Chapter 2

Craniofacial Bone Grafting

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Additional information is available at the end of the chapter

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Abstract

Craniofacial bone grafting plays an important role in the reconstruction of the craniofacial skeleton. Most of the craniofacial surgeons accepted that bony defects of the face must be reconstructed with bone, and soft tissue defects must be reconstructed with soft tissues. Several studies have described the cranial bone grafting procedure that is preferred by most craniofacial surgeons worldwide. In the past and currently, alloplastic and other autogenous materials have been used to reconstruct the craniofacial skeleton. However, alloplastic materials have been abandoned as they are associated with a high risk of complications such as migration, infection, and underlying bone resorption.

Keywords: facial skeleton, skull graft, bony reconstruction

1. History

Craniofacial bone grafting plays an important role in the reconstruction of the craniofacial skeleton. Most of the craniofacial surgeons accepted that bony defects of the face must be reconstructed with bone and soft tissue defects must be reconstructed with soft tissues. Several studies have described the cranial bone grafting procedure that is preferred by most craniofacial surgeons worldwide [1–5]. In the past and currently, alloplastic and other autogenous materials have been used to reconstruct the craniofacial skeleton. However, alloplastic materials have been abandoned as they are associated with a high risk of complications such as migration, infection, and underlying bone resorption [6].

If vascularized free bone flaps and nonvascularized iliac bone grafts for mandibular reconstruction are eliminated, cranial bone grafts are the gold standard for use in the craniofacial skeleton. Because cranial bone grafts are composed of membranous bone, it is felt that they retain their bulk better than other types of bone grafts do, especially if they are rigidly fixed.

2. Necessity

Post-traumatic defects such as orbital floor fractures, postresection defects due to bone tumors, congenital bone defects, and esthetic reasons are some of the indications for the use of cranial bone grafts.

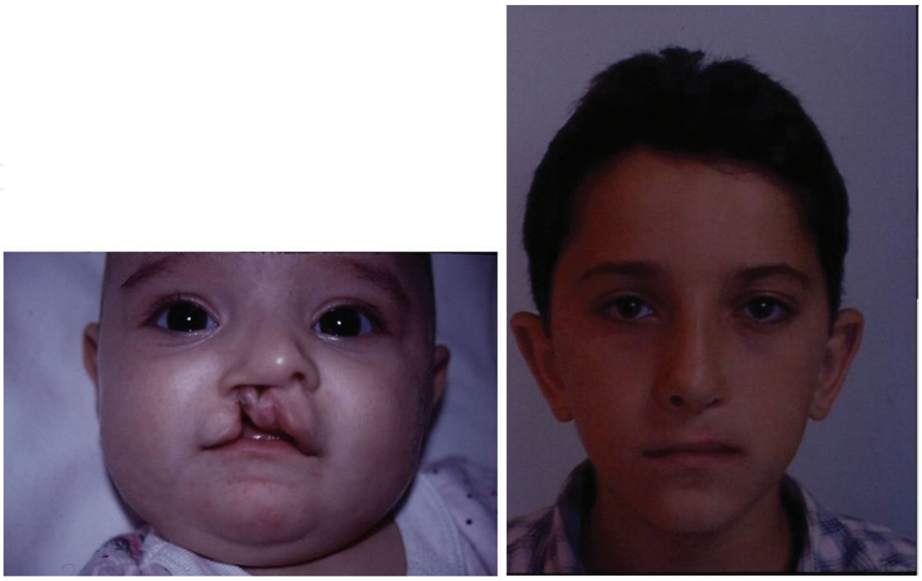
3. Mandibular reconstruction

For small mandibular defects and alveolar clefts, iliac bone chips and cranial bone chips are useful and mostly preferred by surgeons. In the alveolar cleft, our aim is to reconstruct the alveoli during primary cleft repair. In newborns, iliac bone chips are preferred for alveolar reconstruction. In adolescent or late repair, cranial bone chips are another useful graft material for alveolar reconstruction (**Photos 1** and **2**).

Mandibular contour defects should be reconstructed with cranial bone grafts because they have less tendency to resorb than other types of grafts do. Bone defects of the mentum should also be reconstructed with cranial bone grafts.

According to my personal experience, for full thickness defects of the mandible that are up to 10 cm in size, a nonvascularized, drilled iliac bone is the best choice.

One of the most important points when harvesting the iliac bone is to keep the muscle attachments intact and preserve all edges of the iliac bone. The iliac bone graft is harvested from the middle part of the iliac bone.



(a) (b)

Photo 1. Alveolar bone grafting during the primary cleft lip repair.

