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# Commonly Utilized Non Vascularised Bone Grafts in Maxillofacial Reconstruction

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## Abstract

Surgical defects created secondary to oncological resection are often debilitating for patients, both functionally and esthetically. Meticulous surgical planning and intricate knowledge of the vital anatomical structures are essential for understanding the biology of reconstruction in the craniofacial skeleton. Unlike reconstructive procedures in other areas where the functional components may be given priority, reconstruction of the face requires a delicate balance between the esthetic and functional units. Despite new developments, autogenous grafts have frequently remained a reliable alternative that withstood the test of time. Non-vascularized bone grafts are often a subset of autogenous grafts, where the graft solely depends on the recipient's vascularity and is indicated in defect sizes of less than 6 cm.

**Keywords:** non vascularized bone graft, maxillofacial surgery, critical defect, cortico-cancellous graft

## 1. Introduction

Resection and reconstruction are two vital components of surgical oncology. While the former depends primarily on the surgeon's discretion, the latter includes a vital role for the patient. The surgical team must consider the patient's desired outcome (especially in terms of facial esthetics) and remain cautious of critical aspects such as early bone resorption, infection and donor site morbidity.

The first bone graft dates back to 1881 when Sir William MacEwan performed a successful xenograft transfer into a craniofacial defect [1]. Currently, common non-vascularized bone graft (NVBG) options include anterior or posterior iliac crest, cranial vault and costochondral grafts [2]. Multiple studies had demonstrated a relatively high success rate between 85–90% when NVBG were used regardless of the type of injury [3–5].

Bone defects in the craniomaxillofacial complex require three-dimensional structural considerations to ensure proper dental occlusion and temporomandibular joint function. This makes any reconstructive surgery in the craniomaxillofacial skeleton complex and challenging [5, 6]. In most such reconstructions, fresh autogenous bone is the gold standard bone grafting material [7]. There are three typical ways in which fresh autogenous graft can be transferred:

- Non-vascularized grafts,
- Pedicled grafts, and
- Microvascular free flaps.

## **2. Concept of a 'critical-sized bone defect'**

In simple terms, a critical-sized bone defect is the minimum size defect beyond which bone fails to heal spontaneously despite surgical fixation, requiring further surgical intervention [8]. It is imperative to diagnose critical-sized bone defect as this will help surgeons decide the need for surgical intervention [9]. Although there is no clear-cut consensus in the literature regarding minimum defect size measurement, a few studies have estimated this value to be in the range of 4 mm–5 mm [8, 9]. Defect size less than this measurement can be managed by plate and screw fixation, but anything above this value must be considered for grafting and subsequent fixation [8–10].

## **3. Factors to be considered before bone grafting**

- Age of the patient - Older individuals have decreased healing capacities as compared to the younger groups. Moreover, systemic complications such as diabetes, hypertension, and cardiovascular diseases are more common in geriatric patients and must be ruled out [11]. Surgical reinforcements like the bone morphogenic protein (BMP-2) or plasma rich platelet therapy should be considered to promote faster healing [11–13].
- Nature of the disease – NVBG is primarily indicated in benign lesions where the risks of recurrence are low as it aids in better graft uptake. Furthermore, malignant lesions are frequently treated with radiotherapy, which compromises the capacity for angiogenesis into grafted tissues [5, 14].
- Size of the defect – As previously mentioned, 5 cm is the maximum defect size that can be reconstructed with NVBG. Beyond 5 cm, a graft needs its own blood supply in the form of a vascularized graft as NVBG depends solely on recipient site vasculature [15, 16].
- Need for adjuvant Radiotherapy.– Radiation causes compromises blood supply and cellular function in recipient tissue beds. According to the current guidelines of management of head and neck pathologies, NVBG should not be the first choice in patients who require radiation therapy. If radiation is planned, it should be administered at least six months before and after grafting to ensure that the graft develops an adequate blood supply [17].
- Timing of reconstruction – Surgical intervention may occur as a single- or two-staged operation. The single-staged modality refers to immediate reconstruction after ablation. This allows for shorter duration of treatment and maintenance of pre-operative soft tissue contours. On the other hand, the two-staged modality refers to initial ablation followed by reconstruction at a later date. This provides ample time for planning the reconstruction.

The authors favor immediate grafting as it averts the need for a second surgery and minimizes the total treatment duration.

