3 Complications Associated with Distraction Osteogenesis

Suzanne U. Stucki-McCormick and Louis F. Clarizio

Contents

3.1 **Case 1: Small Bone Segment DO** 55
3.2 **Case 2. Preprosthetic Augmentation** 61
3.3 **Case 3: Mandibular Distraction, Vector Control** 62
3.4 **Case 4: Maxillary DO and Arc of Rotation Around First Molar** 62
References 67

Since the application of distraction osteogenesis to the bones of the craniofacial skeleton in the early 1990s, the DO technique has gained success and acclaim [1, 2]. The primary advantage of the distraction osteogenesis (DO) technique is that the slow application of force over time allows for histiogenesis and the generation of all tissues: skin, muscle, nerves, blood vessels, and bone (Fig. 3.1a–c) [3]. The changes in the facial skeleton are impressive, with secondary correction of the affected skeleton not in the original site of distraction including improvement of the airway [4, 5].

S. U. Stucki-McCormick (✉)
Department of Oral and Maxillofacial Surgery, School of Dentistry, University of California Los Angeles, Los Angeles, CA, USA

L. F. Clarizio
Private Practice, Portsmouth, NH, USA

Conventional orthoghnathic surgery allows for the immaediater movement of a bone to its new positon, held in place and allowed to heal. In contrast, the distraction osteogenesis technique requires the application of forec over time with the bones gradually moved to the final position. Conseqently, it is vital that the surgcial team ensures close pateint follow-up during the entire DO process and consolidation phases [6]. As with other techniques of the bony skeleton, complications encountered during and after DO surgery are similar to that of conventional orthognathic and dentoalveolar surgery, and discussed elsewhere [7]. However, the complications unique to distraction osteogenesis can be divided into three categories: poor planning, poor execution, and lack of attention to detail with a lack of close follow-up.

The "consolidation phase" when the DO device is in neutral fixation and the segment has been advanced to its optimal position is the most important for this close follow-up. It is during the

R. Gassner (ed.), *Complications in Cranio-Maxillofacial and Oral Surgery*,
https://doi.org/10.1007/978-3-030-40150-4_3

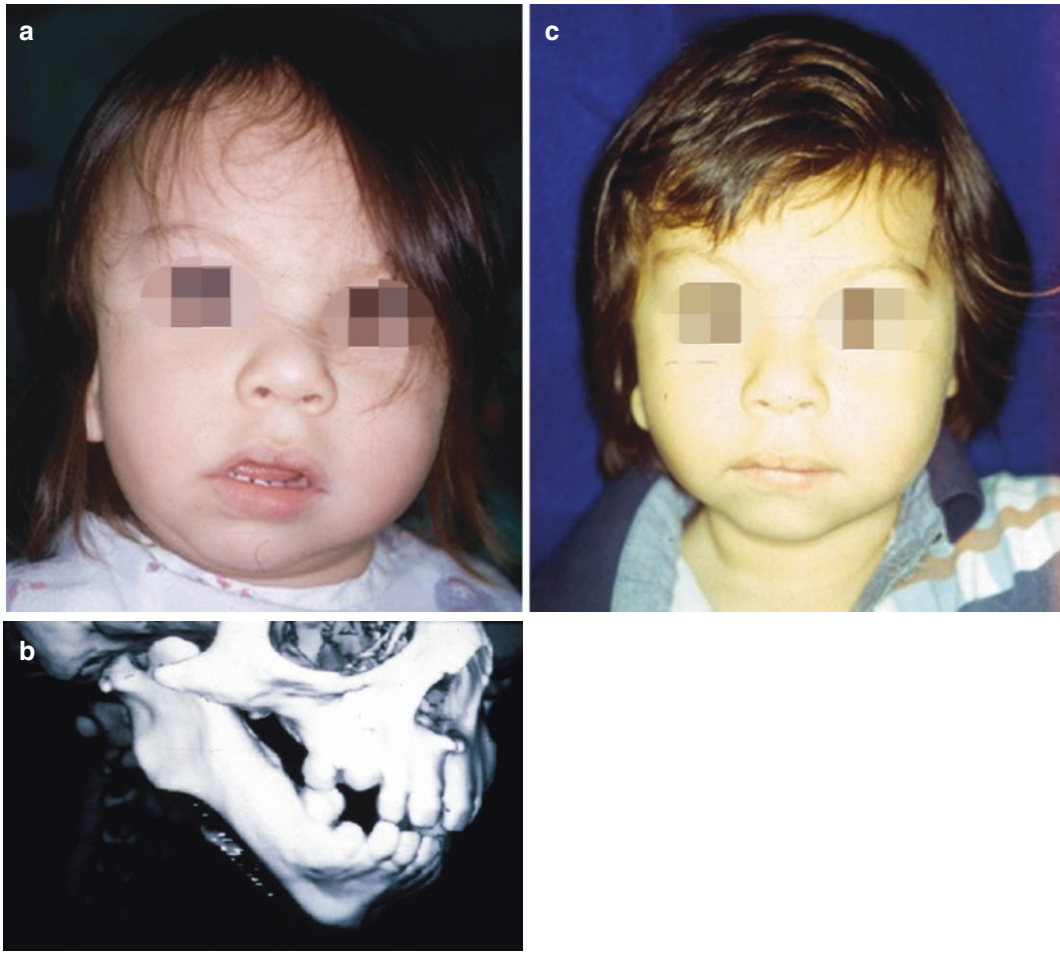


Fig. 3.1 (**a**) A young child with unilateral craniofacial microsomia prior to mandibular distraction osteogenesis (DO). Chin point deviation, occlusal cant, hypoplastic right zygona, and right microtia are noted. (**b**) 3-D CT scan of the patient with Type IIb craniofacial macrosomia. (**c**) After mandibular DO, facial form is reestablished. The power of the distraction technique is noted by the soft tissue response

consolidation phase when the new regenerate bone is at its softest, with minimal ossification. Similarly, at the end of DO, that the DO device is fully "open," when structural stability of the device at its weakest and minor local muscle forces can rotate and torque even the best designed DO devices. Consequently, the regenerate is susceptible to adjacent muscle pull resulting in complications such as open bite, misshaped regenerate, tipping of the regenerate, and other force-related phenomenon including those as a consequence of a patient parafunctional habits.

Distraction osteogenesis allows for the expansion of the osseous skeleton in vectors outside those of traditional orthognathic surgery including mandibular widening (Fig. 3.2a–d). Again all tissues are created allowing for orthodontic movement of teeth into the newly distracted bone. However, as the distraction plane is counter to that of the physiologic skeleton-muscular envelope of the face, the rate of relapse was initially high. This relapse was primarily due to local muscle pull. The advent of newer hybrid distraction devices have overcome this challenge [8].

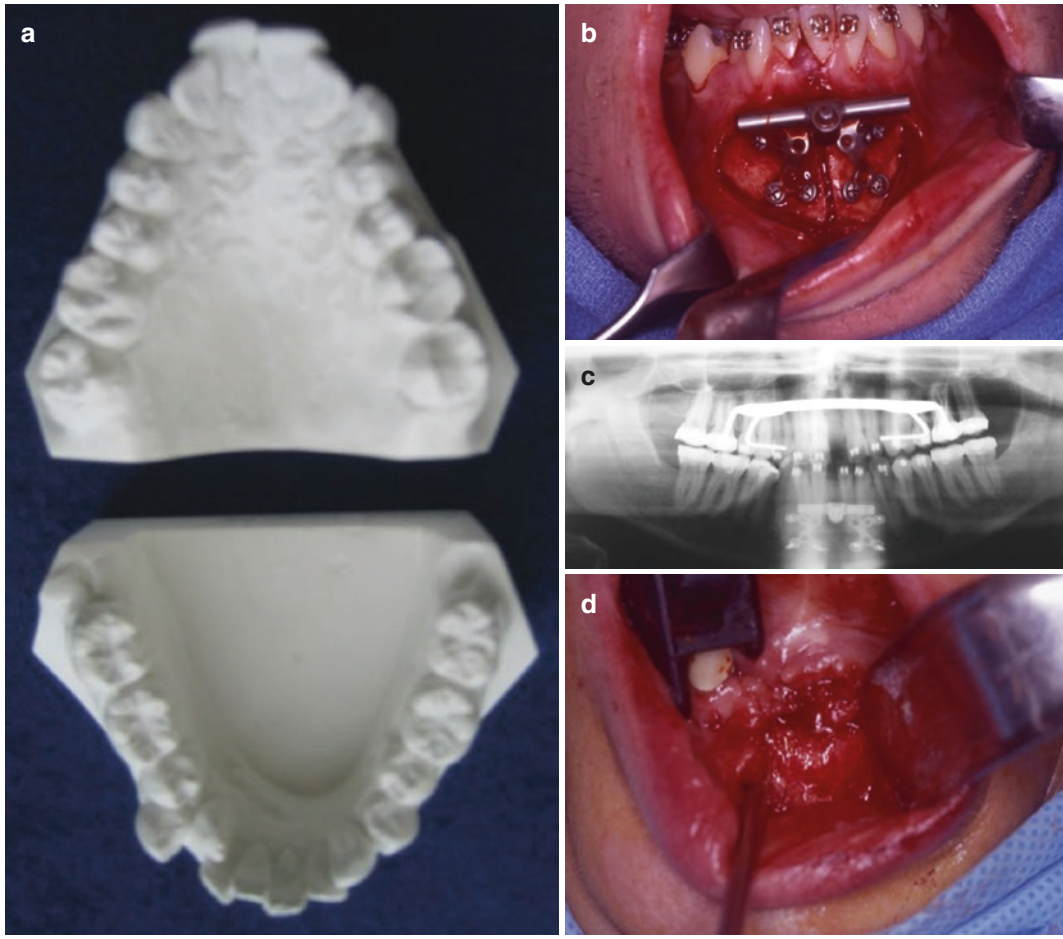


Fig. 3.2 (**a**) A patient with severe constriction of the maxilla and mandible underwent maxillary and mandibular widening using DO. (**b**) The osseous-borne DO device in place for mandibular widening. (**c**) The panoramic radiograph showing maxillary and mandibular widening during DO. (**d**) The osseous regenerate created from the DO process is noted at the time of DO device removal

