The patients discussed in this article were all treated at a level 2 community trauma center located in a suburb of a moderately sized city and serves a community of 1 million persons. With only a few exceptions, the authors are the only users of the Reamer Irrigator Aspirator (RIA) at our hospital. All the authors are fellowship-trained orthopedic trauma surgeons and have practices that are approximately 85% acute trauma and 15% reconstructive and elective general orthopedics. The authors work directly with the general trauma surgeons on the trauma service and have a separate call schedule from the general orthopedic surgeons. The trauma service has an average of 1200 trauma admissions per year. The authors began using RIA in 2003 and, as in many of the centers using RIA shortly after its release, the authors primarily used RIA for the acute treatment of femur and tibia fractures in polytrauma patients with chest injury or with two or more long bone fractures. The general trauma surgeons were highly influential in convincing the hospital of the importance of RIA for our severely injured patients with long bone fractures.

As experience and early reports were disseminated about the benefits of RIA as a bone-harvesting instrument, we began to use RIA increasingly more as a bone graft harvesting tool. The authors have been reluctant to abandon autologous bone graft in favor of the ever-increasing array of bone graft substitutes because of our belief that autologous bone with all of its bone-promoting components is ideal for bone healing. This core belief in addition to the low donor site morbidity of RIA seen in our patients has made RIA-harvested bone graft our graft of choice for most reconstructive surgeries not requiring structural properties.

INDICATIONS

Our group has three main indications for RIA: harvesting of nonstructural bone graft, treating acute or chronic intramedullary infection, and intramedullary nailing of multiple long bone fractures or in patients with a chest contusion and one or more long bone fractures.

In our practice, the most common indication for RIA is for bone graft harvesting. We believe that autologous bone graft is the best bone graft for most bone-healing applications. Because the graft material obtained with RIA is a granular material with varying degrees of gelatinous consistency, it is not useful as a structural graft. Tri-cortical iliac crest or allograft blocks are better suited for this purpose. However, if bone graft material is needed for healing of bone defects, nonunions, and so forth, autologous bone graft harvested with RIA is our first choice. We believe that cortical-cancellous bone harvested from the medullary canal of femurs provides a bone graft with osteogenic, osteoconductive, and osteoinductive properties.\textsuperscript{1–3}

Given the minimal morbidity with harvesting this rich bone graft using RIA, we prefer it to

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demineralized bone matrix, bone morphogenetic proteins, solid allograft preparations, or combinations of these materials. We cannot rationalize using bone graft substitutes in an attempt to mimic autologous bone graft when we can harvest the real thing with little risk and morbidity to the patient. In addition, the volume of graft obtained with RIA can be abundant but can also be voluntarily adjusted to need based on reamer size. On the other hand, the volume of graft harvested with RIA may be limited because of patient age (osteopenia) and systemic diseases that affect bone quality.

Although not one of the early applications of RIA, we have used RIA as a tool to debride and irrigate the medullary canals of long bone infections. We have used RIA in both the femur and tibia and believe that it can debride the entire medullary canal and irrigate and remove the infectious material in an efficient single technique. The suction/aspiration feature of RIA minimizes pressurization of the canal, which theoretically decreases or eliminates dissemination of the infected material deeper into the cortical bone or into the circulation.

