Intramedullary Bone Graft Harvest Using Reamer-Irrigator-Aspirator System: A Case Series

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Autogenous iliac crest bone grating has been the gold standard. Recently, intramedullary bone graft harvest using a reamer-irrigator-aspirator (RIA) had been gaining more interest among orthopedic surgeons. Twenty-four RIA bone graft harvesting procedures in 23 consecutive patients with nonunions were included. The mean age was 37.8 years. Rates of perioperative complications, secondary surgical procedures, and union were assessed for all patients. At mean 10.1 months follow-up, three donor site complications occurred (12.5%), including two fractures (8.3%). Eighteen patients (78%) progressed to radiographic union, three (13%) were lost for follow-up, and two (9%) failed to achieve union. Mean reamer size was 13.7 mm (mode, 14.0 mm), producing an average volume of 39.4 mL (range, 15–90 mL) bone graft. While RIA bone grafting results in predictably high rates of union, patients should be counseled extensively about fracture risk. Tibial RIA may be less optimal as a primary source of bone grafting. (Journal of Surgical Orthopaedic Advances 26(4):233–238, 2017)

Key words: bone graft, iatrogenic complication, intramedullary, nonunion, open fracture, reamer-irrigator-aspirator, RIA, tibia fracture

With over 500,000 bone grafting procedures in the United States each year (1), a variety of autograft, allograft, and synthetic bone substitutes may be considered. Historically, autogenous iliac crest bone graft has been considered the gold standard for the treatment of traumatic bone defects and nonunions, in large part because of its optimal mixture of structural and biological properties (2). However, because of concerns for donor site morbidity and limited graft volume (3, 4), alternative sources are increasingly investigated, particularly the intramedullary canal of long bones.

The reamer-irrigator-aspirator (RIA; Synthes, Paoli, Pennsylvania) system is a newer device that incorporates the benefits of negative pressure reaming with abundant, minimally invasive bone graft harvest from the intramedullary canal of the femur or tibia. With a biologic profile similar to the iliac crest, intramedullary bone harvest may cause less donor site pain while offering greater available graft volume (5). Additionally, intramedullary harvest may obviate the donor site complications traditionally described with iliac crest bone graft harvest, such as neural injury, infection, and hematoma or seroma formation (6). The purpose of the study is to evaluate the efficacy and complications related to intramedullary bone graft harvesting technique using RIA, as well as the clinical results of the nonunions and bone defects treated with this graft source.

Methods

Patient Enrollment

Between 2009 and 2012, all patients with planned intramedullary bone graft harvesting for the secondary treatment of a delayed union, nonunion, or significant bone defect were prospectively identified for inclusion in this study. The study was approved by the authors' institutional review board. Exclusion criteria were incomplete clinical and radiographic follow-up (i.e., <6 months) or primary treatment with bone transport. Patient demographics (age, sex, race), injury characteristics (closed vs. open fractures), surgical indications, concomitant surgical

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procedures, and pertinent clinical data (presence of infection) were recorded.

The primary outcome measures were rates of perioperative complications and secondary surgical procedures. Secondarily, the study evaluated the amount of reaming obtained, size of the reamer, and radiographic union. Radiographic union was determined on computed tomography by crossing trabeculae, or three cortices of bridging callus on anteroposterior (AP) and lateral radiographs, or signs of callus remodeling, while painful single limb stance phase and persistent pain at the fracture site were used to determine clinical nonunion. A computed tomography scan was obtained mainly for patients with external fixation before removal of their fixation because determination of healing was critical in these patients. For patients with internal fixation, assessment was dependent on plain radiographs as described above.

Operative Technique

A single surgeon at a level I trauma center performed all cases. For antegrade femoral RIA (the standard procedure), the patient was positioned supine on a radiolucent table with a bump underneath the hip. The lower extremity was sterilely prepared to allow for free rotation of the extremity and to facilitate C-arm fluoroscopy access. A straight guide pin was used to percutaneously identify the entry point at the tip of the greater trochanter. After verifying the position of the pin by fluoroscopy in both AP and lateral views, a cannulated entry reamer was passed over the guide pin. Bone graft generated from the entry reamer was removed from the flutes and later added to the nonunion site. A ball-tipped guide wire was then passed from the entry point down the canal, using a gentle 20° bend to facilitate passing the wire to the level of the distal physeal scar.

