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Femoral Neck Fractures in Young Patients

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Abstract

Femoral neck fractures in patients 55 years or younger, although relatively uncommon, may cause considerable surgeon stress because they may be thought to be surgical emergencies and are difficult to manage, resulting in serious complications. Orthopaedic surgeons should understand the optimal timing for, the reduction options and techniques for, the fixation options for, and the results of surgical management of femoral neck fractures in patients 55 years or younger. The optimal timing of the surgical management of femoral neck fractures in these patients is a subject of debate. Anatomic reduction, which correlates with patient outcomes, is the goal in the management of femoral neck fractures whether it is attained via open or closed means. Multiple surgical approaches, including the Watson-Jones, Smith-Petersen, and Hueter approaches, may be used for the open reduction of femoral neck fractures. Multiple options are available for fixation, with cannulated screws and the compression hip screw most used in the literature. These implants should provide torsional stability, minimal bone loss, and a length-stable construct. Currently, no ideal implant exists. The outcomes of young patients with a femoral neck fracture who undergo surgical treatment depend more on fracture type, fracture reduction, and stable fixation than early surgical management; however, surgical management should not be excessively delayed.

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Femoral neck fractures in patients younger than 55 years create management challenges primarily because of the concern for the femoral head blood supply. Sevitt and Thompson[1] demonstrated the importance of this in an injection study that showed the importance of the retinacular vessels. Based on literature published in the mid 1980s, femoral neck fractures were deemed surgical emergencies to minimize the risk of damage to the femoral head blood supply, with the belief that emergent reduction and fixation was the best option to restore femoral head blood supply.[2] Studies reported substantially lower rates of osteonecrosis and nonunion in patients with a femoral neck fracture who underwent surgical treatment less than 12 hours postinjury compared with previously published rates.[2-4] The trend toward early surgery in younger patients with a femoral neck fracture who are not good candidates for arthroplasty requires surgeons to emergently manage femoral neck fractures in the operating room but may sacrifice optimal reduction and fixation (**Figure 1**). Delaying treatment to allow for a more controlled surgical setting or the transfer of a patient to a tertiary referral center with more experience in the management of femoral neck fractures may be more beneficial.

High-energy femoral neck fractures, which typically occur in younger patients, are more vertical and are associated with more comminution and displacement compared with

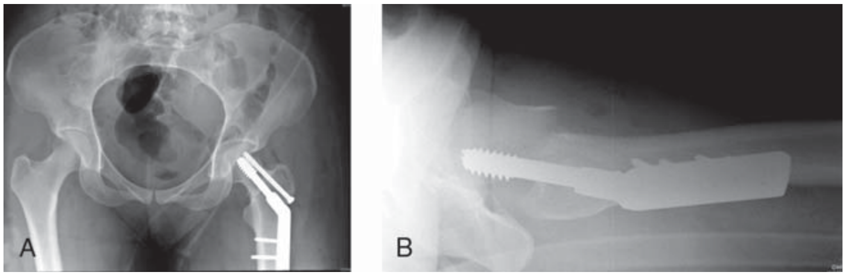

Figure 1 AP radiograph of the pelvis (**A**) and lateral radiograph of the left hip (**B**) of a 25-year-old woman obtained after open reduction and internal fixation of a femoral neck fracture demonstrate rotational malreduction. Instead of transferring the patient to a tertiary referral center, the surgery was performed emergently without adequate ancillary support.

low-energy femoral neck fractures, which typically are observed in older patients. These fracture characteristics make reduction and maintenance of reduction of high-energy femoral neck fractures more difficult given the typical implants used for fixation. Postoperative shortening is common in patients with a high-energy femoral neck fracture and may lead to poor abductor function and a limp, despite fracture healing.[5] Complications, such as osteonecrosis and nonunion, may lead to additional surgical procedures and poor outcomes in these typically young and active patients. When treating patients 55 years or younger who have a femoral neck fracture, orthopaedic surgeons should have an understanding of optimal surgical timing, reduction options and techniques, fixation options, and the results of surgical management.

Surgical Timing

Early studies reported a high rate of osteonecrosis (86%) and nonunion (59%) in young patients with a femoral neck fracture.[6] In a landmark study of 27 patients younger than 50 years with a femoral neck fracture who underwent surgical treatment, Swiontkowski et al[2] reported a considerable reduction in osteonecrosis (20%) and nonunion (zero) if patients underwent anatomic reduction and compressive fixation as soon as possible. Subsequent studies also reported that surgery within 12 hours postinjury in young patients with a femoral neck fracture decreased the historical rate of complications.[3,4,7] With early surgery, Gerber et al[4] reported a 10% rate of osteonecrosis, a 17% rate of delayed union or nonunion, and a 20% rate of revision surgery. Robinson et al[3] reported a 21% complication rate and 17% revision surgery rate in a similar cohort. In a retrospective study of 38 patients younger than 60 years with a subcapital femoral neck fracture who underwent early or delayed surgical treatment, Jain et al[7] reported a significantly lower rate of osteonecrosis in the patients in the early treatment group compared with the patients in the delayed treatment group (zero versus 26%) despite no difference in functional outcomes between the patients in the two groups. The authors recommended early fixation of femoral neck fractures; however, the results of the study may have been biased because the patients were not randomized.

