The Clamshell Osteotomy:
A New Technique to Correct
Complex Diaphyseal Malunions

Surgical Technique

By George V. Russell, MD, Matt L. Graves, MD, Michael T. Archdeacon, MD, MSE, David P. Barei, MD, FRCS(C),
Glenn A. Brien Jr., MD, and Scott E. Porter, MD

Investigation performed at University of Mississippi Medical Center, Jackson, Mississippi; University of Cincinnati Medical Center, Cincinnati, Ohio;
and Harborview Medical Center, Seattle, Washington

The original scientific article in which the surgical technique was presented was published in JBJS Vol. 91-A, pp. 314-24, February 2009

ABSTRACT FROM THE ORIGINAL ARTICLE

BACKGROUND: The treatment of complex diaphyseal malunions is challenging, requiring extensive preoperative planning and
precise operative technique. We have developed a simpler method to treat some of these deformities.

METHODS: Ten patients with complex diaphyseal malunions (including four femoral and six tibial malunions) underwent a
clamshell osteotomy. The indications for surgery included pain at adjacent joints and deformity. After surgical exposure, the
malunited segment was transected perpendicular to the normal diaphysis proximally and distally. The transected segment
was again osteotomized along its long axis and was wedged open, similar to opening a clamshell. The proximal and distal
segments of the diaphysis were then aligned with use of an intramedullary rod as an anatomic axis template and with use of
the contralateral extremity as a length and rotation template. The patients were assessed clinically and radiographically at a
mean of thirty-one months (range, six to fifty-two months) after the osteotomy.

RESULTS: Complete angular correction was achieved in each case; the amount of correction ranged from 2° to 20° in the coro-
nal plane, from 0° to 32° in the sagittal plane, and from 0° to 25° in the axial plane (rotation). Correction of length ranged
from 0 to 5 cm, and limb length was restored to within 2 cm in all patients. All osteotomy sites were healed clinically by six
months. While no deep infections occurred, superficial wound dehiscence occurred in two patients along the approach for the
longitudinal portion of the osteotomy, emphasizing the importance of careful soft-tissue handling and patient selection.

CONCLUSIONS: The clamshell osteotomy provides a useful way to correct many forms of diaphyseal malunion by realigning
the anatomic axis of the long bone with use of a reamed intramedullary rod as a template. This technique provides an alternative
that could decrease preoperative planning time and complexity as well as decrease the need for intraoperative osteotomy pre-
cision in a correctly chosen subset of patients with diaphyseal deformities.

LEVEL OF EVIDENCE: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

ORIGINAL ABSTRACT CITATION: “The Clamshell Osteotomy: A New Technique to Correct Complex Diaphyseal Malunions”

DISCLOSURE: In support of their research for or preparation of this work, one or more of the authors received, in any one year, outside funding or grants in excess of
$10,000 from Synthes. One or more of the authors, or a member of his or her immediate family, received, in any one year, payments or other benefits of less than $10,000
or a commitment or agreement to provide such benefits from a commercial entity (AO North America and Zimmer).

A video supplement to this article will be available from the Video Journal of Orthopaedics. A video clip will be available at the JBJS web site, www.jbjs.org. The
INTRODUCTION
The clamshell osteotomy is a simplified approach to the correction of long-segment, combined angular and translational malunions of the femoral or tibial diaphysis with use of an intramedullary nail. Conceptually, the osteotomy is easy to understand and can simply be thought of as a comminuted diaphyseal fracture which one would treat primarily with an intramedullary rod, wherein the rod acts as an anatomic axis template for the purpose of effecting reduction (Figs. 1-A through 1-J). The clamshell osteotomy offers simplified preoperative planning. The surgical tactic is familiar and readily transferable to other situations. The technique may be used with intramedullary nailing in situations in which intraoperative fluoroscopy is not available, thereby potentially increasing its applicability1.

