Sequential Harvesting of Bone Graft From the Intramedullary Canal of the Femur

JANET D. CONWAY, MD; LIOR SHABTAII, MD; STACY C. SPECHT, MPA; JOHN E. HERZENBERG, MD

abstract

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The effectiveness of using the Reamer/Irrigator/Aspirator (RIA) System (Synthes, Inc, West Chester, Pennsylvania) to obtain bone graft from the intramedullary canal of long bones for the treatment of bone defects and nonunions has been previously documented. However, there is nothing in the literature discussing the potential for reaming the same canal at subsequent surgeries. The authors detail their experience of 8 instances of sequential reaming in 7 patients. Six patients were harvested twice, and 1 patient was harvested 3 times. In each patient, the bone graft was obtained from the same canal. The main outcome measurements were time interval between reamings, reamer head size, indication for reaming, volume of harvested bone graft, and complications. Average volume of graft obtained in the first reaming procedure was 34 mL (range, 25-50 mL). After an average of 9 months (range, 3-16 months), the subsequent reaming was performed. Average volume of graft obtained in the second procedure was 45 mL (range, 28-65 mL). In the authors’ series, no reaming-related complications were observed. The graft volume was the same or increased during the subsequent intramedullary reaming in all but 1 case, suggesting that the intramedullary canal is a potentially renewable source for bone graft. There were no complications related to the sequential reaming procedure. Overall, the authors’ data suggest that sequential reaming with the RIA has the potential to safely and effectively provide a large quantity of bone graft on multiple occasions.

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Large bony defects and nonunions are significant challenges for those working in the fields of trauma and orthopedic surgery. Many studies have been performed to understand how to harvest bone graft with minimal pain and complications while obtaining the greatest amount of high-quality bone graft. Iliac crest bone graft (ICBG) has been the gold standard for bone grafting but can result in complications such as abdominal hernias, peritoneal perforation, sacroiliac joint injuries, avulsion fractures of the anterior iliac spine, and vascular injuries. Despite the potential for these types of complications, ICBG consistently remains the gold standard for tricortical autologous bone grafting. When a tricortical structural bone graft is not necessary and only cancellous bone is needed, harvesting the intramedullary bone with the Reamer/Irrigator/Aspirator (RIA) System (Synthes, Inc, West Chester, Pennsylvania) is an excellent option.

The original concept of the RIA procedure began as a method to prevent fat embolism. It was thought that by reaming and aspirating the contents of the canal prior to nail insertion, intramedullary pressure and temperature would be reduced. At that time, using the leftover reaming for bone graft at a nonunion site was not considered. Since that time, several studies have documented the effective use of the RIA System for harvesting bone graft to treat bone defects and nonunions. This system has been documented to yield bone graft volumes ranging from 25 to 90 cm. Intramedullary bone graft has also been documented as a less painful source of autograft than the iliac crest. On several occasions, the current authors have needed additional autograft months after the intramedullary canal was initially harvested. In these cases it was necessary to use the same femur on multiple occasions due to the location of the nonunion and patient constraints. Furthermore, an effort was made to perform all surgical interventions on the ipsilateral side to improve postoperative rehabilitation. To date, the authors have performed 8 sequential reamings in 7 femurs. To the authors’ knowledge, the safety and effectiveness of using sequential RIA reaming in the same femur has not been previously studied in the literature. The authors hypothesized that sequential RIA reaming of the femur results in a greater quantity than the initial reaming.

**Materials and Methods**

This was a single-center, retrospective, institutional review board–approved study. Only patients who underwent sequential reamings for bone graft using the RIA System were included in the study. This criterion yielded 8 instances of repeat reamings in 7 patients, including 3 females and 4 males (average age, 45 years [range, 15-65 years]) at the first RIA procedure. Six patients had 2 RIA reamings in the same femur, and 1 patient had 3 RIA reamings in the same femur. All surgeries took place between 2007 and 2011. Mean follow-up was 6.5 months (range, 1-17 months). The authors collected data regarding the amount of bone graft obtained, reamer head size, time between reamings, indication for surgery, and complications related to the reaming.

