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Pediatric Mandible Reconstruction: Controversies and Considerations

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Summary: Mandibular reconstruction in pediatric patients has some unique considerations. The method of reconstruction has to factor in the growth potential of the neo-mandible, the native mandible, and the donor site. The condyle is considered the main growth center of the mandible. Current literature indicates that fibula, iliac crest, and scapula osseous flaps do not have the ability to grow. Costochondral grafts exhibit growth because of the costal cartilage component, although the growth is unpredictable. Preservation of the mandibular periosteum can result in spontaneous bone regeneration. Fibula bone harvest in a child mandates close follow-up till skeletal maturity, to monitor for ankle instability and valgus deformity. Dental rehabilitation maintains occlusal relationships, which promotes normal maxillary development. Elective hardware removal should be considered to facilitate future dental implant placement and possible revision procedures. After completion of growth, if occlusion or symmetry is not satisfactory, secondary procedures can be performed, including distraction osteogenesis, orthognathic-type bone sliding operations, and segmental ostectomy. *(Plast Reconstr Surg Glob Open 2020;8:e3285; doi: 10.1097/GOX.0000000000003285; Published online 17 December 2020.)*

Pediatric mandible defects can arise from a variety of causes, such as congenital differences, tumors, trauma, and infections. Reconstruction is challenging because of the small size of facial structures, resulting in a small working space, limited donor sites, growth concerns, and small vessels that are prone to spasm. However, success rates of pediatric free tissue transfer are comparable to or even better than those of adults because of fewer comorbidities, healthy vessels, absence of smoking-related vascular damage, and superior ability to heal.[1]

Reconstructive surgery in children is not a static event. The reconstructive plan has to factor in continued growth of the recipient site as well as long-term effects on the donor site. This article addresses important questions and concerns that come up when undertaking mandible reconstruction in a growing patient. It is an objective review of the current literature on autologous osseous mandibular reconstruction.

GROWTH

Normal development of the craniofacial skeleton occurs because of the harmonious relationship between the cranial base, midface, and mandible. Any disruption of 1 craniofacial subunit will affect development of its adjacent subunit. Reestablishment of normal occlusal relationships is imperative for normal facial growth. Function and aesthetics of the jaw are best restored by skeletal reconstruction with autologous bone.

Mechanisms of Facial Growth

Craniofacial development occurs in a craniocaudal direction.[2] The neurocranium grows rapidly early on to accommodate the growing brain. Viscerocranial growth acceleration occurs later on. Facial growth occurs in an inferior and anterior vector to accommodate the increasing functional needs of the developing airways and oral-pharyngeal structures.[2] The facial skeleton exhibits 3 types of growth: vertical (height), transverse (width), and anteroposterior (depth).[3]

There are 2 main theories regarding growth in the craniofacial skeleton.[4] The intrinsic theory states that bones have intrinsic growth capacity (growth centers) that is genetically programmed. The extrinsic theory (functional matrix theory) states that soft tissue is the primary driver of craniofacial growth.[5] The craniofacial area can be conceptualized as functional spaces (called capsular matrices) that contain periosteal matrices that house skeletal structures. Skeletal growth occurs by 2 mechanisms: 1) As the capsular matrices expand, the skeletal units are translated into space. 2) Periosteal matrices act directly on the skeletal units by depositing and resorbing the bone. There is evidence for both intrinsic and extrinsic growth in animal models.[4]

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Maxillary and Mandibular Growth

Maxillary growth is thought to occur via the following mechanisms:

1. The nasal septum is important for growth of the midface in the first 3–4 years of life. The septum pushes the midface anteriorly and inferiorly.[6,7]
2. Growth of the cranial base causes an increase in transverse width of the maxilla. Most of this transverse maxillary growth occurs by bone deposition at the median palatal suture.[7,8]
3. Surface remodeling results in inferior displacement of the maxilla. Bone resorption occurs on the nasal surface, and bone apposition occurs on the palatal surface.[7]

Mandibular growth is thought to occur via the following mechanisms:

1. The principal growth center is located in the condyle.[9–11] Ossification of condylar cartilage causes an increase in the vertical height of the ramus, which moves the mandible anteroinferiorly. This growth center fuses at the age of 18 years.
2. Regional bony remodeling occurs throughout the mandible.[7] Bone apposition occurs in the posterior ramus and buccal surface, and resorption occurs in the anterior ramus and lingual surface (Fig. 1). The net result of this process is increase in the size of the mandible.
3. The intercondylar distance widens in response to the increasing width of the cranial base.[11] This stimulates transverse growth of the mandible. The mandibular symphyseal synchondrosis fuses by 6–9 months of age.[7,11]

Growth acceleration occurs during the pubertal growth spurt. This increase in size is greater in boys than in girls.[12] In boys, maxillary and mandibular growth is completed by the age of 18 years, although in some individuals a small amount of growth can occur till the age of 21 years (Fig. 2).[3,12–14] In girls, maxillary growth is completed by the age of 15 years, and mandibular growth by 16 years.[12] Completion of growth occurs first in transverse dimension, followed by anteroposterior dimension and finally in the vertical dimension.[15]

Growth in Non-vascularized Bone Grafts

Costochondral grafts are a popular choice for mandible condyle and ramus reconstruction.[16] Costal cartilage is the growth center for the rib (Fig. 3).[17] Therefore, rib grafts harvested with their costal cartilage will have growth potential and this is well documented in literature.[16] However this growth is unpredictable, and can range from no growth to overgrowth.[18–21] It has been hypothesized that the amount of growth is proportional to the cartilaginous component.[19] Different "ideal" sizes for the cartilaginous cap have been proposed, ranging from 2 mm to 2.5 cm.[16,18,19,22,23] This is, however, a matter of speculation.

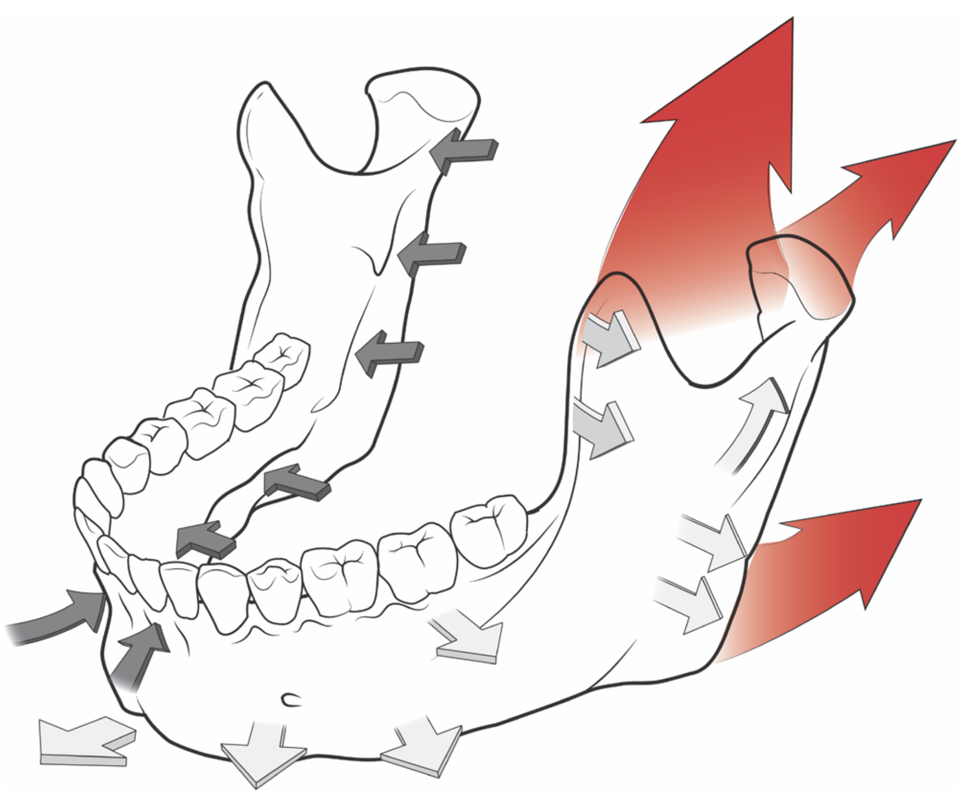

Fig. 1. Mandibular remodeling. Net increase in size (red arrows) occurs as a result of apposition (white arrows) and resorption (black arrows).