SURGICAL TECHNIQUE
Preoperative Evaluation
Preoperative evaluation includes

**Figs. 1-A through 1-J** A fifty-year-old man had a twenty-year history of a left femoral malunion after nonoperative treatment for a femoral shaft fracture. **Fig. 1-A** Preoperative anteroposterior standing radiograph demonstrates medial translation and a 12° varus angulation of the left femur. The blue lines illustrate the anatomic axes of the proximal and distal femoral segments in the coronal plane, highlighting the varus malunion. **Fig. 1-B** Preoperative lateral radiograph of the femur demonstrates 2 cm of posterior translation and recurvatum at the malunion site. The blue lines illustrate the anatomic axes of the proximal and distal femoral segments in the sagittal plane, highlighting the angular and translational deformities.
Fig. 1-C Artist’s rendering of the surgical exposure. Note that only the lateral aspect of the femur is exposed, thereby permitting the preservation of the remaining soft-tissue attachments at the osteotomy site. The dashed lines denote the positions for the transverse osteotomies. The drill-holes have been created for the clamshell portion of the osteotomy. Figs. 1-D and 1-E Postoperative anteroposterior (Fig. 1-D) and lateral (Fig. 1-E) radiographs of the femur, showing the clamshell osteotomy segment with the intramedullary nail in position.
a standard musculoskeletal examination in which the lower extremity length discrepancies are determined clinically by measuring with a tape measure from the anterior superior iliac spine to the tip of the medial malleolus. To further assist with length measurements, blocks of
differing heights are used to level the pelvis in double-limb stance. If the limb-length inequality measures >2.5 cm, scanograms are made. Soft-tissue changes resulting from previous procedures or traumatic open wounds are noted, with specific attention paid to the soft-tissue zone over the segment of the deformity. Range of motion and stability of the joints proximal and distal to the deformity are noted. The rotational profile is judged according to the supine resting posture of the extremity. The thigh-foot axis is determined to assess tibial torsion, and the rotatory hip range-of-motion arc in the supine and prone positions is measured to assess femoral deformity. Radiographic evaluation includes characterization of the malunion with biplanar radiographs, an evaluation of joint status proximal and distal to the deformity with standard radiographs, and standing hip-to-ankle radiographs in the patella-forward position.

Coronal and sagittal plane angulation is determined by drawing the angle formed by the intersection of the anatomic axis of the most distal segment with that of the most proximal segment of the bone involved. Rotation and translation are referenced according to the standard practice of describing the distal segment with respect to the proximal segment. The amount of translation in the coronal and sagittal planes is estimated on the basis of the perpendicular distance between the anatomic axis of the proximal segment and the anatomic axis of the distal segment when a translational as well as an angular deformity is present. Such deformity characterization provides an improved understanding of the preoperative alignment.

Operative Technique

Antegrade Femoral Rod Fixation

A patient with a femoral malunion is positioned supine on a radiolucent table with both lower extremities included in the surgical field. Any standard commercially available locking intramedullary femoral nail system can be used. A positioning wire is introduced into the piriformis fossa with use of fluoroscopic guidance to ensure that the wire is placed in the center of the proximal femoral segment in the anteroposterior and lateral planes. The proximal

![Image: The osteotomy gaps are successively filled with reamings. The left panel shows the reamings at the proximal junction after reaming the proximal segment. The middle panel demonstrates the reamings at the proximal and distal osteotomy sites after “push-pull” reaming. The right panel demonstrates the final appearance at the osteotomy sites after all open spaces have been filled with reamings and supplemented with demineralized bone matrix or autogenous bone graft if required.]
femoral segment is opened with use of the opening reamer, which is placed over the threaded positioning wire. No attempt is made to sequentially ream the proximal segment at this point. An incision is then made on the lateral part of the thigh, spanning the length of the malunited segment. The iliotibial band is identified and incised to reveal the vastus lateralis fascia. The vastus lateralis muscle is then elevated from the posterior part of the femur extraperiosteally, exposing the malunited segment. Care is taken to expose only the lateral surface of the femur to preserve the soft tissue attachments to the planned osteotomy fragments. We emphasize the use of an atraumatic soft-tissue technique. The proximal and distal extents of the malunion are verified with use of fluoroscopy. A 4.5-mm drill-bit is then used to make multiple bicortical holes along the long axis of the malunited segment. The goal is to create a uniform line of stress-risers. A 1-in (2.54-cm) straight osteotome is used to osteotomize the segment through the lateral cortex only with use of the drill-holes as a guide. Osteotomizing only the lateral cortex along the drill-holes and keeping the medial cortex relatively intact prevents propagation of longitudinal fractures into the normal segments. The femur is then transected perpendicular to the
A fifty-year-old man who underwent realignment of a right femoral malunion prior to a total knee replacement.