**Surgical Technique**

The surgical technique used was similar to that reported previously. The surgical technique used was similar to that reported previously. The surgical technique used was similar to that reported previously. The surgical technique used was similar to that reported previously. The surgical technique used was similar to that reported previously.

**Antegrade Technique**

The patient was positioned supine on a radiolucent table with a bump under the buttock. Flexion and adduction of the lower limb over the contralateral side was performed to gain easier access to the femur. Anatomical axes in both planes were identified with a 2.4-mm Steinmann pin on radiographs in both planes aiming on the trochanteric tip. A 2 to 3-cm incision was made, and reaming was performed with an 8-mm cannulated acorn reamer over the inserted pin to broach the greater trochanter (Figure 1). Following this procedure, a 2.5-mm, ball-tipped guidewire was inserted under radiographic control into the femur until the most distal spot was reached in a central position. After measuring the isthmus of the femur on anteroposterior and lateral projections using a radiographic ruler, the correct reamer size was chosen. Reaming was then performed under radiographic surveillance using a gentle approach and withdrawal technique using the RIA System. Reaming was interrupted when the collection filter was full, and it was performed again after changing the collection device (Figure 2). If more bone graft was needed to fill the bone gap, the next reamer head size was used in the same fashion. It is important not to over-ream the cortices more.

**Figure 1** Clinical photograph of the RIA System (Synthes, Inc, West Chester, Pennsylvania) ready for use (A). Clinical photograph of closed incision measuring 1.6 cm (B). (Reprinted with permission of Sinai Hospital of Baltimore.)
than 2 mm on each side because this can lead to cortical thinning and weaken the mechanical strength of the bone. After reaming was successfully finished, the incision was closed in layers. Full weight bearing was allowed if the contralateral side was used, but for the ipsilateral side, full weight bearing was based on the nonunion procedure.

**Retrograde Technique**

The retrograde technique is useful for patients who are morbidly obese where it becomes technically challenging to harvest bone from the femur in an antegrade fashion. The authors have used this retrograde technique multiple times at their institution with minimal postoperative knee swelling and pain and no difference in graft volume when compared with the antegrade technique. The retrograde technique is performed with the patient in the supine position and a bump under the knee. A Steinmann pin is placed through the patellar tendon into the notch of the knee in line with the femoral canal on the anteroposterior and lateral projections. Once the Steinmann pin is perfectly placed, a 1.5-cm incision is made in line with the patellar tendon, and a 8-mm acorn reamer is used to open the femoral canal. The remainder of the technique then proceeds in a fashion similar to the antegrade technique.

**Statistical Methods**

SPSS version 17.0 statistical software (SPSS Inc, Chicago, Illinois) was used to collect and analyze data. Descriptive statistics were used to calculate means and ranges. Differences between groups were evaluated using the *t* test for equality of means. *P* values less than .05 were considered statistically significant.

**RESULTS**

Seven patients underwent 8 repeat reamings of the femur using the RIA System. The indication for the procedure was nonunion of the long bones. Average volume of graft obtained in the first reaming procedure was 34 mL (range, 25-50 mL). The re-reaming was performed after an average of 9 months (range, 3-16 months). Average volume of graft obtained in the second procedure was 45 mL (range, 28-65 mL). Although the volume from the first to second reamings was not significant (*P*=.079), graft volume was the same or increased during the second reaming in all but 1 instance. No reaming-related complications were reported (Table).