Iliac crest, calvarium, outer cortex of mandible and rib without costal cartilage have not been shown to have intrinsic growth capacity.[24]

Growth in Vascularized Bone Grafts

There is no objective evidence of growth of bone flaps. Studies that report continued mandibular growth actually have growth of the residual native mandible. Zhang et al performed a meta-analysis evaluating mandibular growth after fibular free flap reconstruction.[25] Data on growth were available for 51 patients. The analysis showed that "growth potential" was observed in 58% of patients. Factors associated with improved growth potential were condylar preservation, reconstruction performed between 8 and 12 years (period of rapid mandibular growth), and mandibular resection for benign lesions. The majority of these reports comprised retrospective studies, with short follow-ups, subjective evaluations with pictures, and inconsistent pre- and post-operative assessment methods. Maintenance of class 1 occlusion or visible facial symmetry were considered sufficient evidence for mandibular growth.[9,26] A critical comparison of the pre and post-operative radiographs in studies that report continued growth reveals growth at the native condyle (and not in the bone flap) or new bone regeneration at the reconstructed site.[27,28]

Spontaneous Regeneration of the Mandible

In young patients who undergo mandible resection, osteoprogenitor cells in the residual periosteum can regenerate new bone.[29] A genetic predisposition has been suggested.[30] The periosteum and soft tissue keep the space open and form a barrier for influx of granulation tissue. Bone regeneration is usually detected at around 3 months and can continue for up to 2 years.[30] The process, however, is not predictable, with <65 cases of spontaneous bone regeneration reported in literature.[31] In patients with benign condition, it may therefore be prudent to preserve as much of the periosteum and soft tissue as possible; if spontaneous bone regeneration does occur, it will increase bone volume and form difficult-to-reconstruct structures like the condyle.[32]

DONOR SITES

When choosing donor tissue in children, it is important to understand the effects on future growth and development of the donor site (Table 1).

Rib

Ribs are a popular choice for reconstruction, as they are easy to harvest, have low donor site morbidity, and can provide a large amount of bone. They also leave other bone donor sites intact in case a vascularized bone flap is needed after completion of growth.[42]

The most commonly harvested ribs are 6th or 7th rib.[43] Costochondral grafts for ramus/condyle reconstruction are taken from the opposite side to take advantage of the curved shape.[44] Rib is harvested subperiosteally. At the osseocartilaginous junction, periosteum and perichondrium are preserved on the graft to ensure adherence of cartilage to bone.[16] If more than 1 rib is needed, the intervening rib should be skipped to maintain chest wall stability. Chest wall deformity and scoliosis can occur if 2 contiguous ribs are harvested.[45]