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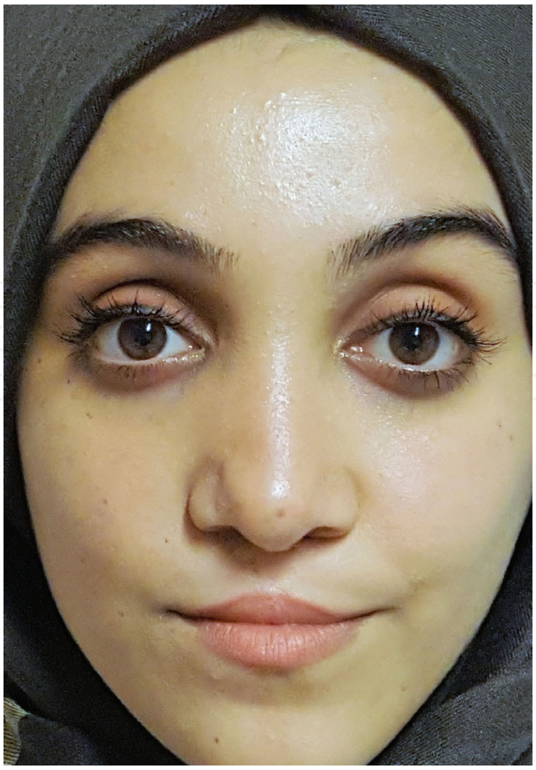

Photo 2. Alveolar bone grafting during the lip-nose revision.

In patients with vertical mandibular asymmetry, the interpositional placement of the iliac bone graft or bone that is resected on the contralateral side is the most preferred in our practice (**Photo 3**).

Mandible is the most dynamic part of the of the oral and craniomaxillofacial region. It includes and neighbors the temporomandibular joint, glenoid fossa, teeth, muscles, ligaments, salivary glands, and the tongue. It creates the boundaries of fossas (submandibular, sublingual, submental, infratemporal, pterygomandibular, submasseteric, and so on) as well. Therefore, reconstruction of the mandible requires to restore all the functional, anatomic, and esthetic aspects.

The functional considerations would include the restorations of occlusion, fonation, mastication and swallowing. Anatomic reconstruction requires adequate three-dimensional maxillomandibular relation. The esthetic outcomes would have balanced facial harmony with symmetry and vertical dimension.

Today, mandible can be reconstructed via non-vascularized bones or different types of free flaps in association with stock or 3D custom-produced titanium screws and plates.

The use of non-vascularized bone grafts and modified approaches for reconstruction of atrophied mandible prior to dental implant and dentures is well defined in literature. However, for larger defects after trauma or neoplasm surgery for the vitality of the bone and soft tissue of the graft is still challenging. Recently, the use of vascularized osteocutaneous free flaps has decreased the morbidity and mortality percentages, especially since the oncological cases and

(a) (b)

Photo 3. Interpositional bone grafting from left mandible to the right side.

osseointegrated dental implants that are installed on these flaps help to improve postoperative masticatory function.

Iliac crest and the fibula are the most favorable donor sides for oromandibular reconstruction with the advantages of minimal donor site morbidity, optimum pedicle length and diameter and two team approach. Various factors must be considered such as localization, residual bone dimensions with or without soft tissue defects, vessels, and bone volume for dental implant rehabilitation, when deciding which flap is the most suitable.

4. Iliac crest free flap

The iliac crest composite free flap has proven to be the one of the most effective and reliable choice for oromandibular reconstruction due to its appropriate and sufficient bone volume and corticocancellous structure and shape. It allows immediate reconstruction that avoids contour distortions of the mandible.

The iliac bone vascularization is maintained by circumflex arteries including the deep, lateral, superficial ones, epigastric superficial inferior and superior gluteal artery, and branches. The deep circumflex iliac artery (DCIA) is the principal blood supply for the flap. The incision should be designed according to need of the skin paddle. Following soft tissue dissection, the periosteum on the superior bone crest is elevated. Down to the level of the deep circumflex iliac artery, internal oblique and iliacus muscles are dissected and divided. According to shape of desired reconstruction of the mandible, the bone osteotomy and vascular pedicles are harvested, and rigid fixation is performed with by plates/screws. Finally, microvascular anastomoses of the vessels are finalized.

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5. Fibula free flap

The free fibula flap has gained popularity due to its bone graft and vessel length for reconstruction of extended mandibular defects. Bone flap can be harvested with adjacent periosteum and soft tissue with or without a skin paddle. The incision starts 5 cm below the lateral epicondyle of the fibula and runs 10–15 cm in a distal direction. After elevating the skin flap anteriorly/posteriorly, the muscle dissection through the intermuscular septum to peroneal muscle and sural muscle is performed to identify fibula. A muscle cuff of 3 mm is left along the fibula. Anterior intermuscular septum is incised by protecting the anterior tibial vessels. Then hallucis longus and tibial muscle through interosseous membrane is dissected. Proximal and distal cuts are performed around minimum 7 cm blow the proximal neck and superior to lateral malleolus according to desired bone length of the reconstruction site. The soleus, hallucis longus, and tibial muscles are dissected to elevate the peroneal vessel pedicles. At the distal site, the outward traction of the bone would help to reach tibial posterior muscle with its raphae, which help to secure the vessels when the muscle dissection is carried out along this raphae. Facial and supra thyroid arteries and external jugular vein is generally preferred for anastomoses. By osteotomy cuts on the harvested fibula, the required shape for mandibular reconstruction is achieved.

6. Upper face and cranium reconstruction

For the entire upper face, including the nose and the cranium, bony reconstruction and cranial bone grafting are the best choices because they are membranous structures that have less tendency to resorb.