The size of the reamer was determined on the basis of the isthmic diameter of the femur on preoperative AP and lateral radiographs. Alternatively, intraoperative assessment with a specific ruler was performed. The chosen reamer, sized approximately 1 to 1.5 mm larger than the measured medullary diameter, was then introduced and continuous flow irrigation through the reamer was assured to avoid the possibility of medullary thermal necrosis. The reamer was advanced slowly over the guide wire. In most cases, marked resistance is encountered in the part of the femur proximal to the lesser trochanter because of changes in reamer trajectory when passing along the medial wall of the proximal femur. After passing the initial resistance, the reamer should start advancing easier in the subtrochanteric region, and an "advance and withdraw" technique is used to clear reamer flutes. The reamer is advanced to the distal metaphysis, with care not to eccentrically ream the anterior cortex in supracondylar region. C-arm fluoroscopy is used throughout the passage of the reamer to ensure proper advancement, central positioning, and an absence of cortical perforation or iatrogenic fracture. If marked resistance is met during reamer passage, a fluoroscope is used to obtain two orthogonal views to exclude peripheral reaming. If the reamer head is found to be excessively larger than the isthmic diameter, the reamer is removed and replaced, downsized approximately 0.5 to 1 mm. If the reamer passes through the medullary cavity with relative ease and there are insufficient reamings (less than 30 mL), another passage is performed with a reamer head that is 0.5 to 1 mm larger in size.

For tibial and retrograde femur, the standard nail entry points were used for tibial cases and retrograde femoral cases. The rest of the procedure is the same as described above.

The reamings were collected and placed into a specimen cup on the back table. Attention was then directed to the nonunion site. After formal debridement of the fibrous nonunion, a planned fixation was performed as dictated by the case. Harvested bone graft was then packed around the nonunion site, and an optional 1 g of vancomycin antibiotic powder was added at the surgeon's discretion.

Results

Twenty-four RIA procedures were performed in 23 consecutive patients with extremity nonunions (one patient had the procedure done twice with a 1-year interval). Fourteen patients were male, and the mean age was 39.0 years (range, 15–66 years). Twenty-three patients had nonunions of long bones of various anatomic locations to include tibia (14), femur (6), and humerus (3). Primary fracture in the cases of nonunion included 16 patients with history of open fractures, while seven patients originally sustained closed injuries.

The mean reamer size used for RIA bone harvest was 14.3 mm (mode 14.0 mm), producing an average of 41.7 mL of bone graft (range, 15–90 mL). Twenty harvestings were from the femur and four were from the tibia.

Concomitant procedures at the time of the 24 bone graftings included revision internal fixation in 14 cases (nine patients had revision plating and five had revision nailing). In eight cases (all of which had tibial nonunion), the same external fixation method was maintained with application of the bone graft reamings to the nonunion site (six had a Taylor Spatial Frame and two had an Ilizarov frame). Two patients had application of a new external fixator (one had a Taylor Spatial Frame and one had a uniplanar frame) at the time of bone grafting.

Three donor site complications occurred among three patients (13%), including two donor site fractures (8.7%) and one reamer failure with retained hardware. The first patient was a 66-year-old female who initially sustained