With the advent of Virtual Surgical Planning (VSP), many of the complications associated with the planning phase of the DO technique have been obviated (Fig. 3.3). VSP allows the clinician to reproduce the osseous anatomic site in 3-D, both on the computer and in a stereolithic model (SLA) (Fig. 3.4). This allows for visualization of critical anatomic structure including neurovascular structures, and unerupted teeth. The computer models can now predict the bony movements planned and the vector of DO device as it is positioned on the bone (Fig. 3.5). The volumetric airway change can also be predicted using VSP simulation [9]. Thus the clinician can customize: 1. choice of size/length of the DO device, 2. the positioning of the DO device, and 3. the placement of DO device retention screws, all as to avoid vital structures and trajectory concerns. Using VSP, the osteotomy can also be planned in 3-D. Here, the bone cut can be modified, angled, or stepped to enhance osseous gain during DO as well as to avoid vital structures [10]. The resultant planned osteotomy is converted to a custom surgical guide (Fig. 3.6a, b). The VSP of the osteotomy and planned movement can identify sites of potential bony interfer-

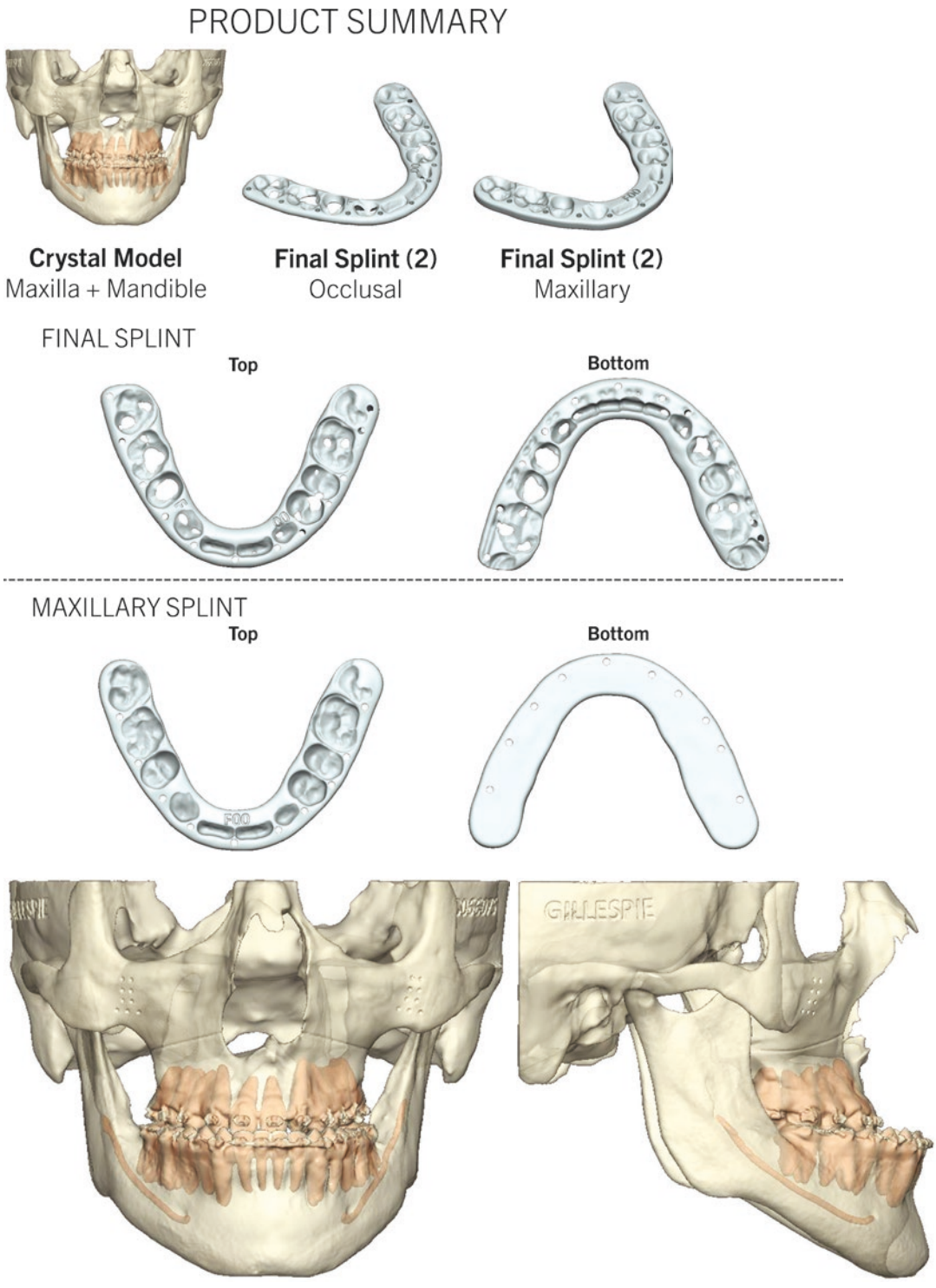


Fig. 3.3 Virtual surgical planning (VSP) allows the surgeon to visualize the maxillary osseous structure, planned osteotomy, and DO device/screw placement here in 3-D. (With permission from Dr. Richard Burton)

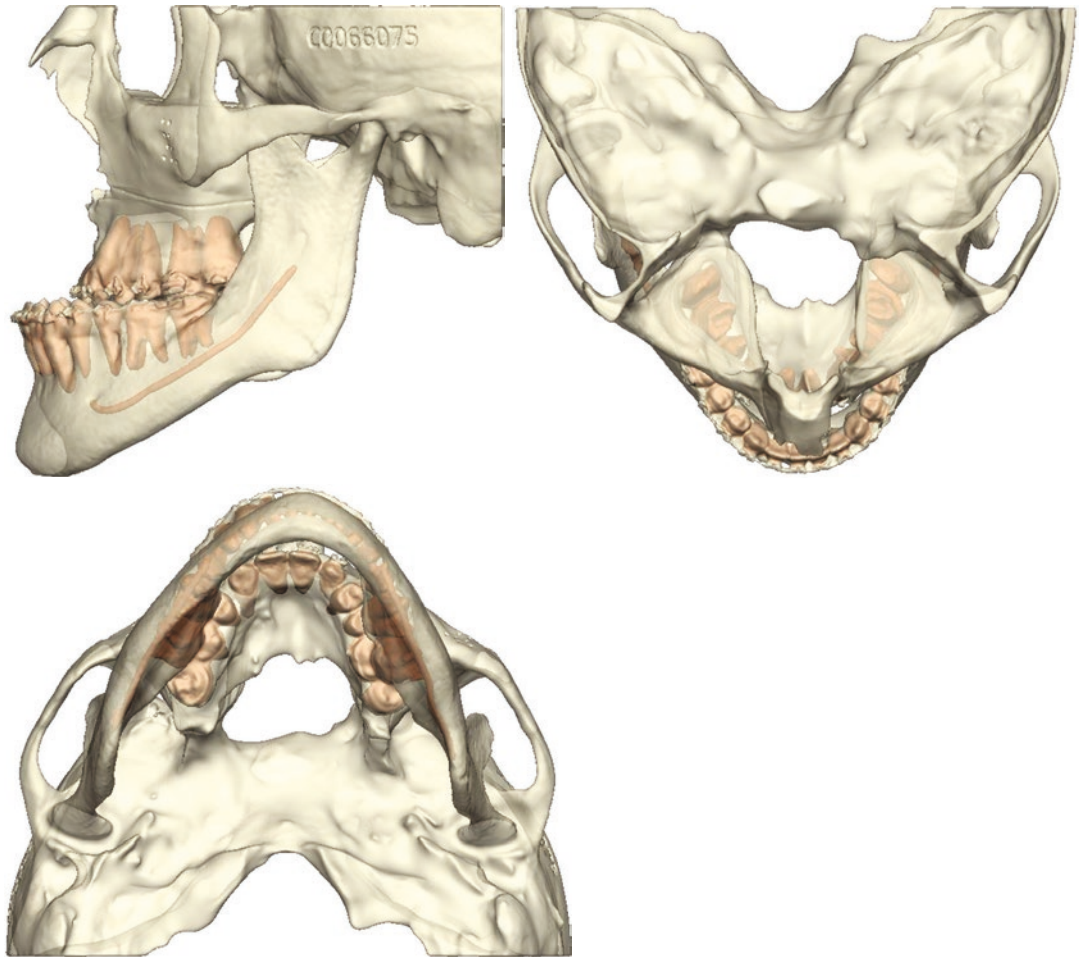


Fig. 3.3 (continued)

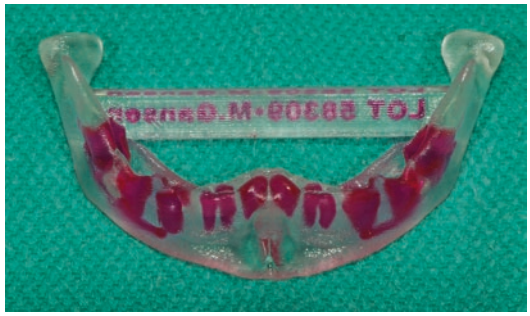


Fig. 3.4 A stereolithic model can be generated during the VSP planning process. The model allows for visualization of vital intraosseous structures including the neurovascular bundle and unerupted teeth in this infant with micrognathia. (With permission from Dr. Richard Burton)

ences or protuberances that may need to be removed prior to closure of the site which are useful and verified during surgery (Fig. 3.7a, b). VSP planning can also identify areas of potential technical/device limitations and failures. In general, submerged devices exhibit less technical failures [11].

