch without dental spaces if possible, we seldom use wrap-around maxillary retainers with dental

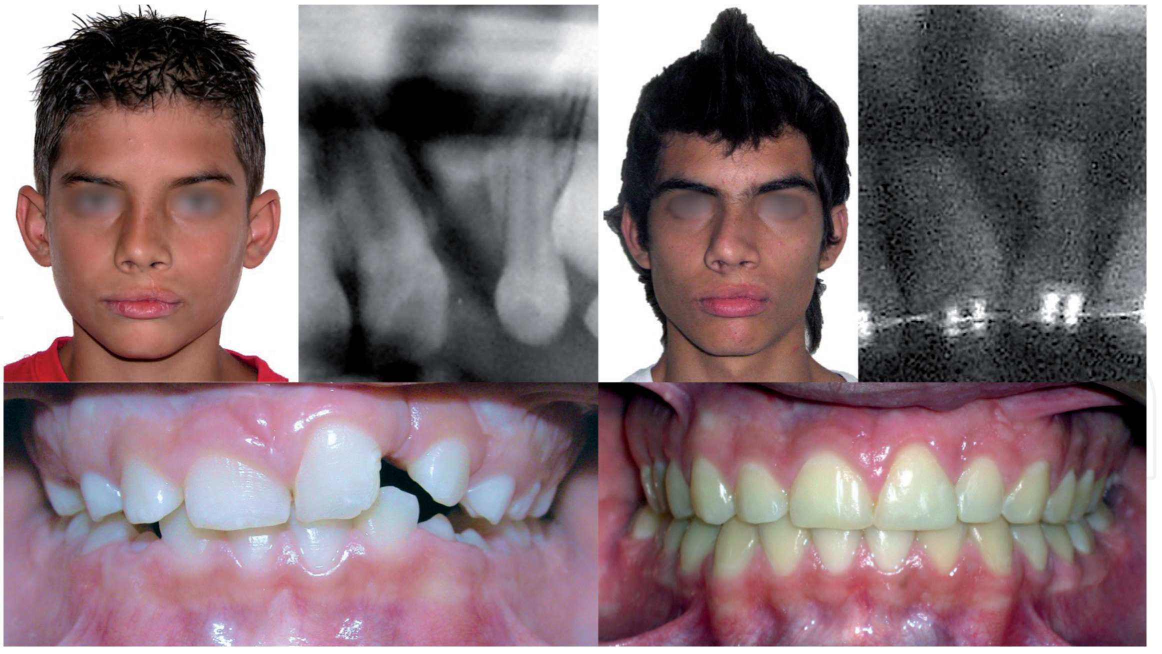

Figure 7.
Patient with UCLP GOSLON2 treated at Mixed Dentition stage. Initial records: a. Frontal facial photograph; b. Periapical radiograph of the alveolar cleft; c. Intraoral frontal view; Final records: d. Frontal facial photograph; e. Periapical radiograph of the alveolar cleft; f. Intraoral frontal view. The application of the compression osteogenesis strategy was fundamental to obtain normal periodontal architecture in the grafted area of the alveolar cleft.

Figure 8.
Patient with UCLP GOSLON2 treated at Permanent Dentition stage. Initial records: a. Frontal facial photograph; b. Intraoral frontal view; Final records: c. Frontal facial photograph; d. Intraoral frontal view. A relatively normal dental and gingival architecture was obtained after the surgical management of a Two-piece LeFort I.

temporary replacements. Our countdown-to-retention includes periodontal evaluation and treatment in patients with GOSLON3+ and more, to address the thin and receding gingiva in cleft-adjacent teeth, associated with genetically-driven periodontal ligament loss described previously (**Figure 6**). In those cases (which have received correction of existing moderate to severe skeletal discrepancies previously), a periodontal connective tissue graft plus dentin matrix protein injections to increase gingival volume and tissue support, and a dual retention strategy with an additional bonded lingual retainer in the maxillary anterior teeth is used.

3.2 Wide alveolar clefts/patients with adult dentition

Young patients affected by UCLP who have severe restriction of maxillary growth and wide oronasal fistulas (GOSLON4, 4+, 5 and 5+), or adult patients with UCLP in all categories of the GOSLON+ yardstick, have been historically (and unsuccessfully) treated using alveolar bone grafting (secondary or tertiary). In addition, inadequate closure of primary incisions, post-operative wound dehiscence and infections could potentially make bone grafting healing worse [35]. Mars et al. recognized that unilateral alveolar bone grafting success was limited to young patients with "average" maxillary growth (patients GOSLON1, 1+, 2, 2+, and 3) and normal gingival thickness compared with an age-matched normal population [4]. What was the problem? They found out that with increased limitation in maxillary craniofacial growth in patients with UCLP, there was an important compromise in making the maxillary segments meet closely to complete a successful bone graft and a greater difficulty to obtain a fair maxillary dentition by subsequent orthodontic treatment [4].

In order to obtain a surgically-created one-piece maxilla [52], craniofacial centers worldwide use strategies based on segmental maxillary advancements (described by Schuchardt [53]). This surgical technique and its modifications were currently used to manage the surgical closure of open bite [54, 55], transverse maxillary deficiency [55–57], or excess [55, 58]. The last two findings are common in patients with UCLP. After proper soft tissue management of severe and longstanding oronasal fistulas [12], this approach favors the 3D maxillary architecture prior to secondary orthognathic surgery, reduces prosthodontic needs and creates a more cost-effective alternative than using either conventional LeFort I advancement plus extensive prosthodontic replacement or interdental osteogenic distraction [58].

A combination of surgical fistula closure followed by a combination of Le Fort I advancements in two segments [59] plus immediate or delayed alveolar bone graft, depending on the need and extension of additional distraction osteogenesis/orthognathic surgery has been used regularly at the Clínica Noel Foundation since 2015, modified from Stal et al. [12] (**Figure 9**). This maxillary procedure could be performed alone or in combination with BSSO during the same surgical procedure. This modified approach produce good bone blood flow [60], and stability [61], with fair gingival architecture due to pre-existing periodontal conditions that can be worsened in some cases by local tension on the flaps during gingival closure [59] (**Figure 5**). Good-to-fair results regarding non-tension flap closure, bone-to-bone contact, and secondary bone healing have been obtained, depending on the degree of cleft maxillary hypoplasia present. For these patients, these successive surgical steps (oronasal fistula treatment followed by segmental maxillary approximation) could be realized previous or simultaneously to the placement of a narrow tertiary alveolar bone grafting and the realization of additional surgical mandibular procedures during orthognathic surgery.