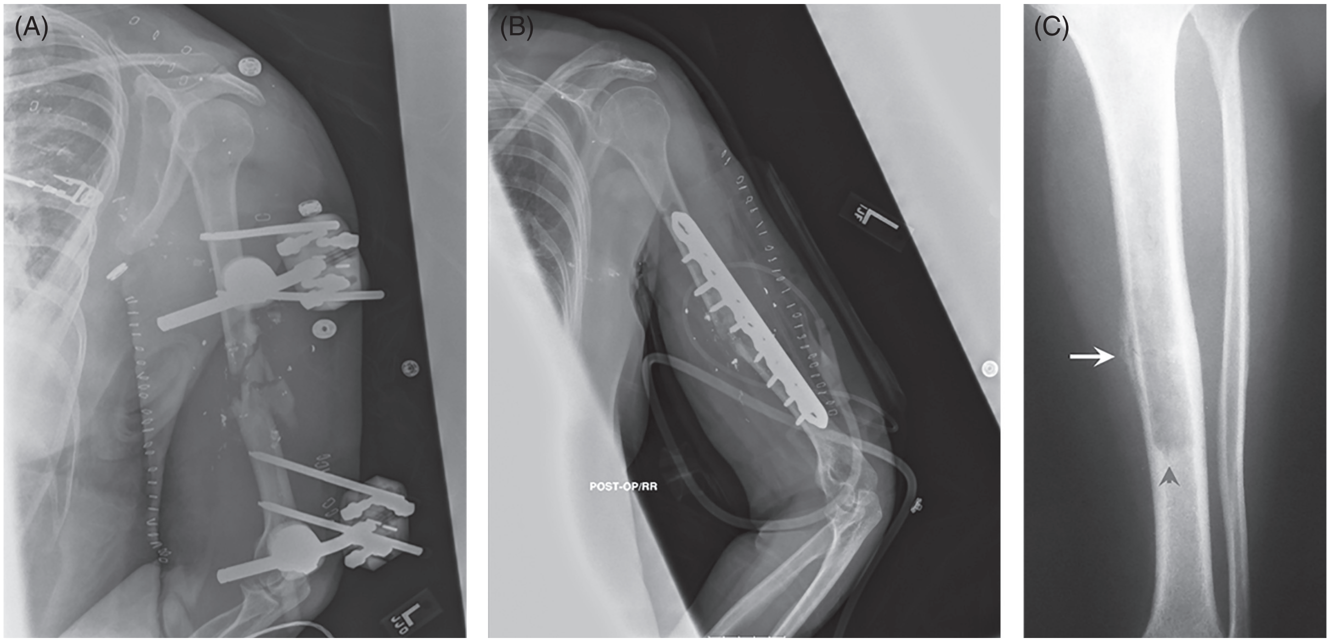

FIGURE 1 (**A**) External fixator used in initial management of type IIIC left humerus fracture. (**B**) Revised to open reduction internal fixation and RIA bone graft. (**C**) Tibia shaft fracture at donor site seen in this radiograph 4 months postoperatively with callus formation (arrow). Notice that the medulla was reamed only just past the middle of the tibia (arrowhead).

a gunshot-related grade IIIC open humeral shaft fracture treated with external fixation that resulted in delayed union. Tibial RIA was performed. During surgery, the surgeons noticed that her reaming was eccentric, resulting in marked thinning of the posteromedial cortex. Because of the eccentric reaming, the procedure was aborted just distal to the middle of the tibia to avoid intraoperative fracture. The patient sustained a marginal fracture of her tibial donor site at 4 weeks postoperatively that healed uneventfully with nonsurgical management (Fig. 1). The second patient was a 22-year-old male with a grade IIIB proximal tibial nonunion and segmental bone loss who underwent bilateral femoral RIA to obtain sufficient bone graft. Four months later, the patient sustained a spiral distal femoral shaft fracture during a fall from a standing height (Fig. 2), which required open reduction and internal fixation. The final complication occurred in a 45-year-old male patient with a IIIB open proximal tibia and tibial shaft fracture that failed previous treatment with acute shortening and bone transport because of persistent nonunion. During attempted antegrade femoral harvest, the reamer failed, with breakage at the junction of the reamer shaft with the reamer head (Fig. 3) with retention of metal debris in the proximal femur.

At an average clinical follow-up of 10.1 months, 18 out of the 23 patients with nonunion (78%) had evidence of radiographic union. Three patients (13%) were lost to follow-up and the authors were unable to verify union. Two patients (8.7%) were deemed failures because of persistent nonunion at greater than 1 year after RIA and the need for subsequent procedures. One of these two patients had persistent infection at the nonunion site after grafting two times, each time requiring debridement and removal of the graft. He eventually was treated with excision of the nonunion and bone transport and healed 1 year later.

This procedure was performed on one pediatric patient, a 15-year-old male, who sustained a type IIIB open tibia fracture that was initially managed with Ilizarov external fixation that went on to a nonunion. He underwent RIA 15 months after his injury with harvest obtained from his ipsilateral femur. The reamings were applied posterolateral with application of a Taylor Spatial Frame.

Discussion

With its osteogenic, osteoconductive, and osteoinductive properties, autologous iliac crest bone grafting has long been heralded as the gold standard for the treatment of nonunions or traumatic bone defects. Accordingly, previous studies have documented rates of union approaching up to 97% after iliac crest bone grafting (7, 8). However, historical case series have acknowledged significant rates of iliac donor site morbidity, which are reported in up to 48% of patients (3, 9, 10). Additionally, donor site symptoms may persist long after bone graft harvest, with 38% and 19% of patients reporting continuing pain at 6-month and 2-year follow-up, respectively