- Type of bone required – Cortical bone resists resorption and maintains its structural integrity post-operatively. Conversely, cancellous bone is more porous and demonstrates a faster rate of resorption. However, there is also rapid neovascularization in cancellous bone when compared to cortical bone. Calvarial grafts have more cortical component, while the iliac crest has a more cancellous component [18, 19].

### **3.1 Graft donor sites**

Following options are available to the surgical team in the reconstruction of maxillofacial defects

- Bone graft from anterior or posterior ileum
- Bone graft from calvarium
- Bone graft from tibia
- Bone graft from rib

## **4. Iliac crest bone graft**

Autogenous bone harvested from the ileum serves as an excellent source of cortico-cancellous graft with a maximum harvest volume of 50 cc for the anterior iliac crest and 100 cc for the posterior iliac crest [2, 5]. In general, harvests from the anterior iliac region are considered easier and safer because they do not require intra-operative repositioning [7, 20].

The important anatomical landmarks that should be considered during surgery are the anterior superior iliac spine (ASIS) and iliac tubercle, which is 6 cm posterior to the ASIS. The iliac crest receives its blood supply from the deep circumflex iliac artery, a branch of the internal iliac artery and the most common bleeding source during surgery [7, 20, 21]. Sensory nerves that must be protected are iliohypogastric nerve and lateral femoral cutaneous nerve. The lateral femoral cutaneous nerve (LFCN) is at increased risk of damage during surgery and must be identified and protected from iatrogenic injuries. According to Mischowski et al. the LFCN courses between 5 to 14.6 mm superiolaterally from the ASIS [22, 23].

### **4.1 Anterior iliac bone harvest**

A curvilinear incision is placed 2 cm superior to the ASIS along the iliac crest to prevent injury to the LFCN, and the dissection is taken down through subcutaneous tissue to the muscular levels. The external oblique muscle and tensor fascia lata are identified and lateralized to expose periosteum. The periosteum is then incised, and the iliacus muscle is identified and retracted medially [2, 7, 24]. Osteotomy is performed along the length of the iliac tubercle joined by two vertical cuts at the ends of the osteotomy along the medial iliac curvature. The cortical bone may be harvested with an osteotome and the cancellous bone using a bone gouge [2, 24]. There are various other approaches described in the literature for harvesting the anterior

iliac crest. In the trapdoor approach, the medial or lateral bony cortex is pedicled with an attached muscle to gain visualization to the cancellous bone. The Tschopp technique involves obliquely osteotomizing the iliac crest. A third approach, the Tessier approach, involves medial and lateral oblique osteotomies to gain access to the underlying cancellous bone [25–27].

The trapdoor technique allows direct access to the cancellous bone while preserving the attachments to the muscle and abdominal fascia [26]. On the contrary, Tschopp and Tessier techniques preserve the natural contour of the iliac crest, improving post-operative cosmesis [24, 26, 27].

A maximum of 3 x 5 cm of cortical bone and 50 cc of cancellous bone [2, 23, 24] can be harvested from anterior ileum. This is typically sufficient to reconstruct mandibular segmental defect up to 5 cm [2, 6, 7].

## **4.2 Posterior iliac crest bone graft**

The posterior ileum can provide up to 100 cc of corticocancellous, uncompressed bone [2, 6]. The posterior iliac crest also demonstrates extremely low rates of post-op morbidity including gait and neurosensory disturbances [2, 6, 27–29]. However, additional anesthetic risks are present associated with the prone position [2, 6, 28].

Relevant anatomy – The sacroiliac joint is the primary anatomical landmark. Just below the joint, the gluteus maximus muscle attaches to the triangular tubercle which measures approximately 3 x 4 cm. The superior and medial cluneal nerves arise from the dorsal rami of L1, L2 and L3 and lies approximately 6.5 cm from the posterior superior iliac spine (PSIS) [2, 6, 29]. Surgical approach to the posterior iliac graft begins in the prone position with 210-degree reverse hip flexion. The incision is designed 1 cm from the PSIS and carried 5–6 cm along the crest superolaterally to avoid injury to the cluneal nerves [2, 29]. Dissection is then carried out incising skin then subcutaneous tissues to the level of fascial attachments of the internal oblique and gluteus maximus muscles. The dissection is also performed between superior and middle cluneal nerves to expose the posterior iliac periosteum [6, 29]. Sharp incision of periosteum is then conducted using electrocautery taking care not to damage the sacroiliac ligaments. Depending on the graft volume requirement, an osteotomy may be made approximately 4 to 5 cm inferior to the iliac crest.