As alluded to earlier, we still use RIA in selected acute long bone fractures. Because of anecdotal reports of increased nonunion rates in acute fractures, we do not use RIA for isolated femur fractures. Although this nonunion concern is unproven and unsubstantiated, we do not feel there is any advantage to RIA for acute femoral nailing in isolated femur fractures; however, if a patient with a femur fracture has a significant pulmonary contusion, we would choose to use RIA in an effort to decrease or eliminate marrow embolism. The other acute fracture indication is in patients with bilateral femur fractures with or without associated tibia fractures. However, we have not used RIA in patients with lung injury or multiple long bone fractures in the past 2 years mainly because of our practice of damage control orthopedic procedures (provisional external fixation with delayed intramedullary nailing) in these at-risk and borderline patients. Because the negative effects of marrow embolism associated with reaming of tibia fractures are not as clearly defined as they are in reaming of the femur fractures, we do not feel that RIA is indicated for acute tibia fractures associated with pulmonary injury. The technique of RIA in tibias is much more difficult because the smallest reamer size is 12 mm and because of the eccentric starting point and relatively acute turn that the reamer needs to make in the proximal tibia. The rigid 5 to 6 cm at the tip of the RIA and semi-rigid tube reduces the flexibility of the RIA and increases the chance of a complication when used in the tibia. However, with a retro-patellar entry point technique, these complications may possibly be eliminated. We have not used retro-patellar technique to date, but we would consider it if we decided we needed to use RIA in the tibia.

**TECHNIQUE OF HARVESTING INTRAMEDULLARY BONE WITH THE REAMER IRRIGATOR ASPIRATOR**

RIA-harvested bone graft is obtained through a system that incorporates a nitinol drive shaft, a single-use sharp reaming head, and a disposable plastic tube. The components are assembled in a manner that allows the delivery of a cooling irrigant, usually 0.9% normal saline, through the center portion of the nitinol shaft and out through the center port of the reamer head through gravity feed. While spinning in a high-speed, low-torque manner, the reamings become mixed with the irrigant solution and are aspirated through several ports in the sides of the reamer head, out through the plastic tube that surrounds the drive shaft, and into an inline collection filter.

When choosing a starting point for obtaining RIA graft, we consider several options. We often choose an ipsilateral site when harvesting for a lower extremity graft to minimize immobility. When femoral RIA harvesting is used for upper extremity grafts, the desire of the patient is taken into consideration (ie, right versus left), when possible. In aseptic nonunions of the femur, after hardware has been removed, that same ipsilateral femur may be harvested to obtain graft, with the understanding that the yield may be lower. The tibia is not usually used for obtaining graft for concern of thinning the posterior cortex as the bone is harvested, although it has been used on multiple occasions for debridement of endosteal infection within the tibia, where the leg is supported by splinting or other means after debridement.

Hence, we obtain most RIA graft harvestings from the femur, through one of four different starting points. Proximal starting points consist of the piriformis fossa and the greater trochanter, with a larger number of trochanteric start points for ease of manipulating the stiff plastic/nitinol assembly, ease of obtaining the starting point correctly, and with the perception that the trochanteric cortical bone is thinner and cancellous bone more abundant than the piriformis region, yielding more graft from the proximal femur. These two sites mirror those starting points used for antegrade femoral nailing. The distal femoral sites are either an extra-articular medial starting point, chosen to avoid violating the knee joint anterior and proximal to the insertion of the
medial collateral ligament, or an intra-articular site anterior to the anterior cruciate ligament (ACL), in a manner identical to our retrograde femoral nailing entry point.

We position the patient supine on a radiolucent table, and use the fluoroscope to confirm the proper starting point and assist with determining reamer head size. With proximal femoral stating points, we place a small bump under the ipsilateral hip before sterile skin prep, and adduct the leg to ease insertion. To determine reamer head size, we place a radiolucent measurement guide (Synthes, Paoli, PA) against the side of the diaphysis, near its isthmus, at the same level as the bone. If placed on top of the thigh or leg, the body habitus of the patient may make the distance from the bone to the skin large enough to introduce error owing to differences in magnification. Depending on how much bone is anticipated to be required, we choose a reamer 1 to 2 mm larger than the endosteal canal width. The thickness of the cortex must be taken into account, so as not to introduce risk of fracture by overthinning of the cortex, especially with older patients.