In terms of craniofacial surgeons' preferences for cranial bone grafts, this is the gold standard. Even for dorsal nasal reconstruction, the cranial bone is the most popular in craniofacial surgery departments [6, 7]. Rib cartilage has a high rate of resorption and undesired shrinkage. Diced or blocked rib cartilage is not incorporated into the underlying nasal bones. One of the fans of rib grafts was popular rhinoplasty surgeon Jack Sheen, who turned to use the cranial bone for nasal reconstruction.

7. Harvesting of cranial bone graft

Cranial bone grafts can be harvested as split-thickness or full-thickness bone grafts according to the condition of the recipient area. In the case of full-thickness cranial bone graft harvesting, a neurosurgeon should be involved in the surgery team. The desired shape and size of the bone graft are drawn on the skull after the scalp is subperiosteally dissected. Then the neurosurgeon opens burr holes at the planned areas. The burr holes are connected by cutting the cranium with an electrical craniotome. The dura is dissected carefully, releasing the cranial bone from the brain. In most conditions, harvested full-thickness cranial bone is split from diploe obtaining pieces of split-thickness cranial bone grafts.

Usually, the outer table of the cranium is used to reconstruct the donor site, which is fixated without any step to protect the cranium against undesired irregularities (**Illustration 1**). In children up to 10 years old, the diploe does not exist. The diploe may not exist in women and men who had a poor diet during their period of growth. In those with syndromic cranial anomalies, an undesired forehead shape may be corrected by transferring a nice part of the cranium to the forehead (**Photo 4**). In the case of split-thickness cranial bone graft harvesting, the desired shape is drawn on the temporoparietal skull with a pencil. Then, the graft area is cut down to the diploe with a special electrical osteotome. One of the edges of the bone graft is exposed, and a tiny wedge of bone is removed.

Then, a curved, tiny chisel or specially designed, L-shaped electrical osteotome is used to release the outer table of the cranium. Cranial bone graft-donor sites are reconstructed with tiny bone chip lamellae that are harvested from the area that is adjacent to the donor area (**Illustration 2**). This procedure is associated with a low incidence of patient complaints, thereby suggesting higher patient satisfaction [8]. This approach to cranial bone grafting appears to have a high patient acceptance [8].

Cranial bone grafts can also be harvested as bone chips, especially in patients who undergo alveolar cleft repair [9].

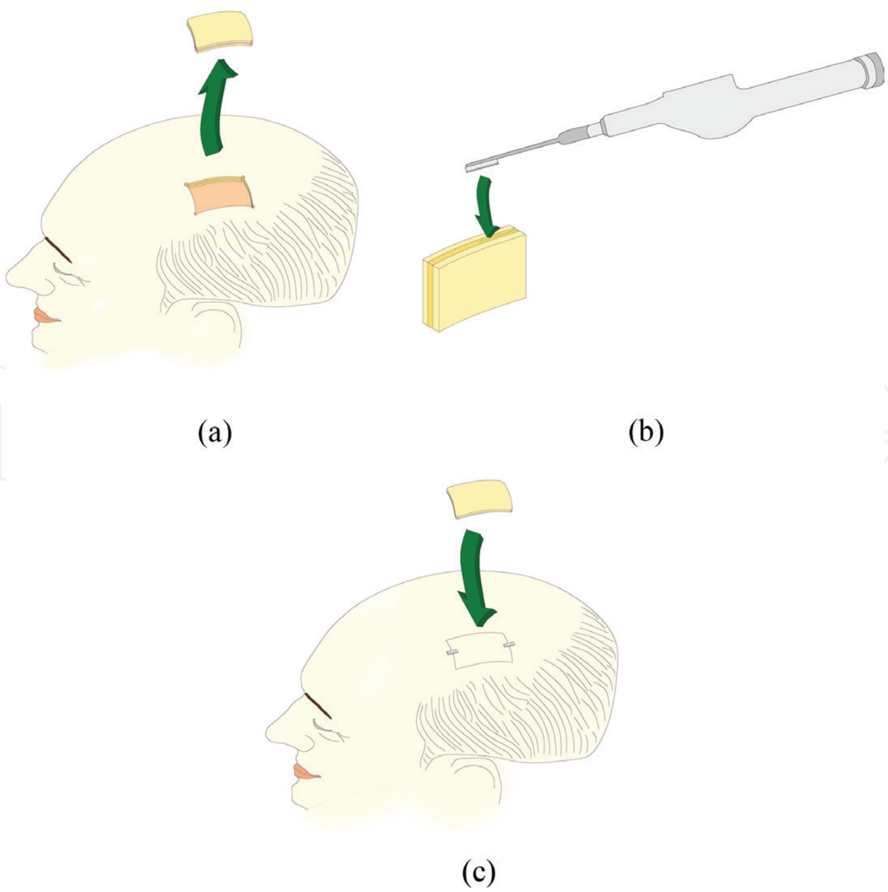

Illustration 1. Full-thickness cranial bone graft harvesting.