A 2012 study by Abramowicz et al. demonstrated that bone graft from the posterior iliac crest benefits from decreased blood loss and fewer post-op morbidities when compared to the anterior graft. On the contrary, intraoperative and anesthesia times were significantly lower in the anterior graft [30].

## **4.3 Complications**

The most commonly documented complications in anterior iliac graft harvest are hematoma, seroma, gait disturbance, pelvic instability, persistent pain, abdominal pain, and infection [31, 32]. In their ten years of analysis, Antonio et al. reported predominantly minor complications that would frequently self-correct within five weeks [33]. Another study by Manar et al. of 372 patients reported only two major complications consisting of fracture and seroma [34]. Various authors have recommended the use of a reciprocating saw and to maintain a clear margin of at least 3 cm posterior to ASIS to prevent fracture of the iliac spine [2, 4, 26, 29].

Posterior iliac graft harvesting tends to have fewer complications which can include bleeding, ureteral injury, abdominal hernia, paresthesia, seroma and infection [32, 35]. Studies by Elke Ahlmann et al., Nkenke et al., and Mazock et al. concluded that harvesting of the posterior iliac graft is associated with a significantly lower number of complications [28, 36, 37].

Overall, bone harvest from the iliac region is general safe and provides an adequate amount of good quality cortico-cancellous bone.

## 5. Calvarial bone graft

Historically, calvarial bone is one of the most commonly harvested grafts in the reconstruction of craniofacial defects [2]. The calvarium shares a common embryological origin as the other bones of the maxillofacial region and develop through intramembranous ossification [2, 18]. As a result, they demonstrate slower resorption rates than many other NVBGs. The calvarial grafts are also advantageous in that they are frequently obtained from the same surgical field and that they are anatomically distant from critical structures like vessels and nerves. This allows the graft to be harvested with decreased morbidity and technicality [2, 38].

However, potential complications do exist including dural tears, post-operative structural deformity, alopecia, and an inadequate amount of cancellous bone [39]. The calvarial bone graft is particularly indicated where structural integrity is needed in reconstructions of the maxilla, nasal dorsum, zygomatic pillars, orbital floors and the frontal bone [2, 38, 40].

Relevant anatomy and surgical technique: Anatomically, the calvarium comprises of singular frontal and occipital bones as well as paired parietal and temporal bones. Calvarial bone grafts are best harvested from the parietal region that measures approximately 8x10 cm. The skull is made up of the outer cortex (cortical bone), the medullary space (cancellous bone), and inner cortex (cortical bone) all of which may be harvested for use [18]. Surgeons must remain diligent when approaching the inner cortex to avoid tears to the underlying dura covering the brain [2, 18]. Inadvertent dural injuries can lead to hematoma and/or CSF leakage. In a case series of 23 patients, Harsha et al. reported three cases of perforation of the inner cortex, one of which incurred dural tear that required primary closure [41]. Another anatomical limit that must be taken into account is the temporoparietal suture, as any osteotomy below this line risks intracranial exposure because of the thinness of the bone.

The calvarial bone graft may be taken at three different levels [38, 42]

- i. Partial-thickness outer cortex: only a strip of the outer cortex is harvested. It is suitable for children between 4 to 6 years of age, especially in the reconstruction of craniofacial anomalies.
- ii. Full-thickness outer cortex: whole outer cortex is harvested. This is more suitable for adult patients.
- iii. Inner cortex: in some cases, where craniotomy has previously been performed, the inner cortex can be harvested leaving the outer cortex behind.

In cases where a broad area of reconstruction is required, the bicortical technique is preferred, where the two cortices are split, thereby doubling the graft's available surface area [42].

Surgical technique – The coronal incision is the most preferred technique as it allows a wide area of visualization to the underlying parietal bone. The incision starts from one helical crus to the other, approximately 2 to 3 cm posterior to hair-line [2, 7, 42, 43]. Once the scalp flap is raised, an avascular plane is created between the pericranium and the galea, and the external surface of the skull is then exposed through subgaleal dissection. All osteotomies must be made at least 2 cm away from

the temporoparietal and sagittal sutures. Venturing beyond these landmarks leads to increased risks of perforating the dural layer [38, 43, 44]. Based on the technique mentioned above, the surgeon may make the harvest using a Gigli saw and osteotome. Once a strip of bone is harvested, the defect may be filled with an alloplastic substitute that helps maintain the natural contour of the skull. The closure is then performed in layers, and a pressure pack is applied for 48–72 hours [2, 38, 43, 44].