The debate with regard to surgical timing continued with other studies that reported no significant relationship between surgical timing and patient outcomes. In a review of 51 patients 50 years or younger with a femoral neck fracture who underwent surgical treatment, Haidukewych et al[8] reported no significant differences in the rates of osteonecrosis and nonunion based on time to surgery. The authors concluded that fracture displacement and the quality of reduction were the factors that most affected patient outcomes. In the only randomized prospective comparative trial of 92 patients 50 years or younger with a femoral neck fracture who underwent surgical treatment,

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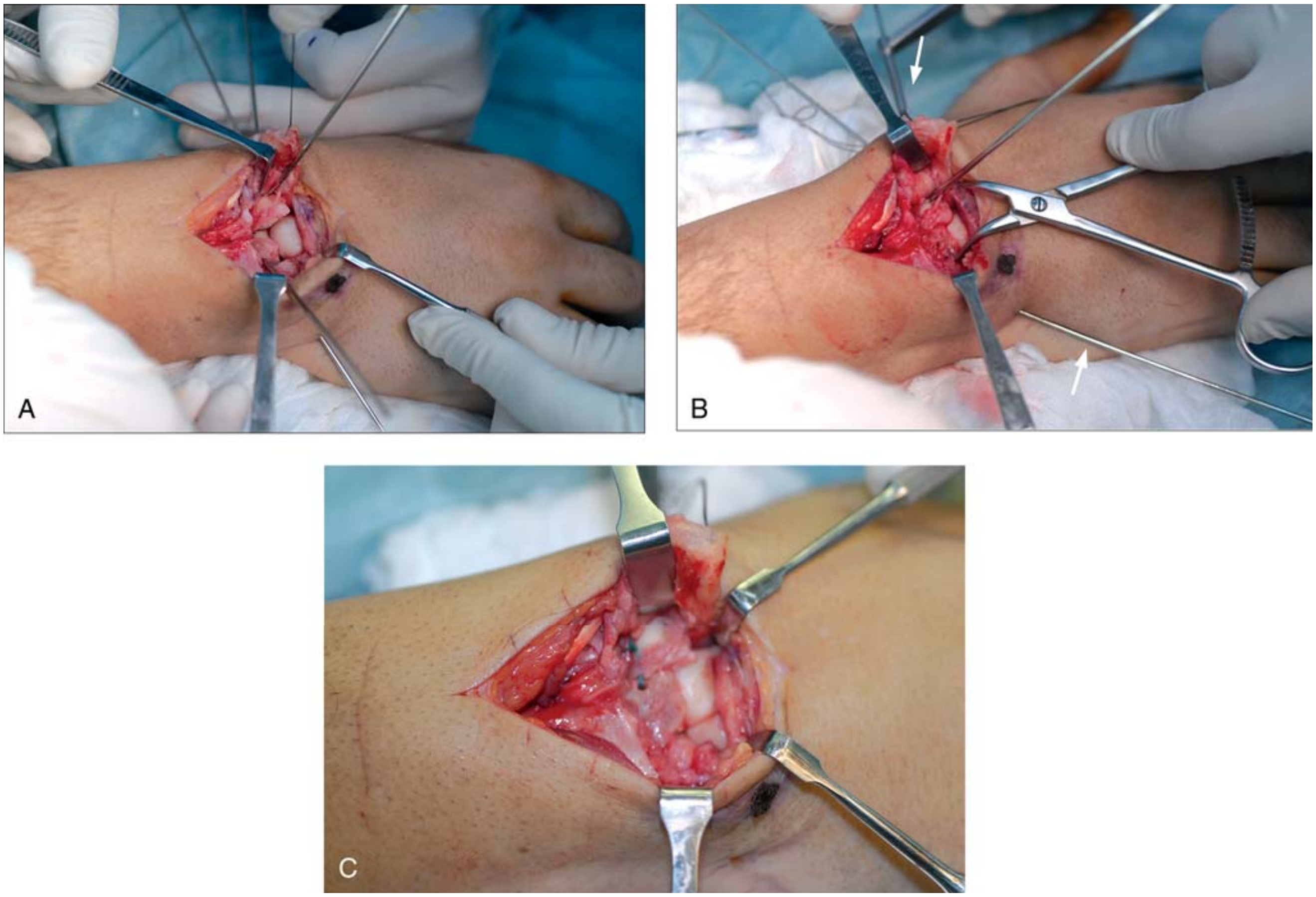

Figure 11 Intraoperative photographs of a wrist show open reduction of a purely ligamentous perilunate injury via the dorsal approach. **A,** Wide separation of the scapholunate interval is attained, after which two Kirschner wires, one in the lunate and another in the scaphoid, are used as joysticks to attain reduction. **B,** Reduction is temporarily maintained with the use of pointed reduction forceps, if necessary. The scapholunate and the lunotriquetral joints are then stabilized with the use of percutaneously placed Kirschner wires (arrows). **C,** The scapholunate ligament is repaired with the use of anchor sutures.

limitations. The volar lunotriquetral ligament, which is the stouter component of the lunotriquetral interosseous ligament, should be repaired in patients who undergo open reduction via the volar approach (**Figure 13**).

Combined/Dual Approach

Capo et al[20] reported reasonable functional and clinical outcomes in patients with a perilunate fracture-dislocation who undergo open reduction via the combined/dual volar-dorsal approach. The combined/dual approach allows for repair of the palmar capsule, assessment of reduction from the dorsum, and repair of the dorsal scapholunate and the volar lunotriquetral ligaments. No evidence shows that open reduction via the combined/dual approach results in better outcomes than open reduction via the dorsal approach only. Moreover, some studies have indicated that patients with a perilunate fracture-dislocation who undergo open reduction via the combined/dual approach may have substantially lower outcome scores compared with patients with a perilunate fracture-dislocation who undergo open reduction via the dorsal approach only; however data with regard to which approach for open reduction is most beneficial are very limited.[16,21]

Postoperative Management

Postoperatively, the patient's wrist is immobilized in a neutral position with the metacarpophalangeal joints free for finger motion with the use of a short arm plaster splint for 2 weeks. The splint is then removed, and a short arm-thumb spica cast is used for an additional 6 weeks. The K-wires should not be removed earlier than

8 weeks postoperatively. The patient should wear a removable splint until 12 weeks postoperatively, during which time gentle active motion of the wrist is performed. Patients with a perilunate injury should be informed of the likelihood of permanent limited range of motion because of the severity of the injury and the extended period of immobilization.