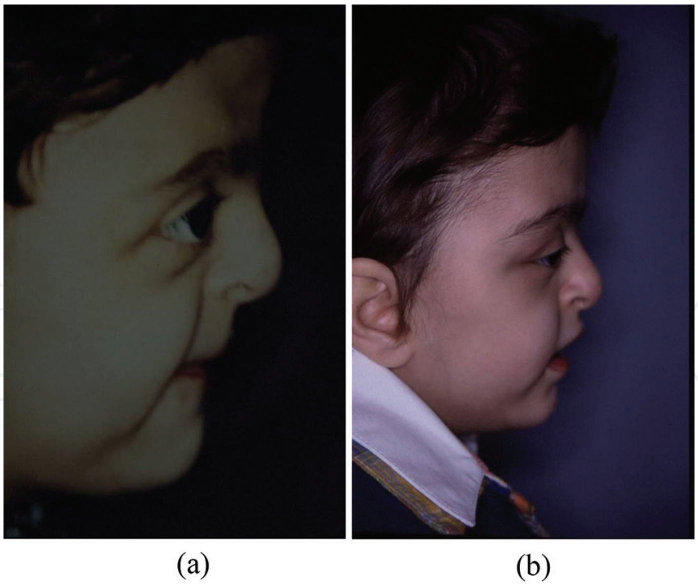

Photo 4. Temporoparietal bone block transferred to the forehead.

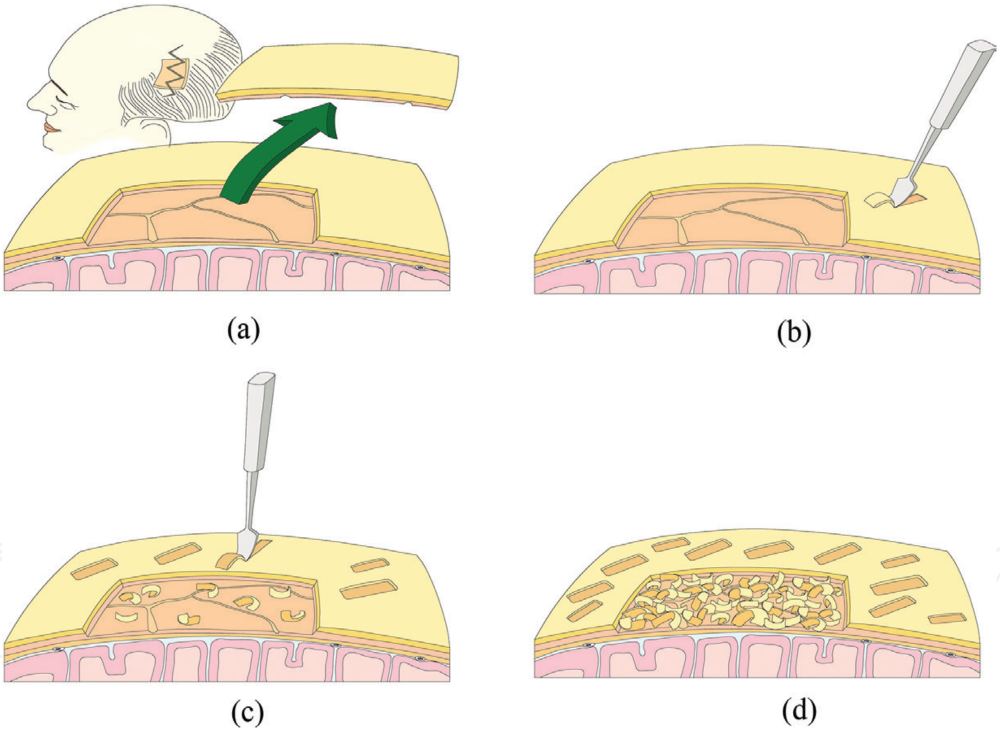

Illustration 2. Cranial bone graft donor site reconstruction.

7.1. Cranium reconstruction using cranial bone graft

Cranial defects must be reconstructed with cranial bone grafts. All alloplastics have different side effects and complications, while cranial bone grafts are durable and strong.

Split-thickness, outer table cranial defects may not be reconstructed, but we described a technique in which cranial bone chips were used to reconstruct the outer table of the cranium [8] (**Photo 5**).