Care must be taken during the VSP phase as to verify the location of the planned osteotomies versus the local muscles. A bone cut anterior to the masseteric muscle sling can result in proximal segment rotation due to local muscle pull, much like an unfavorable fracture of the mandible. For large mandibular advancements, the infrahyoid musculature is most pronounced to

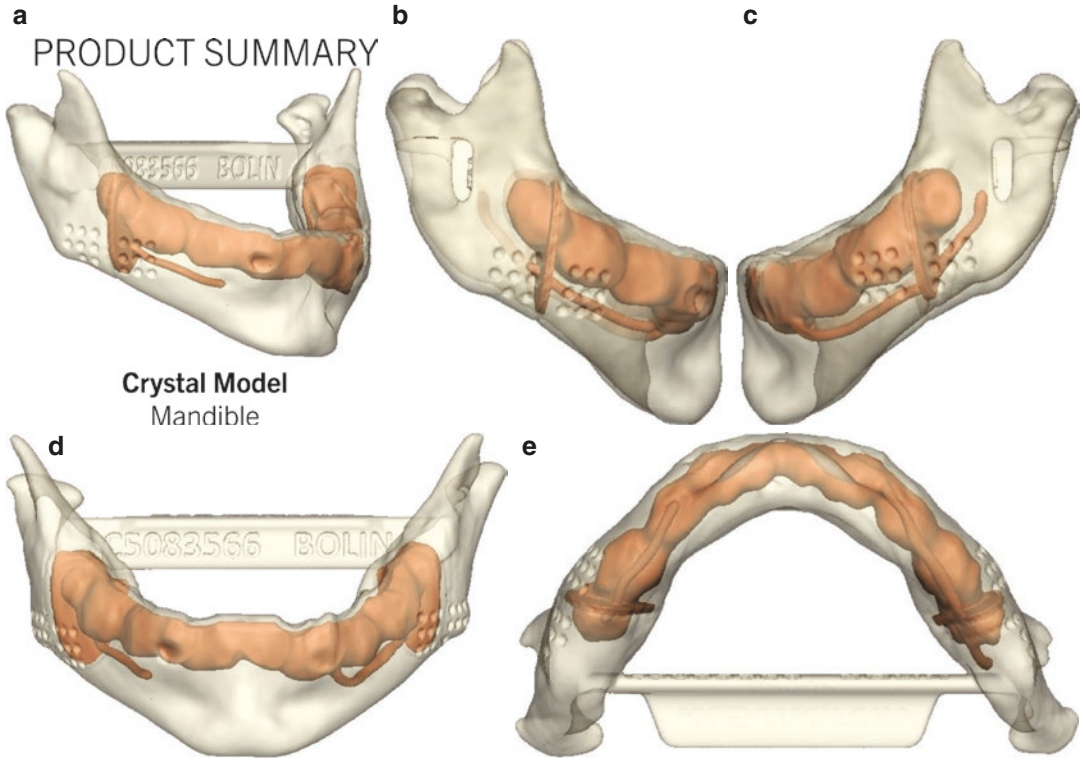


Fig. 3.5 (**a**) Virtual surgical planning (VSP) allows for accurate identification of anatomic landmarks including the IAN and tooth buds for infant distraction osteogenesis. (**b**, **c**) VSP allows the clinician to identify and plan the site of the DO bone cut as well as the device placement/trajectory and retention screw sites for the infant airway DO device in both lateral views right (**b**) and left (**c**). (**d**, **e**) The device placement and trajectory can be verified in the frontal (**d**) and submandibular (**e**) views. Additionally, the device footplate and retention screw hole sites can be verified in these views as to avoid vital structures

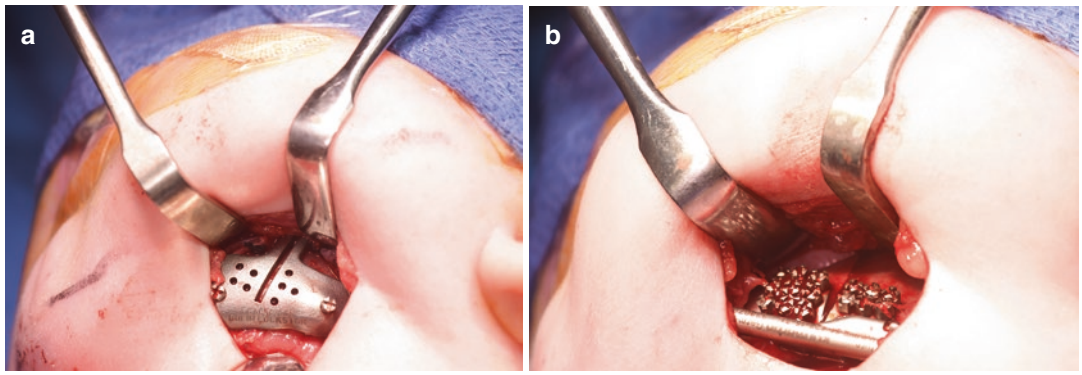


Fig. 3.6 (**a**, **b**) The planned surgical guide is in place. Here the osteotomy is angled, as to avoid vital intraosseous structures. The DO device is placed in the planned orientation. (With permission from Dr. Richard Burton)

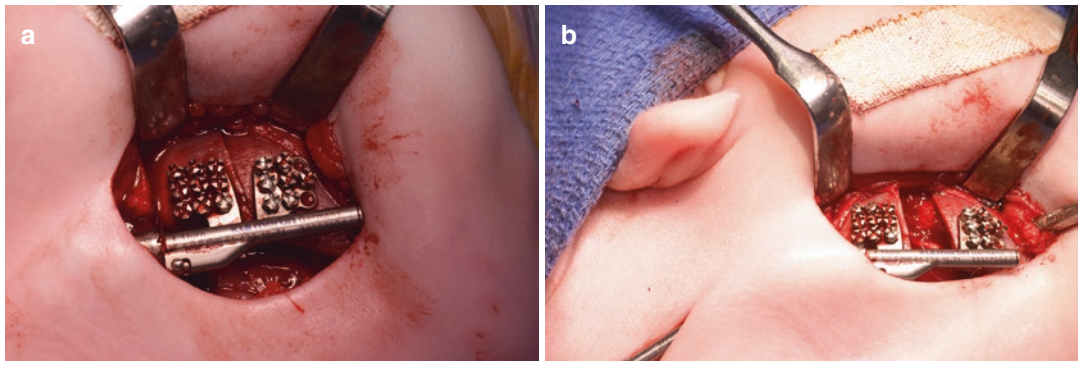


Fig. 3.7 (**a**, **b**) On the contralateral side, the device is placed in the planned position. The device is activated to ensure free movement of the DO site. The IAN can be visualized. (With permission from Dr. Richard Burton)

affect a clockwise rotation of the distal segment, especially during the end of DO, during the consolidation phase. Similarly, vertical alveolar DO can be affected by the pull of the mylohyoid if its insertion is high on the lingual aspect of the mandible. Thus unexpected challenges can be encountered during surgery necessitating a "Plan B." The following are four complications representing categories of challenges that occur during distraction osteogenesis. Many of these complications are "old school," and occurred prior to the advent of virtual surgical planning, VSP. However even with VSP, these occurrences represent the most common complications associated with DO of the craniofacial skeleton. Thus identifying these challenges/complications and how they were addressed gives insight and highlights the need for attention to detail during the entire DO process, from planning to final DO device removal.

3.1 Case 1: Small Bone Segment DO

A 35-year-old male presented to the office with complaints of periodontal involvement around a dental implant to area #8. Several years earlier, he was playing water polo and was struck in the face, with damage to tooth #8 (Fig. 3.8a). At the time #8 was removed and an immediate implant placed. The implant was placed, immediately into the remaining bone, 2 mm below the crest of the bone, as was the standard of care then, back at the time when the implant was placed into an immediate extraction site (Fig. 3.8c, d). This led to the implant being placed significantly below the level of the alveolus to the adjacent teeth. A longer crown and long custom abutment were fabricated which over time led to localized periodontal involvement, as the site was difficult to clean (Fig. 3.8e).

Physical examination revealed that the overlying gingival tissue had acceptable contour and concern was raised that removal of the implant and subsequent localized bone grafting might result in a lesser gingival contour (Fig. 3.8f–h). Consequently, it was decided to perform small segment distraction osteogenesis, DO whereby the implant would be part of the small DO/transport disc, as to vertically reposition the osseointegrated implant [12–15]. First, the overly elongated crown was removed and a temporary crown fabricated, as to allow adjustment/reduction of the incisal edge of the crown during the DO process, as the implant was distracted vertically downwards, from its original submerged positon, towards the crest of the alveolar ridge (Fig. 3.8i).

The site was approached through a vestibular incision. The small alveolar DO device (Track 1.0, KLS Martin LLP) was modified and used for the DO (Fig. 3.8j). The osteotomy was planned to be a two vertical bone cuts and one horizontal cut leaving approximately 1 mm of bone around the

implant laterally and 2 mm of bone vertically to the implant, as to avoid the teeth on both sides and the floor of the nose.

Taking advantage of the curvature of the alveolus and the concavity of the bone in the cuspid region, the vertical activation portions was located in the cuspid fossa with the activation site exposed in the vestibule between the cuspid and lateral incisor (Fig. 3.8k, l). This site was chosen as to help hide the DO device when smiling versus placement of the DO device more proximally, adjacent to the central incisors. As the bone segment was

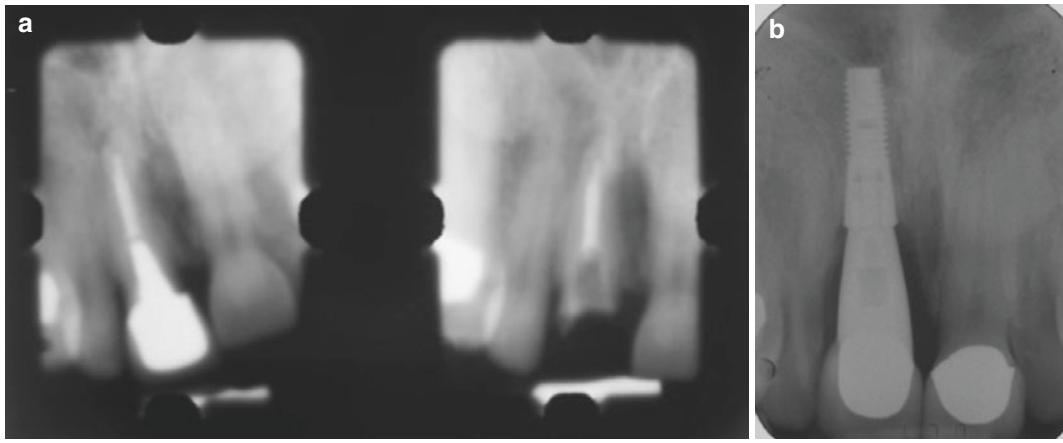


Fig. 3.8 (**a**) Adult patient with endodontically treated central incisor, now with water polo sports injury resulting in root fracture. At the time of tooth removal, there was existing vertical alveolar bone loss. (With permission from Dr. Richard Burton). (**b**–**d**) The fractured tooth was removed and an immediate implant placed. The immediate implant was placed 2 mm below the remaining crest of the ridge, according to the protocol at the time. This resulted in the need for a custom abutment with a long abutment neck as noted on the periapical (**b**), panoramic (**c**), and lateral cephalometric (**d**) views. (**e**) The implant integrated and the bone remodeled as noted on this periapical radiograph 5 years after implant placement. (**f**, **g**) The gingival esthetics and health were compromised due to the long custom abutment noted on the facial (**f**) and palatal (**g**). (**h**) A low smile line is noted that helped to camouflage the gingival compromise. (**i**) The crown was removed and a new resin crown was fabricated to allow for small bone segment distraction osteogenesis (DO). (**j**) A 1.0 Track alveolar DO device (KLS Martin LLP) was modified. Note the bending of the lateral arms in a "butterfly" pattern. As to allow adaptation of the DO device to the curvature of the maxilla. (**k**) The planned osteotomy was created as to avoid the teeth on either side and the floor of the nose: two vertical bone cuts with 1 mm cuff of bone lateral to the implant and one horizontal cut leaving approximately 2 mm of bone apical to the implant. (**l**) The aid in esthetics and comfort, track device was positioned so that the activation site and vertical arm was positioned in the canine fossa (O). (**m**) As the site was small, only the lower arm with a single screw was used in the transport disc containing the implant. (**n**) During active DO, the resin crown was reduced vertically, as the distraction proceeded. (**o**) At the end of DO, the small segment was held in place to allow for ossification. The implant remained integrated during the DO process. (**p**) After DO, the implant positon was improved yet short of the ideal, as the small segment rotated, due to the long cantilever arm for the Track device positioned in the canine fossa. (**q**) A 5-year periapical radiograph revealed the distracted implant to be well healed with good bone stability of the distraction sites and crestal bone levels