**Fig. 2-A** Standing bilateral lower extremity radiographs illustrating a right femoral malunion with varus angulation and lateral translation.

**Fig. 2-B** Lateral radiograph of the right femur, demonstrating apex anterior angulation and posterior translation of the distal fragment.
normal portions of the diaphysis just proximal and just distal to the malunited segment with use of a sagittal saw, creating a free intercalary segment of bone. The free intercalary segment is wedged open initially with a 1-in (2.54-cm) osteotome and subsequently with a lamina spreader. The lateral cortex is separated widely, hinging open the medial cortex until it, too, is separated. This step has been likened to opening a clamshell, hence the name. If, however, the medial cortex does not open easily, then an osteotome may be used to cut the medial cortex, after which...
the lamina spreader is used again to open the osteotomy. Occasionally, separate fracture lines are accidentally propagated within the osteotomized segment during the opening of the clamshell. These may be ignored.

After realignment of the proximal and distal femoral segments with use of indirect reduction techniques, a guide rod is placed from the center of the anatomic axis of the proximal segment through the osteotomized segment into the center of the distal femoral segment, with careful attention paid to ensuring that the entrance angle is collinear with the distal segment. Passage of the guidewire into the distal femoral shaft may be assisted by direct manipulative means through the osteotomized femoral segments. The length of the guidewire is then measured.

The vastus lateralis is then allowed to drape over the exposed osteotomy segments in order to retain bone fragments produced by subsequent reaming. Medullary reaming is carried out in the proximal segment until the osteotomized segment is encountered. The reamer is then pushed through the osteotomy zone until the intact distal femoral fragment is encountered. No attempt is made to control the osteotomized fragments; the reamer is pushed through the osteotomy zone to prevent binding on the osteotomy fragments. Reaming of the distal fragment is then performed. Reaming in this sequence creates a “push-pull”
effect on the reamings. As the reamer is passed through the proximal segment, the reamings are pushed out from the proximal segment and deposited at the proximal osteotomy sites. The converse is true as the reamer is retrieved from the distal segment; the reamings are pulled along and deposited at the distal osteotomy sites. We believe that these reamings are critical for healing of the osteotomy gaps. Reaming is continued in 0.5-mm increments until cortical chatter is obtained. A femoral rod measuring 1 mm less in diameter than the final reamer is then implanted. Interlocking bolts are placed in the proximal femoral fragment in the static position with use of the jig. At this point, sagittal and coronal plane alignment will have occurred, with use of the femoral rod as a template. Final length and rotational corrections are performed at this time on the basis of preoperative measurements and with use of the contralateral lower extremity for comparison. Length and rotation corrections may be maintained with manual traction provided by an assistant or with the use of a femoral distractor or an external fixator. Distal interlocking bolts are then placed, under fluoroscopic guidance, with use of the freehand perfect circle technique.

The vastus lateralis is then retracted to expose the osteotomy zone. If substantial displacement of the osteotomy fragments is noted, a dental pick may be used to gently realign the fragments about the nail. Fixation of the osteotomized segments is not attempted; the osteotomy zone is likened to a comminuted fracture and thus no attempt is made to supple-
The clamshell segment is now free and the femur is prepared for intramedullary nailing. Fig. 2J Radiograph demonstrating the intramedullary reamer being passed through the clamshell segment. Figs. 2K and 2L Anteroposterior (Fig. 2K) and lateral (Fig. 2L) postoperative radiographs showing anatomic alignment of the femur over the intramedullary rod. (Figures 2-A through 2-L, courtesy of Dr. Paul Tornetta.)
ment rod stabilization. Care is taken not to disrupt the soft-tissue sleeve except as necessary to expose the lateral aspect of the malunited segment. The secondary gaps created by the restoration of length, alignment, and rotation are then inspected. The reamings generally fill the osteotomy gaps as a result of the “push-pull” technique (Fig. 1-H). However, if an osteotomy gap is not completely filled in, then demineralized bone matrix (DBX; Synthes, Paoli, Pennsylvania) or autogenous bone graft is used to supplement the reamings to ensure that there is no space left between the intact femoral shaft and the osteotomy fragments. The iliotibial band and skin are then closed in layers (Figs. 2-A through 2-L).