Outcomes

Because of the severity of perilunate injuries, recovery to prior level of function is uncommon and some degree of pain may persist postoperatively. Delayed management, open injuries, injuries with osteochondral fractures of the capitate head, persistent carpal malalignment, and inadequate fixation are associated with poor outcomes.[1,22,23] Significantly lower outcome scores have been reported in manual laborers and patients with a perilunate injury who require open reduction via the combined/dual volar-dorsal approach.[16] Early, accurate reduction and stable fixation with repair or reconstruction of the dorsal scapholunate interosseous ligament is associated with good outcomes; however, almost all patients who sustain a perilunate injury experience decreased grip strength and decreased wrist range of motion postoperatively.[10,17]

Most studies of patients who undergo treatment for a perilunate injury include short-term and midterm outcomes; however, some studies include long-term outcomes.[3,4,22,24-26] The long-term outcomes of most patients who undergo treatment for a perilunate injury include maintenance of adequate reduction, scaphoid healing, and the ability to return to work. Evidence of midcarpal or radiocarpal arthritis may be observed on postoperative

Figure 12 CT scans of a wrist with scaphocapitate syndrome. **A,** Coronal CT scan shows a 90°-rotated fracture of the capitate head (arrow) and a scaphoid fracture. **B,** Sagittal CT scan shows dorsal dislocation of the capitate and a rotated fracture of the capitate head.

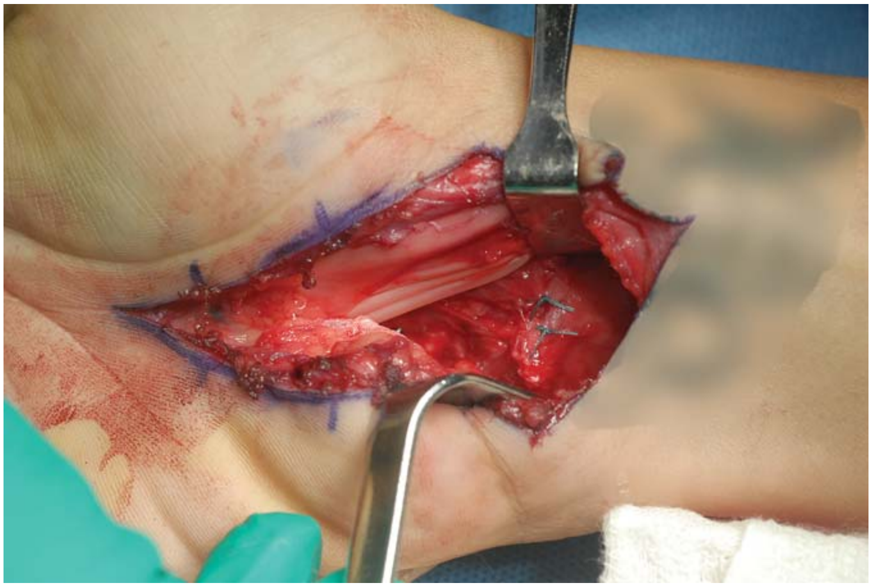

Figure 13 Intraoperative photograph of a wrist shows open reduction of a perilunate injury via the volar approach and repair of the lunotriquetral ligament.

those who have a fracture only.[65] In an analysis of 51 pediatric patients with a subaxial cervical spine injury, Dogan et al[65] reported that C6-C7 was the most frequently injured level. Similar subaxial cervical spine injury patterns, including burst fractures, compression fractures, facet dislocations, and fracture-dislocations, are observed in pediatric patients and adults (**Figure 5**). However, fractures that traverse the physeal end plates, which may result in considerable instability, are only observed in pediatric patients.[66]

Initial treatment involves realignment of the spinal canal and relief of spinal cord compression via reduction of any deformity. Reduction is attained via gentle traction after a halo ring is applied in the operating room. Reduction should be performed in patients who are awake, alert, and oriented. In obtunded patients, MRI is required to rule out a concurrent herniated disk, which necessitates open reduction.

Definitive treatment in patients with a simple facet dislocation, unilateral fracture, or burst fracture consists of 3 months of immobilization in a halo vest. Patients with bilateral fractures or a fracture-dislocation often require surgical treatment, given the degree of associated instability. Surgical stabilization may consist of anterior cervical diskectomy and fusion or anterior corpectomy with plate fixation, posterior fixation with wiring or lateral mass screw fixation, or combined anterior and posterior procedures, all of which are associated with high rate of union.[65] Options for fixation in pediatric patients in whom posterior lateral mass screw fixation is not possible include traditional onlay bone grafting with sublaminar or spinous process wiring followed by postoperative halo vest immobilization. In a multicenter prospective cohort study of 313 patients with an acute cervical SCI, 182 of whom underwent early decompression and stabilization (<24 hours postinjury) and 131 of whom underwent delayed decompression and stabilization (>24 hours postinjury), Fehlings et al[67] reported improved neurologic outcomes in the patients who underwent early decompression and stabilization. Although this study excluded patients younger than 16 years, the findings should be considered in the treatment of pediatric patients with a cervical SCI.