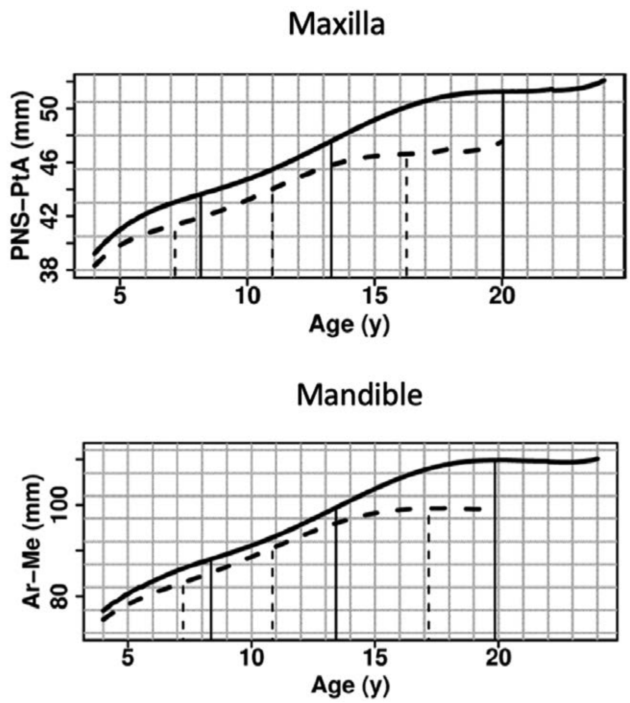

Fig. 2. Anteroposterior growth of the maxilla (A) and mandible (B). Data from the Fels longitudinal study—the world's longest running study of human growth. Ar: articulare, Me: menton, PNS: posterior nasal spine, PtA: point A. Reprinted with permission from John Wiley and Sons from *Anat Rec (Hoboken)*. 2014;297(7):1195–1207.

Ribs have the ability to regenerate after their removal. Regeneration occurs from the bone stumps and remaining periosteum.[46,47] The process takes approximately 3–6 months.[48] Studies have reported complete regeneration in 44%–98% of ribs harvested in growing children.[47] Factors promoting regeneration are younger age and shorter gap of missing rib.[46,47] Therefore, the rib periosteum should be preserved and the periosteal sleeve be closed after harvest.[33] Maintenance of the rib bed space with a scaffold like Gelfoam has been shown to improve the speed and quality of bone regeneration.[49] The regenerated rib is generally not of adequate quality for reharvest.[33,45]

Complications with rib grafts include resorption and temporomandibular joint ankylosis.[16,18] Ankylosis is thought to occur due to conversion of costal cartilage to bone and fracture at the osteochondral junction.[19,22] Therefore it has been proposed that leaving a smaller cartilage cap reduces the risk of ankylosis by decreasing the amount of ossified cartilage and reducing the chance of cartilage fracture.[19] The risk of ankylosis may also be related to the duration of post-operative mandibulomaxillary fixation.[50]

Rib bone is softer at young ages, making reconstruction difficult. Tahiri et al recommend that costochondral graft correction of hemifacial microsomia be performed