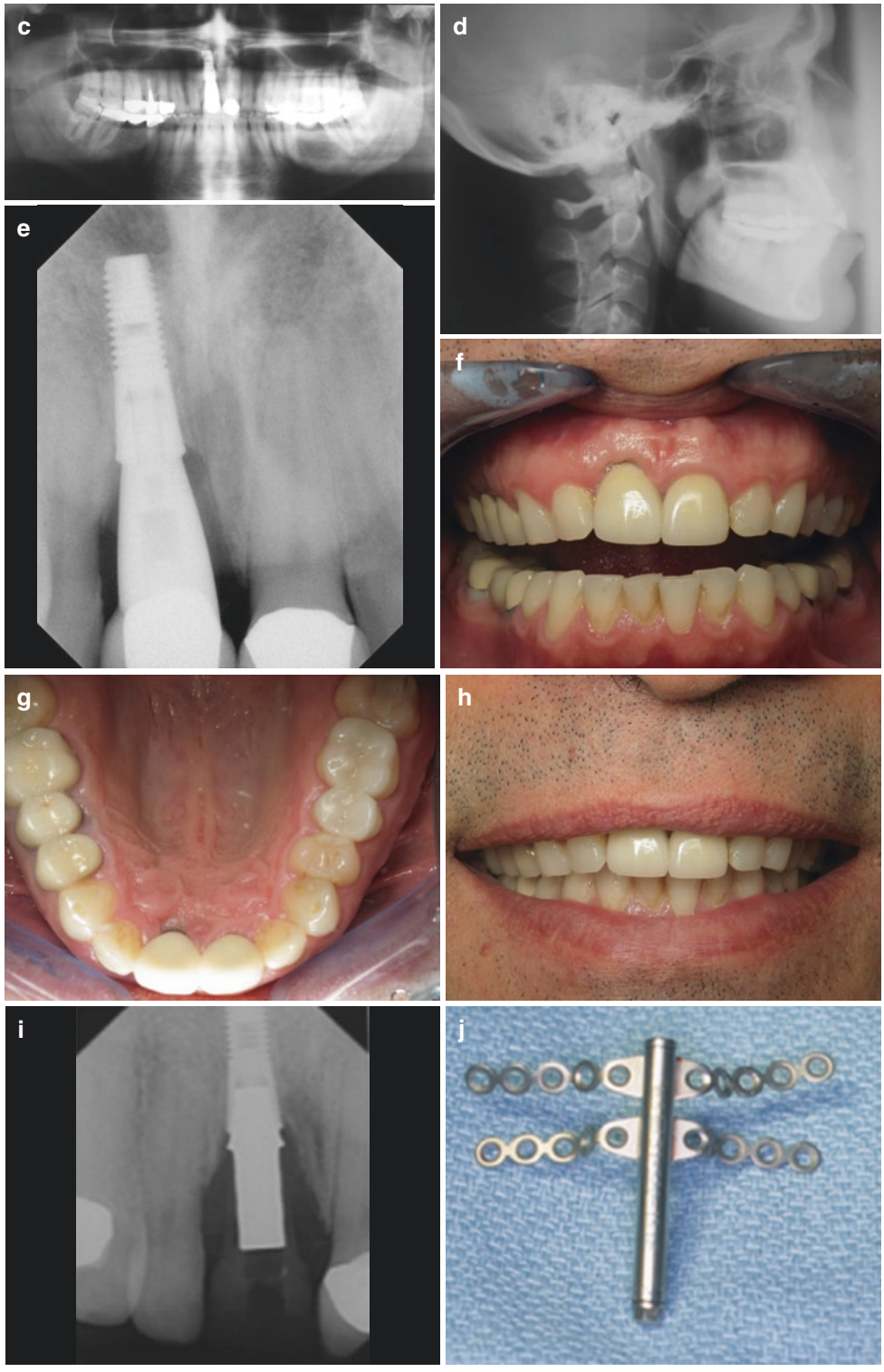


Fig. 3.8 (continued)

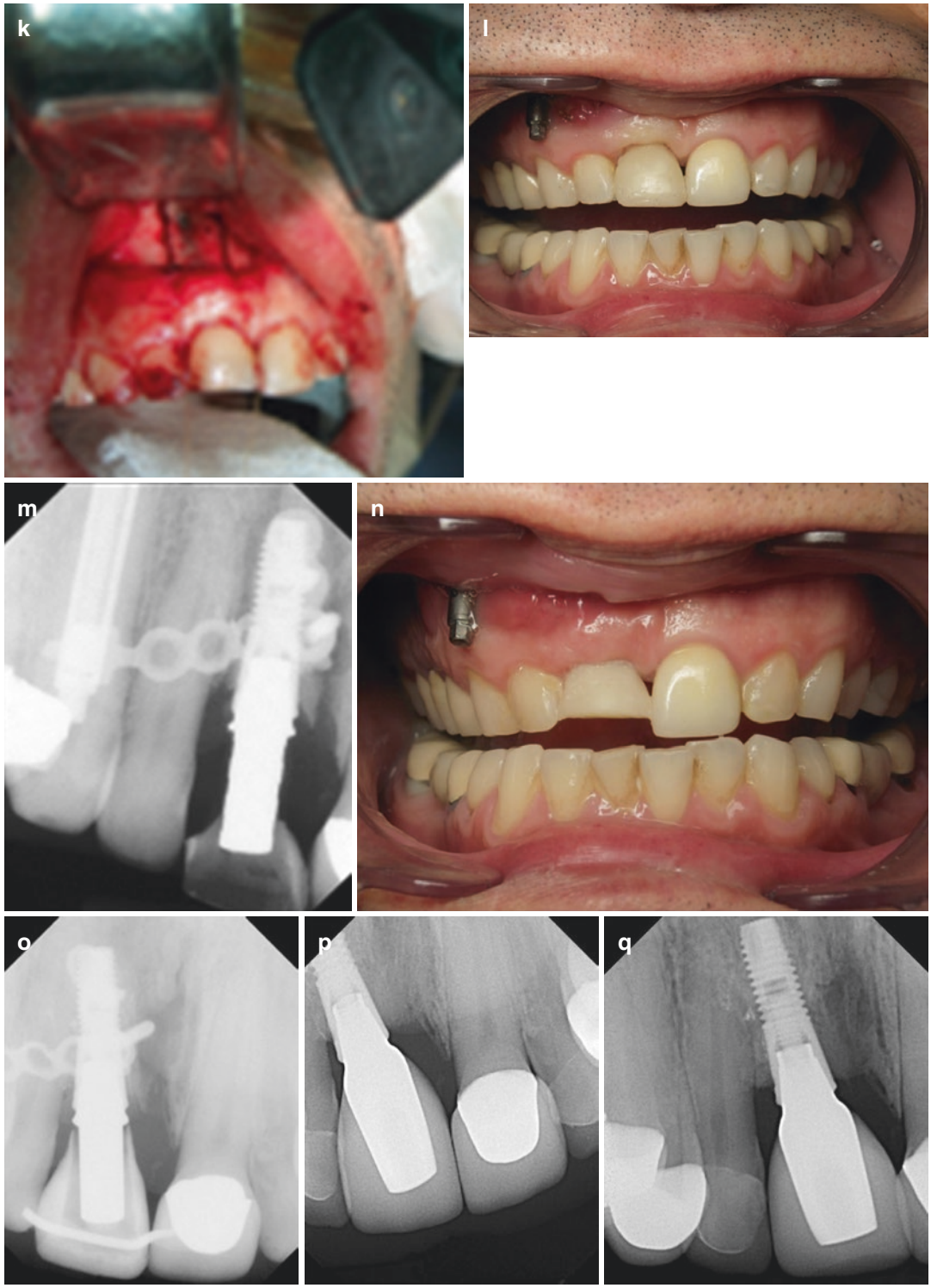


Fig. 3.8 (continued)