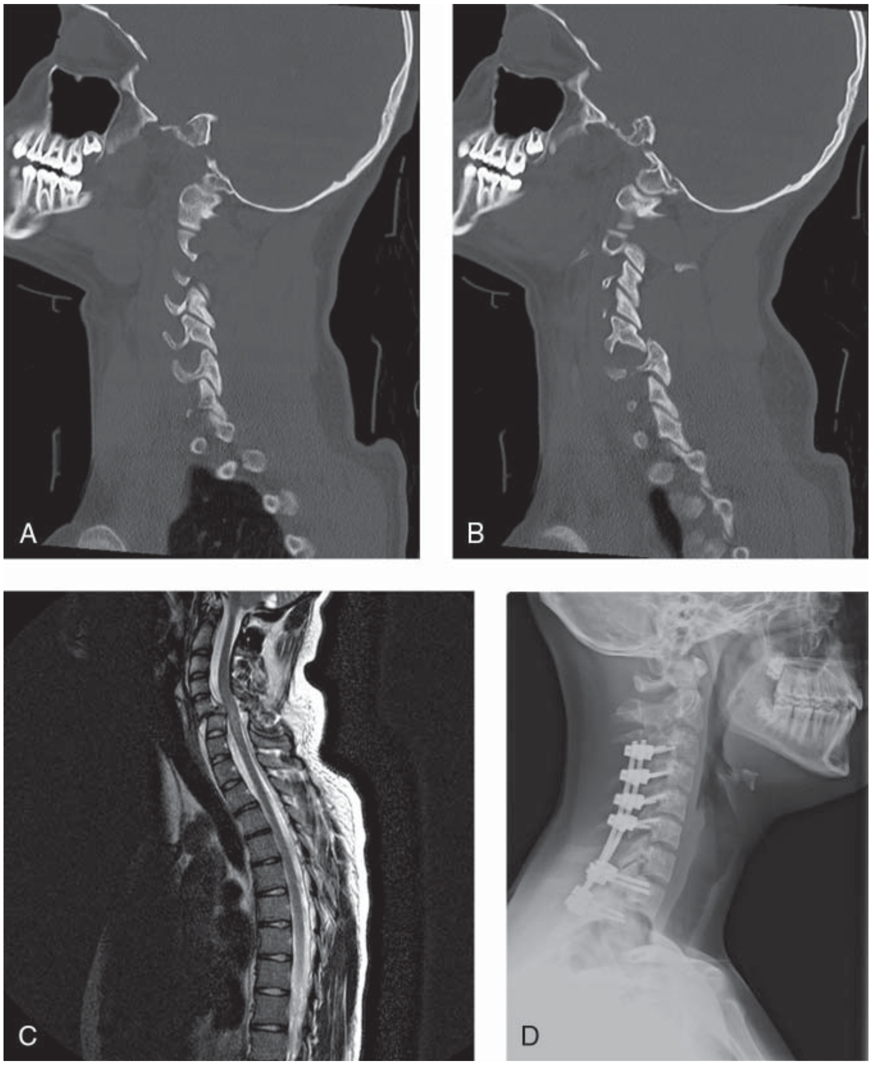

Figure 5 Images of the cervicothoracic spine of a 15-year-old boy who sustained an incomplete spinal cord injury while wrestling. Sagittal CT scans show a right C5-C6 facet subluxation (**A**) and a left C5-C6 facet dislocation (**B**). **C,** Sagittal T2-weighted MRI shows an increased signal in the spinal cord at C5-C6. **D,** Lateral radiograph obtained after C3 through T2 posterior cervical fusion with the use of lateral mass screws and T1 and T2 pedicle screws demonstrates restoration of alignment.

Thoracolumbar Spine Injuries

Common causes of thoracolumbar spine trauma in pediatric patients include motor vehicle collisions, falls, sports, and child abuse, with motor vehicle collisions being the most frequent cause of thoracolumbar spine trauma.[68] Compression fractures are the most common thoracolumbar spine fractures that occur in pediatric patients.[68] In a retrospective case series of 137 pediatric patients with a spinal injury, Carreon et al[69] reported that 42% of the patients had one or more compression fractures; however, a small number of the compression fractures were in the lower cervical spine. Most thoracolumbar spine fractures without subluxation in pediatric patients are not associated with SCI or neurologic deficit and can be treated nonsurgically.[22] Thoracolumbar compression fractures involve failure of the anterior column, with the superior end plate failing more commonly than the inferior end plate.[24] Thoracolumbar burst fractures result from an axial load and involve failure of the anterior and middle columns.[68] Compression fractures, which can occur at multiple levels, frequently are managed nonsurgically via activity restriction or with the use of an external orthosis.[24] Similarly, stable burst fractures in patients without neurologic deficit typically are managed with the use of a thoracolumbosacral orthosis brace or a hyperextension cast.[68] Progressive kyphosis secondary to an incompetent anterior column or posterior ligamentous complex disruption is rare in pediatric patients but is a relative indication for surgical stabilization. Surgical stabilization of thoracolumbar spine injuries can be performed via an anterior, a posterior, or a combined approach based on the injury pattern and surgeon preference (**Figure 6**). Typically, patients older than 12 years are treated similar to adults.