**CASE REPORTS**

**Patient 1**

A 15-year-old girl with congenital pseudoarthrosis of the tibia, osteofibrous dysplasia, and a history of multiple tibial nonunions underwent her first RIA reaming when she developed a nonunion following deformity correction of her valgus tibia. A 13-mm reamer was used in an antegrade approach to obtain 28 mL of bone graft. Although the patient was healing well otherwise, she developed a hypertrophic nonunion, which was treated with a second RIA reaming 7 months later. During this procedure, a 12.5-mm reamer was

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<th>Time From 2nd to 3rd Reaming, mo</th>
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*Abbreviations: F, female; M, male
aThe numbers in parentheses denote the number of times the bone was reamed.*
used to obtain 50 mL of bone graft. The patient went on to heal all but 1 small defect on the proximal part of the tibia. This was again treated with RIA reaming of the right femur 10 months after the previous intervention. A 12.5-mm reamer was again used to obtain 50 mL of bone graft. The patient healed well, although at her most recent clinic visit, some lucency was noted at the proximal part of the left tibia. Because the patient was nonsymptomatic in that area, she began using an external bone stimulator to promote bone healing while increasing the amounts of calcium and vitamin D intake.

Patient 2

A 63-year-old morbidly obese woman presented with a 19-cm segmental bone defect of the right femur and tibia following an infected total knee arthroplasty. She received an exchange knee fusion rod as well as allograft, bone morphogenetic protein 2 (BMP-2), and autograft. The autograft was obtained from the left femur using a 15-mm RIA in a retrograde approach, yielding 45 mL of bone graft. The patient recovered without complication but developed a hypertrophic nonunion at the distal aspect of the allograft docking site. Ten months after the initial bone grafting, the patient underwent a second procedure to repair the nonunion. Using the RIA System, 65 mL of bone graft was obtained from the left femur with a 14-mm reamer head. This patient shows continued progress toward full healing.

Patient 3

A 64-year-old woman who sustained a humeral shaft fracture after falling was treated with intramedullary nail fixation. On insertion, a supracondylar fracture was noted and was treated with a locking plate. One year later, the patient presented with proximal humerus nonunion and underwent debridement, nail removal, and locking plate fixation, as well as BMP-2 and autograft insertion. The autograft was obtained from the femur using a retrograde approach, yielding 35 mL of bone. Sixteen months later, the patient presented with distal humeral fracture nonunion following aggressive physiotherapy and underwent a second procedure to repair the nonunion using the RIA System. Thirty-five milliliters of bone graft was obtained from the same femur with a 12.5-mm reamer head in a retrograde fashion, as well as BMP-2 and posterolateral plate insertion. The proximal humeral nonunion underwent full healing; however, in the distal humeral nonunion, there was delayed nonunion, and the patient began using an external bone stimulator and oral calcium and vitamin D intake to promote bone healing.

Patient 4

A 54-year-old man who sustained a severe open fracture of the right femur af-
ter a boating accident presented for bone grafting to the docking site following a previous bone transport and knee fusion. A 14-mm reamer was used with an antegrade approach to obtain 45 mL of bone graft from the left femur. The patient went on to develop a nonunion at the knee fusion site, which was treated with a second bone graft using the RIA System 1 year later. During this procedure, a 16.5-mm reamer was used to obtain 65 mL of bone from the left femur. At his most recent clinic visit, radiographs showed evidence of good healing, although complete union could not be confirmed. Currently, the patient is lost to follow-up secondary to long-term incarceration.

**Patient 5**

A 65-year-old man who sustained a femur fracture after a motor scooter accident presented with a femoral nonunion and a broken femoral intramedullary rod. A 16-mm reamer was used in a retrograde manner to obtain 25 mL of bone graft from the right femur. The bone began bridging, although incomplete healing was noted on computed tomography scan. Because of this, the patient underwent a second surgery 3 months later for repeat bone grafting. A 16.5-mm RIA was again used to harvest 35 mL of bone graft from the right femur. Complete femoral union was noted 3 months after the second bone-grafting procedure. He continues to follow up with the authors (Figures 3-5).

