

Bone Grafting in the Management of Femoral Nonunion: Principles, Graft Options, and Contemporary Reconstructive Strategies

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Abstract:

Background: Femoral nonunion remains one of the most challenging complications following fracture fixation because successful healing requires restoration of both mechanical stability and biological activity. Bone grafting plays an essential role in the management of bone defects, delayed union, and nonunion by providing biological and mechanical support for fracture healing. Autologous bone graft remains the gold standard because of its osteogenic, osteoinductive, and osteoconductive properties. Different graft sources and substitutes, including iliac crest bone graft, Reamer-Irrigator-Aspirator graft, allografts, synthetic grafts, demineralized bone matrix, bone morphogenetic proteins, and bone marrow aspirate concentrate, may be used according to the characteristics of the nonunion and bone defect. In atrophic nonunion, stable fixation combined with autologous bone grafting is essential to restore the biological environment, whereas large segmental defects may require advanced reconstructive procedures such as the Masquelet technique, vascularized fibular grafting, or bone transport. Despite emerging technologies, autologous grafting continues to provide the most comprehensive biological properties for complex femoral nonunion. Appropriate graft selection, meticulous debridement, stable fixation, and adequate biological augmentation remain fundamental principles for achieving successful union while minimizing complications and donor-site morbidity.

Keywords: Femoral nonunion; Bone grafting; Autologous bone graft; Iliac crest bone graft; Reamer-Irrigator-Aspirator; Bone graft substitutes; Fracture healing; Masquelet technique.

Introduction:

Nonunion of bone is the body's inability to heal a fracture. The most agreed-upon standard definition of nonunion made by the FDA is a fracture that persists for a minimum of 9 months without signs of healing for three months. (1)

Union is considered to have occurred when the patient is pain free and there is radiological evidence of bridging callus across more than 75% of the fracture ends within six months. (2)

Up to one in ten fractures of femur may not show signs of bone union. Existing research identified factors that may influence bone healing after fractures. These factors may be patient related (e.g. age, substance abuse status, nutritional status, comorbidities) , injury related (e.g. fracture severity, soft tissue damage, fracture site of the bone) ,or treatment related (e.g. operative vs. non-operative management, plate fixation vs. intramedullary nail fixation) . (3)

Bone grafting is one of the fundamental techniques in orthopedic trauma surgery. It plays an indispensable role in managing bone defects, delayed union, and nonunion by providing biological and mechanical support for fracture healing. Despite advances in fixation techniques, biologics, and tissue engineering, autologous bone grafting remains the gold standard for reconstruction of bone loss and stimulation of healing in difficult fractures. Femoral nonunion represents one of the most challenging complications after fracture fixation because of the high mechanical stresses across the femur and the significant biological impairment that often accompanies severe trauma. Successful management requires restoration of both mechanical stability and biological activity. Bone grafting is therefore an essential component in most reconstructive procedure. (4,5)

Principles of Bone Grafting: (5)

An ideal bone graft should provide:

- **Osteogenesis:**

Living osteoblasts and osteoprogenitor cells capable of producing new bone. Only autograft possesses true osteogenic capacity.

- **Osteoinduction:**

Recruitment and differentiation of mesenchymal stem cells through growth factors such as:

- BMP-2, BMP-7, TGF- β , PDGF, VEGF.

Osteoconduction:

Provides scaffold allowing vascular invasion and new bone formation.

- **Structural Support:**

Some grafts provide immediate mechanical stability, especially cortical grafts.

Types of Bone Grafts: (5,6)

1. Autogenous Bone Graft:

- **Definition:**

Bone harvested from the same patient and considered the gold standard.

- **Common Donor Sites:**

- Iliac crest
- Reamer-Irrigator-Aspirator (RIA) harvested femoral graft
- Distal femur
- Proximal tibia

- **Advantages:**

- Osteogenic
- Osteoinductive
- Osteoconductive

- No disease transmission
- No immunogenicity

- **Disadvantages:**

- Donor-site pain
- Infection
- Hematoma
- Limited quantity
- Increased operative time

Iliac Crest Bone Graft (ICBG):

Most commonly used graft contains cancellous bone and cortico-cancellous bone with advantages like excellent biological activity but with complications like chronic pain, lateral femoral cutaneous nerve injury and pelvic fracture (rare).

Reamer-Irrigator-Aspirator (RIA) Graft:

Introduced as an alternative source of large-volume autograft with advantages like large graft volume, rich in stem cells, less donor-site pain than iliac crest and excellent for femoral nonunion but with disadvantages like blood loss, femoral fracture (rare) and fat embolism (rare). RIA has become increasingly popular in revision surgery for femoral nonunion.