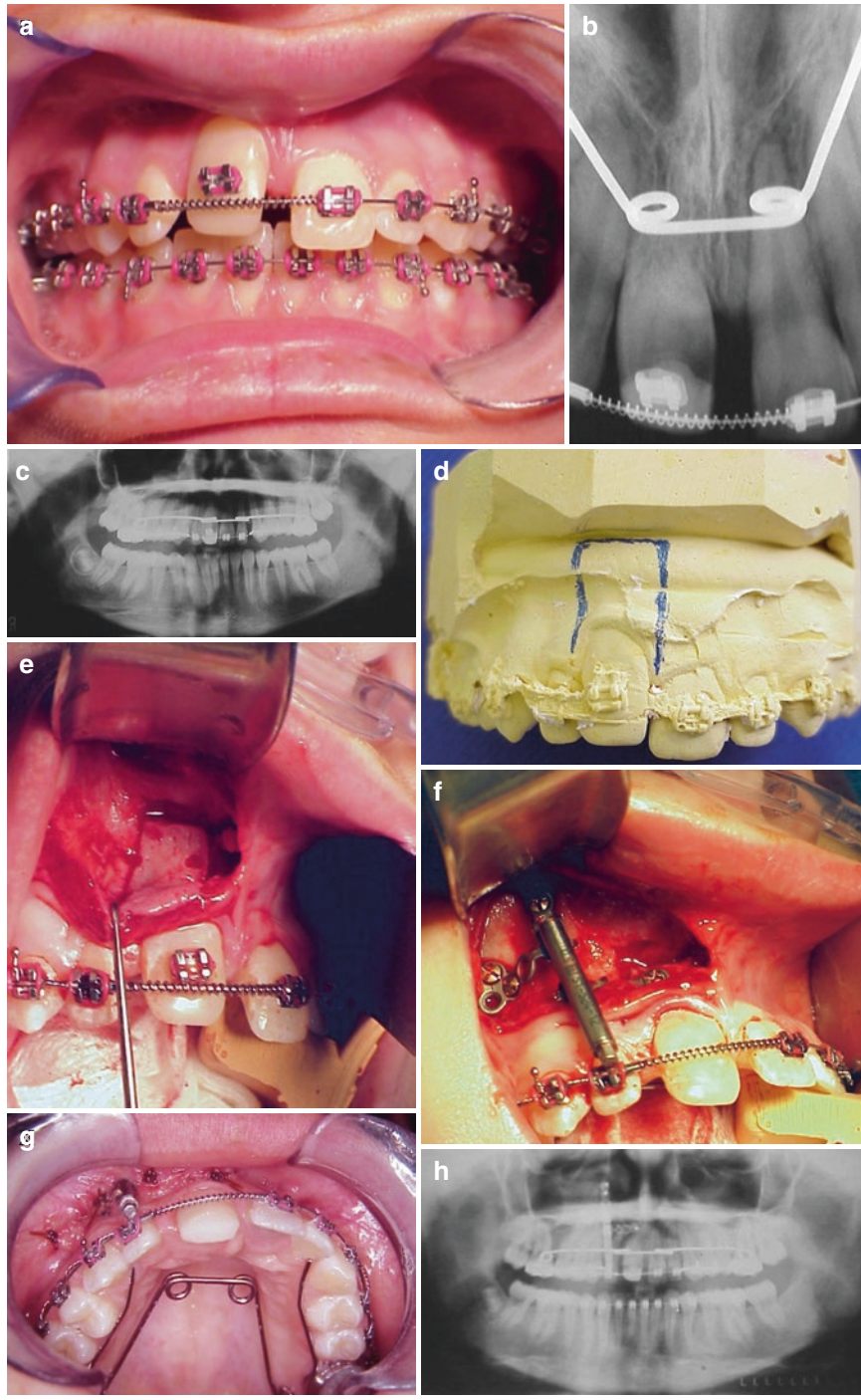


Fig. 3.9 A second case of dentoalveolar ankylosis, was a patient whose the central incisor underwent trauma as a child. To camouflage, tooth colored material was placed at the incisive edge to make the two central incisors symmetrical (**a**). The tooth is noted to have internal/external resorption on the periapical radiograph (**b**). The associated alveolar bone is located vertically high, as compared to the remaining alveolus as seen on the periapical and panoramic radiograph (**b**, **c**). (**d**, **e**) The distraction segment was planned on the model and created in the maxilla leaving a cuff of bone as to protect the adjacent teeth and floor of nose. (**f**) The 1.0 Track device (KLS Martin LLP) was adapted to fit the curvature of the maxilla. Due to the small segment size, only one of the lateral arms was utilized for the transport DO. (**g**, **h**) Orthodontic traction was utilized to guide the tooth and associated bone and soft tissue, down into proper position

small, only one of the horizontal arms could be used on both sides, with only one screw placed into the bony segment apical to the implant, and two screws placed into the horizontal bone above the apices of the premolar teeth (Fig. 3.8m).

The site was closed and active DO was started 5 days after surgery. The distraction technique went well with the implant and surrounding bone being transported vertically towards the crest of the ridge with the adjacent soft tissue. The incisal edge of the crown was periodically reduced, to allow for vertical distraction, thus bringing the implant, along with the surrounding bone and soft tissue, down towards the crest of the ridge from its original submerged location (Fig. 3.8n). Although greatly improved, the final planned result was shy of the optimal vertical position in which the implant would be coincident with the remaining alveolar height (Fig. 3.8o, p). A 5-year follow-up shows maintenance of the implant health and osseous integrity in the new distracted site (Fig. 3.8q). Close evaluation of the radiographs revealed the following complications occurred, which limited the complete vertical distraction to the preplanned site:

1. The long lever arm of the DO device allowed for bending of the horizontal arms of the distraction device and rotation of the transport segment. The vertical portion of the DO device was placed near the cuspid fossa to avoid the nasal floor and take advantage of the piriform rim for esthetics and patient comfort. This placement did create a long lever arm of the horizontal portion of the DO device. Therefore as DO progressed, the horizontal DO arm bent during the later stages of active DO. Additionally as there was only one screw in the transport segment for fixation, the transport segment was able to rotate as the DO device was advanced. Note the angle change of the implant. Originally the implant was parallel with the roots of the adjacent teeth. At the end of DO, the implant was slightly angled from vertical (Fig. 3.8n–q).
2. VSP could have helped with the planning portion of this surgery, especially to create bone cuts as to allow more rigid fixation of the DO device. The newer Micro TRACK is ideal for this clinical situation. Additionally it must be remembered that during active DO, there is NOT a 1:1 correlation between the activation of the device and the amount of movement of the transport/DO site. Here this phenomenon was heightened as the lever arm from the vertical, activation site of the DO device was very long to the site of force application into the transport segment. With a longer lever arm, the amount of DO advancement per turn of device activation was significantly reduced.
3. Use of orthodontic traction would have helped guide the DO transport bone segment containing the implant into the final site (Fig. 3.9a–h).
   (a) A 42-year-old female presented for implant consultation. She had prior trauma to tooth # 8 as a child, resulting in ankyloses of the tooth in a more vertical position (Fig. 3.9a–c). This was camouflaged by placing acrylic on the incisal edge. With time, the tooth experienced internal resorption requiring removal. However, to achieve optimal bone and soft tissue contour, it was planned to distract the tooth and alveolus prior to extraction of the tooth (Fig. 3.9d).
   (b) A similar vertical and horizontal bone cuts were created, and using distraction osteogenesis, the tooth and alveolus were distracted vertically along with the soft tissue (Fig. 3.9e–g). Here, orthodontic guidance was used to assist in the path of draw of the transport segment (Fig. 3.9h). Additionally the new TRACK alveolar device (KLS Martin) with the vertical foot plate was utilized, which prevented lateral rotation of the DO device. The scalloped gingival contour was maintained and respotitoned vertically as a result of the distraction technique. Once osseous healing occurred, the tooth was removed and optimal implant reconstruction completed.

3.2 Case 2. Preprosthetic Augmentation

A 42-year-old male presented for implant reconstruction of three missing maxillary teeth: first bicuspid, canine, and lateral incisor. The patient had a history of wearing a removable partial denture such that there was adequate bone width, yet inadequate bone height and a "U"-shaped vertical alveolar deformity (Fig. 3.10a). The defect was appreciated as the patient could extend his tongue through the defect while in maximal occlusion (Fig. 3.10b).

Dentoalveolar distraction was planned and performed [6, 7]. Using a vestibular incision, the bone cuts were made, the DO device placed, path of draw verified, the site closed, and DO commenced after a 5-day latency (Fig. 3.10c, d). DO proceeded without incident continuing until the site was distracted fully, "over-distracted" with the regenerate extending beyond the crest of the alveolus (Fig. 3.10e). It has been suggested that the DO site should be planned for a 20% over-distraction to allow for maturation of the site prior to implant placement [16–19].The site was held in neutral fixation for osseous consolidation/healing. During the consolidation period, a bony protuberance was noted on the palatal (Fig. 3.10f). Additionally, exposure of the distraction device and screws were noted (Fig. 3.10g). The site was managed without incident and sufficient bone was generated through the DO process as to place three osseointegrated implants. This case highlights two complications that can occur during alveolar DO: 1. displacement of the small DO transport segment and 2. exposure of the distraction device and screws.

1. During the final stage of DO, the soft tissue pull upon the site of distraction can be considerable, especially in the alveolus where there is a significant difference in the tightness of the soft tissue: loose tissue buccal, and dense tissue on the palatal. Here, at the end of DO, when the DO device is fully expanded, the differential alveolar tissue pull, the effect of local muscles including the orbicularis oris and the patient's parafunctional habit of placing their tongue through the surgical site, allowed the DO device to "fall" toward the palate thus dislodging the transport disc/alveolar DO segment. This was managed by manually pushing the alveolar segment buccal as to align the site (Fig. 3.10h, i).
   (a) This complication was common with early cases of dentoalveolar DO, and led to the advancement of DO technology. The DO device was modified and a small footplate added to the base of the vertical portion of the TRACK distraction devices, as to prevent the tipping of the device and bone segment. Utilizing this footplate is essential to ensure clinical success with DO for preprosthetic augmentation [13–15].
   (b) Additionally, orthodontic and/or prosthetic appliances can be constructed to prevent this tipping and guide the transport disc to ideal position.
2. VSP would also help in this case, as the computer 3-D image would show that the "U"-shaped bony deformity was actually not uniform: the bone height was taller next to the central incisor as compared with the bone height adjacent to the bicuspid. Recognizing this would allow the surgeon to trim the bone slightly on the one edge of the distraction segment. The shape of the new alveolar bone can be visualized when the path of draw of the distraction device is verified, prior to closure of the site.
3. The exposure of the DO device plate and screw can occur. It is best to treat the site locally with chlorohexidine both as rinses and topically. If tissue tension is noted, the DO protocol can be modified to allow for smaller daily incremental advancements of the DO device. For example, ½ turn 4 times a day versus 1 turn twice a day. Slow application of the distraction force allows the soft tissue envelope to stretch and passively advance the osseous segment.