**Patient 6**

A 32-year-old man presented with a nonunion following fixator-assisted nailing for a varus deformity in his proximal tibia. A 12.5-mm reamer was used with an antegrade approach to obtain 35 mL of bone graft from the left femur. Four months later, the nonunion was not healed, and a second femoral RIA reaming was performed. A 12.5-mm reamer was used to obtain 28 mL of bone graft from the left femur. Six months following the repeat reaming, complete healing of the nonunion was noted. A sample of the reaming was sent to pathology for analysis. The bone seen had a mixture of patterns. Some of the fragments were purely woven, and some were purely lamellar. Others had woven bone centrally with superimposed lamellar bone externally. There was no cartilaginous component, just woven and lamellar bone. There were hemosiderin-laden macrophages in the fibrous scar, namely from bleeding at the first bone harvesting. The mixture of woven and lamellar bone is nonspecific but can be seen in stress reaction/fracture. All photomicrographs were taken with 40× high-power objective (Figures 6-8).

**Patient 7**

A 25-year-old man who was involved in a motorcycle accident 4 years prior presented to the authors’ institution with ankle osteomyelitis after undergoing 3 prior surgeries at another institution. He underwent intramedullary rod removal, irrigation and debridement of the infected bone, and a long course of intravenous antibiotics. Later, he underwent a supra-malleolar osteotomy and a midshaft tibial osteotomy using the Taylor spatial frame for correction of a proximal tibial deformity and equinus varus of the ankle. Five months later, he presented with double-level nonunion, which was treated with bone graft obtained from the right femur with the RIA, as well as insertion of BMP-2. Thirty milliliters of bone was obtained in an antegrade manner using a 16-mm reamer. Although the proximal nonunion healed well, the distal segment showed little sign of improvement. Treated again with irrigation and debridement and long antibiotic treatment, the patient eventually required a second bone graft using the RIA System 1 year after the first procedure. During this procedure, a 16.5-mm reamer was used to obtain 35 mL of bone from the right femur. At his most recent follow-up, there was no sign of infection.

![Figure 6: Bone graft prior to implantation (A). Mixed woven and lamellar bone in 1 bony trabecula, polarized (B). The brighter lamellar bone is laid down after the woven bone. (Reprinted with permission of Sinai Hospital of Baltimore.)](image1)

![Figure 7: Lamellar bone with focal osteoblastic rimming. (Reprinted with permission of Sinai Hospital of Baltimore.)](image2)

![Figure 8: Woven bone with fibrous scar. (Reprinted with permission of Sinai Hospital of Baltimore.)](image3)
or loosening, with good callus formation on radiographs.

There were no complications related to the RIA reaming during any of the procedures. Average amount of graft obtained increased in consecutive reamings, from 34 to 45 mL ($P=0.079$). Although this is not statistically significant, studies with larger populations will help determine whether this finding is consistent.

**Discussion**

Treatment strategies for large bony defects and nonunions include the use of autogenous materials (iliac crest and intramedullary reaming), allogenic bone, bone substitutes, and stimulating growth factors such as BMP-2, BMP-7, or growth factors containing platelet-rich plasma (PRP). The use of recombinant osteoinductive materials is sometimes limited because of apprehension regarding immune sensitization, inflammatory reaction, and use in oncology patients. Despite these developments, autologous bone graft is still the gold standard in defect reconstruction.

Several current clinical trials have shown that reaming debris and endosteal bone are rich in growth factors. A study by Sagi et al investigated an intrapatient comparison of bone graft from RIA and ICBG, showing that RIA graft contains many of the same properties as ICBG. This finding justifies its use as an alternate source of autologous bone graft. Bone graft harvested with the RIA System was superior concerning cluster of differentiation 146, connective tissue growth factor, BMP-2/4, and bone sialoprotein. Bone sialoprotein showed an increased expression by 760%. Despite those findings, ICGB performed better relative to vascular endothelial growth factor, hypoxia inducible factor 1, runt-related transcription factor, and osteocalcin.