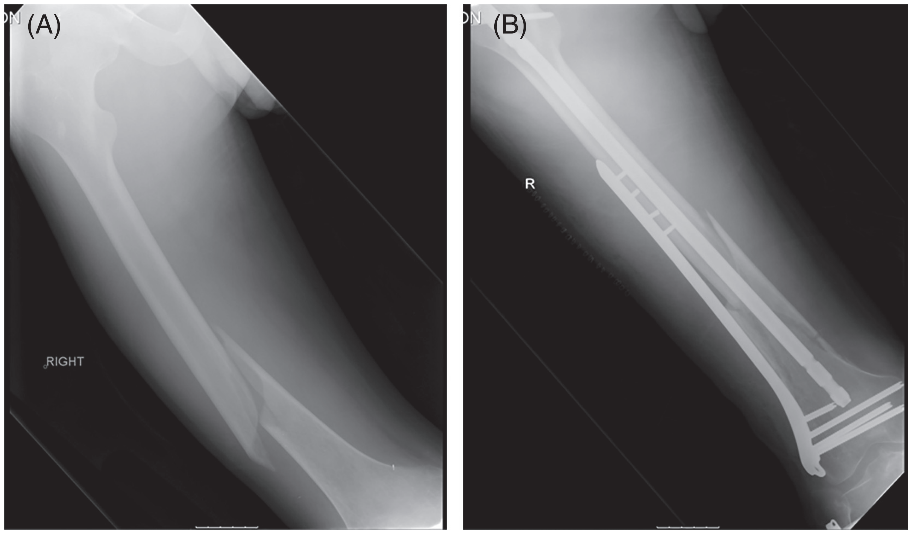

FIGURE 2 (**A**) AP view of femoral shaft fracture after RIA harvest. (**B**) Fracture treated with intramedullary nail and plate.

(11). Furthermore, other, more rare complications have also been identified with iliac crest bone graft harvest, including neurovascular injury, fracture, hernia, and even pelvic discontinuity (12). Given these concerns, other sources of bone graft have been increasingly explored. The intramedullary canal offers a rich biological profile and serves as an alternative with an abundant supply of cancellous bone graft (5). The proponents of intramedullary harvest have emphasized the potential diminution in surgical sites and donor site morbidity, as well as ease of access to large quantities of bone graft (6, 13, 14).

Multiple analyses have established the biological viability of intramedullary reaming debris (15–18) and more recent studies have attempted to quantify the comparative advantages of bone graft obtained through RIA compared with other autogenous bone graft sources. In a prospective comparative study of bone graft harvested from both the iliac crest and intramedullary canal in the same patient, Sagi et al. demonstrated greater expression of bone morphogenic proteins and vascular endothelial growth factor receptors than that harvested from the iliac crest (5). Schmidmaier et al. (19) reported similar findings, with elevated levels of bone morphogenic protein 2, platelet-derived growth factor, insulin-like growth factor I, fibroblast growth factor α, and transforming growth factor $\beta 1$ found in intramedullary samples. RIA samples also demonstrated greater concentration of mesenchymal stem cells, early endothelial progenitor cells, and possibly greater regenerative potential (5, 20), as previously indicated by other studies (21–23).

FIGURE 3 Broken reamers during harvest.

Clinically, intramedullary bone graft has been successfully used in the treatment of segmental bone defects, nonunions, and malunions. In this prospective series, bone grafting with intramedullary harvest led to radiographic union in 78% of patients with extremity nonunion or significant bone defect. Only two patients (8.7%) in this series failed RIA grafting, one of them because of persistence of infection. Healing was not able to be confirmed in the rest of the patients (three patients). In a retrospective comparative study, Belthur et al. reported successful union in 37 of 41 patients undergoing RIA for varying indications, while only 32 of 40 patients in a historical patient cohort reached a similar end point after anterior iliac crest bone grafting (14). Furthermore, patients receiving intramedullary harvest reported significantly lower pain scores than patients with iliac crest harvest at all three measured time points postoperatively. Finkmeier et al. similarly showed limited donor site pain or functional limitations in 15 patients undergoing antegrade femoral harvest using RIA, with all patients reporting excellent results on their Oxford hip score (7). In the current study, strict radiological and clinical criteria were used to assess healing. Thirteen percent of the patients were lost for follow-up before their final healing was confirmed; these patients have been excluded from the healing percentage. These two factors (strict criteria for healing and patient lost for follow-up) may contribute to the relatively lower (78%) healing rate compared with other studies.

While persistent nonunion of and recipient site complications have been documented (7, 24), reports on the donor site complications and rates of reoperation are limited (6). Among the current cohort, three patients (13%) sustained donor site complications, including two individuals (8.7%) with fracture at the harvest site, one of whom required reoperation. In a recent systematic review, Dimitriou et al. identified a comprehensive complication rate of 6% ($n = 14$) among a cohort of 233 patients undergoing RIA for intramedullary harvest versus 19.37% for iliac crest bone graft harvest (4). In their RIA group, these authors identified four donor site fractures (two femoral shaft, one intertrochanteric, one tibial shaft), four anterior femoral cortex perforations, one intra-articular breach of the knee joint, one aggressive femoral neck harvest requiring prophylactic fixation, and one case of intraoperative bradycardia and hypotension after prolonged reamer extraction with RIA technique (25).