3.3 Case 3: Mandibular Distraction, Vector Control

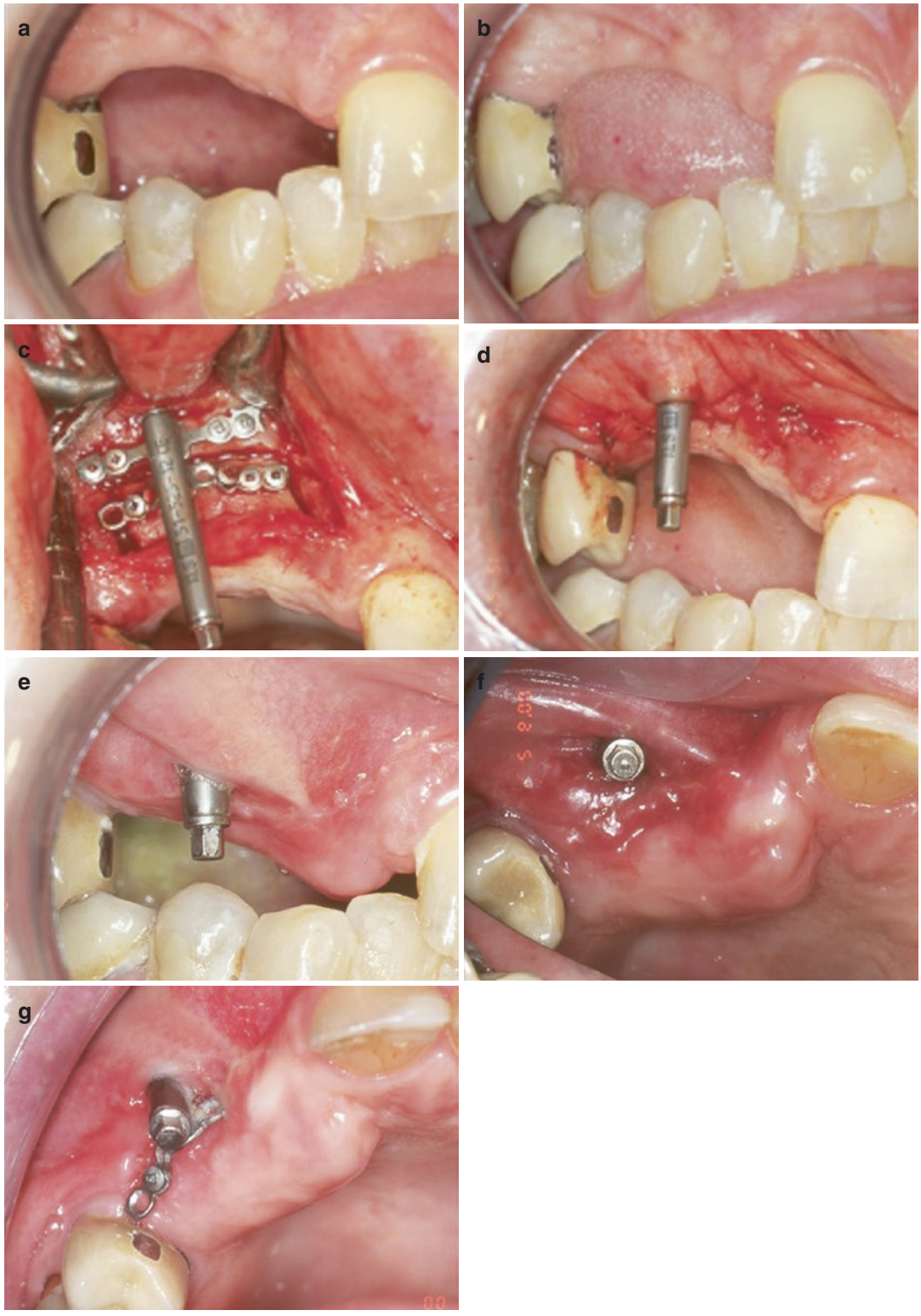
A 20-year-old female with mandibular hypoplasia underwent mandibular distraction. The mandibular DO proceeded uneventfully yet an open bite was created during the distraction process. Careful review of the radiographs revealed poor planning of the vector of DO as well as the effect of muscle pull on the distraction site. This case was managed with the removal of the DO device prior to the completion of the consolidation phase, and elastic traction; "bone floating" was performed to close the open bite [20–23].

1. Review of the radiographs revealed that the DO device has been placed with the DO device oriented more parallel to the inferior boarder rather than more parallel with the occlusal plane. As distraction advanced, the mandible moved in a forward and downward direction (Fig. 3.11a). Additionally, the osteotomy was placed anterior to the masseteric muscle sling such that the proximal segment was influenced by vertical muscle pull, and the distal segment affected by the supra-hyoid muscles in an inferior direction both contributing to an open bite (Fig. 3.11b). As this case was early in the evolution of DO devices, the number of screw holes available in the footplates of the DO device were few in number. This led to the development of DO devices designed with larger array of footplate screw fixation sites.
2. VSP would aid in the prevention of this complication. However, attention to detail of the location of the osteotomy versus the location of potential muscle pull vectors must be maintained. In this case, the open bite only became apparent after active DO was completed and the site held in neutral fixation as to allow ossification of the regenerate. As the open bite was noticed early, the regenerate could be manipulated and correct the complication. Here the DO device was removed prior to complete ossification, and using elastic traction, the open bite was closed and elastic force applied until consolidation was complete (Fig. 3.11c).

3.4 Case 4: Maxillary DO and Arc of Rotation Around First Molar

Maxillary DO has changed the treatment options especially for severe maxillary cleft lip and palate hypoplasia and other craniofacial deformities [24–28]. Even from the early experience with maxillary DO using a Petit Delaire mask in the nonsyndromic patient, it was noted that when slow force is applied to the freed maxilla, an anterior open bite usually occurs (Fig. 3.12a, b). This is because there is an arc of rotation of the maxilla centered above the root of the maxillary first molar, rotating the maxilla in a counterclockwise vector to produce an open bite [29]. A 13-year-old female presents with her mother for maxillary DO. She is status post repair of a bilateral cleft lip and pate and is in need of 15+

Fig. 3.10 (**a**, **b**) A patient with a "U"-shaped alveolar defect was evaluated for distraction osteogenesis. The defect was large enough to allow the patient to protrude his tongue while in occlusion. (**c**, **d**) The bone cuts were created using a vestibular incision and the distraction device adapted and placed. Note the distraction segment is trapezoidal in shape with the alveolar height is taller adjacent to the central incisor (**c**). The site was closed and distraction proceeded without incident (**d**). (**e**) The site was over-distracted such that the segment was distracted vertically above the level of the CEJ of the adjacent teeth. On the mesial, a triangular bony protuberance was noted. This protuberance occurred as the defect was "U" shaped. Consideration for trimming of such bony irregularities/sites at the time of surgery should be included in the treatment plan. (**f**) The bony protuberance is also noted on the palatal, highlighting the need to plan the distraction segment in 3-D. (**g**) During the portion of active distraction and during consolidation, a small portion of the DO device arm became exposed. Exposure is controlled with local measures. Note the gingiva is pink and not inflamed/infected despite the exposure


a
b
c
d
e
f
g

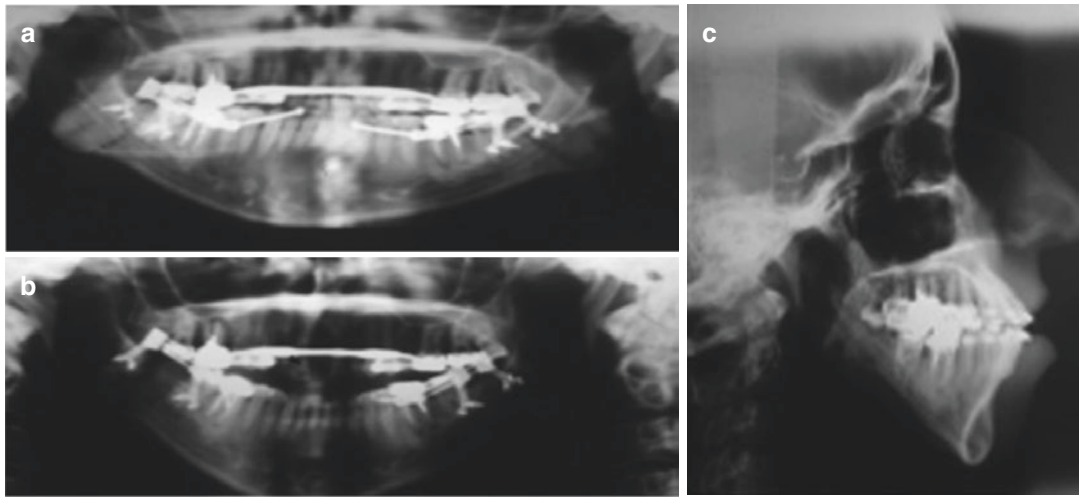


Fig. 3.11 (**a**, **b**) A 20-year-old patient underwent mandibular distraction. The vector of the DO device was not ideal, with the vector parallel to the steep mandibular plane angle (**a**). Consequently an open bite occurred during active DO (**b**). (**c**) The open bite was addressed by removing the DO device prior to complete consolidation, and using elastic/orthodontic traction, the open bite was closed

mm advancement of the maxilla (Fig. 3.12c). She underwent Le Fort I maxillary advancement using the RED device (KLS Martin) [30–32] (Fig. 3.12d). The DO technique proceeded uneventful, and she did well so that after maxillary DO, her facial form married that of her mother (Fig. 3.12e, f). This case highlights a commonly overlooked complication of maxillary DO: the potential for the creation of an open bite.

1. The arc of rotation of the maxilla around the skull base is centered just above the maxillary first molar. This phenomenon is commonly observed with maxillary advancement including the use of a frame such as a Petit DeLaire mask. All patients undergoing maxillary DO using either intraoral or external devices should be carefully monitored and followed for this occurrence. Using an external halo frame, RED device, forces to the maxilla can be adjusted to allow for the DO advancement of the maxilla uneventfully adjusting the arms for elastic traction inferiorly as DO progresses. When using an intraoral device, care must be taken during the planning stage to orient the device in a vector to counteract this usual arc of rotation. For intraoral devices, elastic traction can be used but is not as effective as direct device reorientation, as can be accomplished with the RED, halo device. For either intraoral or extra-oral devices, at the time of maxillary DO device removal, additional intraoral elastic traction can be used via orthodontic appliances to address any residual concerns.

Distraction osteogenesis is a powerful tool to correct bone and soft tissue deformities associated with the craniofacial skeleton. As such, the technique is intuitive as DO correlates with conventional orthognathic surgery. With the advent of virtual surgical planning, VSP, and newer DO devices, many of the complications encountered by early DO techniques have been obviated. Yet close attention to detail must be maintained throughout the entire DO process. The rate for DO of the craniofacial skeleton has been established at 1.0 mm per day, yet a rate of 2 mm per day is suggested for children less than 12 months of age [11]. Yet should activation of the device become difficult, especially near the end of the planned distraction, then premature ossification should be considered.