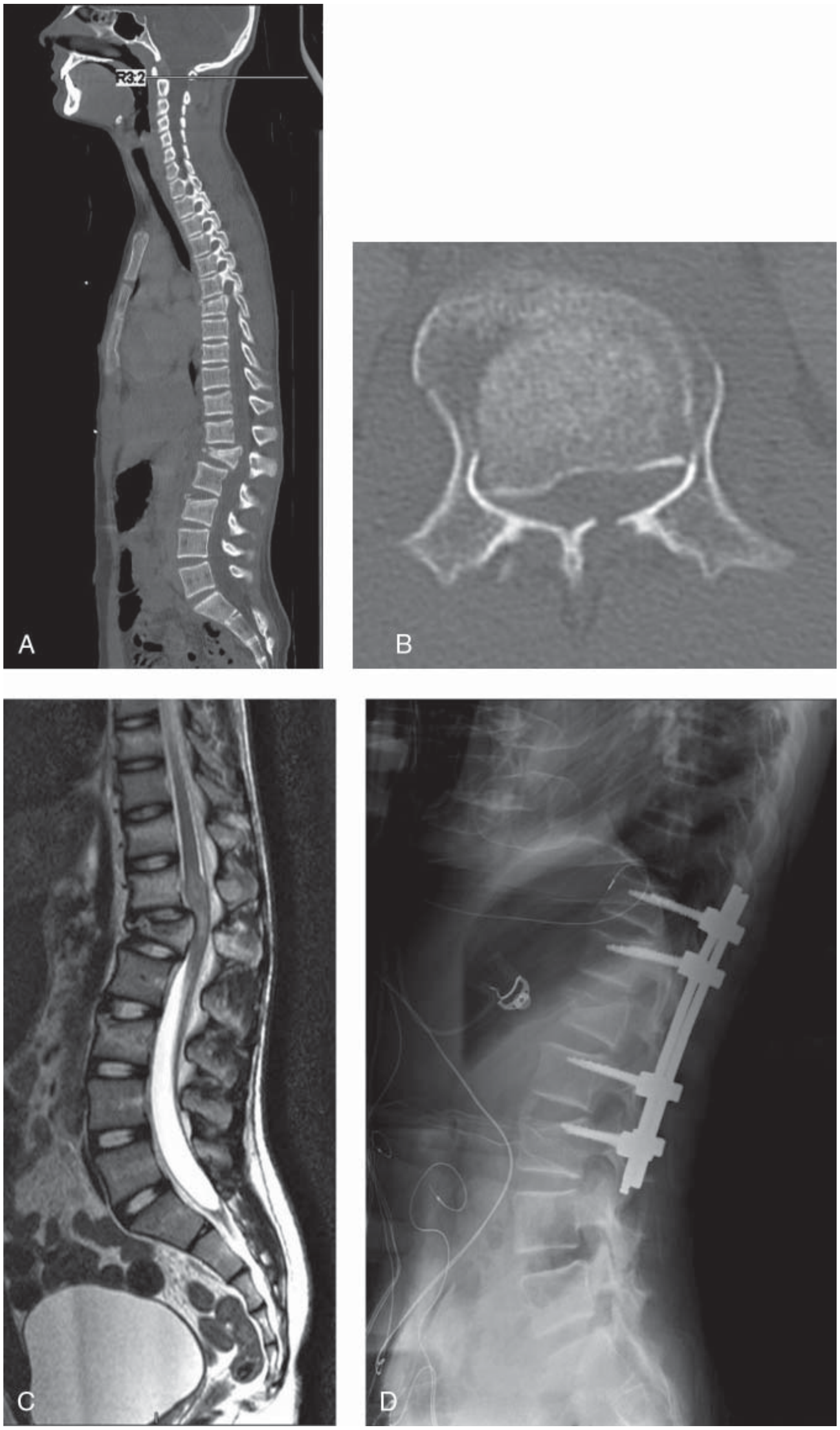

Figure 6 Images of the spine of a 14-year-old boy who sustained an incomplete spinal cord injury (American Spinal Injury Association Impairment Scale grade C) after falling 30 feet from a tree. Sagittal (**A**) and axial (**B**) CT scans and sagittal T2-weighted MRI (**C**) show an L1 burst fracture. **D,** Lateral radiograph obtained after T11 through L3 posterior spinal decompression and fusion with the use of pedicle screws demonstrates restoration of alignment.