## **5.1 Complications**

Complications related to calvarial harvests are few and depend on the technique performed. The bi-cortical harvesting technique significantly increases the risk of complications because it interferes with the inner cortex, which lies close to the dural layer [2, 42]. In a study by Frodel et al. 3 cases of dural tear were reported in 121 patients who underwent bicortical grafts, of which 2 were less than 1 cm and required minimum intervention. In one case, however, there was an intracerebral injury, requiring neurosurgical intervention [38]. In another study of 511 cases by Sandrine Touzet et al., 13 cases of immediate complications were noted, including 2 cases of hematoma of the scalp and 11 cases of dural exposure. Late complications occurred in 12 patients with alopecia, 2 with residual pain, 8 with dysesthesia, and 420 with skull depression [45].

Most dural complications may be avoided via the use of pre-operative computed tomography to measure the thickness of the parietal bones [2, 7, 38–44]. Post-op skull depressions may also be addressed via secondary alloplastic grafting [46]. With increasing sophistication of practice, the number of complications associated with calvarial bone grafts has dropped significantly in the past few years.

## **6. Tibial bone graft**

Bone harvested from the proximal tibia is an excellent source of cancellous bone, which is helpful in addressing “spacial defects” like pneumatized maxillary sinuses and 3 to 4 osseous wall defects [47]. This procedure is generally indicated in adults where skeletal maturity has been achieved [2, 47, 48]. The amount of cancellous bone obtained from the tibia is approximately 20 cc, somewhat less than the bone obtainable at the anterior iliac crest. Bone grafts from the tibia can be harvested either from the medial or the lateral side, but the lateral approach is preferred because of a decreased rate of complications [2, 47].

Relevant anatomy – The most important anatomical landmark for the lateral approach of harvesting tibial bone graft is Gerdy’s tubercle [2, 7, 47, 49]. It is the insertion site of the iliotibial tract on the proximal and the lateral aspects of the tibia. Gerdy’s tubercle is a bony prominence and is a key marker to be noted before placing an incision [49]. Other anatomical landmarks include the patella, patellar ligament, tibial tuberosity, and the fibular head, which includes Gerdy’s tubercle. The lateral cutaneous branch of the sural nerve frequently crosses over Gerdy’s tubercle and the surgeon must remain diligent while dissecting along the course of this nerve. Small terminal branches of the inferior genicular and the recurrent anterior tibial arteries may also cross Gerdy’s tubercle, which can be readily cauterized during surgery [47]. Avoidance of major neurovascular structures is done with relative ease, rendering the proximal tibia a safe alternative harvest site [7, 47].

Surgical technique – Identification of Gerdy’s tubercle is the key step of this technique. Once identified and confirmed with palpation, a 3–4 cm incision is made directly over the tubercle. The incision is then continued to the periosteum, which is then elevated to gain access to the cortical plate [47, 49]. A cortical window is made

with an osteotome or surgical drill to gain access to the cancellous component of the bone. The required cancellous bone is then harvested until the inferior component of the cortical bone is reached [49]. The wound is then closed in a layer, with the iliotibial tract approximated with resorbable sutures.

## 6.1 Complications

Apart from the common post-operative surgical complications like infection, wound dehiscence, pain, gait disturbance, and paraesthesia, proximal tibia fractures have seldomly been reported in the literature [2]. A study by O'Keeffe et al. of 230 patients reported only one case of fracture [50]. Hughes et al. reported 2 cases of proximal tibial fracture out of 75 cases, but these fractures were associated with alleged external injuries [51]. In a retrospective study by Ana Lucia et al. on 31 patients who underwent tibial bone harvesting, only 5 cases of minor complications were noted which all self-resolved within three weeks [52]. Kushner reported a complication rate of just 1.4% in a series of 141 patients [49]. In a meta-analysis, Shmidt et al. reported 63 complications out of 1,137 cases. Most of the complications were minor, but there were 5 cases of fracture and 1 case of osteomyelitis [48].

Despite its safety and ease, the proximal tibial harvest has not attained the same level of popularity as the iliac crest or calvarial grafts possibly as a result of unfamiliarity [47–49]. A review of the current literature nonetheless demonstrates that the tibia may be an appropriate alternative.