3.3 Treatment of extreme cleft maxillary hypoplasia: the application of distraction osteogenesis using the RED system

Distraction osteogenesis is a treatment technique that deals with the genesis and growth of new bone in a specific body area, through the application of gradual tensile stress [62–66]. Distraction Osteogenesis can be applied to the surgical correction of hypoplasias of the craniofacial skeleton to replace extensive bone and

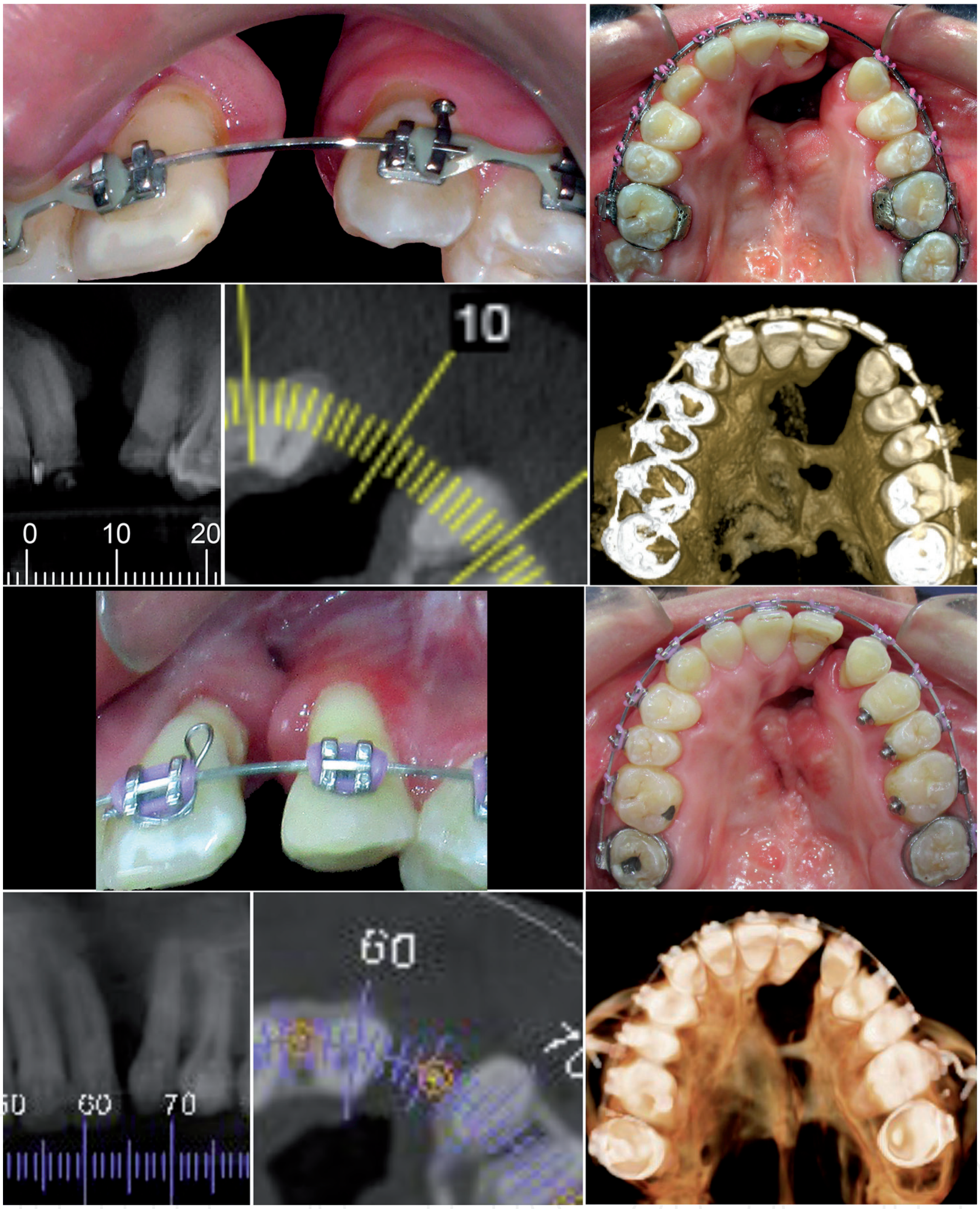

Figure 9.
Application of Segmental Maxillary Advancement to reduce the Alveolar Cleft prior to Final Bone Grafting. Pre-surgical records. a. Close-up of alveolar cleft, b. Occlusal view, c. Periapical radiograph, d. CT close-up occlusal view: 10 mm gap between internal radicular surfaces, e. CT occlusal maxillary view; Post-surgical records. f. Close-up of alveolar cleft, g. Occlusal view, h. Periapical radiograph, i. CT close-up occlusal view: 5 mm gap between internal radicular surfaces, j. CT occlusal maxillary view. The left segmental advancement reduced in half the distance to be covered by a tertiary bone grafting and increased the chances of closure success.

soft tissue deficiencies without requiring the use of bone grafts [67]. This technique additionally provides the benefit of expanding the overlying soft tissues, which are frequently deficient in these patients.

After the introduction of gradual elastic maxillary distraction to advance a segmental Le Fort I osteotomy (an incipient form of Distraction Osteogenesis -DO) by Wassmund [68], maxillary DO using facemask and elastic traction was successfully reintroduced by Molina and coworkers 60 years later [69], after several animal studies corroborated its feasibility [70, 71]. After the arrival of the Rigid External Distraction (RED) technique for its use for upper and mid-face hypoplasia in 1997 [72], Polley and Figueroa applied their maxillary DO technique in cleft patients [73, 74] and Figueroa and co-workers reported their immediate and long results in this population [75, 76]. In patients with either UCLP or BCLP that present severe maxillary hypoplasia (GOSLON 5 and 5+), worsened by previous pharyngeal repairs that apply additional tension to an already deficient cleft maxillary development, this alternative surgical technique allows the progressive forward displacement of the maxillary complex, while exerts moderate but increasing tension in the pharyngeal musculature that favors their rearrangement in the final maxillary position [73–76].

Patients prior to the surgical procedure received preferably a customized rigid labial-palatal arch with external vertical hooks adapted partially from a face-bow, or with detachable external hooks located distal to the lateral incisors (**Figure 10**). These orthodontic options facilitate further distraction modifications and appliance removal in dental settings. After this, the patient was submitted to a high LeFort I osteotomy (in segments according to cleft type), avoiding tooth germs and external halo frame positioning. After 5–7 days latency period, active distraction is performed at 1 mm/day at 0.5 mm each 12 hours, until an additional 20% of the planned DO is achieved. Orthodontic follow-up is highly recommended to control the amount of distraction remaining, to change the direction of distraction when needed, and to give additional instructions to the patient and relatives on how to adjust the distraction if any AP and transverse maxilla-mandible asymmetry is developing. The average amount of maxillary RED distraction in such cases was 9.6 mm [76]. A consolidation period of 3+ months with the distractor in place must be observed to allow maxillary bone to mature from the initially delayed woven bone and guaranteed the obtained results.

Despite the appearance of other maxillary DO external and internal devices, the RED system allows the application of important pulling forces to advance the receding maxillary complex without risking external frame integrity, permits to correct direction of distraction due to their flexibility in distractors' positioning on vertical and horizontals bars [77], and manage a wider range of maxillary distraction than internal DO devices. A maxillary cleft case treated with this approach appears below (**Figure 11**).

Figure 10.
Intraoral Tooth-Supported Devices for RED system. a. Customized rigid labial-palatal arch with external vertical hooks adapted partially from a face-bow, b. Customized rigid labial-palatal with detachable external hooks located distal to the lateral incisors.