We then introduce a 3.2-mm guide pin into the site and advance it enough to allow passage of a cannulated, fluted 6.0- to 10.0-mm step drill (Synthes). Once the canal is entered, we introduce a 2.5-mm ball-tipped reaming rod and confirm a center placement at the distal end by fluoroscopy, or in cases of multiple passes, we direct it toward the desired area of metaphyseal bone in one or the other femoral condyle. We pass the reamer slowly down the intramedullary canal in an “advance-withdraw” technique, where the reamer is advanced several centimeters, then withdrawn slightly, then advanced again, until reaching the opposite end of the canal. We take care to monitor the outflow of irrigant through the tube to ensure suction is not lost by clogging within the tube, which could cause malfunction of the RIA system or potentially harm the graft. This occurs commonly in younger patients with dense bone. We collect the reamings, but the effluent irrigant solution is not currently retained. Reamings are kept in a sealed container until use.

APPLICATION OF THE GRAFT/WHEN WE USE ADJUNCTS

After preparation of the site for bone grafting, we place the RIA graft similar to other autologous bone grafts. RIA graft has a consistency similar to moist sawdust. We recommend irrigating the wound before application of the graft to minimize loss, as the graft is not solid and could wash away if exposed directly to would irrigation. We use the RIA graft to fill voids in nonunion sites as well as in acute lengthening. The soft tissue adjacent to the graft should be healthy, and direct contact between the fracture/osteotomy site, RIA graft, and muscle is preferable. When the handling characteristics of the RIA graft are not ideal for that particular application, we manipulate it in one of two ways. If enough volume is present, we can compress it by placing it into a 30- or 60-mL syringe and compact it with the plunger, rendering the plug more dense. In the case of older patients, where yield is unexpectedly low or with high fat content, we may supplement the RIA graft with demineralized bone matrix (DBX, Synthes) to improve volume or improve handling characteristics, so that the graft is more likely to remain where placed.

PITFALLS

Several circumstances can result in complications postoperatively. Pain is the leading complaint after RIA, and this resolves quickly in most patients. Some of our patients had virtually no pain at the RIA harvest site; however, on occasion, pain did linger. Some patients formed a hematoma at the harvest site, although none required surgical drainage. This has led us to attempt sealing of the entry portal using a thickened version of an absorbable gelatin hemostatic agent (Surgifoam, Johnson and Johnson, Cincinnati, OH), which is mixed as a thick paste and deposited into the entry portal. Consistently delivering the absorbable hemostat to the entry portal has been difficult, but can best be controlled when we fill a 15-cm section of left-over RIA tubing with the agent, place it into the entry portal, push the agent through the tube with a solid rod, and remove the plastic tube.

When making multiple passes with RIA, we are careful not to breach the far-sided cortex. This could result in pain or iatrogenic fracture. In one case where the patient had prolonged knee pain after antegrade RIA harvesting, MRI revealed no cortical violation but intense extra osseous edema adjacent to the lateral femoral epicondyle. This has discouraged us from redirecting the guide wire in multiple sites in the distal femur. As mentioned, our experience with RIA in the tibia has been limited to reaming for acute fractures and infection; both circumstances require stabilization of the tibia regardless of the reaming procedure, while neither circumstance provided the confidence for obtaining bone graft. The femur is longer, with more opportunity for harvesting cancellous bone along with the cortical bone,
and as such is our preferred long bone for harvesting.

The multiple literature reports of hip and knee pain after femoral fracture with intramedullary nailing demonstrate inconclusive evidence regarding the superiority of a specific entry portal.\textsuperscript{5–8} Knee pain can exist after antegrade nailing, whereas hip pain can occur after retrograde nailing. Piriformis and trochanteric starting sites have been shown to have similar incidences of hip pain. Our group of patients did demonstrate hip pain that rapidly resolved, leading us to conclude that perhaps other factors associated with the traumatic injury to the femur or the instrumentation of the femur are more responsible for chronic hip pain than the reaming of the proximal femur.

There are several unpublished reports of fracture of the femur occurring after RIA harvesting in the femur and tibia, although none in our series. Care must be taken to avoid eccentric reaming of the proximal cortex of the femur or tibia, or in the case of the distal femoral extra-articular start, the distal lateral femur. Reamer head size must be chosen carefully, and with a small diameter canal, RIA may not be appropriate, as it is currently available only from 12 mm and larger. Osteoporosis is a relative contraindication for RIA harvesting if no internal instrumentation or protection from weight bearing follows the harvest, as the risk of fracture would be unacceptably high.