## 7. Costochondral graft

The costochondral graft was arguably the first developed autogenous graft used to reconstruct a segmental defect of the mandible. A unique advantage of rib grafts is that they can be harvested with their cartilage, active growth, and bony components, and that it may continue to grow even after application. This makes the costochondral graft a possible option for reconstruction in growing patients [53]. Anatomically, the rib's long, curvilinear shape makes it an adequate replacement for lateral defects of the mandible involving the angle and the ramus. The cartilaginous portion can function in the temporomandibular joint even in growing individuals [54, 55]. Maxillofacial surgeons have also incorporated costochondral grafts to reconstruct the nasal dorsum and septum in cleft individuals [56, 57]. Reports of using free rib graft to reconstruct the medial and orbital floor also exist [58]. A study by Tetsuji et al. demonstrated no significant complications after in an 8 week cohort [59].

However, the growth potential of a harvested rib is difficult to predict, as is its tendency to resorb. Literature recommends the use of relatively shorter cartilage portions (2–3 mm) [60] to limit unwanted growth [5, 61].

Relevant anatomy and surgical technique - The fifth, sixth, and seventh ribs are commonly selected for the harvesting. The cartilaginous component makes up approximately 1/3rd of the total length. An incision is placed 5 mm above the inframammary fold, and the incision is carried to the muscle level. The costochondral perichondrium lies immediately deep to the muscular fascia and must be exposed with care [2, 7, 53]. Then bony and the cartilaginous components of the ribs must be clearly identified so that the incision is placed along the longitudinal axis, and to safeguard the cartilage from any inadvertent injury [53]. The perichondrium is then reflected until the posterior aspect of the rib is exposed. Continuous palpation of the rib is essential to prevent pleural injury leading to the pneumothorax. The last step involves dividing the cartilaginous rib medially at the sternum and proximally at the bony rib [7, 53].



The graft is then shaped into the desired form by multiple osteotomies and fixated at the recipient site. Layered closure is executed at the donor site, ensuring tight closure of the perichondrium to decrease postoperative pain. A Valsalva maneuver should be conducted to check for any air leakage that can lead to post-op pneumothorax. A surgical drain is usually placed to reduce the risk of pleuritis [53, 62].

## **7.1 Complications**

Complications associated with the rib graft can be categorized into early and delayed. Early complications include pneumothorax, pleuritis, and infection; while examples of delayed complications are graft resorption and unpredictable graft growth [63, 64]. In a meta-analysis, Wee et al. studied 458 patients who underwent rhinoplasty with rib cartilage and reported 42 cases of unpredictable growth of the nasal dorsum, 4 cases of resorption, and 19 cases of hypertrophic scar formation. A systematic review by Kiran et al. reported similar findings as well [65]. A long-term study of 55 patients by Awal et al. reported that after 10 years, there were 58.9% of cases with unpredictable growth and graft resorption, 12.9% of cases with pneumothorax, and 1.8% of cases warranted immediate tracheostomy [66]. In fact, a 2015 study concluded that evidence for costochondral growth may not be sufficient. Sidebottom advises avoiding these grafts altogether due to scar tissue formation, which reduces vascular supply [67]. However, most studies stipulate that costochondral grafting is an acceptable procedure with adequate outcomes in repairing craniofacial anomalies [2, 4, 7, 53, 54, 56–59, 62, 68–70].

## **8. Osteointegration of NVBG**

Bone healing remains unique because it relies on cellular regeneration of a calcified matrix. In NVBGs, regeneration of the graft relies entirely on recipient site vasculature, which typically initiates neo-angiogenesis starts after three days of consolidation [19, 71]. The surgeon must therefore maintain the integrity of the periosteal envelope at the recipient site as this serves as the sole nutritional source to the graft until vascularization.

There are three possible mechanisms by which bone grafts heal or integrate, and in most cases, these mechanisms work synergistically to form a new bone [19].

1. **Direct osteogenesis** – In direct osteogenesis, new bone forms from the surrounding periosteum and the endosteum. Surviving osteocytes within the graft play a crucial role in direct osteogenesis by recruiting new osteoblasts. Generally, the cancellous component of the bone graft heals by direct osteogenesis.
2. **Osteoconduction** – Here, the grafted material serves as a scaffold for the production and extension of the osseous matrix from the surrounding host bone. This matrix then serves as a conduit for additional osteoblasts and the periosteum.
3. **Osteoinduction** – Signaling molecules within the graft trigger osteoinduction by stimulating the osteoprogenitor cells within the surrounding host bone. Once triggered, the osteoprogenitor cells transform into osteoblasts which initiate osteogenesis. Bone morphogenetic proteins are some of the most well-studied and widely utilized osteoinducing compounds in maxillofacial surgery today.