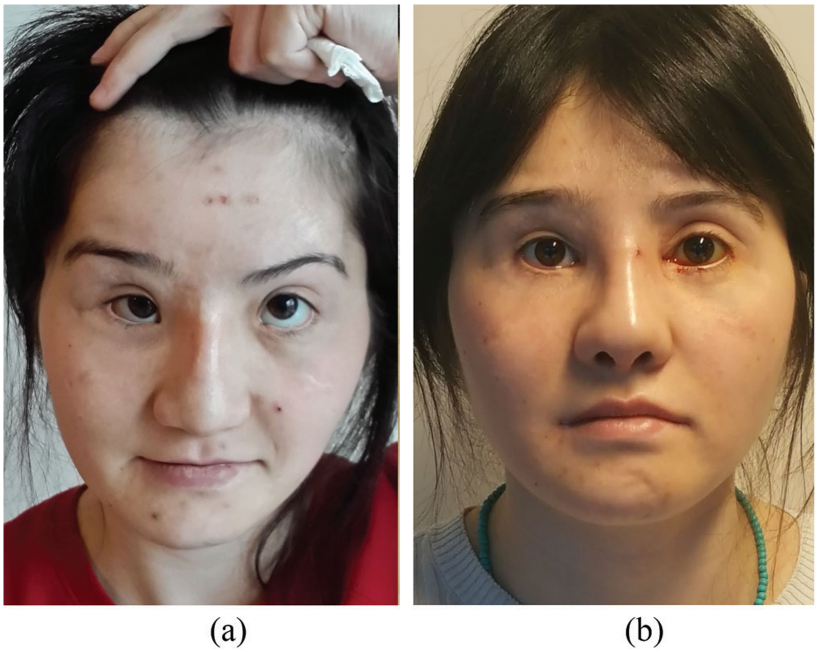

Photo 5. Orbital floor and medial orbital wall reconstructed using split cranial bone grafts.

Full-thickness cranium defects must be reconstructed because of the possible risk of brain injury. For this purpose, the shape of the defect is drawn on the donor area, and a full-thickness graft is harvested and split into two pieces.

The outer table is used to reconstruct the donor site, avoiding any step deformity. The inner table is used to reconstruct the defect.

7.2. Orbital floor reconstruction with cranial bone

In the case of blow-out fracture of the orbit with a tiny bone defect on the floor, the size of the defect is drawn on the donor area, and the periosteum must be kept on the cranial bone. Then, the area around the graft is outlined with a tiny curved chisel. Finally, the graft that is 3 mm in thickness is harvested. This curved graft with a few fractures is inserted into the orbital floor through transconjunctival incision and is not fixed. The periosteum keeps the fractured, small cranial bones in one piece.

Large orbital defects are reconstructed with split-thickness cranial bone grafts. The shape of the defect is drawn on the temporoparietal cranium. After harvesting the desired graft, the surgeon fixes a miniplate to the harvested bone graft (**Illustration 3a** and **Photo 6**). Then, the graft is placed on the orbital floor and fixed to the anteroinferior part of the orbit (**Illustration 3b**).

7.3. Dorsal nasal reconstruction with cranial bone

According to my 22 years of experience, a cranial bone graft is the best choice for dorsal nasal reconstruction. Jackson et al. described the cranial bone grafting for nasal reconstruction in 1983 [2].

They published a long-term follow-up paper about the use of cranial bone grafts in dorsal nasal augmentation [6]. They mentioned that they formed various impressions about the use

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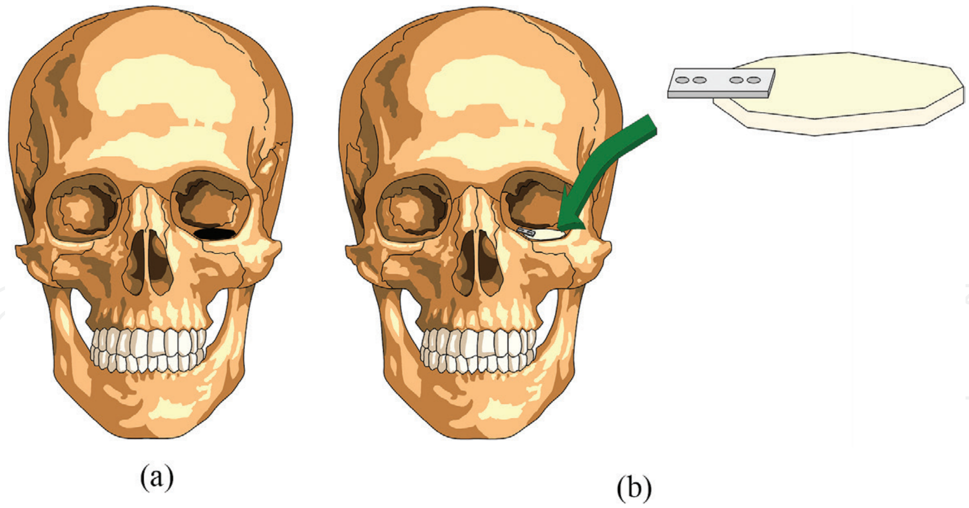

Illustration 3. Orbital floor reconstruction using split cranial bone graft.

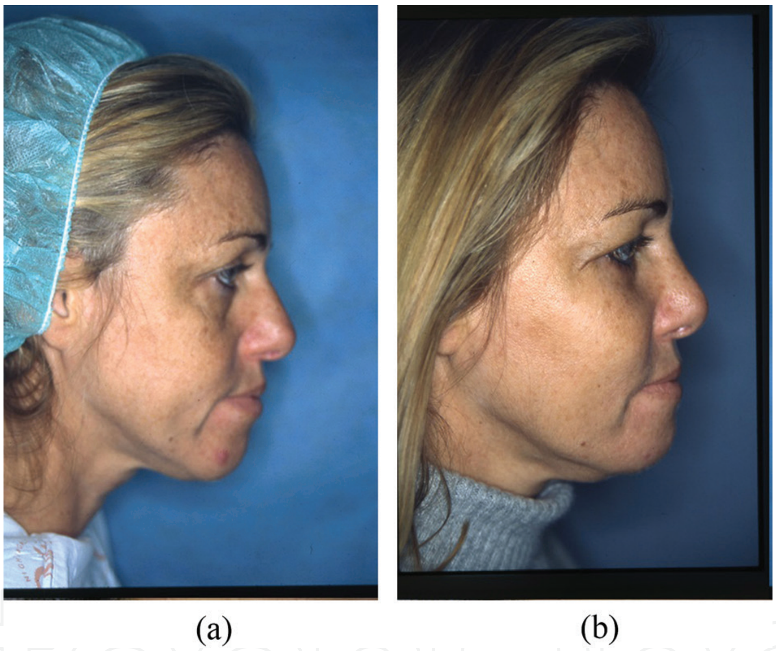

Photo 6. Malar augmentation with cranial bone graft.