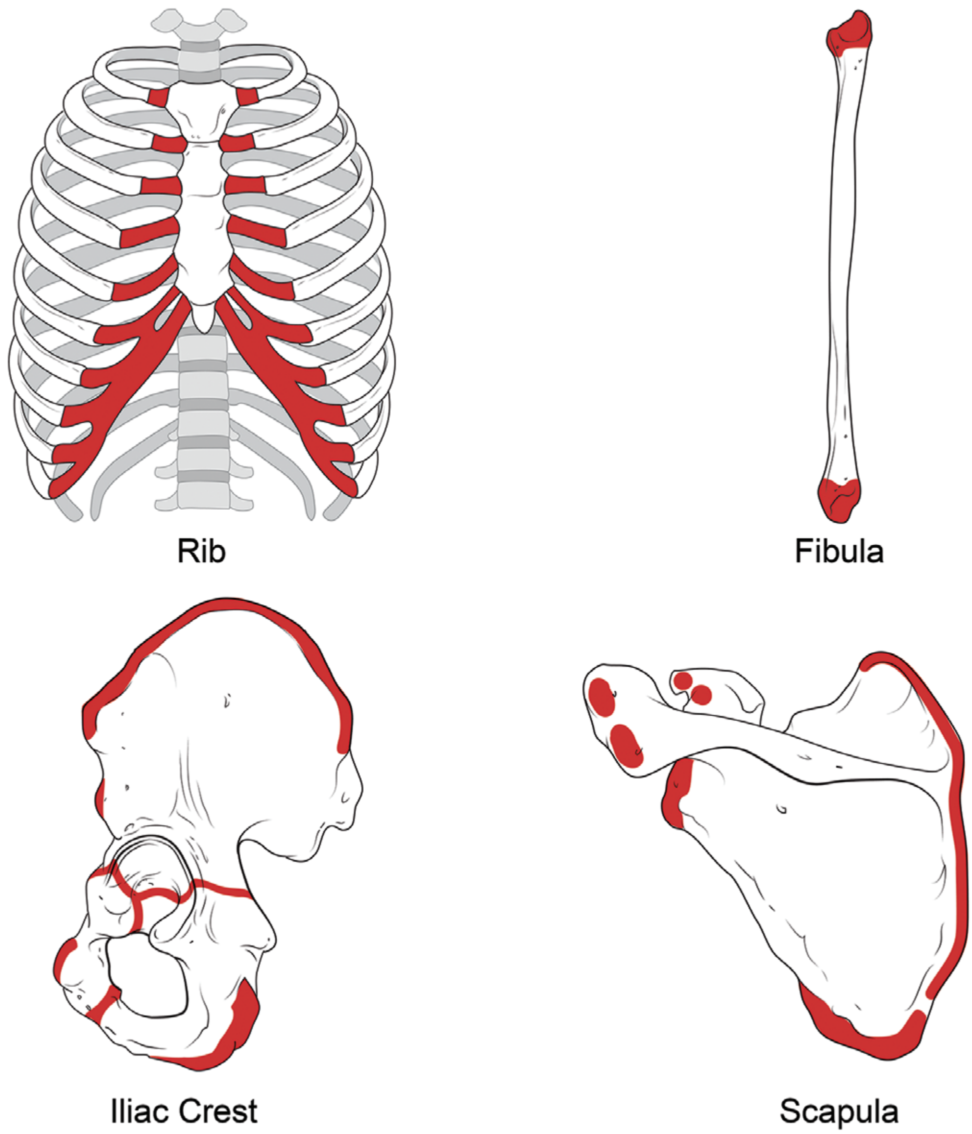

Fig. 3. Growth centers (red) of ribs, fibula, pelvis, and scapula.

in children >5 years of age due to suboptimal bone quality at younger ages.[16]

Fibula

The fibula has epiphyseal growth plates within 1–2 cm of the 2 ends of the bone (Fig. 3). There is more growth at the proximal than distal growth plate, which causes gradual distal migration of the fibula in relation to the tibia.[51] Harvest of the fibular shaft has not been shown to affect limb growth.

Valgus deformity of the ankle can occur after fibula flap harvest in skeletally immature patients. The primary pathology is thought to be proximal migration of the distal fibular segment, which results in progressive lateral shift of the talus, causing stress on the lateral distal tibial growth plate.[52] Over time the ankle grows asymmetrically resulting in a valgus deformity. Radiographic features of this condition includes proximal fibular migration, anteromedial fibular physeal arrest, lateral tibial epiphyseal atrophy, and subluxation of the talus (Fig. 4A).[34] The deformity can occur in up to 40% of fibula harvests in growing children.[34] The risk increases with younger age and shorter remaining distal fibular lengths.[34,53] Age-residual fibula index (age in years + length of residual fibula in cm) <16 has been proposed as predictive for development of valgus deformity.[54] Some surgeons advocate prophylactic tibiofibular stabilization at the time of fibula harvest in all growing patients to prevent proximal fibular migration, while others recommend close follow-up, with stabilization only if ankle deformity starts to develop.[34,52,55] Tibiofibular fixation, however, does not guarantee again development of the deformity and therefore all growing children who undergo fibula harvest should be followed closely.[52,53] Primary tibiofibular stabilization is most commonly performed with a quadricortical syndesmotic screw (Fig. 4B).[52] In established deformities,

Table 1. Characteristics of Common Donor Sites for Mandible Reconstruction

Donor	Growth Center	Advantages	Drawbacks
Costochondral	Hyaline cartilage	– Growth potential, albeit unpredictable – Rib regeneration if periosteum is preserved at the donor site – Relatively quick and technically simple operation – Obviates microsurgery	– Insufficient bone volume for osseointegrated implants – Risk of pneumothorax – Chronic chest wall pain, in up to 6.8% patients[33]
Fibula	Proximal and distal epiphysis	– Longest segment of bone available – Multiple osteotomies possible – Osseointegrated implants possible – No problems with limb growth	– Valgus deformity and ankle instability[34,35] – Ankle weakness[35] – Sensory disturbances (peroneal and sural nerve injury)[35] – Chronic pain in 6.5% patients[35] – Flexion contracture of great toe[35] – Distal tibial fracture[36] – Risk of TMJ ankylosis when used for ramus/condyle reconstruction[37]
Iliac crest	Ossification centers throughout the iliac crest and at acetabulum Iliac crest is a traction epiphysis	– Good bone stock – Osseointegrated implants possible – No problems with limb or pelvic growth	– Gait disturbances[38] – Hernias[39] – Contour deformity of donor site[38] – Sensory disturbances (injury to lateral cutaneous nerve of the thigh)[38] – Bone bleeding during harvest
Scapula	Ossification centers at glenoid fossa, scapular tip, and medial border Lateral border is a traction epiphysis	– Large amount of soft tissue available – No impairment of upper limb function	– Bone stock may be insufficient for osseointegrated implants (alveolar height augmentation frequently needed with add–on bone grafts)[40] – Scapular growth impairment with harvest of lateral border and tip[41]

