Intramedullary nail fixation is the treatment of choice for impending and pathologic fractures secondary to metastatic cancer; however, this procedure has been shown to cause systemic embolization of intramedullary contents. This article reports the use of the reamer–irrigator–aspirator (RIA) (Synthes, Paoli, Pennsylvania) instead of a standard femoral reamer to decrease tumor intravasation during femoral intramedullary nail fixation for impending or pathologic fractures.

Twenty-one consecutive patients indicated for fixation of malignant femoral lesions were treated with intramedullary nail placement. The RIA was used for canal preparation, and solid reamings were collected and submitted for analysis by a single pathologist. The volume of each specimen was recorded, and representative samples were examined histologically to determine their percent tumor content. These data were then used to estimate the volume of tumor retrieved by the RIA in each case. The mean volume of reamings collected by the RIA was 75.0 cc per case (range, 23.4-196.0 cc), and the mean tumor content was 24.8% (range, 1.0%-60.0%). The mean estimated volume of tumor retrieved in each case was 16.7 cc (range, 0.35-36.0 cc). In 2 cases, the tip of the RIA dissociated from the device intraoperatively but was retrieved without adverse consequence to the patient. Use of the RIA in cases of femoral intramedullary nail fixation for pathologic lesions or fractures effectively retrieves variable amounts of intramedullary contents, including tumor. By preventing the systemic dissemination of malignant cells, this technique may reduce the risk of distant metastases.

Figure: Schematic diagram of the reamer–irrigator–aspirator. (2011 © Synthes, Inc. or its affiliates. All rights reserved.)
Intramedullary fixation is frequently indicated when metastatic carcinoma affects weight-bearing long bones. In addition to stabilization of pathologic fractures, nailing is performed prophylactically when lytic lesions weaken a bone to the extent that fracture is imminent. Prior studies have demonstrated significant embolization of intramedullary contents during the insertions of both reamed and unreamed nails for the treatment of fractures, as well as during nail insertion into intact long bones. This fat intravasation has been shown to result in systemic consequences such as pulmonary and cerebral embolism.

In cases of intramedullary fixation for metastatic carcinoma, malignant cells in the medullary canal are likely forced into the circulation during the procedure, thereby theoretically increasing the rate of distant metastasis. Although fracture fixation is not intended to cure patients with metastatic malignancies, appropriate steps should be taken to limit the progression of disease. For this reason, the volume of tumor dispersed throughout the body during surgical procedures should be minimized.

The reamer–irrigator–aspirator (RIA) (Synthes, Paoli, Pennsylvania) is a version of the standard flexible reamer designed to remove intramedullary contents for the purpose of minimizing heat generation and fat embolization, harvesting bone graft, or clearing intramedullary infection. Its deep-fluted, end-cutting design is similar to that of the standard reamer but incorporates inflow and outflow through the central cannula, thereby allowing for irrigation and aspiration during the reaming process. In nononcologic cases, use of the RIA device has been shown to decrease the rate of marrow intravasation and the number of pulmonary emboli compared with a standard femoral reamer. The purpose of this study was to demonstrate that malignant cells could be retrieved by using a RIA during intramedullary fixation of femoral lesions. By capturing a tumor that otherwise would have been forced into the systemic circulation, use of the RIA may decrease the risk of malignant embolization associated with this procedure.

**Materials and Methods**

Between April 2008 and January 2010, twenty-one consecutive patients indicated for fixation of malignant femoral lesions were treated with intramedullary nail placement using the RIA device (Figure 1). The study group comprised 15 women and 6 men with a mean age at surgery of 69 years (range, 53-92 years). Three patients underwent surgery for pathologic fracture, and 18 were indicated for prophylactic fixation of a symptomatic lesion that was at or distal to the level of the lesser trochanter, >2.5 cm in diameter, or involving >50% of the femoral cortex.

A trochanteric entry point was used in all cases. Because the RIA technique uses a 1-step reamer, the size of the intramedullary nail was determined preoperatively based on radiographic templating. In all cases, the largest reamer deemed to be safe was used to maximize templating. After preparing the femoral canal, an intramedullary nail 2 mm smaller in diameter was selected; according to this method, fourteen 11-mm, four 13-mm, and three 10-mm intramedullary nails were implanted. During the reaming process, 300 mm Hg of suction was applied using a Neptune vacuum source (Stryker, Mahwah, New Jersey). The Neptune is typically set at 200 mm Hg (40%) for routine intraoperative suctioning but was adjusted to 300 mm Hg (60%) for use with the RIA to retrieve a higher volume of intramedullary contents. Suction was not increased beyond 300 mm Hg because, at higher settings, outflow from the suction source would diminish inflow from the irrigator, creating theoretical concern for thermal necrosis of the endosteal blood supply.