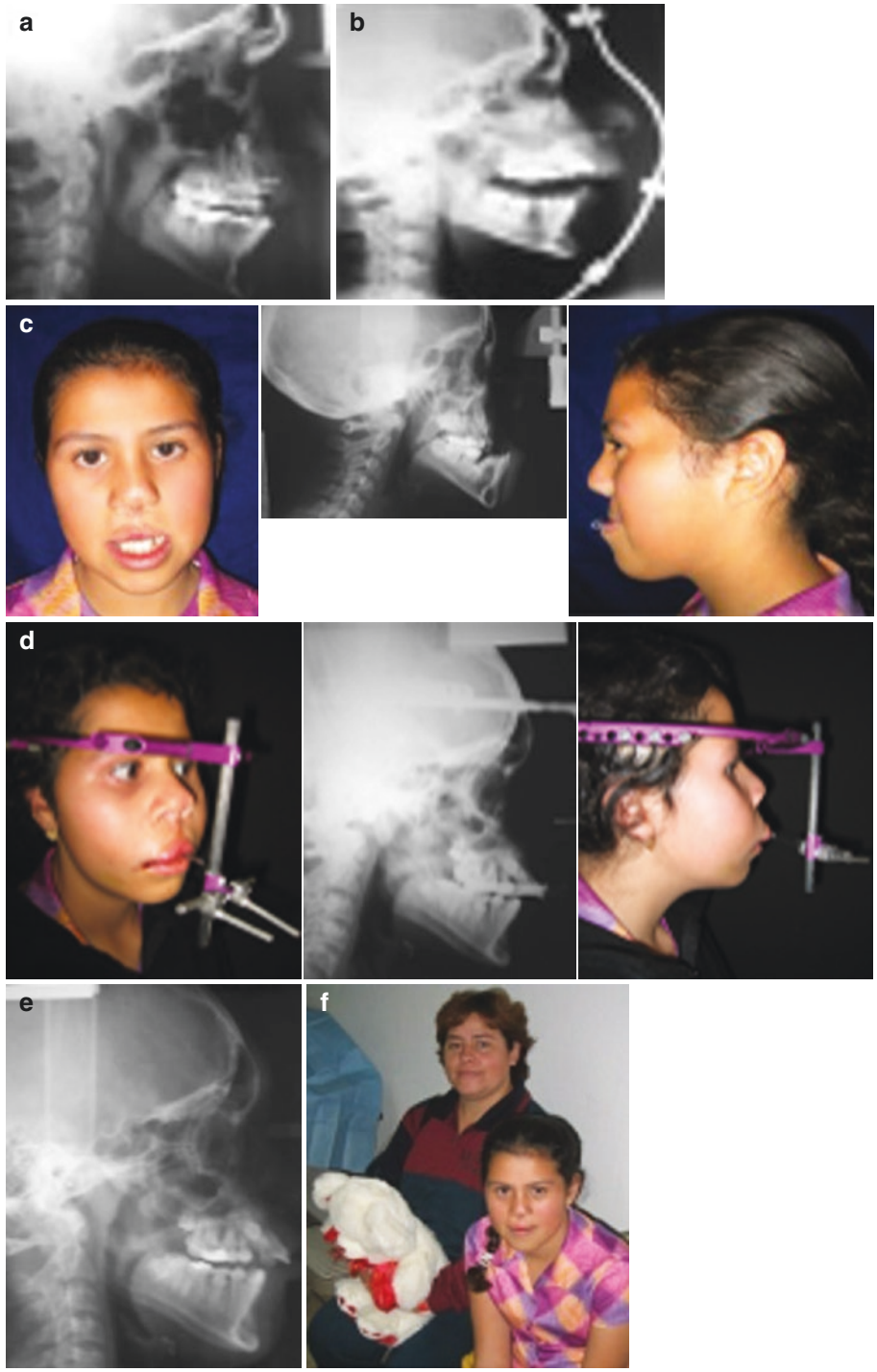


Fig. 3.12 (**a**, **b**) Open bite occurs with DO, either via skeletal halo frame (**a**) or tooth bone (**b**) Petit Delaire devices as the maxilla rotates around a point centered above the maxillary first molar. (**c**) A 13-year-old female with repaired cleft lip-cleft palate presents with severe maxillary hypoplasia. (**d**) She underwent maxillary Le Fort DO for maxillary advancement. The open bite was corrected during active DO, by adjusting the vertical and horizontal aspects of the traction arms. (**d**, **e**) The maxilla was overcorrected during DO to achieve a positive result. (**f**) Facial harmony is resorted after maxillary distraction; now the child's face mirrors her mother's

This attention to detail is paramount after active DO, during consolidation when both the surgical team and patient/parent of a patient are more "relaxed" often assuming that the only challenge is the final osseous healing. It is during this time of neutral DO fixation that the device is fully extended, and the regenerate is malleable that forces can affect the shape of the mandibular regenerate. Some have reported early open, surgical callus manipulation as to obtain the desired functional and esthetic results [21, 23]. Consequently all extrinsic forces, especially the local muscles attached to the distal bony DO site, can work and pull to affect the final shape and positon of the distracted bone. Close observation during this and all time periods associated with the DO process can avoid these muscular forces as well as to intervene and correct for them as necessary. This may necessitate early device removal and placing elastic traction to allow the bone to be guided to its final, correct position. These incidents are usually minor in nature and easily addressed [33]. Both the patient and or the parents of the patient are a useful member of the team as to identify and assist in the shaping of the final regenerate form. Active involvement and observation by the patient and family is encouraged. Long-term follow-up is recommended as active physical therapy may be required to overcome learned muscle motion such as deviation with opening, which has been associated with "late relapse" of mandibular distraction [20]. Simple techniques such as chewing gum placed on the contralateral side of the deviation with opening will assist in avoiding this occurrence. TMJ ankyloses has been reported, however rarely, after mandibular DO [34]. This too can be avoided with active opening exercises during and long term after DO. It cannot be assumed that a congenital deformity be overcome with DO during infancy/early childhood, without observation and gentle orthodontic/orthopedic therapy during growth.

Interestingly, unlike mandibular DO where vectors are influential, relapse is the primary concern for both maxillary DO, at all levels Le Fort I, II, and III as well as vertical alveolar DO. It has thus been suggested that for dentoalveolar DO, the site should be over-distracted by 20% as to account for the potential vertical relapse [12]. Yet, once an implant is placed in the new, DO-generated bone, the bone continues to mature and acts as the native bone with similar implant success rates. Similarly, maxillary DO is stable once the tenancy for the rotation around the maxillary first molar during active DO has been accounted for. Yet age-related relapse has been reported for treatment of cleft maxillary hypoplasia, with the least amount of relapse occurred when the surgery was performed when the child was 11–15 years old 6% versus 16–25% for all other age groups [35]. This may be due to the nature of a multiple operated site associated with cleft maxillary hypoplasia. Periodic follow-up is recommended for all patients after DO until the surgeon is satisfied the incidence of long-term occurrences is rare.

Dentoalveolar DO has two unique complications reported: tipping of the distraction segment 16% and fracture of the basal bone 2% occurrence [18]. Fracture of the basal bone can be obviated by avoiding sharp internal line angles to the osseous cut [20]. Our tendency is to create a "box like cut" to the DO segment (Fig. 3.13). For the maxilla this is less critical. Yet there is unique muscle pull on the mandible exerting compressive/tension forces on the superior boarder and expansive forces on the

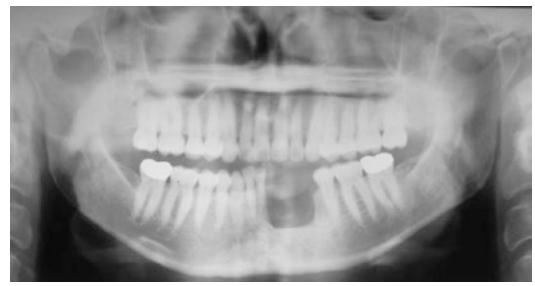


Fig. 3.13 For alveolar DO, the osteotomy created should have rounded internal lines as to avoid stress concentration at the corners of the osteotomy. Here the DO is fully extended, with the transport disc at the level of the alveolus and the osseous regenerate site radiographically darker, until it ossifies

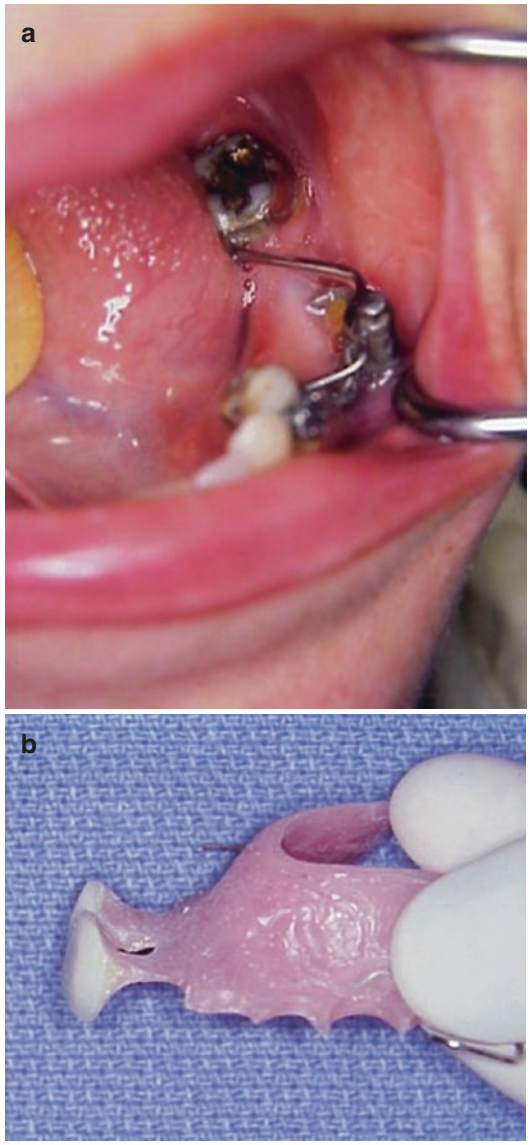


Fig. 3.14 (**a**, **b**) Appliances are created to stabilize the vertical DO activation arm here with an orthodontic retained design (**a**), or using a prosthetic device with an access hole (**b**)

inferior boarder of the mandible as one opens and closed their mouth. These forces are transmitted throughout the bone such that a box-shaped osteotomy for DO can lead to fracture of the basal bone right at the internal angle/junction of the horizontal and vertical components of the osteotomy. Rounded, "U"-shaped internal line angles are suggested for alveolar DO. The most common minor complication associated with alveolar DO is displacement of the transport segment. This can be overcome with the use of orthodontic or prosthetic guidance appliances (Fig. 3.14a, b).