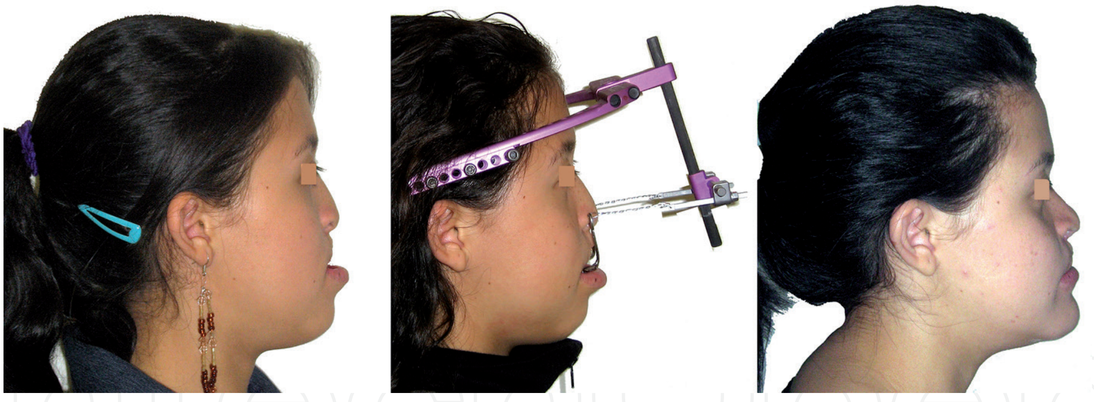

Figure 11.
Patient with Maxillary Cleft undergoing Maxillary RED. a. Before maxillary DO; b. During Distraction Osteogenesis; c. After DO. Notice the improvement on maxillary projection at the infraorbital level.

3.4 Surgical management of maxillo-mandibular asymmetry: alternative strategies in the correction of UCLP and application of surgery-first (early) approach and self ligation to accelerate final orthognathic results

Adult patients affected by CL ± CP require reduced treatment times while obtaining optimal craniofacial results. After obtaining a one-piece maxilla (Except in patients GOSLON2, some GOSLON2+, and GOSLON3 that finished ortho-surgical treatment at the end of SABG) and at the end of maxillary DO in patients GOSLON5 and 5+, the Craniofacial Ortho-Surgical team has to properly plan and execute orthognathic surgery that address three-dimensionally all problems related with the surgical correction of an asymmetric patient. Could a combination of treatments according to the state of the art be used to reduce treatment times in an interdisciplinary scheme? There are several contemporary alternatives from the orthodontic-surgical treatment stand point that can be used in this scenario: First, the re-appearance of self-ligating systems (with passive -regular [e.g. Damon™ System, Ormco Corp., Orange, CA] or CAD-CAM individualized brackets [e.g. Insignia™ System, Ormco Corp., Orange, CA]-, or interactive brackets [e.g. CCO™ System, Dentsply Sirona Orthodontics, York, PA]), and second, the spreading use of Surgical Treatment Acceleration (Surgery-First and Surgery-Early surgical approaches).

Both alternatives are not new. Passive Self-Ligation is an old therapeutic alternative available for clinical use in the 70’s [78] and 80’s [79]. The concept was commercially reintroduced in the late 90’s by the Ormco™ Task Force, to give origin to the Damon™ System [80, 81]. One of its objectives is supposedly to reduce clinical activity time and treatment time -reduction in wire changes and face-to-face clinical activity-, and increase clinical efficiency by simplifying orthodontic mechanics and materials. The passive effect of friction reduction by bracket design is especially noticed during tooth leveling and alignment in severe dental crowding, dentoalveolar expansion, and in less extent during major tooth movements [80, 81]. The second objective is to take advantage of the active use of orthodontic archwires with variable activation temperature. This is the most important change from early self-ligating appliances. Buehler and coworkers were the first to explain the physical properties of the Variable Transformation Temperature concept [82], while Tien and collaborators in 1982 described its application in orthodontics [83]. Later, Burstone and others published on the alloy characteristics and clinical behavior in depth [84–87]. Thermo-activated wires allow clinicians (1) to use a differential alloy sequence, that permit early cross-sectional form changes and wire gauge increments to fill entirely the bracket’s slot at early treatment stages with early effect of torque, and (2) to take advantage of wider archforms than in current straight-wire systems. This characteristic is potentiated with self-ligation to produce a "free" vestibular tooth movement by using wider arch shapes on unconventional alloys in a shorter period of time [88–90]. Total appointment time and treatment length could be shorter due to the fulfillment of both objectives in most cases. However, no differences in the positions of incisors and the transverse dimension changes of the maxillary arch were found when self-ligated appliances and conventional-ligated appliances plus Quad-Helix were compared [91]. There is insufficient evidence to justify or contraindicate its use in surgical orthodontics in patients with CL ± CP [30].

Surgical Treatment Acceleration is not a new technique either. During the 1960–1970's, the early orthognathic surgery approaches were performed without orthodontist intervention (Surgery first -independent-), and subsequent orthodontic treatment was poorly encouraged by maxillofacial surgeons afterwards [92–94]. Several problems, including the lack of interrelation of orthodontic and surgical treatments, and difficulties for space generation needed for correct orthodontic decompensation, aroused from these early attempts. After the realization that occlusal relationships were a key component of orthognathic surgery results, the orthodontist gained a role in both craniofacial and maxillofacial teams with the objective to eliminate dental compensations before surgery and facilitate posterior orthodontic treatment [95]. The basic sequence of procedures is still applied today. However, creating a maxilla-mandibular decompensation, alignment, and correct maxilla-mandibular anterior and transversal relationships is a long process, even today. A different approach was proposed by Epker and Fish in [96]. They affirmed that it was best to perform surgical procedures as soon as possible to obtain immediate post-surgical benefits for orthodontic treatment (accelerated orthodontic movement after surgery following surgical correction), surgical improvement (early recovery of facial and dental function), and functional aspects (improvements on speech and deglution). Sugawara and Tohoku University/University of Connecticut group in 2009 proposed their Surgery First Approach (SFA) -also called Surgery-First/Early Orthognathic Approach (SFEA) [97]- combined with Skeletal Anchorage System (SAS) for the treatment of a skeletal Class III patient, obtaining excellent results based on the premises mentioned previously [98]. In 2019, the same group published its extensive follow-up on Temporo-Mandibular Symptoms and Function in Class III malocclusion using SFEA compared with Orthodontics-First Approach (OFA) patients, without significant differences between groups [99]. CES University, in conjunction with the mentioned consortium [100], and with the Universidad del Valle [101] have applied SFEA schemes in Latin-American patients. SFEA rely on performing orthognathic surgery at the beginning of treatment with minimal preoperative orthodontics [102]. This treatment protocol allows the reduction in time of pre-surgical treatment (obtaining one-year reduction in average), with the patient's benefit of an early improvement in facial esthetics. It can be applied not only in patients with UCLP and Class III malocclusion (GOSLON3+ onwards), but also in patients with UCLP and Class II malocclusion (GOSLON 1 and 1+), with or without skeletal vertical discrepancies.

Chang Gung Memorial Hospital group general guidelines for such approach states the following advantages of the procedure as follows [103, 104]: (1) Shorter pre-surgical orthodontic treatment time; (2) Reduction in the difficulty of post-surgical treatment through Regional Acceleratory Phenomena (RAP) [104]; (3) Possibility of planning and computer-guided execution (CAD-CAM); (4) Same effect on ATM as with traditional scheme, in addition to the surgical and functional advantages already mentioned. The post-operative rapid (accelerated) orthodontic tooth movement after SFEA in both dental arches is significant and is due to the increase in odontoclasts activity and dentoalveolar metabolic changes [105]. However, some disadvantages of SFEA include: (1) The need of careful orthodontic-surgical planning; (2) The preparation of the orthodontic-surgical team; (3) The appearance of possible post-surgical orthodontic problems; (4) A poor post-operative stability [97], in opposition to favorable long-term stability reported previously [96].