Several studies have documented that the femoral canal is a source of multipotent stromal cells. Cox et al described the large abundance of multipotent stromal cells present in long bone fracture marrow. The study demonstrated that the intramedullary cavity contained more abundant numbers of multipotent stromal cells than the iliac crest of the same patients. It also demonstrated that the large numbers of stromal cells in the long bone canal were functionally competent by easily differentiating into osteoblasts in vitro. The authors proposed that this cellular mechanism in the long bones contributes to the efficiency with which long bone fractures heal. In another study comparing multipotent stromal cells, Henrich et al also found a significantly higher percentage of multipotent stromal cells in the intramedullary autograft when compared with ICBG. These mesenchymal stem cells from the femur also had a significantly higher capability for calcium deposition than the mesenchymal stem cells from the iliac crest. These studies support the effectiveness of the contents of the intramedullary canal as a bone graft source at least equivalent to, if not better than, the iliac crest. This is especially true when the complication rates and graft volumes are compared with iliac crest.

Low et al reported graft volumes ranging from 40 to 90 cm$^3$ for RIA vs 13 to 30 cm$^3$ for ICBG. In general, intramedullary bone graft resulted in more volume than anterior ICBG and at least as much as posterior ICBG. In addition, there is generally less pain, quicker return to function, and fewer complications when using intramedullary bone graft.

Another benefit of intramedullary canal bone graft is that it is harvested using a reamer. Tulia et al performed a study on harvesting progenitor cells from trabecular bone. The femoral head from the same patient undergoing total hip arthroplasty was reamed using an acetalubular reamer, but bone was also harvested from the same femoral head using a curette and then minced. Not only did the cells from the reaming proliferate in vitro more rapidly than the cells harvested using a curette, but there were also a significantly larger number of cells in the cultures of the reamed vs the curetted cells. The study attributed this finding to the smaller and finer bone fragments generated by the reamer, which resulted in a release of more multipotent stromal cells from the trabecular bone.

Moed et al reported their findings in 4 patients who had reharvesting using the trap-door technique in the anterior iliac crest. They described an average time between harvestings of 34.5 months (range, 24-60 months) and a graft volume ranging from 15 to 40 cm$^3$. Montgomery and Moed conducted a canine study to evaluate the possible potential of reharvesting the posterior iliac crest. They found that replacement of new cancellous bone was achieved after 1 year, and because canines have a healing rate twice as fast as humans, a period of 2 years between reamings was suggested for humans. There has been 1 case report published on reharvesting the posterior iliac crest. Papadopoulos et al reported a case of revision spinal fusion with repeat bone graft harvesting of the posterior iliac crest 4 years following the initial harvest in a 70-year-old man. Preoperative computed tomography of the iliac crest confirmed the presence of cancellous bone. Forty millimeters of bone was harvested, with histological confirmation of mature bone. The authors concluded that regeneration of the iliac crest was possible.

To the current authors’ knowledge, their study is the only one that describes in detail the repeated use of the intramedullary canal of the femur as a source of autograft. Qvick et al reported their experience as a single center using the RIA System. They treated 184 patients, 4 of whom had the same bone harvested twice. No additional details were provided regarding the specific patients. The fact that the intramedullary canal has the capacity to regenerate cancellous bone following reaming is documented in the current study. It is the current authors’ hy-
pothesis that the initial reaming stimulates a fracture-healing response in the femur. This has been initially confirmed given the replenishment of the canal graft after the first reaming as well as the histological findings in their case sample. What remains to be determined is whether the reaming stimulates a fracture response at the cellular level and how quickly the canal regenerates. This study is limited by the small population of patients, as well as the fact that all the femoral canals were reharvested at different time periods.

Another limitation of this study is that the authors did not specifically look at the biologic efficacy of the harvested bone graft, but rather just the volume. A prospective study is planned that specifically answers the question of biologic activity of the RIA reharvested graft. For the time being, the authors can conclude that it is feasible to harvest additional bone marrow from a previously reamed medullary canal. The femoral canal is a safe, renewable source of cancellous autograft in the same patient.

CONCLUSION

The femoral intramedullary canal was found to yield bone graft of sufficient quality and quantity to be used in consecutive grafting procedures in the same patient. This study documented the ability to reharvest the femoral canal safely, with no complications. Additional studies are needed to determine the growth factors in the additional reamings, as well as the optimal time to wait for reharvesting.

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