\textbf{Results}

Over an 18-month period, from June 2005 to December 2006, we performed 23 procedures requiring the use of the RIA. There were 13 males and 10 females. Nineteen procedures were for treating nonunions, two for malunions, two for polytraumatized patients with pulmonary injuries, and one for osteomyelitis. Of the nonunions, seven were in the tibia, four were in the femur, five were in the humerus, one was in the radius, one was in the ulna, and one was in the pelvis. There were 13 males and 10 females. The average age of the patients was 50 years (range 21 to 77 years). Of the two patients who had malunions, both were in the femur. Both required acute femoral lengthenings and derotation osteotomies. Of the two polytraumatized patients who had pulmonary injuries, one patient had a femur shaft fracture, and the other had both femur and tibia shaft fractures. One patient had tibial osteomyelitis.

In most cases, RIA was used in the femur shaft entering the proximal femur in antegrade fashion through a trochanteric entry portal. In the other cases, RIA was used in the tibial shaft, from the medial femoral condyle, or in the femur in a retrograde fashion. In the cases where RIA was used to harvest bone, variable amounts of harvested bone were obtained, ranging from 20 mL to more than 100 mL.

To investigate the morbidity of RIA, we retrospectively reviewed our cases in which RIA was used in the femur via an antegrade approach with a trochanteric starting point. Fifteen patients were able to be identified who met these criteria. The morbidity was assessed using the Oxford hip score as an outcome measure. The Oxford hip score is an outcome instrument that assesses hip pain by using a 12-item questionnaire. The minimum total score of 12 points indicates normal function and the maximum score of 60 indicates severe disability.\textsuperscript{9} This was modified to grade responses as excellent if the final score fell between 12 and 27, good if the score was between 28 and 43, and poor if the final score was between 44 and 60. The average Oxford hip score for these patients was 15.8 (range 12 to 27), indicating an excellent result.

After the initial study period, we have performed 14 procedures using RIA: 2 cases were infections and 12 cases were nonunions.

\textbf{Complications}

During our initial study period, we had three complications. The first was a failure to achieve union in a distal tibial nonunion. The patient required a second procedure, which included harvesting bone graft from the contralateral femur using RIA. The patient healed after the second procedure. The second complication was in a patient with a femur malunion. He had complaints of medial-sided knee pain in the distribution of the saphenous nerve. This had subsided at last follow-up. Our third complication was an infection of the ankle. This patient had an open fracture and tibial infection after her index procedure. RIA was used in her tibia to harvest bone graft for an ankle arthrodesis. Four months after her ankle arthrodesis, she presented with erythema and purulent drainage necessitating repeat debridements and removal of hardware. Her multitude of problems included avascular necrosis of the talus, recurrent ankle infection, and nonunion of the ankle and subtalar joints. She chose amputation as definitive treatment.

\textbf{SUMMARY}

RIA is a successful implement for the harvesting of large volumes of nonstructural autologous bone graft. It provides an osteogenic, osteoinductive, and osteoconductive environment for bone
healing. It is easy to learn, as many surgeons are already familiar with the technique for intramedullary nailing. Once beyond the “learning curve,” harvesting with RIA takes less time than traditional autologous iliac crest harvesting. RIA is highly effective in promoting the healing of nonunions and segmental defects, including acute lengthenings. It can also be used for treatment of endosteal long bone infections of the tibia and femur. The complication rate for RIA harvesting is lower than that expected for harvesting of autologous iliac crest graft, although it is not without risk, especially if reamer size is too aggressive, reaming technique is indiscriminant, or bone quality is poor. Its contribution to chronic hip pain appears to be minimal. In our community trauma practice, RIA has replaced iliac crest bone grafting as the autologous graft of choice for nonstructural defects and nonunions.

REFERENCES