Mahmood and coworkers suggested that implementing a modified Surgery-Early protocol to speed-up final orthodontic-surgical treatment for CL ± CP patients would be useful [102]. However, Seo and coworkers found smaller incisor overjet, maxillary intercanine and intermolar ratios, and ratio of intercanine and intermolar distance in a group of surgical patients with UCLP and Class III malocclusion prepared to be treated with SFEA, than in a non-cleft group with a dentofacial deformity. The same group had also smaller anterior teeth contact number and larger incisor overjet than patients with UCLP and Class III malocclusion treated with a conventional protocol [106]. These difficulties have to be weighed when planning surgical procedures under this approach.

As a summary of the SFEA application, this modified version of the steps for performing orthognathic surgery under this approach are [103]: (1) Short period (≤6 months) of AP and vertical maxilla-mandibular decompensating orthodontics before the operation; (2) Reduction of possible dental collisions and minimal decompensation of mandibular teeth, through segmental maxillary surgery planning, surgically assisted rapid palatal expansion, or post-operative orthodontic tooth movement; (3) First / Early Modified Surgery 3D Model; (4) First/Early surgery based on specific therapeutic planning. Total treatment time is shortened in around 1 year, depending of the complexity of the remaining orthodontic treatment [103]. Treatment results of a patient with UCLP GOSLON4+ are shown in **Figure 12**.

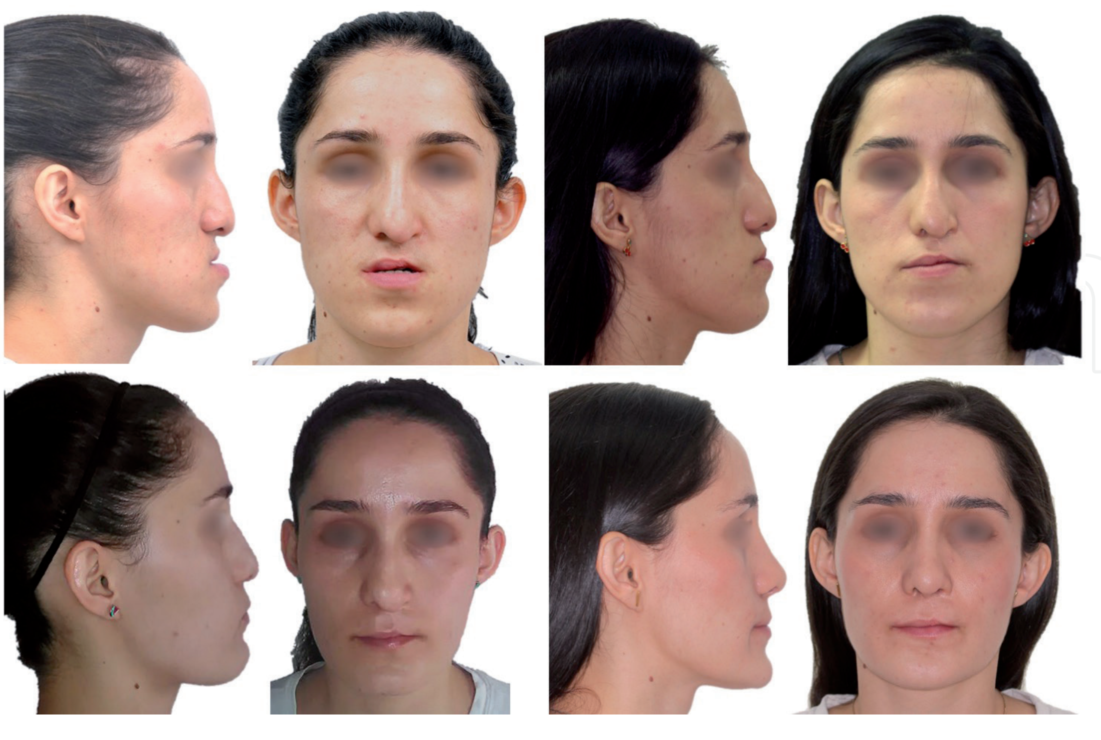

Figure 12.
Patient with UCLP undergoing maxillo-mandibular asymmetry correction through Surgery-First/Early Approach and Passive Self-ligation. a. and b. Before treatment; c. and d. Previous to Surgery-Early Approach. Noticed the dental changes obtained in the maxillary dentition by the use of passive self-ligation appliances; e. and f. After Surgery-Early Approach; d. After the end of treatment. Treatment time before treatment-surgery: 6 months, 25 days; Total Treatment time: 20 months, 25 days.

4. Current algorithm of treatment of patients with UCLP

The anterior information can be summarized to perform apparently different treatment choices in a rational order that will allow clinicians to identify the increasing difficulty of surgical orthodontic approaches used in the resolution of alveolar cleft with or without distraction osteogenesis and final orthognathic surgery (**Figures 13** and **14**).

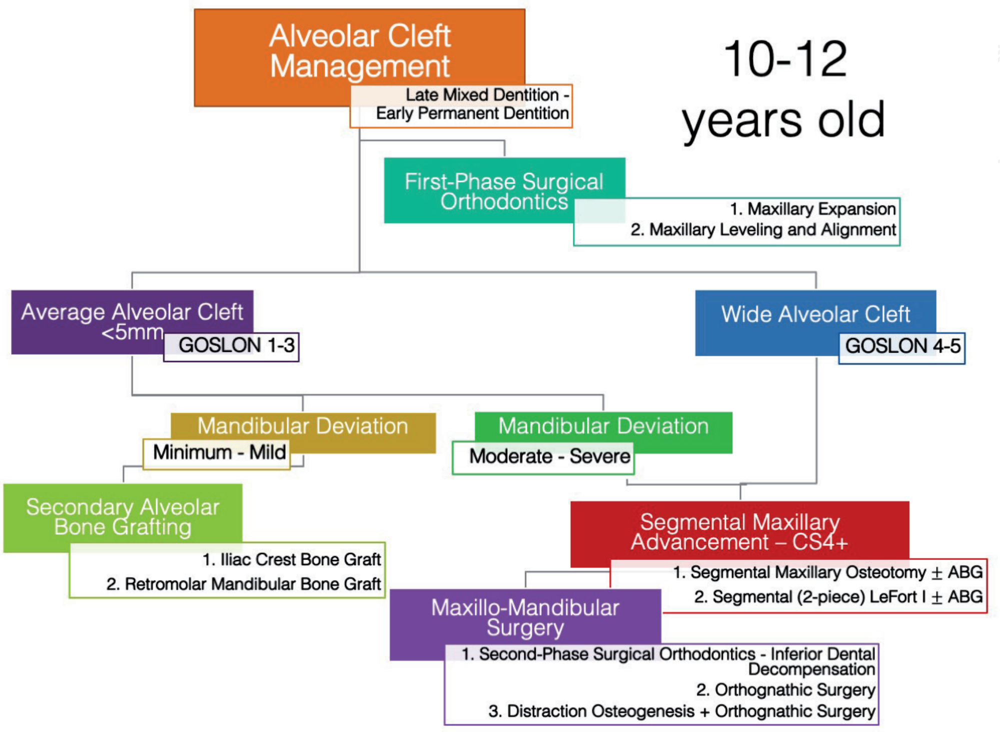

Figure 13.
Mixed dentition treatment algorithm for patients with UCLP. The final prognosis and outcome using this approach depends on severity of the cleft, the degree of mandibular deviation, and the surgical ability of the craniofacial team to obtain the desired goals.