**Retrograde Femoral Rod Fixation**

The patient is positioned supine on a radiolucent operating table...
with both of the lower extremities included in the surgical field. The involved lower extremity is placed atop a radiolucent triangular positioning device, allowing the knee to be flexed approximately 45°. A medial parapatellar approach is used to gain access to the starting point. The starting point and the entrance angle into the distal segment are confirmed radiographically, and the threaded introduction wire is advanced with care to ensure that it is in the center of the distal fragment on the anteroposterior and lateral fluoroscopic images. The opening reamer is then placed over the starting wire for a depth of approximately 15 cm. The malunited femoral segment is then managed exactly as discussed above with the antegrade rodding technique. After the osteotomy has been created, a ball-tipped guidewire is passed from the distal segment across the osteotomy zone into the proximal segment, with care taken to ensure that it is centered in both the sagittal and coronal planes. The reaming rod is passed over the guidewire through the distal femoral segment, through the osteotomy segment, and up to the piriformis fossa in the proximal segment, with care taken to ensure that it is centered in both the sagittal and coronal planes. The reaming is created in the fibula to allow for a larger surface area for contact and healing. A medial parapatellar or a transpatellar tendon entrance to the previously defined safe zone for the tibial rod starting point is used. We have no preference as to tibial nail entry site. With use of fluoroscopy, care is taken to ensure an appropriate entrance angle into the proximal tibial segment. The proximal tibial segment is then opened with use of a threaded wire over which an opening reamer is passed. No attempt is made to sequentially ream the proximal tibial segment at this time. The osteotomy site is exposed next.

A longitudinal incision is made over the anterior compartment, one fingerbreadth lateral to the tibial crest along the proposed longitudinal osteotomy site. The anterior compartment musculature is translated posteriorly, allowing for an extraperiosteal exposure of the lateral aspect of the malunited segment. An atraumatic soft-
Figs. 4-A through 4-H A thirty-three-year-old man sustained Gustilo type-IIIB open fractures (extensive soft-tissue loss with periosteal stripping and bone exposure) of the tibia and fibula in a crushing injury. The fractures were treated with an external fixator. The patient presented for treatment of the malunion two years after the injury. **Fig. 4-A** Anteroposterior standing radiograph of the lower extremity, showing a shortened tibia with a medially translated distal tibial segment. Also, there is a varus malunion at the inferior end of the intercalary segment. **Fig. 4-B** Lateral radiograph demonstrating the marked deformity of the tibia, highlighted by marked posterior translation and apex posterior angulation at the superior end of the intercalary segment. **Fig. 4-C** Artist’s drawing of the tibial clamshell osteotomy, with the soft tissues included. The anterolateral muscular sleeve is being retracted posteriorly, exposing the lateral aspect of the tibia. The osteotomy is initiated 3 to 5 cm posterior to the anterolateral tibial prominence and angled posteromedially and parallel to the subcutaneous surface of the tibia. **Fig. 4-D** Artist’s drawing of the surgical exposure for the tibial osteotomy. Note that the anterolateral muscular envelope has been retracted posteriorly. The transverse osteotomies are denoted by dashed lines. The circles represent the drill-holes for the clamshell osteotomy.
tissue technique is emphasized, and only the anterolateral portion of the tibia is exposed. The positions of the proximal and distal transverse osteotomies are localized with radiographic guidance, and a Kirschner wire is placed perpendicular to the anatomic axis in order to guide the osteotomies.

Because of the triangular cross section of the tibia, the coronal plane clamshell osteotomy used for the femur cannot be used. Instead, the clamshell component of the osteotomy is created parallel to the medial tibial face, beginning just posterior to the anterolateral subcutaneous prominence of the tibia and aiming in a posteromedial direction (Fig. 3).