Distraction osteogenesis is a powerful tool as it allows for the reconstruction of all tissues in and adjacent to the surgical site (Fig. 3.12a–f). However used in the growing child, it must be recognized that a second orthognathic procedure may be revised later, at the end of normal physiologic growth [36, 37]. It has been shown that DO itself does not hinder normal growth of the site such that early correct of a dentofacial deformity can improve socialization and self-perception as the child progresses in school.

References

1. McCarthy JG. Our surgical past: an aid to understanding the present and a guide to the future. J Craniofac Surg. 2017;28(5):1121–2. https://doi.org/10.1097/SCS.0000000000003806.
2. Vyas RM, Alperovich M, Grayson BH, McCarthy JG, Rodriquez ED. From multidisciplinary to interdisciplinary to transdisciplinary care: an evolution in craniofacial surgery. Plast Reconstr Surg. 2015;135(4):796e–7e. https://doi.org/10.1097/PRS.0000000000001137.
3. Rossini G, Vinci B, Rizzo R, Pinho TM, Deregibus A. Mandibular distraction osteogenesis: a systematic review of stability and the effects on hard and soft tissues. Int J Oral Maxillofac Surg. 2016;45(11):1438–44. Epub 2016 Sep 5. https://doi.org/10.1016/j.ijom.2016.08.012.
4. Archual A, Black JS. Avoidance of tracheostomy using mandibular distraction in an infant with severe condylar dysplasia and airway obstruction. J Craniofac Surg. 2017;28(8):2053–5. https://doi.org/10.1097/SCS.0000000000003978.
5. da Costa A, Manica D, Schweiger C, Kuhl G, et al. The effect of mandibular distraction osteogenesis on airway obstruction and polysomnographic parameters in children with Robin sequence. J Craniomaxillofac Surg. 2018;46(8):1343–7. Epub 2018 May 18. https://doi.org/10.1016/j.jcms.2018.05.030.
6. Wang X, Feng S, Tang X, Shi L, et al. Incidents of mandibular distraction osteogenesis for hemifacial microsomia. Plast Reconstr Surg. 2018;142(4):1002–8. https://doi.org/10.1097/PRS.0000000000004812.
7. Moran I, Virdee S, Sharp I, Sulh J. Postoperative complications following LeFort 1 maxillary advancement surgery in cleft palate patients: a 5-year retrospective study. Cleft Palate Craniofac J. 2018;55(2):231–7.

https://doi.org/10.1177/1055665617736778. Epub 2017 Dec 14.
8. Rougier G, Diner PA, Rachwalski M, Galliani E, Tomat C, et al. Mandibular symphyseal distraction osteogenesis: 20 years of experience treating transverse deficiencies with an internal hybrid device. J Craniomaxillofac Surg. 2019;47(4):586–91. https://doi.org/10.1016/j.jcms.2019.01.001. Epub 2019 Jan 11.
9. Humphries LS, Yates EK, Mhlaba JM, Collins JM, Baroody FM, Reid RR. Airway volume simulation in virtual mandibular distraction: a cohort study. Plast Reconstr Surg. 2018;141(4):1003–9. https://doi.org/10.1097/PRS.0000000000004249.
10. Şensoy AT, Kaymaz I, Ertaş Ü, Kiki A. Determining the patient-specific optimum osteotomy line for severe mandibular retrognathia patients. J Craniofac Surg. 2018;29(5):e449–54. https://doi.org/10.1097/SCS.0000000000004470.
11. Breik O, Tivey D, Umapathysivam K, Anderson P. Does the rate of distraction or type of distractor affect the outcome of mandibular distraction in children with micrognathia? J Oral Maxillofac Surg. 2016;74(7):1441–53. https://doi.org/10.1016/j.joms.2016.01.049. Epub 2016 Feb 2.
12. Elnayef B, Monje A, Gargallo-Albiol J, Galindo-Moreno P, et al. Vertical ridge augmentation in the atrophic mandible: a systematic review and meta-analysis. Int J Oral Maxillofac Implants. 2017;32(2):291–312. https://doi.org/10.11607/jomi.4861.
13. Kofod T, Würtz V, Melsen B. Treatment of an ankylosed central incisor by single tooth dento-osseous osteotomy and a simple distraction device. Am J Orthod Dentofacial Orthop. 2005;127(1):72–80.
14. Kisnisci RS, Iseri H. Dentoalveolar transport osteodistraction and canine distalization. J Oral Maxillofac Surg. 2011;69(3):763–70. https://doi.org/10.1016/j.joms.2010.11.035.
15. Senışık NE, Koçer G, Kaya BÜ. Ankylosed maxillary incisor with severe root resorption treated with a single-tooth dento-osseous osteotomy, vertical alveolar distraction osteogenesis, and mini-implant anchorage. Am J Orthod Dentofacial Orthop. 2014;146(3):371–84. https://doi.org/10.1016/j.ajodo.2013.10.02.
16. Jensen OT, Block M. Alveolar modification by distraction osteogenesis. Atlas Oral Maxillofac Surg Clin North Am. 2008;16(2):185–214. https://doi.org/10.1016/j.cxom.2008.04.001.
17. Reininger D, Rodriguez-Grandjean A, López-Quiles J. Analysis of resorption and need for overcorrection in alveolar distraction osteogenesis. Int J Oral Maxillofac Implants. 2016;31(4):865–9. https://doi.org/10.11607/jomi.4424.
18. Zhao K, Wang F, Huang W, Wu Y. Clinical outcomes of vertical distraction osteogenesis for dental implantation: a systematic review and meta-analysis. Int J Oral Maxillofac Implants. 2018;33(3):549–64. https://doi.org/10.11607/jomi.6140.
19. Block MS. Dental implants: the last 100 years. J Oral Maxillofac Surg. 2018;76(1):11–26. https://doi.org/10.1016/j.joms.2017.08.045. Epub 2017 Oct 13.
20. Stucki-McCormick SU, Fox RM, Mizrahi R, Erikson M. Distraction osteogenesis for congenital mandibular deformities. Atlas Oral Maxillofac Surg Clin North Am. 1999;7(1):85–109.
21. Hoffmeister B. The effect of sagittal orientation of the distractor on the biomechanics of mandibular lengthening. J Oral Maxillofac Surg. 1999;57(10):1221–2.
22. Samchukov ML, Cope JB, Cherkashin AM. The effect of sagittal orientation of the distractor on the biomechanics of mandibular lengthening. J Oral Maxillofac Surg. 1999;57(10):1214–22; discussion 1221-2.
23. Pereira AR, Neves P, Rosa J, Bartlett S. Curvilinear segmental mandibular reconstruction utilizing distraction osteogenesis and early open callus manipulation. Plast Reconstr Surg Glob Open. 2017;5(1):e1229. eCollection 2017 Jan. https://doi.org/10.1097/GOX.0000000000001229.
24. Guerrero CA. Cleft lip and palate surgery: 30 years follow-up. Ann Maxillofac Surg. 2012;2(2):153–7. https://doi.org/10.4103/2231-0746.101342.
25. Molina F. From midface distraction to the "true monoblock". Clin Plast Surg. 2004;31(3):463–79, vii.
26. Arnaud E, Marchac D, Renier D. Reduction of morbidity of the frontofacial monobloc advancement in children by the use of internal distraction. Plast Reconstr Surg. 2007;120(4):1009–26.
27. Mathijssen I, Arnaud E, Marchac D, Mireau E, Morisseau-Durand MP, Guérin P, Renier D. Respiratory outcome of midface advancement with distraction: a comparison between Le Fort III and frontofacial monobloc. J Craniofac Surg. 2006;17(4):642–4.
28. Figueroa AA, Polley JW, Figueroa AD. Biomechanical considerations for distraction of the monobloc, Le Fort III, and Le Fort I segments. Plast Reconstr Surg. 2010;126(3):1005–13. https://doi.org/10.1097/PRS.0b013e3181e3b70f.
29. Staggers JA. From MS Thesis, Orthodontics. Personal communication, private practice Winchester, VA. 2006.
30. McCarthy JG, Stelnicki EJ, Mehrara BJ, Longaker MT. Distraction osteogenesis of the craniofacial skeleton. Plast Reconstr Surg. 2001;107(7):1812–27.
31. Troulis MJ, Padwa B, Kaban LB. Distraction osteogenesis: past, present, and future. Facial Plast Surg. 1998;14(3):205–15.
32. Nout E, Wolvius EB, van Adrichem LN, Ongkosuwito EM, van der Wal KG. Complications in maxillary distraction using the RED II device: a retrospective analysis of 21 patients. Int J Oral Maxillofac Surg 2006;35(10):897-902. Epub 2006 Sep 27.
33. Verlinden CR, van de Vijfeijken SE, Tuinzing DB, Becking AG, Swennen GR. Complications of mandibular distraction osteogenesis for acquired deformities: a systematic review of the literature. Int J Oral Maxillofac Surg. 2015;44(8):956–64. https://

doi.org/10.1016/j.ijom.2014.12.008. Epub 2015 Apr 1.
34. Galié M, Candotto V, Elia G, Clauser LC. Temporomandibular joint ankylosis after early mandibular distraction osteogenesis: a new syndrome? J Craniofac Surg. 2017;28(5):1185–90. https://doi.org/10.1097/SCS.0000000000003612.
35. Richardson S, Krishna S, Khandeparker RV. A comprehensive management protocol to treat cleft maxillary hypoplasia. J Craniomaxillofac Surg. 2018;46(2):356–61 . Epub 2017 Dec 13. https://doi.org/10.1016/j.jcms.2017.12.005.
36. Ruiz RL, Turvey TA, Costello BJ. Mandibular distraction osteogenesis in children. Oral Maxillofac Surg Clin North Am. 2005;17(4):475–84.
37. Zhang RS, Lin LO, Hoppe IC, Swanson JW, Taylor JA, Bartlett SP. Early mandibular distraction in craniofacial microsomia and need for orthognathic correction at skeletal maturity: a comparative long-term follow-up study. Plast Reconstr Surg. 2018;142(5):1285–93. https://doi.org/10.1097/PRS.0000000000004842.