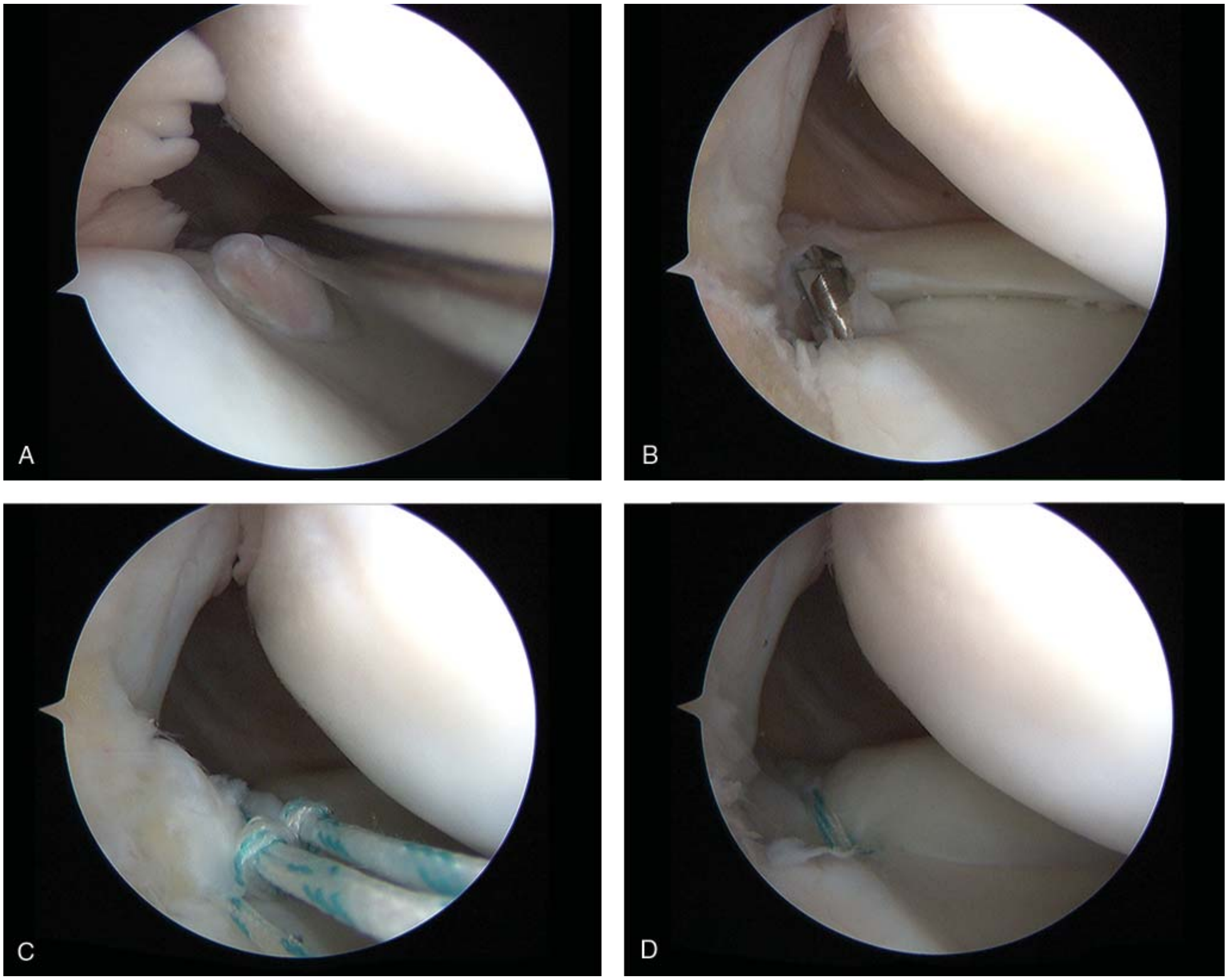

Figure 3 Arthroscopic images of a knee with a meniscal root tear show medial meniscal root repair via the transtibial technique. **A,** Image shows the meniscal root tear. **B,** Image shows removal of a portion of the tibial spine. **C,** Image shows the passage of two self-cinching sutures through the meniscal root. **D,** Image shows the final repair construct.

increased in patients with an oversized graft, and contact stresses are increased within the graft in patients with an undersized graft.[46]

The type of allograft determines the surgical technique for MAT. Maintenance of the anatomic relationship between the meniscal horns improves MAT function because it better preserves resistance to hoop stresses. This anatomic relationship can be maintained with MAT via the bridge-in-slot technique.[47] MAT also is commonly performed via the bone-plug technique. MAT via the bone-plug technique avoids the cruciate ligaments and, therefore, is commonly used in patients who undergo medial MAT. Technical advances in drill guides and the development of the retrograde reamer have made MAT via the bone-plug technique easier and more reliable. The bone-plug technique is the MAT technique of choice for patients who undergo concomitant ACL reconstruction. Appropriate tensioning of the meniscus, however, is difficult in patients who undergo MAT via the bone-plug technique. In a study of 59 patients who underwent medial MAT via the bone-plug technique, Kim et al[48] reported significant differences in the position of the native meniscus preoperatively compared with the position of the meniscal allograft postoperatively. The anterior and posterior horns of the meniscal allograft were observed in a posteromedial position on postoperative MRI;

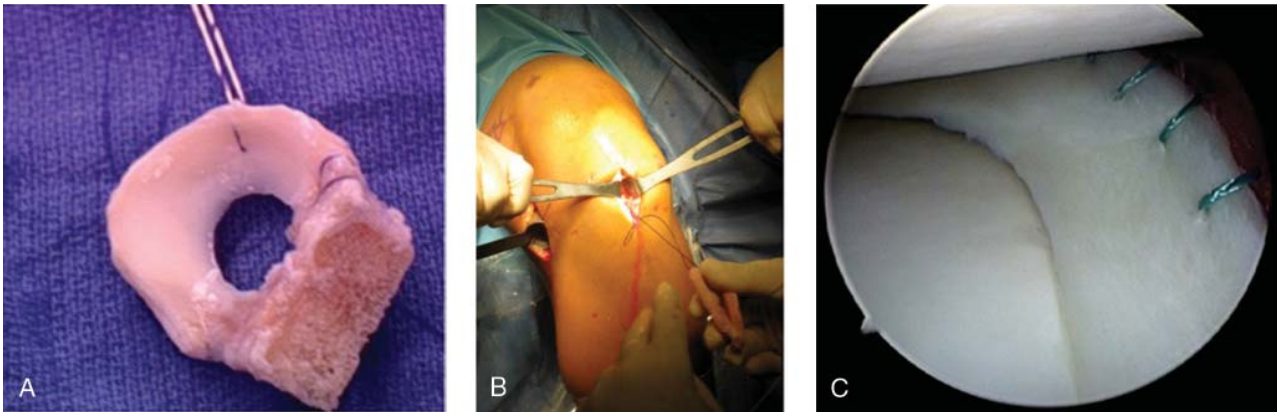

Figure 4 Images show lateral meniscal allograft transplantation via the bridge-in-slot technique. **A,** Clinical photograph shows a prepared meniscal allograft. **B,** Intraoperative photograph of a knee obtained after insertion of the meniscal allograft shows peripheral fixation. **C,** Arthroscopic image of the knee obtained after meniscal allograft transplantation shows the inside-out sutures that were placed in a vertical mattress fashion.

however, this did not appear to affect function.

For medial MAT, the authors of this chapter prefer to use the bone-plug technique with 6-mm bone plugs that are placed at the anterior and posterior horns. An accessory portal and an arthrotomy are made in line with the anterior and posterior horns of the remnant meniscus. The tibial guide from a retrograde cutter set is placed at the site of the posterior horn, and the retrograde cutter is advanced until visualized at the tibial guide. The cutter is used in a retrograde fashion to ream an approximately 20-mm posterior bone tunnel. The same process is performed to create a bone tunnel for the anterior bone plug. The meniscal allograft is inserted into the joint space, and the bone plugs are tensioned into the anterior and posterior tunnels. The sutures are passed through the reamed tunnels and are tied over buttons. The peripheral rim of the meniscus is repaired with the use of inside-out sutures, and the posteriormost aspect of the allograft is repaired with the use of all-inside sutures to avoid neurovascular injury.