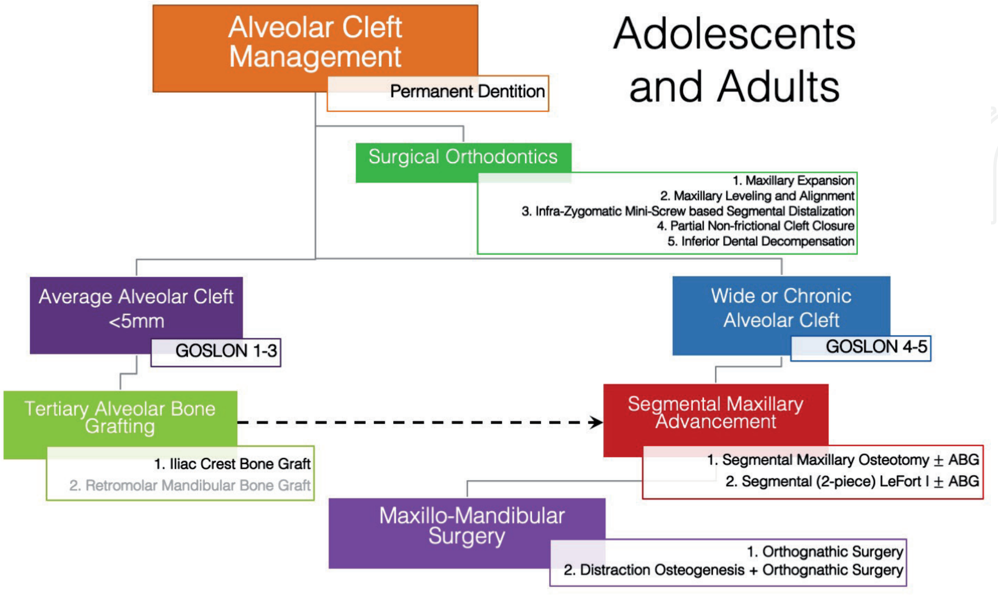

Figure 14.
Alternative treatment algorithm for adult patients with UCLP. A more expedite protocol following the same parameters (severity of the cleft, degree of mandibular deviation, and surgical ability of the craniofacial team) is performed in all patients with UCLP who have non-repaired clefts and require a definitive solution to their craniofacial difference.

5. Conclusion

Orthodontic treatment for patients with unilateral cleft lip and palate varies in the level of difficulty due to the increased involvement of orthodontic and surgical procedures involved, the correct timing of applying the complete treatment strategy, and the need of additional procedures to treat several dental anomalies present in teeth adjacent to the cleft, such as dental form and size anomalies, localized enamel hypoplasia, abnormal teeth number, and dental formation disturbances.

Our modified GOSLON+ yardstick allow us to categorize patients with UCLP in several discrete groups according to maxillary growth. Our treatment algorithms allow us to deliver appropriate treatment of the adolescent and young adult patients requiring effective orthodontic intervention for all surgical needs in our patient-based hospital settings in Colombia.

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References

[1] Human Genetics Programme – 2002, Management of Noncommunicable Diseases, World Health Organization. Global strategies to reduce the health-care burden of craniofacial anomalies: report of WHO meetings on International Collaborative Research on Craniofacial Anomalies, Geneva, Switzerland, 5-8 November 2000; Park City, Utah, U.S.A., 24-26 May 2001. [Internet]. World Health Organization. Geneva, Switzerland: World Health Organization; 2002. 1-148 p. Available from: https://apps.who.int/iris/bitstream/handle/10665/42594/9241590386.pdf;jsessionid=AAF943318BDAB5DFD5C42406CAF15EB1?sequence=1

[2] American Cleft Palate-Craniofacial Association. Parameters for evaluation and treatment of patients with cleft lip/palate or other cranofacial anomalies. Cleft Palate-Craniofacial J. 1993;30(SUPPL.).

[3] Bureau of Health Care Delivery and Assistance. Division of Maternal and Child Health US, Office of the Surgeon General. Public Health Service US. Surgeon General's Report: Children with special health care needs [Internet]. 1987. Available from: http://resource.nlm.nih.gov/101584932X515

[4] Mars M, Plint DA, Houston WJ, Bergland O, Semb G. The Goslon Yardstick: a new system of assessing dental arch relationships in children with unilateral clefts of the lip and palate. Cleft Palate J [Internet]. 1987 Oct;24(4):314-22. Available from: http://www.ncbi.nlm.nih.gov/pubmed/3479277

[5] Ozawa TO, Shaw WC, Katsaros C, Kuijpers-Jagtman AM, Hagberg C, Rønning E, et al. A new yardstick for rating dental arch relationship in patients with complete bilateral cleft lip and palate. Cleft Palate-Craniofacial J. 2011;48(2):167-72.

[6] Huddart AG, Bodenham RS. The evaluation of arch form and occlusion in unilateral cleft palate subjects. Cleft Palate J [Internet]. 1972 Jul;9(3):194-209. Available from: http://www.ncbi.nlm.nih.gov/pubmed/4505892

[7] Mossey PA, Clark JD, Gray D. Preliminary investigation of a modified Huddart/Bodenham scoring system for assessment of maxillary arch constriction in unilateral cleft lip and palate subjects. Eur J Orthod. 2005;27(5):507-11.

[8] Pruzanski S, Aduss H. Arch Form and the Deciduous Occlusion in Complete Unilateral Clefts. Cleft Palate J [Internet]. 1964 Oct;30(4):411-8. Available from: https://cleftpalatejournal.pitt.edu/ojs/cleftpalate/article/view/49/49

[9] Gray D, Mossey PA. Evaluation of a modified Huddart/Bodenham scoring system for assessment of maxillary arch constriction in unilateral cleft lip and palate subjects. Eur J Orthod. 2005;27(5):507-11.

[10] Haque S, Alam MK, Arshad AI. An overview of indices used to measure treatment effectiveness in patients with cleft lip and palate. Malaysian J Med Sci. 2015;22(1):4-11.

[11] Jabbari F, Reiser E, Thor A, Hakelius M, Nowinski D. Correlations between initial cleft size and dental anomalies in unilateral cleft lip and palate patients after alveolar bone grafting. Ups J Med Sci [Internet]. 2016 Jan 2;121(1):33-7. Available from: https://ujms.net/index.php/ujms/article/view/6320

[12] Stal S, Klebuc M, Taylor TD, Spira M, Edwards M. Algorithms for the treatment of cleft lip and palate. Clin Plast Surg [Internet]. 1998 Oct;25(4):493-507, vii. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9917970

[13] Hopper RA, Al-Mufarrej F. Gingivoperiosteoplasty. Clin Plast Surg. 2014;41(2):233-40.

[14] Santiago PE, Schuster LA, Levy-Bercowski D. Management of the alveolar cleft. Clin Plast Surg [Internet]. 2014;41(2):219-32. Available from: http://dx.doi.org/10.1016/j.cps.2014.01.001

[15] Yu X, Guo R, Li W. Comparison of 2- and 3-dimensional radiologic evaluation of secondary alveolar bone grafting of clefts: a systematic review. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2020;130(4):455-63. Available from: https://doi.org/10.1016/j.oooo.2020.04.815

[16] Bajaj AK, Wongworawat AA, Punjabi A. Management of Alveolar Clefts. J Craniofac Surg. 2003;14(6): 840-6.