A 3.5-mm drill-bit is used to create the path for the longitudinal osteotomy with the goal of creating a bicortical uniform plane of stress-risers (Figs. 4-A through 4-H). Completion of the osteotomy of the near cortex only is accomplished with an osteotome with use of the drill-holes as a guide. A sagittal saw is then used to create the transverse proximal and distal osteotomies. The far cortex of the osteotomized segment is split parallel to the medial face with use of an osteotome and a lamina spreader. The longitudinal osteotomy of the intercalary segment is separated with a lamina spreader, and the posterior cortex is hinged on the periosteal sleeve. If, however, the posteromedial cortex does not open easily, then an osteotome may be used to cut the posteromedial cortex, after which the lamina spreader is again used to open the osteotomy.

The limb is placed over a radiolucent triangle. The guide rod is passed from the proximal tibial segment through the osteotomized segment into the distal segment with the aid of fluoroscopic guidance. The length of the guidewire is measured. Care is taken to ensure that the entrance angle and the ending point in the distal segment are in the center of the tibia on both the anteroposterior and lateral fluoroscopic images2. Prior to reaming, the anterior muscular compartment is allowed to drape over the cortex to preserve the bone fragments produced by subsequent reaming at the osteotomy sites. The proximal and distal segments are then reamed until cortical chatter is noted. The “push-pull” effect of the reaming should result in deposit of the reamings at the osteotomy gap sites as described

**Figs. 4-E and 4-F** Deformity correction in the coronal (Fig. 4-E) and sagittal (Fig. 4-F) planes.
for the femur. The reamer is pushed through the clamshell segment to protect the neurovascular structures and to avoid binding against the osteotomized fragments. Reaming is continued in 0.5-mm increments until cortical chatter is obtained. A tibial rod measuring 1 mm less in diameter than the final reamer is selected. The rod is then passed, and standard proximal interlocking is accomplished. The jig is removed from the proximal aspect of the tibial nail, and the limb is removed from the positioning pillow and placed flat on the operating table. Sagittal and coronal plane corrections have been accomplished with use of the nail as a template (Figs. 4-E and 4-F); therefore, only the length and the rotation need to be corrected at this point. The other limb is used as a guide to final length and rotational alignment. The length and rotational corrections are created by an assistant applying manual traction or with the use of a femoral distractor or an external fixator, after which distal interlocking bolts are placed with use of fluoroscopic guidance.

The anterior compartment is then retracted posteriorly from the lateral part of the tibia to facilitate inspection of the osteotomy sites. The bone fragments produced by intramedullary reaming usually fill the osteotomy sites. For gaps of ≥1 cm, demineralized bone matrix or autogenous bone graft is used to ensure that there is no space left between the osteotomy fragments and the intact proximal or distal parts of the tibia. The fascia over the anterior compartment is approximated loosely. If, however, there is any concern regarding excessive swelling that may contribute to compartment syndrome, the anterior compartment fascia is not closed. We have not performed prophylactic fasciotomies to date. Closure of the extensile approach to the malunited segment is achieved with use of the Allgöwer modification of the Donati technique, emphasizing careful soft-tissue handling.

**Postoperative Protocol**

Patients are admitted to the hospital, where patient-controlled analgesia and oral narcotics are used for pain control. The patient must be monitored closely for signs and symptoms of compartment syndrome, and regional block anesthesia is not used for this reason. Intravenous cephalosporin is administered for twenty-four hours postoperatively. Mobilization begins on the first postoperative day, with the patient using crutches.
The Journal of Bone & Joint Surgery · Surgical Techniques September 2010 · Volume 92-A · Supplement 1, Part 2 · jbjs.org

## CRITICAL CONCEPTS

### INDICATIONS:
This procedure is indicated to treat a combined angular and translational malunion of the femoral or tibial diaphysis. The clamshell osteotomy is especially helpful for the treatment of malunions that have a long malaligned segment. It provides for simplified planning and offers the biomechanical advantage of intramedullary fixation.