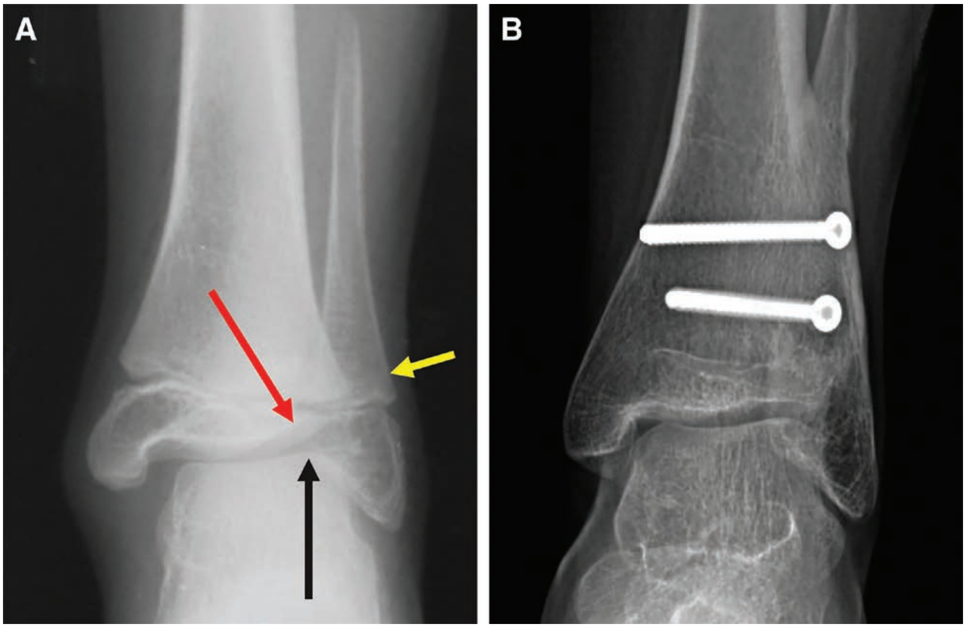

Fig. 4. Radiographic features of ankle valgus deformity: proximal fibular migration (yellow arrow), lateral tibial epiphyseal atrophy (red arrow), and talar subluxation (black arrow) (A); tibiofibular stabilization with syndesmotic screw (B).

fibular osteotomy and distraction may be needed to lower the lateral malleolus before screw fixation.[56] Patients with ankle valgus are at a high risk of developing osteoarthritis later on in life.

Vascularized proximal epiphyseal transfer, although well described for extremity reconstruction, has not been reported for mandible reconstruction.[57] Harvest of the fibular head has not been shown to cause knee instability, but has a significant risk of peroneal nerve injury.[58]

Iliac Crest

The pelvis develops from multiple ossification centers (Fig. 3). The entire iliac crest is cartilaginous at birth. It has 2 epiphyses, 1 for the anterior superior iliac spine and anterior half of the crest, and the other for the posterior superior iliac spine and the posterior half of the crest. Ossification at these centers occurs between the age of 12 and 20 years.[59] The iliac crest also acts as a traction epiphysis, growing in response to the pull of the attached muscles.[9]

Abnormalities of pelvic or limb growth have not been reported after iliac crest harvest. Cancellous bone is commonly harvested from the iliac crest and has not shown to cause growth disturbances.[60]

