# Vascularized Bone Grafts in Spinal Reconstruction: An Overview of Nomenclature and Indications

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## Abstract

Several vascularized bone grafts (VBGs) have been introduced for reconstruction and augmenting fusion of the spine. The expanding use of VBGs in the field of spinoplastic reconstruction, however, has highlighted the need to clarify the nomenclature for bony reconstruction as well as establish the position of VBGs on the bony reconstructive algorithm. In the current literature, the terms "flap" and "graft" are often applied inconsistently when describing vascularized bone transfer. Such inconsistency creates barriers in communication between physicians, confusion in interpreting the existing studies, and difficulty in comparing surgical techniques. VBGs are defined as bone segments transferred on their corresponding muscular attachments without a named major feeding vessel. The bone is directly vascularized by the muscle attachments and unnamed periosteal feeding vessels. VBGs are best positioned as a separate entity in the bony reconstruction algorithm between nonvascularized bone grafts (N-VBGs) and bone flaps. VBGs offer numerous advantages as they supply fully vascularized bone to the recipient site without the microsurgical techniques or pedicle dissection required for raising bone flaps. Multiple VBGs have been introduced in recent years to optimize these benefits for spinoplastic reconstruction.

**Keywords**
- bone graft
- vascularized bone graft
- bone flap
- spine reconstruction
- bone reconstruction
- spinal fusion

Reconstruction of bony defects presents a unique set of challenges to the plastic surgeon. Defects may arise in several contexts and anatomical locations, with complicating patient factors, and various reconstructive requirements. Indications for bony reconstruction include posttraumatic skeletal defects, oncologic bony defects following tumor resection, augmentation of fusions, and treatment of nonunions. The management of these bony defects has evolved with advances in the fields of plastic surgery, orthopedic surgery, neurosurgery, and industry.[1–4] Technological advancements have led to new bone substitutes and growth factors available for use. An improved understanding of bone biology and properties of bone grafts, that is, osteoconduction, osteoinduction, and osteogenesis, has guided an expansion of surgical approaches to bony defects.[5–7] Microsurgical techniques are applied to a growing number of donor sites, thus broadening available reconstructive options. Further, vascularized bone grafts (VBGs), bone transported on a pedicled muscle attachment, are used more frequently and with expanding indications in such scenarios as spinal

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reconstruction.[8–14] Despite the growing field of bone reconstruction, the current reconstructive algorithm has lagged behind.

Vascularized bone transfer to the spine is indicated as both a primary approach to aid in spinal fusion, as well as a salvage modality for patients with previously failed fusion attempts requiring revision. The size and location of the defect, as well as patient factors, all weigh into the decision of which reconstructive plan will be most appropriate for each patient. Vascularized bone transfer may be indicated when there is high risk for nonunion or pseudoarthrosis. The expanding use of vascularized bone transfer in the field of spinoplastic reconstruction has highlighted the need to clarify the nomenclature of bony reconstruction. In the existing literature, the terms "flap" and "graft" are often applied inconsistently when describing vascularized bone transfer. In this brief overview article, we aim to clarify the existing literature regarding bone grafts and flaps utilized in spinoplastic reconstruction, as well as to propose a modified bony reconstruction algorithm that incorporates VBGs.

## Current Algorithm for Bone Reconstruction

The generally accepted current bony reconstruction algorithm consists of four separate rungs including allografts, bone substitutes, autografts, and free bone transfer (►**Fig. 1**). Allografts include both cortical and cancellous cadaveric bone that can be fresh, fresh-frozen, or freeze-dried. Allografts do not require harvest from a living donor and are readily available off the shelf. Allografts are primarily osteoconductive in nature, with some additional potential for osteoinduction depending on the processing employed. They are gradually incorporated by the adjacent bone and rely on the surrounding tissues for vascularization. Since allografts are foreign materials, they may be subject to higher rates of infection and immunogenicity.[15,16] In the next rung are bone substitutes which include synthetics, biologic products, and growth factors. Numerous synthetic bone substitute options exist including calcium phosphate, calcium sulfate, and hydroxyapatite. These synthetics offer osteoconductive properties and are often cheaper alternatives to provide structural support or fill bony defects. Biologic products such as demineralized bone matrix do not provide structural support but can demonstrate osteoinductive properties through maintained growth factors.[17] Finally, isolated growth factors such as bone morphogenic protein can be utilized as an adjunct to stimulate cell differentiation and ultimately bone production.[18]

The third rung includes autografts, which can be further divided into cortical, cancellous, and corticocancellous bone grafts. Cortical bone provides structural integrity and promotes healing primarily by osteoconduction. Alternatively, cancellous bone offers all three benefits of osteoconduction, osteoinduction, and osteogenesis, but provides less structural integrity than cortical bone.[15,18,19] Cortical bone is most commonly harvested from the iliac crest and calvarium, while cancellous bone can be taken from the iliac crest, femur, tibia, and distal radius.[20–22]Corticocancellous grafts can be harvested from the fibula and rib, as well as those sites listed for cancellous grafts.[23] While many bone substitutes and allografts are now available, autografts are still considered the gold standard for bone grafting. However, the main drawbacks with this approach stem from donor-site morbidity.

The final rung in the bony reconstructive algorithm includes free bone transfer. Traditionally, free bone transfer has been reserved for large bony defects greater than 6 cm in length or defects within previously irradiated surgical sites.[15] Advantages of free bone transfer over autografts include increased resistance to infection, faster time to arthrodesis, and an increased number of viable osteogenic cells.[8–14] Free vascularized bone flaps (VBFs) have become increasingly routine at many institutions with advances in microsurgical techniques, operating microscopes, and increased surgeon comfort. Common sites of bone harvest for free VBFs include the fibula, distal femur, anterior iliac crest, lateral scapula, and rib.[24,25] Although many common free VBFs demonstrate reproducible techniques to harvest, recipient vessels for anastomoses may pose an additional challenge and should be equally considered for flap success.