[17] Vig KW. Alveolar bone grafts: the surgical/orthodontic management of the cleft maxilla. Ann Acad Med Singapore [Internet]. 1999 Sep;28(5):721-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10597360

[18] Park Y-H, Park S, Baek S-H. Alignment Strategy for Constricted Maxillary Dental Arch in Patients With Unilateral Cleft Lip and Palate Using Fixed Orthodontic Appliance. J Craniofac Surg [Internet]. 2018 Mar;29(2):264-9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29135724

[19] Bench RW. The quad helix appliance. Semin Orthod. 1998;4(4):231-7.

[20] Wilson WL, Wilson RC. Modular 3D lingual appliances. Part 1. Quad helix. J Clin Orthod. 1983;17(11):761-6.

[21] Chang C-S, Wallace CG, Hsiao Y-C, Chiu Y-T, Pai BC-J, Chen I-J, et al. Difference in the Surgical Outcome of Unilateral Cleft Lip and Palate Patients with and without Pre-Alveolar Bone Graft Orthodontic Treatment. Sci Rep [Internet]. 2016 Jul 4;6(1):23597. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27041697

[22] Brandt S, Ricketts RM. Interview: Dr. Robert M. Ricketts on growth prediction. 2. J Clin Orthod [Internet]. 1975 Jun;9(6):340-9, 352-62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1056932

[23] Enemark H, Jensen J, Bosch C. Mandibular bone graft material for reconstruction of alveolar cleft defects: Long-term results. Cleft Palate-Craniofacial J. 2001;38(2):155-63.

[24] Uzel A, Benlidayı ME, Kürkçü M, Kesiktaş E. The Effects of Maxillary Expansion on Late Alveolar Bone Grafting in Patients With Unilateral Cleft Lip and Palate. J Oral Maxillofac Surg. 2019;77(3):607-14.

[25] Aizenbud D, Ciceu C, Rachmiel A, Hazan-Molina H. Reverse Quad Helix Appliance. J Craniofac Surg [Internet]. 2012 Sep;23(5):e440-3. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22976698

[26] Liou EJ-W, Tsai W-C. A New Protocol for Maxillary Protraction in Cleft Patients: Repetitive Weekly Protocol of Alternate Rapid Maxillary Expansions and Constrictions. Cleft Palate-Craniofacial J [Internet]. 2005 Mar 15;42(2):121-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15748102

[27] Cozza P, De Toffol L, Mucedero M, Ballanti F. Use of a modified butterfly expander to increase anterior arch length. J Clin Orthod. 2003;37(9):490-5.

[28] Suzuki A, Takahama Y. A jointed fan-type expander: a newly designed expansion appliance for the upper dental arch of patients with cleft lip and/or palate. Cleft Palate J [Internet]. 1989 Jul;26(3):239-41; discussion 241. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2667812

[29] Kumar A, Ghafoor H, Khanam A. A comparison of three-dimensional stress distribution and displacement of naso-maxillary complex on application of forces using quad-helix and nickel titanium palatal expander 2 (NPE2): a FEM study. Prog Orthod [Internet]. 2016;17(1). Available from: http://dx.doi.org/10.1186/s40510-016-0131-3

[30] Deswita Y, Soegiharto BM, Tarman KE. Camouflage treatment of skeletal Class III malocclusion in an adult cleft-palate patient using passive self-ligating system. Am J Orthod Dentofac Orthop [Internet]. 2019;155(1):117-26. Available from: https://doi.org/10.1016/j.ajodo.2017.07.028

[31] Isaacson RJ, Lindauer SJ, Davidovitch M. The ground rules for arch wire design. Semin Orthod. 1995; 1(1):3-11.

[32] Davidovitch M, Rebellato J. Two-couple orthodontic appliance systems utility arches: a two-couple intrusion arch. Semin Orthod. 1995;1(1):25-30.

[33] Rebellato J. Two-couple orthodontic appliance systems: transpalatal arches. Semin Orthod. 1995;1(1):44-54.

[34] Lindauer SJ, Isaacson RJ. One-couple orthodontic appliance systems. Semin Orthod. 1995;1(1):12-24.

[35] Liou EJW, Chen PKT. Intraoral Distraction of Segmental Osteotomies and Miniscrews in Management of Alveolar Cleft. Semin Orthod [Internet]. 2009 Dec;15(4):257-67. Available from: http://dx.doi.org/10.1053/j.sodo.2009.07.002

[36] Haas Junior OL, Guijarro-Martínez R, de Sousa Gil AP, da Silva Meirelles L, de Oliveira RB, Hernández-Alfaro F. Stability and surgical complications in segmental Le Fort I osteotomy: a systematic review. Int J Oral Maxillofac Surg. 2017;46(9):1071-87.

[37] Garcia MA, Yatabe M, Fuzer TU, Calvo AM, Trindade-Suedam IK. Ideal versus late secondary alveolar bone graft surgery: A bone-thickness cone-beam computed tomographic assessment. Cleft Palate-Craniofacial J. 2018;55(3):369-74.

[38] Matsui K, Echigo S, Kimizuka S, Takahashi M, Chiba M. Clinical Study on Eruption of Permanent Canines after Secondary Alveolar Bone Grafting. Cleft Palate-Craniofacial J [Internet]. 2005 May 15;42(3):309-13. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15865467

[39] Wang YC, Liao YF, Chen PKT. Outcome of gingivoperiosteoplasty for the treatment of alveolar clefts in patients with unilateral cleft lip and palate. Br J Oral Maxillofac Surg [Internet]. 2013;51(7):650-5. Available from: http://dx.doi.org/10.1016/j.bjoms.2012.09.012

[40] Rawashdeh MA, Telfah H. Secondary Alveolar Bone Grafting: the Dilemma of Donor Site Selection and Morbidity. Br J Oral Maxillofac Surg [Internet]. 2008 Dec;46(8):665-70. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18760515

[41] Weissler EH, Paine KM, Ahmed MK, Taub PJ. Alveolar Bone Grafting and Cleft Lip and Palate. Plast Reconstr Surg [Internet]. 2016 Dec;138(6):1287-95. Available from: http://journals.lww.com/00006534-201612000-00025

[42] Jackson IT, Helden G, Marx R. Skull bone grafts in maxillofacial and craniofacial surgery. J Oral Maxillofac Surg [Internet]. 1986 Dec;44(12):949-55. Available from: http://dx.doi.org/10.1016/S0278-2391(86)80048-9

[43] Lilja J. Alveolar bone grafting. Indian J Plast Surg [Internet]. 2009 Oct;42(3):S110-5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19884665

[44] Santoni BG, Pluhar GE, Motta T, Wheeler DL. Hollow calcium phosphate

microcarriers for bone regeneration: in vitro osteoproduction and ex vivo mechanical assessment. Biomed Mater Eng [Internet]. 2007;17(5):277-89. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17851170

[45] Urist MR. Bone transplants and implants. In: Urist MR, editor. Fundamental and Clinical Bone Physioogy. Philadelphia: Lippincott, Williams & Wilkins; 1980. p. 331-68.

[46] Boyan BD, Weesner TC, Lohmann CH, Andreacchio D, Carnes DL, Dean DD, et al. Porcine Fetal Enamel Matrix Derivative Enhances Bone Formation Induced by Demineralized Freeze Dried Bone Allograft In Vivo. J Periodontol. 2000;71(8):1278-86.