Scapula

The scapula develops from ossification centers in the acromion, coronoid, glenoid, body, inferior angle, and medial border (Fig. 3). At birth, the glenoid, inferior angle, and entire medial border are cartilaginous. The epiphysis of the coracoid, glenoid, acromion, inferior angle, and medial border completes fusion between the age of 15 and 23 years, in that order.[61] The lower pole growth center is responsible for development of majority of the scapular surface.[62] The lateral border of the scapula is a traction epiphysis that grows in response to the pull of the attached muscles.[9]

Harvest of scapula bone flap in children can affect growth, resulting in a smaller size of the scapula compared with that in the contralateral side.[41] However, this does not cause problems with the function of the upper extremity.

DENTAL REHABILITATION

Dental rehabilitation has functional, aesthetic, and psychologic benefits. Dental prostheses promote normal midface development by maintaining normal occlusal relationships. They also prevent supra-eruption of opposing maxillary teeth. They facilitate normal speech and salivary continence.[63] In the literature, there are very few reports on dental rehabilitation in growing patients after osseous mandibular reconstruction.[64–66] Dental rehabilitation can be performed with removable partial dentures or osseointegrated implants with removable overdenture prostheses versus fixed prostheses.

Osseointegrated implants in children in the native mandible and maxilla are generally avoided because they have a high complication rate.[67] Implants act as ankylosed teeth and do not exhibit normal movements with expansion of the jaw as do native teeth. They can get displaced, relocated, embedded, and interfere with the eruption of the adjacent teeth.[68] Most practitioners recommend delaying implant placement till skeletal maturity.[8] On the other hand, osseointegrated implant placement in bone flaps is well established.[69] Because bone flaps do not have intrinsic growth capacity, these implants do not undergo the same movements. However, as the native jaw grows, the relative position of the implants in relation to the dentition may change. Osseointegrated implants transmit masticatory forces to the bone flap, which promotes maintenance of bone volume.

Dental prostheses are designed so that they do not impede growth of adjacent normal mandible or maxilla.[70] All children who undergo dental rehabilitation need a close follow-up for periodic prosthetic modifications.[68] Compared with osseointegrated implant-based prostheses, removable partial dentures require less close follow-up. Their disadvantages are poor compliance, increased dental caries, and alveolar bone resorption.

HARDWARE REMOVAL

Removal of hardware from the growing craniofacial skeleton is advocated by many surgeons to remove any constrictive effects of rigid plates and screws on bony growth.[71,72] However, the evidence for this growth restriction is equivocal.[71,73] Animal studies have not shown a detrimental effect of titanium plates on mandibular growth.[74]

There are several advantages of electively removing hardware. Over time, plates get enveloped by bone, making future removal difficult. Embedded hardware makes secondary bony procedures very challenging.[75] Screws can interfere with dental implant placement. Therefore, several groups advocate removal of hardware at 6–18 months after surgery or after radiographic conformation of bony union.[9,76,77] Olvera-Caballero et al, in their series, avoided plate placement altogether by performing bone fixation with wires along with 3 weeks of mandibulomaxillary fixation and demonstrated normal bone healing.[78]

SECONDARY PROCEDURES

Malocclusion, occlusal cants, or altered facial profile may develop due to suboptimal mandibular growth. Secondary procedure to correct these problems are met with 3 main challenges:

1. There is a risk of devascularizing the bone flap from periosteal stripping, osteotomies, and inadvertent pedicle injury.
2. Hardware gets embedded in bone over time, making it difficult to remove.
3. Bone stock may be insufficient to perform osteotomies.

The paucity of reports about secondary procedures in previously reconstructed mandibles attests to their difficulty. Three types of revision procedures have been described: distraction osteogenesis, orthognathic-type procedures (bone sliding), and bone repositioning by segmental ostectomy.

Distraction Osteogenesis

Mandibular distraction osteogenesis procedures are of 2 types: 1) longitudinal distraction to increase the length of the ramus and body 2) vertical distraction to increase alveolar height.