For lateral MAT, the authors of this chapter prefer to use the bridge-in-slot technique with a 7-mm bone bridge that is placed in an 8-mm rectangular slot. An arthrotomy is made in line with the anterior and posterior horns of the remnant meniscus, through which a superficial reference slot is created with the use of a burr. A depth gauge is used to aid in the insertion of a guide pin in the posterior cortex, which is overreamed with the use of an 8-mm reamer. A box chisel and rasp are then used to create an 8-mm rectangular slot. The meniscal allograft is inserted into the slot, and fixation is achieved with the use of a 7- × 23-mm biointerference screw that is placed central to the bone bridge. The peripheral rim of the meniscus is repaired with the use of inside-out sutures, and the posteriormost aspect of the allograft is repaired with the use of all-inside sutures to avoid neurovascular injury (**Figure 4**).

Postoperative rehabilitation for patients who undergo MAT involves toe-touch weight bearing that progresses to full weight bearing as tolerated at 2 weeks postoperatively. A hinged knee brace set at 0° and 90° is used for the first 6 weeks postoperatively. Stationary bike riding is initiated at 8 weeks postoperatively, and jogging is initiated at 3 months postoperatively. Return to sport is possible at 6 to 9 months postoperatively.

Two commonly cited studies reported satisfaction rates of 86% and 90% in patients who underwent MAT.[49,50] In a recent meta-analysis of 1,136 MATs, Elattar et al[51] reported an 89% satisfaction rate and determined that MAT is a safe and reliable option for the management of refractory post-meniscectomy symptoms in appropriately selected patients. In a series of 41 patients who underwent MAT, Verdonk et al[50] reported no difference in the results of medial MAT and lateral MAT, with stable transplants reported at a final follow-up of 10 years based on a comparison of clinical outcomes with radiographic and MRI findings.

Some studies have suggested that MAT may slow arthritic degeneration. Animal model studies have reported that MAT slowed the progression of degenerative chondral changes from

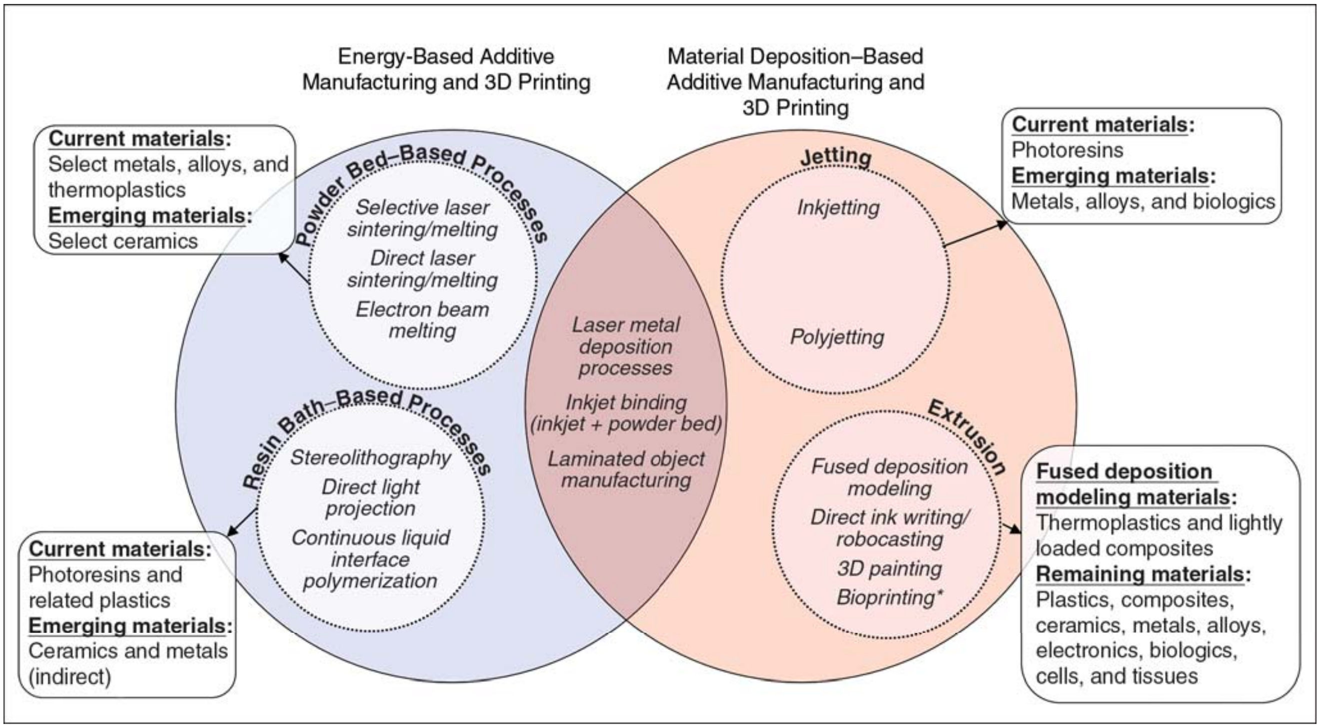

Figure 1 Venn diagram shows the types of additive manufacturing and three-dimensional (3D) printing technologies. The asterisk indicates that bioprinting is not restricted to extrusion-based additive manufacturing methods; however, extrusion-based additive manufacturing methods are the most common approach used for bioprinting living cells and tissues.

is required. Finally, these technologies currently are not compatible with multiple materials.