[47] Goldberg VM, Stevenson S. Natural history of autografts and allografts. Clinical Orthopaedics and Related Research. 1987. p. 7-16.

[48] Klein Y, Kunthawong N, Fleissig O, Casap N, Polak D, Chaushu S. The impact of alloplast and allograft on bone homeostasis: Orthodontic tooth movement into regenerated bone. J Periodontol. 2020;91(8):1067-75.

[49] Canady JW, Zeitler DP, Thompson SA, Nicholas CD. Suitability of the Iliac Crest as a Site for Harvest of Autogenous Bone Grafts. Cleft Palate-Craniofacial J [Internet]. 1993 Nov;30(6):579-81. Available from: http://www.cpcjournal.org/doi/abs/10.1597/1545-1569%281993%29030%3C0579%3ASOTICA%3E2.3.CO%3B2

[50] Vasco Ramírez M. Training future anesthesiologists in obstetric care. Curr Opin Anaesthesiol. 2017 Jun 1;30(3):313-8.

[51] Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallén O, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg Suppl [Internet]. 1977;16:1-132. Available from: http://www.ncbi.nlm.nih.gov/pubmed/356184

[52] Rocha R, Ritter DE, Locks A, Ribeiro GL. Maxillary segment surgical advancement for treatment of cleft lip and palate: Case report. J World Fed Orthod [Internet]. 2013;2(4):e199-211. Available from: http://dx.doi.org/10.1016/j.ejwf.2013.09.002

[53] Schuchardt K. Formen des offenen Bisses und ihre operativen Behandlungsmöglichkeiten. Fortschr Kiefer Gesichtschir. 1955;1:222-6.

[54] Ermel T, Hoffmann J, Alfter G, Göz G. Long-term stability of treatment results after upper jaw segmented osteotomy according to Schuchardt for correction of anterior open bite. J Orofac Orthop. 1999;60(4):236-45.

[55] Baeg S, On S, Lee J, Song S. Posterior maxillary segmental osteotomy for management of insufficient inter-maxillary vertical space and intermolar width discrepancy: a case report. Maxillofac Plast Reconstr Surg [Internet]. 2016;38(1). Available from: http://dx.doi.org/10.1186/s40902-016-0074-0

[56] Bailey LJ, White RP, Proffit WR, Turvey TA. Segmental lefort I osteotomy for management of transverse maxillary deficiency. J Oral Maxillofac Surg. 1997;55(7):728-31.

[57] Carpentier S, Van Gastel J, Schoenaers J, Carels C, Poorten V Vander, Coucke W, et al. Evaluation of transverse maxillary expansion after a segmental posterior subapical maxillary osteotomy in cleft lip and palate patients with severe collapse of the lateral maxillary segments. Cleft Palate-Craniofacial J. 2014;51(6):651-7.

[58] Posnick JC, Adachie A, Choi E. Segmental Maxillary Osteotomies in

Conjunction With Bimaxillary Orthognathic Surgery: Indications – Safety – Outcome. J Oral Maxillofac Surg [Internet]. 2016;74(7):1422-40. Available from: http://dx.doi.org/10.1016/j.joms.2016.01.051

[59] Leshem D, Tompson B, Phillips JH. Segmental LeFort I Surgery: Turning a Predicted Soft-Tissue Failure into a Success. Plast Reconstr Surg [Internet]. 2006 Oct;118(5):1213-6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17016192

[60] Kretschmer WB, Baciut G, Baciut M, Zoder W, Wangerin K. Changes in bone blood flow in segmental LeFort I osteotomies. Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology [Internet]. 2009;108(2):178-83. Available from: http://dx.doi.org/10.1016/j.tripleo.2009.04.029

[61] Blæhr TL, Jensen T, Due KM, Neumann-Jensen B. Stability of the Anterior Maxillary Segment and Teeth after Segmental Le Fort I Osteotomy and Postoperative Skeletal Elastic Fixation With or Without Occlusal Splint. J Oral Maxillofac Res. 2014;5(3):1-7.

[62] Ilizarov GA, Ledyaev VI. The Replacement of Long Tubular Bone Defects by Lengthening Distraction Osteotomy of One of the Fragments. 1969. Clin Orthop Relat Res. 1992; 280(July):7-10.

[63] Ilizarov GA. The principles of the Ilizarov method. Bull Hosp Jt Dis Orthop Inst. 1988;48(1 (Spring)):1-11.

[64] Ilizarov GA. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. Clin Orthop Relat Res [Internet]. 1989 Jan;238(238):249-81. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2910611

[65] Ilizarov GA. The Tension-Stress Effect on the Genesis and Growth of Tissues: Part II. The Influence of the Rate and Frequency of Distraction. Clin Orthop Relat Res. 1989;239(Feb):263-85.

[66] Ilizarov GA. Clinical Application of the Tension-Stress Effect for Limb Lengthening. Clin Orthop Relat Res. 1990;250(Jan):8-26.

[67] McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the Human Mandible by Gradual Distraction. Plast Reconstr Surg [Internet]. 1992 Jan;89(1):1-8. Available from: http://journals.lww.com/00006534-199289010-00001

[68] Wassmund M. Frakturen und Luxationen des Gesichtsschädels: unter Berücksichtigung der Komplikationen des Hirnschädels: ihre Klinik und Therapie: praktisches Lehrbuch. Berlin: Hermann Meusser; 1927. 384p.

[69] Molina F, Monasterio FO, de la Paz Aguilar M, Barrera J. Maxillary Distraction: Aesthetic and Functional Benefits in Cleft Lip-Palate and Prognathic Patients during Mixed Dentition. Plast Reconstr Surg [Internet]. 1998 Apr;101(4):951-63. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9514327

[70] Block MS, Brister GD. Use of distraction osteogenesis for maxillary advancement: Preliminary results. J Oral Maxillofac Surg [Internet]. 1994 Mar;52(3):282-6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/8308627

[71] Rachmiel A, Potparic Z, Jackson IT, Sugihara T, Clayman L, Topf JS, et al. Midface advancement by gradual distraction. Br J Plast Surg [Internet]. 1993 Apr;46(3):201-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/8490698

[72] Polley JW, Figueroa AA. Management of Severe Maxillary Deficiency in Childhood and Adolescence Through Distraction Osteogenesis With an

External, Adjustable, Rigid Distraction Device. J Craniofac Surg [Internet]. 1997 May;8(3):181-5. Available from: http://journals.lww.com/00001665-199705000-00008

[73] Polley JW, Figueroa AA. Rigid External Distraction: Its Application in Cleft Maxillary Deformities. Plast Reconstr Surg [Internet]. 1998 Oct;102(5):1360-72. Available from: http://journals.lww.com/00006534-199810000-00007

[74] Figueroa AA, Polley JW. Management of severe cleft maxillary deficiency with distraction osteogenesis: Procedure and results. Am J Orthod Dentofac Orthop [Internet]. 1999 Jan;115(1):1-12. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0889540699703100

[75] Figueroa AA, Polley JW, Ko EW-C. Maxillary distraction for the management of cleft maxillary hypoplasia with a rigid external distraction system. Semin Orthod [Internet]. 1999 Mar;5(1):46-51. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10371940