While a learning curve should be acknowledged (26), certain precautions may mitigate perioperative complications with RIA. In addition to careful patient selection (e.g., patient without osteoporosis, advanced age, or abnormal medullary alignment), judicious surgical technique with central guide wire placement and liberal use of intraoperative fluoroscopy may avoid eccentric reaming and the creation of stress risers, which could lead to secondary fracture. Furthermore, proper reamer selection based on canal diameter in preoperative imaging and a vigilant, incremental advancement and withdrawal technique may prevent excessive cortical thinning and isthmic seizing of the reamer. While most authors recommend choosing a reamer size 1 to 2 mm greater than the measured isthmic canal to limit biomechanical compromise (7, 26), Pratt et al. (27) suggested that the torsional strength of the femoral shaft was dramatically reduced when the ratio of the reaming diameter to bone diameter exceeded 0.48. When there is a concern for risk of secondary fracture, surgeons should always consider weight-bearing restrictions and activity limitations until remodeling occurs.

The tibial fracture in this case series occurred in the second tibial RIA because of eccentric medullary reaming. Since then, the authors have abandoned the tibia as a primary source of RIA. The authors have since performed tibial RIA, but only in two cases that had tibial nonunion over an intramedullary nail in which the secondary procedure was exchange nailing. Reaming for the new nail was done using RIA. The risk of fracture in these cases is minimal because a new nail will be applied after the reaming. Herscovici et al. successfully used tibia RIA harvest in 28 patients undergoing ankle and hindfoot arthrodesis without any fractures (28). Of these, 25 patients underwent a tibiotalocalcaneal arthrodesis by intramedullary nail where reaming was performed for the intramedullary nail placement using RIA.

One patient in the current study experienced reamer failure with retention of metallic debris and limited graft harvest. While not previously reported to the authors' knowledge, device failure may occur as a result of improper assembly of the reamer head into the drive shaft with intraoperative failure (26). Given proper setup, this complication likely occurred because of incarceration of the reamer head within the canal while the power reamer continued to rotate the drive shaft, resulting in excessive torsion at the narrow reamer–drive shaft junction and ultimate failure.

Given its ample supply and minimally invasive surgical exposure, intramedullary bone graft is ideal for extensive or segmental bony defects (24). In the current study, the average volume of harvested bone graft required for patients was approximately 41 mL. Other authors have documented larger yields with intramedullary harvest (6, 7), with up to 100 mL harvested from a single site (7, 26). However, this may further increase risk of iatrogenic or delayed fracture, as well as other aforementioned complications. By comparison, traditional methods of iliac crest harvest have been limited to less than 30 mL of autogenous graft (6), although volume of bone graft may vary by harvest techniques or individual surgeon. Additionally, given the preponderance of repeat surgical procedures after primary bone grafting, the current study documents the significant volume obtained by repeat intramedullary harvest and supports its potential utility for the treatment of persistent nonunion. The authors recommend exercising extreme caution with repeat harvest to avoid eccentric reaming, cortical thinning, and secondary fracture from stress risers.

The strengths of the current study include its prospective nature and clinical and radiographic follow-up. However, certain limitations must be acknowledged. First, given the rarity of nonunion, the patient series was limited to only 23 patients despite 3 years of prospective enrollment at a busy, tertiary referral, trauma hospital. Second, while surgical technique was similar between patients, method of fixation, recipient, and donor site were not standardized, which may contribute to selection bias. Similarly, this patient series also represents a diverse patient demographic, including one pediatric patient, with a broad array of associated injuries and underlying medical comorbidities. Finally, the senior author (AA) is a fellowship-trained orthopaedic trauma surgeon with experience in the treatment of nonunion, particularly using RIA. As a result, this experience may limit external validity and not adequately reflect the variable learning curve associated with this harvest technique. Future prospectively randomized studies should attempt to comparatively evaluate the rate of donor site morbidity and secondary surgical interventions after intramedullary or iliac crest bone graft harvest.

Conclusion

In a series of 24 intramedullary bone graft harvests using RIA in 23 patients, the rates of total donor site complication and postoperative fractures (13% and 8.7%, respectively) are higher than previously described in the literature. Intramedullary bone grafting offers an abundant source of autogenous bone graft with potentially diminished donor site morbidity, although the rates of perioperative complications are not negligible and may necessitate reoperation. Patients should be counseled extensively about the risk of harvest site fracture. Tibial RIA may be better avoided as a primary source of bone grafting; however, this procedure needs further biomechanical studies.

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