## Proposed Algorithm for Bone Reconstruction

The proposed bone reconstruction algorithm consists of six separate rungs designating allografts, bone substitutes, nonvascularized bone grafts (N-VBGs), VBGs, pedicled VBFs, and free bone flaps (►**Fig. 2**). Introduction of VBGs into the bony reconstructive algorithm first requires a discussion of the nomenclature of "grafts" versus "flaps."


**Fig. 1** Current bony reconstructive algorithm.


**Fig. 2** Proposed bony reconstructive algorithm, with suggested modifications highlighted.

 

To date, these two terms have been applied interchangeably across the literature when describing bone transfer, and thus requires clarification. Traditionally, the term "graft" refers to tissue that is transferred without a blood supply and relies on the vascular network of the recipient site for survival or incorporation.[26] The term "flap" describes tissue that maintains its blood supply when relocated to the recipient site.[26,27] Flaps are based off of named vessels, major branches, or the corresponding perforators.[26,27] While VBGs are also transferred with their native blood supply, they are supplied by direct muscle attachments and small unnamed periosteal feeding vessels.[28,29] Thus, VBGs are best categorized as their own entity, located between N-VBGs and bone flaps. N-VBGs designate the traditional cortical, cancellous, and corticocancellous grafts. In this new algorithm, bone flaps are further divided into pedicled bone flaps and free bone flaps due to the significant jump in complexity between these two procedures. Pedicled bone flaps provide a regional option for transfer of vascularized bone similar to VBGs; however, they are distinct from VBGs in that they involve bony segments isolated and transported on their major vascular pedicle. VBGs are transported solely on their muscular attachments. Common pedicled bone flaps include the rib, lateral scapula, humerus, radius, fibula, and cuboid flaps.

## Discussion

VBGs occupy a central position in the reconstructive algorithm offering many benefits over standard autografts without the complexity and risks inherent in the more complex forms of reconstruction. Compared with N-VBGs and allografts, VBGs have an increased number of viable osteogenic cells which can promote more rapid arthrodesis and provide superior biomechanical support during the critical early phases of healing. Additionally, the vascularized nature of these grafts allows them to survive in a poorly vascularized, previously irradiated, or previously infected recipient bed.[8–14]These hostile wound beds would not be amenable to synthetics or allografts. Compared with free bone flaps, VBGs do not require the technical precision of microvascular anastomosis and are associated with shorter operative times and reduced blood loss.[12] Further, VBGs may reduce hospital stay and rehabilitation time compared with free tissue transfer where intensive care unit (ICU) admission and extensive rehabilitation may be warranted.

The VBG approach is particularly attractive in the field of spinoplastic reconstruction. Spinal fusions are often lengthy procedures with limited access to donor sites when the patient is positioned prone. It is, therefore, ideal to augment the fusion with a graft that can be harvested and inset efficiently, without a significant increase in operative time. Importantly, many VBGs may be dissected from a prone position when position changes are not feasible. Further, many of these VBGs may also be harvested through the original posterior midline incision, thereby saving the patient from an additional donor site and subsequent potential complications.[8–14]

Several different VBGs have been utilized across the growing field of spinoplastic reconstruction. The literature supports successes with the implementation of VBGs in spinal reconstruction utilizing the occiput,[30,31] clavicle,[10] scapula,[8,32,33] rib,[34–38] iliac crest,[12,13,22] and posterior elements (i.e., the laminae, transverse processes, and spinous processes).[14] Again, these reports are often inconsistent in nomenclature and classification, demonstrating the need for standardization in the literature. Each VBG, the corresponding muscular attachment, and the general indication are listed in ►**Table 1**.

The options for reconstruction of bony defects are broad and continually expanding. The proposed bony reconstructive algorithm provides a concise and organized structure for surgeons approaching spinal reconstruction. We suggest that the current bony reconstruction algorithm be expanded to include separate rungs for N-VBGs, VBGs, pedicled VBFs, and free VBFs. As with any algorithm for reconstruction, we intend for this framework to guide the process of surgical planning in a dynamic manner based on patient-specific factors, load-bearing requirements, defect size and type, and location. Surgeons can move up these rungs in a stepwise fashion, or instead choose to use a "reconstructive elevator" approach based on the overall analysis of the case. Ultimately, by clarifying and separating these terms, we hope that plastic surgeons will be able to better communicate with each other and across specialties and recognize VBGs as a robust reconstructive option.

**Table 1** Vascularized bone grafts with associated muscular attachments and indications

| Vascularized bone graft | Muscle attachments | Indications |
|---|---|---|
| Occiput | Semispinalis capitis | Posterior cervical spinal reconstruction (occiput–C7/T1) |
| Clavicle | Sternocleidomastoid | Anterior cervicothoracic spinal reconstruction (C2–T2) |
| Medial scapula | Subscapularis | Posterior spinal reconstruction (occiput–T8) |
| Rib | Serratus anterior<br>Latissimus dorsi<br>Intercostal muscles | Posterior spinal reconstruction<br>(occiput–S2) |
| Posterior iliac crest | Quadratus lumborum<br>Paraspinal muscles | Posterolateral spinal reconstruction (L1–S1) |
| Posterior elements | Sacrospinalis | Posterior lumbosacral spinal reconstruction of ipsilateral intertransverse space at next inferior level |

 

**Conflict of Interest**
None declared.

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