Resin Bath–Based Processes

Resin bath–based lithographic processes include stereolithography, direct light projection, continuous liquid interface polymerization, and two-photon polymerization. Feedstock resins primarily are comprised of carbon-based monomeric units and photoinitiator molecules. In general, polymerization results from exposure to specific wavelengths of light, which leads to observable solidification of the exposed region of the resin bath. Polymerization may be discrete, may occur layer-by-layer, or, in continuous liquid interface polymerization processes, may be continuous. Although resin bath–based lithographic additive manufacturing is a high-resolution process, materials for resin bath–based lithographic additive manufacturing are primarily restricted to photocurable plastics; therefore, the resulting objects primarily are used as visual prototypes, models, and guides rather than functional implants and load-bearing structures. In addition, objects created via resin bath–based lithographic processes are not used or currently recommended for implantation because all toxic monomeric units and photoinitiator molecules cannot be removed.

Powder Bed–Based Processes

Powder bed–based processes include selective laser sintering, direct laser melting, and electron beam melting. Feedstock powders may be thermoplastics, such as polycaprolactone, acrylonitrile butadiene styrene, polylactic acid, or polyether ether ketone, or may be prealloyed metals, such as 300 series stainless steels, grade 5 titanium alloys (Ti-6Al-4V), or cobalt-chromium alloys. The powders must be a specific size and shape to attain optimal packing for successful sintering. After the powders are packed and level, a high-energy laser or electron beam is used to sinter or melt the powder particles together in the outline of the particular layer/cross section of the object being fabricated. The application of high-energy laser or electron beams in combination with the small size and environmental reactivity of the dry powders requires extensive safety precautions to be taken before, during, and after processing. In addition, the

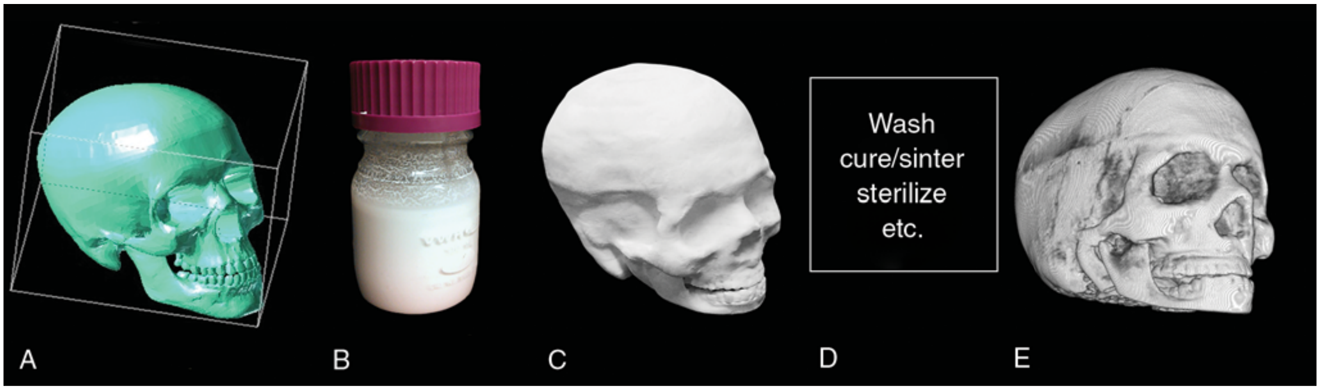

Figure 2 Images show the general workflow for additive manufacturing and three-dimensional printing. **A,** Data (eg, CT scan) are obtained and converted to a stereolithographic file type. **B,** The material is selected based on the compatibility of available hardware and the intended application of the final object. **C,** The hardware platform is chosen based on the selected material and the required resolution of the final object. **D,** The object undergoes postprocessing (eg, washing, curing, sintering, sterilization, etc.). **E,** The final object is validated before use.

additive manufacturing process and maintain their 3D printability (ability to be extruded and maintain shape on deposition), bioprinting materials frequently are polysaccharides or natural or synthetic proteinaceous hydrogels.

Combined Technology

Inkjet Binding

Inkjet binding uses an inkjet head, which selectively jets adhesive binder onto the surface of a powder bed, selectively gluing particles together. The resulting solid object, which is known as a green body, is extracted from the bed and postprocessed via sintering to yield a final object. Inkjet binding frequently is used to create ceramic models and molds.

Laser Metal/Wire Deposition

Laser metal/wire deposition is a complex additive manufacturing process that requires the operation and movement of a high-powered laser in combination with metal powder spray or metal wire deposition. The laser continuously sinters the sprayed metal powder or wire as it is deposited. Laser metal/wire deposition is used to create complex 3D objects and is primarily used to repair or refurbish existing metal parts.

Laminated Object Manufacturing

Laminated object manufacturing is the collective name given to additive manufacturing processes that involve precisely cut individual sheets of material that are positioned, layered, and fused or laminated together to create a 3D object. Laminated object manufacturing is one of the oldest additive manufacturing techniques and was originally used to create architectural models from layers of cut paper. It currently is used in combination with advanced composite sheet feedstocks. The process used to cut individual layers from sheet of material is material dependent but includes physical cutting with the use of blades and energy beams (laser, electron, or ion beams). Fusion of the individually cut and stacked layers together also is highly material dependent but includes liquid or gel adhesives, thermal welding, and mechanical/ultrasonic welding.

Workflow

Many additive manufacturing processes follow the same general workflow, which consists of five steps, beginning with the acquisition of raw data and/or a digital 3D file and ending with the final usable object (**Figure 2**).

Digital Data, File Types, and Manipulation

The object must be digitally defined in three dimensions and represented as a stereolithographic file type before fabrication begins. The digital data that represent the geometry of the 3D object are obtained via one of three general methods. The first method is to design the object geometry using computer-aided design software. The second method is to use representations of an existing physical entity, such as a patient's body part, which is then exported as a stereolithographic file and 3D printed. The third method, which is a combination of the first two methods, uses digital reconstructions that are based on 3D scans and can be digitally modified before 3D printing.