Longitudinal distraction of both non-vascularized and vascularized bone grafts has been reported.[79–85] Most studies are case series of secondary distraction of costochondral grafts used for reconstruction of the ramus in hemifacial microsomia. The success of distraction is dependent on good bone stock.[86] Complications of distraction are pin site infections, hardware failure and fibrous non-union.[87]

Vertical distraction of fibula and scapula flaps can increase alveolar height if it is insufficient for dental rehabilitation.[88–91] Implant placement is facilitated by increasing bone stock and creating an alveolar sulcus.

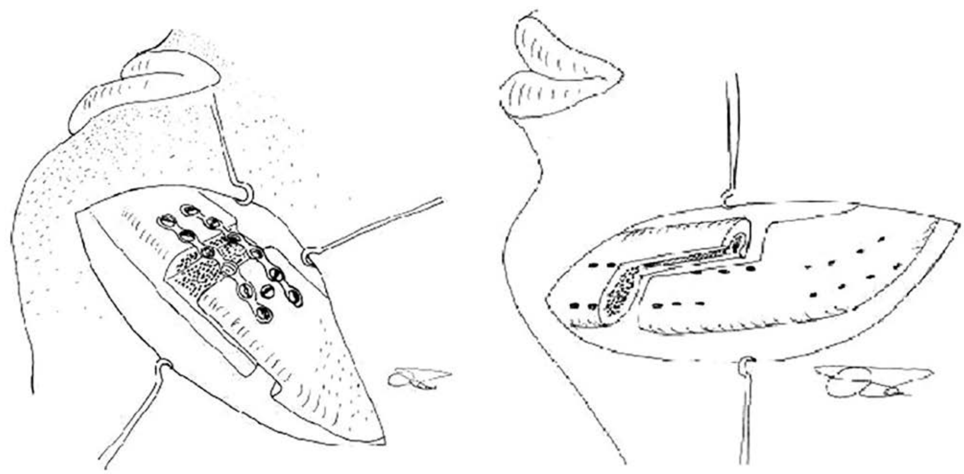

Fig. 5. Sagittal split osteotomy on iliac crest flap (A); step osteotomy with bone sliding on fibula flap (B). Reprinted with permission from Wolters Kluwer Health LWW from *J Craniofac Surg.* 2010;21(4):1238–1240.

Orthognathic-type Bone Sliding Procedures

There are very few reports regarding orthognathic-type bone sliding procedure on bone flaps. Sagittal split osteotomies have been successfully reported for fibula and iliac bone flaps.[92–94] Genarro et al reported their experience with orthognathic surgery in 8 patients who had undergone free flap mandibular reconstruction.[95] The iliac crease acts more like native mandible in the amount of cortical and cancellous bone; therefore, a traditional sagittal split type of osteotomy was performed (Fig. 5). The fibula is thinner and has more cortical bone; therefore, a step osteotomy with bone sliding was designed (Fig. 5). Strategies to preserve bone vascularity included pedicle identification and limited periosteal stripping. However, these procedures are very challenging with significant risk of complications.[75]

Segmental Ostectomy

Segmental resection of the bone flap at its junction with the native mandible can be performed to reposition the jaw. Chang et al reported that they successfully corrected 7 patients with malocclusion, using this technique.[96] Eski et al successfully performed segmental resection of fibula flap to setback a mandible that was too prognathic.[97] Yang et al performed a mandibular setback by segmental resection of an overgrown rib graft, in combination with a sagittal split osteotomy of the contralateral native mandible.[21]

CONCLUSIONS

The followings are important considerations for mandible reconstruction in skeletally immature patients:

1. Fibula, iliac crest, and scapula flaps do not grow. Costochondral grafts grow but unpredictably.
2. The condyle should be preserved, if possible, to maximize the growth potential of the remaining mandible.
3. The periosteum should be preserved, if possible, to allow the possibility of bone regeneration.
4. Fibula flap harvest in growing patients warrants continued follow-up until skeletal maturity to monitor for ankle instability and valgus deformity.
5. Elective hardware removal should be considered to facilitate future dental implant placement and a possible revisionary bone surgery.
6. Dental rehabilitation with osseointegrated implants facilitates normal maxillary development, prevents supra-eruption of opposing teeth, and minimizes bone resorption.

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