of cranial bone grafts in other areas of the face. Cranial bone grafts are composed of membranous bone, and it is felt that they retain their bulk better than other types of bone grafts do.

In patients with cranial bone grafts on the nose, these grafts should be examined more effectively than grafts that are placed on other areas of the face because the grafts are in such an obvious and easily examined area and are covered with thin skin.

According to Jackson et al.'s technique, the cranial bone from the radix to the tip of the nose is used. However, this technique has two disadvantages: it causes the nasal tip to become rigid and the nose is rendered because of traumatic forces. Therefore, we described a modified technique for dorsal nasal reconstruction with the cranial bone [7]. We believe that the bony segment of the nose must be reconstructed with bone and cartilage segment and a cartilage graft when performing anatomic nasal reconstruction. The idea for our technique arises from the principles of anatomic reconstruction, which means that the bony part of the nose is reconstructed with cranial bone and the cartilage part is reconstructed with cartilage (**Illustration 4**).

According to our technique, the surgery is planned after the nose is examined. Nasal reconstruction is planned using cranial bone for the bony part of the nose and a double layer of ear cartilage for the distal part. The dimensions of the graft are measured on the nose and drawn on the skull with a marking pen. Then, the margins of the graft are cut down to the diploe with a special electrical osteotome. On one side of the margins, a wedge-shaped bone is removed to expose the diploe. Then, the bone graft is elevated using a tiny, curved chisel or an L-shaped electrical osteotome. After harvesting the bone and cartilage grafts, dorsally at the caudal end of the bone graft, the surgeon burrs away that is two millimeter in thickness. This burred area is deepened to create a space at the proximal end of the upper layer of the cartilage block. On the burred area, six small holes are opened using a tiny drill.

The cranial bone graft is shaped as desired with a contouring drill. The upper layer of the cartilage is fixed to the bone through these holes using 5-0 nylon sutures.

Then, another layer of cartilage graft is sutured posteriorly to the first layer, which is adapted to the bone graft that was created at the beginning of this step. The bone-cartilage block is

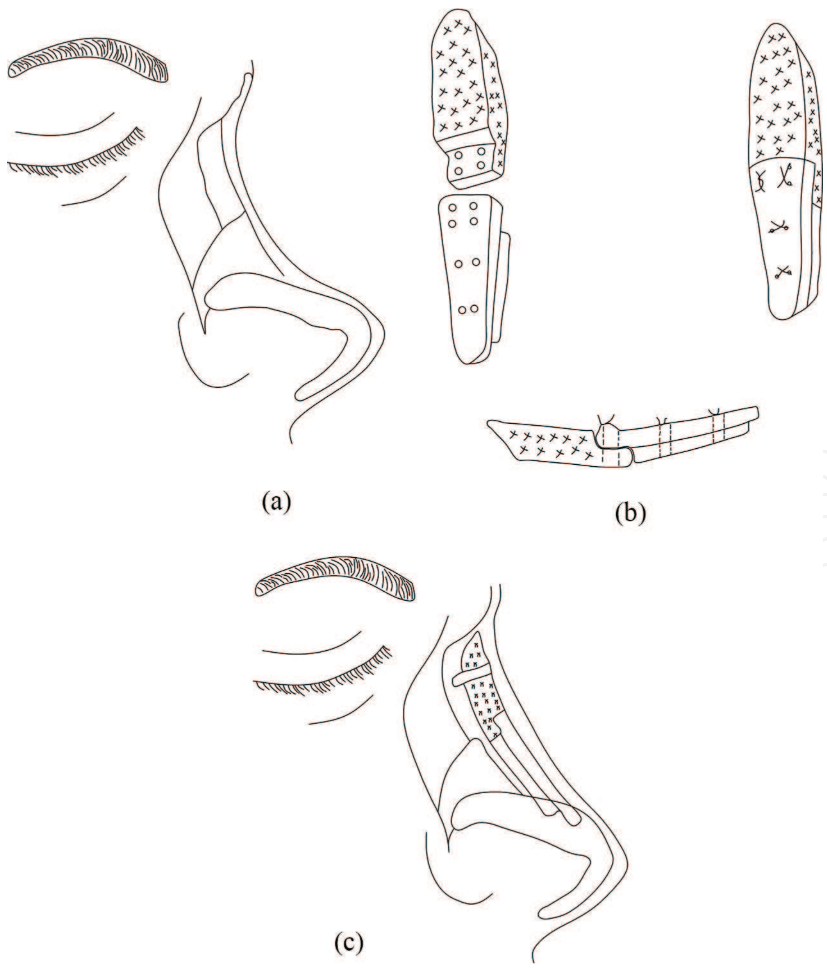

Illustration 4. Nasal reconstruction using both cranial bone and ear cartilage.