2. Allograft Obtained from cadaveric donors:

- **Types:**

- Fresh frozen
- Freeze dried
- Demineralized bone matrix (DBM)

- **Advantages:**

- Unlimited supply
- No donor-site morbidity

- **Disadvantages:**

- No living cells
- Slower incorporation
- Disease transmission (very low)
- Reduced osteogenic potential

3. Xenograft Derived from another species:

• **Examples:**

- Bovine bone
- Porcine bone
- Rarely used in orthopedic trauma.

4. Synthetic Bone Grafts:

- Calcium Sulfate
 - Characterized by rapid resorption but poor mechanical strength.
- Calcium Phosphate
 - Characterized by good compressive strength and Excellent scaffold.
- Hydroxyapatite
 - Characterized by slow resorption and high osteoconductivity
- Bioactive Glass
 - Stimulates bone formation through ionic release.

5. Bone Graft Substitutes: (6)

Demineralized Bone Matrix (DBM) Produced by acid extraction of allograft bone contains BMPs and collagen matrix with advantages of osteoconductive and osteoinductive usually combined with autograft.

Bone Morphogenetic Proteins (BMPs) like BMP-2 BMP-7 stimulate mesenchymal stem cell differentiation into osteoblasts for Complex nonunion and bone defects but with Limitations due to its Cost and Heterotopic ossification.

Platelet-Rich Plasma (PRP) contains PDGF VEGF TGF- β but evidence remains controversial in femoral nonunion.

Bone Marrow Aspirate Concentrate (BMAC) is rich in mesenchymal stem cells and growth factors often combined with DBM or synthetic grafts.

Indications of Bone Grafting in Femoral Nonunion: (7)

Bone grafting is indicated when there is:

- Atrophic nonunion
- Bone defect
- Revision fixation
- Infection after eradication
- Segmental bone loss

- Failed previous surgery
- Biological insufficiency

Bone Grafting According to Nonunion Type: (7)

- **Hypertrophic Nonunion:**

Hypertrophic nonunion is primarily caused by mechanical instability, while the biological healing potential remains intact. Treatment focuses on improving stability through exchange intramedullary nailing, compression plating, or a combined nail–plate construct. Bone grafting is usually unnecessary unless there is an associated biological deficiency or repeated treatment failure.

- **Atrophic Nonunion:**

Atrophic nonunion is characterized by poor biological activity and inadequate vascularity. Management requires thorough debridement, stable fixation, and autologous bone grafting, which remains the gold standard for restoring the biological environment and promoting fracture healing.

- **Large Bone Defects (>5 cm):**

Segmental femoral defects larger than 5 cm require advanced reconstructive techniques, including the Masquelet induced membrane technique, vascularized fibular graft, bone transport, or RIA-harvested autologous graft, depending on the size of the defect, infection status, and patient factors.

Masquelet Technique: (8)

The Masquelet technique is a two-stage procedure involving radical debridement and placement of a PMMA cement spacer to induce a vascularized membrane. After 6–8 weeks, the spacer is removed and the membrane is filled with cancellous autologous bone graft, making this technique particularly effective for infected femoral nonunion and critical-sized bone defects.

Vascularized Fibular Graft:

A vascularized fibular graft is indicated for large bone defects (>6–8 cm), especially in young patients or after multiple failed reconstructions. It provides living vascularized bone with excellent healing potential but requires microsurgical expertise and is technically demanding.

Complications of Bone Grafting: (9)

- Donor-site pain
- Infection
- Hematoma
- Graft resorption
- Nonunion persistence
- Disease transmission (allograft)
- Heterotopic ossification (BMP)
- Neurovascular injury.

Future Directions: (10)

- Emerging technologies include:
- Mesenchymal stem cell therapy
- Gene therapy
- 3D-printed scaffolds
- Tissue-engineered constructs
- Smart biomaterials
- Growth-factor delivery systems
- These techniques aim to enhance biological healing while minimizing donor-site morbidity.

Bone grafting remains an essential component in the management of femoral nonunion. Successful treatment requires restoration of both biology and biomechanics. Autologous bone graft continues to be the gold standard due to its osteogenic, osteoinductive, and osteoconductive properties. The RIA system has emerged as an excellent alternative source of autograft, particularly in femoral reconstruction. Bone graft substitutes and biologics serve as useful adjuncts but cannot consistently replace autologous graft in complex nonunion. Application of the Diamond Concept, meticulous debridement, stable fixation, and appropriate biological augmentation provide the highest rates of successful union. (7)

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