### CONTRAINDICATIONS:
- An unsuitable soft-tissue sleeve for the open exposure of the malunited segment
- A metaphyseal malunion
- Intramedullary osteomyelitis
- An absent medullary canal
- Morbid obesity precluding intramedullary nail placement
- Open physes

Relative contraindications include:
- Lengthening of the femur by >5 cm and lengthening of the tibia by >3 cm

### PITFALLS:
- Poor understanding of limb biomechanics
- Soft-tissue stripping of the osteotomized fragments
- Attempts to secure the osteotomized fragments, such as with a cerclage wire, are counterproductive in that they increase soft-tissue stripping. Also, cerclage wiring at the osteotomy site will limit micromotion of the osteotomy fragments and may prevent the formation of callus that is essential for the osteotomy to succeed.
- The clamshell osteotomy of the tibia may seem counterintuitive due to the cross-sectional anatomy of the tibia. The surgeon must carefully determine the appropriate osteotomy plane to prevent the creation of a unicortical osteotomy.
- Careful soft-tissue technique is essential, particularly for the tibial osteotomies.

### AUTHOR UPDATE:
There have been two substantive changes in the technique. The first is the discontinuation of use of the fracture table when using antegrade nails after a clamshell osteotomy. We have found that a free-leg antegrade femoral nailing technique is simpler to perform and that the contralateral limb may be included in the sterile field so that it may be used as a guide for more accurate length and rotatory corrections of the osteotomized limb. The second change is that, after the starting hole has been created, sequential reaming is delayed until after the osteotomy. Initially, attempts were made to ream the segment adjacent to the starting hole, but we now advocate reaming after the osteotomies have been created so as to encourage displacement of the reamings into the gaps created by the osteotomies. Two minor changes have also been made in the technique. Larger drill-bits may be used to create the template for the longitudinal osteotomies. A 4.5-mm drill-bit may be used for femoral osteotomies and a 3.5-mm drill-bit may be used for tibial osteotomies.

with toe-touch weight-bearing under the direction of a physical therapist. Weight-bearing is advanced incrementally as osteotomy healing progresses, with a goal of full weight-bearing by twelve weeks. Prophylaxis against thromboembolic disease is provided by the use of low-molecular-weight heparin until the patient is discharged from the hospital. The patients are followed in an outpatient setting beginning two weeks postoperatively. Postoperative clinical and radiographic evaluation continues at monthly intervals until union of the osteotomy sites has occurred. Biplanar radiographs are evaluated for progression of healing and maintenance of the anatomic axis realignment that was achieved at the time of surgery. Biplanar radiographs of the joint proximal and distal to the correction and standing hip-to-ankle radiographs are made after healing and are used to screen for signs of degenerative arthritis and to evaluate the lower extremity mechanical axes with respect to those on the contralateral, uninjured side.
The authors wish to thank Dr. Paul Tornetta for the images used in Figures 2-A through 2-L.

George V. Russell, MD
Matt L. Graves, MD
Department of Orthopaedic Surgery and
Rehabilitation, University of Mississippi Medical
Center, 2500 North State Street, Jackson, MS
39216. E-mail address for G.V. Russell: gvrussell@umc.edu. E-mail address for M.L. Graves: mgraves@umc.edu

Michael T. Archdeacon, MD, MSE
Department of Orthopaedic Surgery, University of
Cincinnati College of Medicine, P.O. Box 670212,
231 Albert Sabin Way, Cincinnati, OH 45267-0212

David P. Barei, MD, FRCS(C)
Department of Orthopaedic Surgery, Harborview
Medical Center, P.O. Box 359798, 325 9th Avenue,
Seattle, WA 98104-2499

Glenn A. Brien Jr., MD
Capital Orthopaedic Sports Medicine Center, 290
Layfair Drive, Suite A, Flowood, MS 39232

Scott E. Porter, MD
Department of Orthopaedic Surgery, Greenville
Hospital System, 701 Grove Road, 2nd Floor Support
Tower, Greenville, SC 29615

REFERENCES
1. Zirkle LG Jr. Injuries in developing
countries—how can we help? The role of or-
2008;466:2443-50.
2. Freedman EL, Johnson EE. Radiographic
analysis of tibial fracture malalignment follow-
ing intramedullary nailing. Clin Orthop Relat
3. McConnell T, Tornetta P 3rd, Tilzey J, Casey
D. Tibial portal placement: the radiographic
correlate of the anatomic safe zone. J Orthop
4. Sagi HC, Papp S, Dipasquale T. The effect of
suture pattern and tension on cutaneous blood
flow as assessed by laser Doppler flowmetry in