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inserted in to the nose through an open approach incision, and the bony segment is fixated to the radix with a screw through a vertical glabellar incision.

7.4. Malar augmentation with cranial bone graft

Cranial bone graft is the first and best choice for malar augmentation in our practice. First, the malar area is exposed with subperiosteal dissection. Then, the augmentation thickness and size of the malar area are. The donor site is selected according to the size and shape of the required bone graft. Usually, a short, running Z incision is used for harvesting (**Illustration 2**). The desired graft is harvested and shaped using a contouring drill. When the graft is ready to be inserted, the best location is selected according to its esthetic appearance during a visual examination. Two screws are used for fixing the cranial bone graft to the underlying malar bones.

7.5. Cranial bone grafting for fixation during the maxillary osteotomy

If maxillary osteotomies are performed to elongate or advance the maxillae, there is a significant risk of the relapse, even fixation with a plate and screw. When we examine the maxillae of patients with a cleft palate, there is retrusion and hypoplasia. In patients with these conditions, the maxillae should be advanced and elongated.

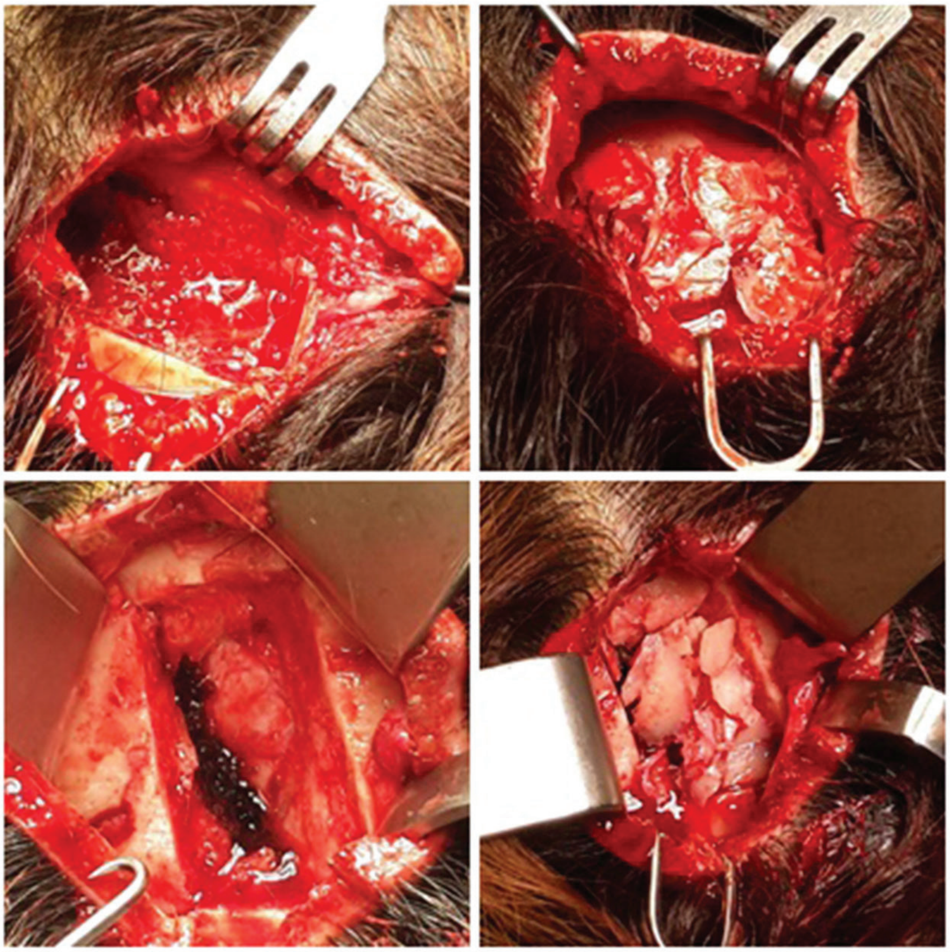

Photo 7. Reconstruction of the donor site of cranial bone graft.

Elongation and advancement are performed using Le Fort I osteotomy, and there is no bony contact between the advanced part and the maxillae.

However, this condition is subject to the relapse because of advancement and elongation. In most patients with midface retrusion, when the maxillae are advanced, malar retrusion becomes more prominent. Therefore, a cranial bone graft is used to both provide strong fixation of the Le Fort I osteotomy and augment malar retrusion. Usually, a preplanned, large split-thickness cranial bone graft can solve both problems on one side of the face.

Cranial bone grafts are used for all types of upper face bone defects and chin defects, mandibular contour augmentation, periapertural augmentation, and augmentation of asymmetric deformities (**Photo 7**).