[76] Figueroa AA, Polley JW, Friede H, Ko EW. Long-Term Skeletal Stability after Maxillary Advancement with Distraction Osteogenesis Using a Rigid External Distraction Device in Cleft Maxillary Deformities. Plast Reconstr Surg [Internet]. 2004 Nov;114(6):1382-92. Available from: http://journals.lww.com/00006534-200411000-00003

[77] Swennen G, Figueroa AA, Schierle H, Polley JW, Malevez C. Maxillary distraction osteogenesis: A two-dimensional mathematical model. J Craniofac Surg [Internet]. 2000;11(4):312-7. Available from: http://sci-hub.tw/10.1097/00001665-200011040-00006%0A

[78] Gottlieb EL, Wildman AJ, Hice TL, Lang HM, Lee IF, Strauch EC. The Edgelok bracket. J Clin Orthod [Internet]. 1972 Nov;6(11):613-23 passim. Available from: http://www.ncbi.nlm.nih.gov/pubmed/4510446

[79] Hanson GH. The SPEED system: a report on the development of a new edgewise appliance. Am J Orthod [Internet]. 1980 Sep;78(3):243-65. Available from: https://linkinghub.elsevier.com/retrieve/pii/0002941680902705

[80] Damon DH. The rationale, evolution and clinical application of the self-ligating bracket. Clin Orthod Res [Internet]. 1998 Aug;1(1):52-61. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9918646

[81] Damon DH. The Damon low-friction bracket: a biologically compatible straight-wire system. J Clin Orthod. 1998;32(11):670-80.

[82] Buehler WJ, Gilfrich J V., Wiley RC. Effect of Low-Temperature Phase Changes on the Mechanical Properties of Alloys near Composition TiNi. J Appl Phys [Internet]. 1963 May;34(5):1475-7. Available from: http://aip.scitation.org/doi/10.1063/1.1729603

[83] Tien HC, Yang FZ, Liu H, Guo JF. Orthodontic TiNi wire. J Rare Met China. 1982;29:69-75.

[84] Burstone CJ, Qin B, Morton JY. Chinese NiTi wire—A new orthodontic alloy. Am J Orthod [Internet]. 1985 Jun;87(6):445-52. Available from: http://www.ncbi.nlm.nih.gov/pubmed/3890554

[85] Chen R, Zhi YF, Arvystas MG. Advanced Chinese NiTi alloy wire and clinical observations. Angle Orthod [Internet]. 1992;62(1):59-66. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1445516

[86] Gil FJ, Planell JA. Effect of copper addition on the superelastic behavior of Ni-Ti shape memory alloys for

orthodontic applications. J Biomed Mater Res. 1999;48(5):682-8.

[87] Dalstra M, Melsen B. Does the transition temperature of cu-niti archwires affect the amount of tooth movement during alignment? Orthod Craniofacial Res. 2004;7(1):21-5.

[88] Miles PG. Self-ligating brackets in orthodontics: Do they deliver what they claim? Aust Dent J. 2009;54(1):9-11.

[89] Papageorgiou SN, Konstantinidis I, Papadopoulou K, Jäger A, Bourauel C. Clinical effects of pre-adjusted edgewise orthodontic brackets: A systematic review and meta-analysis. Eur J Orthod. 2014;36(3):350-63.

[90] Yang X, Xue C, He Y, Zhao M, Luo M, Wang P, et al. Transversal changes, space closure, and efficiency of conventiona and self-ligating appliances: A quantitative systematic review. J Orofac Orthop. 2018;79(1):1-10.

[91] Atik E, Taner T. Stability comparison of two different dentoalveolar expansion treatment protocols. Dental Press J Orthod. 2017;22(5):75-82.

[92] Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. Oral Surgery, Oral Med Oral Pathol. 1957; 10(7):677-89.

[93] Poulton DR, Taylor RC, Ware WH. Cephalometric x-ray evaluation of the vertical osteotomy correction of mandibular prognathism. Oral Surgery, Oral Med Oral Pathol. 1963;16(7):807-20.

[94] Obwegeser HL. Surgical correction of small or retrodisplaced maxillae. The "Dish-face" Deformity. Plast Reconstr Surg. 1969;43(4):351-65.

[95] Worms FW, Isaacson RJ, Speidel TM. Surgical Orthodontic Treatment Planning: Profile Analysis and Mandibular Surgery. Angle Orthod. 1976;46(1):1-25.

[96] Epker BN, Fish LC. Surgical-orthodontic correction of open-bite deformity. Am J Orthod [Internet]. 1977 Mar;71(3):278-99. Available from: http://www.ncbi.nlm.nih.gov/pubmed/265137

[97] Wei H, Liu Z, Zang J, Wang X. Surgery-first/early-orthognathic approach may yield poorer postoperative stability than conventional orthodontics-first approach: a systematic review and meta-analysis. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2018; 126(2):107-16. Available from: https://doi.org/10.1016/j.oooo.2018.02.018

[98] Nagasaka H, Sugawara J, Kawamura H, Nanda R. "Surgery first" skeletal Class III correction using the Skeletal Anchorage System. J Clin Orthod [Internet]. 2009 Feb;43(2):97-105. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19276579

[99] Yamauchi K, Takahashi T, Yamaguchi Y, Suzuki H, Nogami S, Sugawara J. Effect of "surgery first" orthognathic approach on temporo-mandibular symptoms and function: a comparison with "orthodontic first" approach. Oral Surg Oral Med Oral Pathol Oral Radiol [Internet]. 2019;127(5):387-92. Available from: https://doi.org/10.1016/j.oooo.2018.10.008

[100] Villegas C, Uribe F, Sugawara J, Nanda R. Expedited correction of significant dentofacial asymmetry using a "surgery first" approach. J Clin Orthod [Internet]. 2010 Feb;44(2):97-103; quiz 105. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20552809

[101] Aristizábal JF, Martínez-Smit R, Díaz C, Pereira Filho VA. Surgery-first approach with 3D customized passive self-ligating brackets and 3D surgical planning: Case report. Dental Press J Orthod. 2018;23(3):47-57.

[102] Mahmood HT, Ahmed M, Fida M, Kamal AT, Fatima F. Concepts, protocol, variations and current trends in surgery first orthognathic approach: a literature review. Dental Press J Orthod [Internet]. 2018;23(3):36.e1-36.e6. Available from: http://www.ncbi.nlm.nih.gov/pubmed/30088563

[103] Liou EJW, Chen PH, Wang YC, Yu CC, Huang CS, Chen YR. Surgery-first accelerated orthognathic surgery: Orthodontic guidelines and setup for model surgery. J Oral Maxillofac Surg. 2011;69(3):771-80.

[104] Huang CS, Chen YR. Orthodontic principles and guidelines for the surgery-first approach to orthognathic surgery. Int J Oral Maxillofac Surg [Internet]. 2015;44(12):1457-62. Available from: http://dx.doi.org/10.1016/j.ijom.2015.05.023

[105] Liou EJW, Chen PH, Wang YC, Yu CC, Huang CS, Chen YR. Surgery-first accelerated orthognathic surgery: Postoperative rapid orthodontic tooth movement. J Oral Maxillofac Surg. 2011;69(3):781-5.

[106] Seo HJ, Denadai R, Pai BC-J, Lo L-J. Modern Surgery-First Approach Concept in Cleft-Orthognathic Surgery: A Comparative Cohort Study with 3D Quantitative Analysis of Surgical-Occlusion Setup. J Clin Med. 2019; 8(12):2116.