The mechanism of NVBG osteointegration remains similar irrespective of the donor site. However, the rate and amount of final bone formation differ in each case, as other factors such as recipient site integrity, nature of disease, and other patient factors also play crucial roles in final healing. In general, cortical bone heals by a method called creeping substitution [72], in which osteoclasts begin to resorb the graft material as a response to direct injury to donor's bone. These osteoclastic cells subsequently allow fibroblasts to grow and form a matrix, thereby enabling neo-vascularisation. The osteoclasts are soon occupied by osteoblastic cells from the osteoid [19, 72–74].

Further mineralization is initiated by osteoblastic cells. The synchronous activity of osteoblasts and osteoclasts forms a bone that is then remodeled prior to final maturation. The donor cortex never goes through complete resorption and remains intermixed with the new bone.

In cancellous bone, apposition precedes resorption by the ingrowth of scaffolds, on which osteoblasts form new bone [19, 74]. Structurally, cancellous bone contains marrow which allows it to revascularize rapidly. Unlike the cortices, cancellous bone undergoes complete resorption, which is then replaced by vasculature and mature bone [19, 73, 75].

Surviving osteoblasts secrete different growth factors at different periods, which expedite the healing process. Among the several growth factors, the most commonly identified ones include PDGF (plasma-derived growth factor), TGF (transforming growth factor), VEGF (vasculoendothelial growth factor), and EGF (extra-cellular growth factor). These growth factors are secreted during the second week of healing until maturation ceases [71]. Recently - with a better understanding of growth factors at the molecular level - surgeons have begun treating bone grafts with external sources of growth factor at the time of surgery. The growth factor is thought to promote healing even at the earlier stages of the graft as the host growth factors do not fully mobilize until the second week [73]. Moreover, these growth factors may promote new bone formation in the compromised recipient site which may lack healing potential as a result of devascularization or loss of embedded osteocytes.

### **8.1 Efficacy of craniofacial versus distal donor bone**

Bone harvested from the craniofacial region usually has demonstrates lower rate of resorption than those from distant regions like the ileum, tibia, and rib. Many investigators hold that embryologic similarity in the donor and host bones allow the graft to perform better [19, 71–74, 76]. This phenomenon may be a result of the congruence of the progenitor cells and signaling factors. Others show that craniofacial bones typically contain more vascular channels, which aid in early vascularization [77, 78].

### **8.2 Fate of bone graft**

NVBGs taken from distant sites undergo post-op resorption that typically require over-compensation of volume by approximately 20%. Animal studies using zygomatic and the iliac donor sites showed significant loss of the iliac graft and minimal loss of the zygomatic graft [18]. Preservation of the periosteum also appears to play a similar role, as intact periosteal envelopes were associated with rapid revascularization and minimal graft site volume loss [79].

## **9. Recent advancements in NVBG**

Reconstructive surgeries have undergone significant advancements over the last few decades, both in technique and technology. Intra-operative use of platelet-rich

plasma and fibrin (PRP and PRF) have shown promise in increasing graft success at minimal cost [80, 81]. In fact, leukocyte rich plasma rich fibrin (L-PRF) may stimulate osteoblastic action even more so than the traditional PRF or PRP [81]. Other biological agents like bone morphogenic protein (BMP), transforming growth factor (TGF), and insulin growth factor (IGF) have also been associated with improved success rates albeit at a higher cost [82, 83]. BMP-2 in particular has received approval from the U.S. Food and Drug Administration for its efficacy and stability [84].

Another notable advancement in the field of reconstructive surgery is intra-operative navigation. Navigation guided surgery begins by assisting surgeons in pre-operative planning and defect volume calculation in all the three planes. A spacial locator instrument is utilized intra-operatively so that the location of the instrument tip may be displayed on a rendering of the patient radiograph. With it, surgeons are able to harvest graft accurately according to the pre-operatively planned margins. Navigation also assists in ablative surgery by demonstrating the location of critical anatomical landmarks that are otherwise difficult to visualize. Surgeons can avoid nerves, arteries, and other structures without dissecting for them, reducing the risk of iatrogenic injury and subsequently the rate of graft failure [85].

## 10. Conclusions

NVBG remains the gold standard for managing small to mid-sized defects. Among NVBGs, the most common bone grafts used by oral and maxillofacial surgeons include the iliac crest, rib, tibia, and calvarium. With the advent of modern techniques, proximal or distal graft harvest has become a generally safe and successful component of craniofacial reconstruction.


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