8. Cranial bone graft donor site reconstruction

The most important concern, in my entire experience with cranial bone grafting procedures, is managing the donor site of the bone graft, such as the donor site cavity through harvesting and weakening of the cranium. The most frequent patient complaint, following cranial bone grafting for esthetic indications, is the presence of a cavity at the donor site. I previously described a technique for cranial bone graft donor site reconstruction. The cranial bone graft donor site is reconstructed with tiny bone chip lamellae that are harvested from the area that is adjacent to the donor site. This approach to cranial bone grafting appears to have high patient acceptance. Our 15-year experience with donor site reconstruction following cranial bone grafting has demonstrated that the procedure is simple, safe, and satisfying. Herein, we provide a detailed description of our technique for donor site reconstruction.

9. Surgical technique

As mentioned before, donor site reconstruction following cranial bone grafting involves the use of thin bone chip lamellae that are harvested from the cranial bone that is adjacent to the donor site.

We have successfully performed this procedure in more than 200 patients in a 15-year period. This reconstruction technique is applicable to mild-to-moderate donor site defects, and is useful for treating in both, split- and full-thickness donor site defects.

An initial Z-type scalp incision is made, followed by subperiosteal dissection to create a periosteal cover for the grafted bone chips. The galea over the periosteum is preserved to ensure that the periosteal blood supply is adequate. The use of subperiosteal dissection is essential in order to close the reconstructed donor site. Following graft harvesting of the cranial bone, thin cranial bone lamellae are harvested from the adjacent cranial bone by using a curved chisel (**Illustration 2** and **Photo 5**). The bone dust and small bone chips that are obtained during harvesting are collected and also used for reconstruction. The thin harvested bone chips are placed in the donor site cavity to over-correct the defect. Then, a block of gelatin sponge

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is placed over the bone grafts to avoid displacement during the operation. The procedure is completed by closing the periosteum and skin in separate layers.

Among the patients we have treated, the reconstructed defects initially appeared to be undercorrected, which prompted us to modify our procedure by overfilling the cavity with cranial bone chips.

As a craniofacial surgeon, I observed my mentors Henry Kawamoto and Ian Jackson perform cranial bone graft harvesting. My main concern was that patients might not accept the appearance of the donor site defect, especially when the procedure was performed for esthetic reasons. I described a technique of nasal bony reconstruction and performed it in a large number of patients. My initial experience with this procedure demonstrated that there was poor patient acceptance of the cranial bone grafting procedure owing to the presence of a defect at the donor site. Therefore, I reconstructed the donor site defect using tiny bone chips that are harvested from the cranial bone that is adjacent to the donor site. After the procedure was introduced, a higher proportion of my patients accepted the use of cranial bone grafts. The bone dust and small bone chips that are obtained during harvesting are also collected and placed in the donor site cavity, along with the tiny harvested bone chips. Overcorrection is advised to account for the potential dead spaces between the bone chips. Several reports have described reconstructing the donor site following full-thickness cranial bone grafting by splitting another full-thickness bone graft or using a split graft.

In our experience, reconstructing split-thickness and full-thickness donor sites with cranial bone chips is a simple, safe, and satisfying procedure. This technique is useful to fill the donor site during cranial bone grafting, which is a concern for esthetic surgeons.

10. Discussion

Overall, scientific studies have shown that bony defects of the craniofacial structures must be reconstructed with autogenous bone grafts. Although some studies have found that irradiated bone or autoclaved homografts are useful for bony reconstruction, our clinical experience contrasts with these studies.

Alloplastic materials such as medpor, silicon, and hydroxyapatite are not useful for bony reconstruction of the craniofacial skeleton. For defects of the mandible that are up to 10 cm in size, drilled, nonvascularized iliac bone grafting is an easy and suitable reconstruction method. The donor site of nonvascularized iliac grafts must be harvested at the midportion of the iliac bone instead of at the edge of the anterior part. For large or total reconstruction of the mandible, free iliac or fibula bone grafts are preferred. Free iliac grafts are superior to free fibula grafts for dental restoration because of their spongy structures.

As I mentioned before, cranial bone grafts are the best choice to reconstruct the upper face and cranium. Some research studies investigated resorption of cranial bone grafts on the craniofacial skeleton, and they showed minimal rates of resorption [5, 6]. According to my 23-year experience with cranial bone grafts, these grafts have minimal or no resorption. In the past, surgeons used materials from other sites for dorsal nasal augmentation: the rib, iliac crest, olecranon, mandible, or cartilage. It was reported that a cranial bone graft can be harvested by a surgeon who has had proper training, with an extremely low incidence of serious complications [10–13].

Cranial bone resorbs less than other bone does, does not warp, has a hidden donor site, and has an excellent shape [5]. Solid silicone, silicone sponges, medpor, and proplast are easy to use but lead to a high rate of complications in Caucasian patients. This does not occur in Asian people.

Nasal reconstruction with a calvarial bone graft from the radix to the tip of the nose may cause problems such as pain in the nose, graft fracture, graft displacement, and an immobile nasal tip [6].

We believe that the bony segment of the nose must be reconstructed with bone and the cartilage segment should be reconstructed with a cartilage graft when anatomic nasal reconstruction is performed.

In conclusion, nasal reconstruction with a cranial bone-ear cartilage complex facilitates anatomic reconstruction, creating a flexible nasal tip that benefits from the use of autogenous materials.

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