The inline trap from each RIA device and its contents were submitted to the Department of Pathology. The volume of reamings was measured, and representative sections were cut and prepared using hematoxylin-eosin stain according to standard histological protocols. A single pathologist (L.D.A.) determined the percentage of tumor cells in each sample based on the relative amounts of metastatic tumor cells and adjacent unremarkable bone tissue from multiple representative samples. Appropriate immunohistochemical staining was performed for cases in which the percentage of metastatic tumor cells was minimal (<5%) or confirmation of the primary tumor was required. The volume of tumor retrieved by the RIA for each case was then estimated by multiplying the volume of reamings by their respective percent tumor contents.

Warfarin was used as the standard form of prophylaxis for 3 weeks postoperatively due to the risk factors of embolization associated with venous stasis and malignancy.

**Results**

The RIA device retrieved solid intramedullary contents (Figure 2), in which tumor cells were histologically identified (Figure 3) in all cases. The mean volume of reamings collected by the RIA was 75.0 cc per case (range, 23.4-196.0 cc) (Figure 4A). No statistically significant correlation was found between the size of the nail to the volume of reamings obtained (Pearson correlation coefficient, =0.183). The mean...
tumor content was 24.8% (range, 1.0%-60.0%) (Figure 4B), and the mean estimated volume of tumor retrieved in each case was 16.7 cc (range, 0.35-36.0 cc) (Figure 4C).

In 2 cases, the tip of the RIA drive shaft broke during reaming of the canal. The tip was subsequently retrieved by removing the beaded guidewire, and a standard reamer was used to complete the case. No significant delays in operative time were observed, and patient outcomes were not affected. No canal perforations or other complications were associated with use of the RIA, and no patients sustained clinically significant fat or pulmonary emboli intraoperatively.

**DISCUSSION**

Our study demonstrates that tumor embolization may be reduced by using the RIA during intramedullary nail placement for femoral malignancies. Several previous reports have explored the relationship between intramedullary fixation and embolization of marrow contents. Intramedullary pressures have been shown to correlate with fat intravasation, both of which are significantly increased in reamed as well as unreamed nailing.1-7 This is clinically significant because it can lead to systemic pathology, most commonly pulmonary embolism. This phenomenon has been well documented in the trauma population, where it is particularly dangerous in the setting of concomitant lung injury. Oncologic patients may have impaired pulmonary function secondary to metastatic disease, and intraoperative hemodynamic accidents have been documented in 10.5% to 13% of these patients undergoing intramedullary nailing for pathologic femur fractures.12-16 Moreover, it has been suggested that hypoxia itself may promote the metastatic process.17 Cerebral embolization is also a concern; transcranial Doppler ultrasound has been used to detect emboli of the middle meningeal artery in 20% of patients undergoing reamed intramedullary fixation of tibia or femur fractures.18

Marrow intravasation and fat embolization secondary to intramedullary nailing of long-bone fractures have been well documented in the trauma literature.1-7,18 These consequences have also been demonstrated in sheep models of unfractured long bones; furthermore, the risk of embolism may be even greater in cases of prophylactic nail insertion than fracture fixation because the intact cortex prevents the release of intramedullary pressure.

Venting, or drilling a hole in the cortex of the femur, has been used by some orthopedic surgeons to decrease this pressure, thereby theoretically reducing the risk of embolism.19 This technique has been shown to reduce intramedullary pressures by as much as 90% during reaming of femur and tibia specimens.20 Roth et al21 studied the effect of venting on intramedullary pressure and tumor displacement in cadaveric femurs with metastatic disease. They found that placement of proximal and distal vents decreased maximum pressures and the duration of pressures surpassing the embolic threshold by >50%. However, even with venting, distal intramedullary pressures continued to exceed the estimated threshold for embolization. In addition, venting lead to increased tumor disbursement in the extraskeletal tissue, as seen on post-test sectioning of the specimens. The authors concluded that although venting may reduce tumor intravasation during prophylactic nail insertion, it may not be effective in preventing pulmonary emboli.
lactic nailing, it does not eliminate the problem and may actually result in spread to local soft tissues.²¹

Studies of nail placement in animals have demonstrated that the RIA device minimizes the increase in intramedullary pressure and fat invasation associated with canal reaming.²⁻¹¹ Husebye et al¹¹ illustrated this in a sheep model by measuring intramedullary pressures at various times during the nailing of femur fractures with either the RIA device or traditional reamer. They found that pressures were significantly lower during reaming with the RIA (mean, 33±8 mm Hg) than the traditional reamer (mean, 188±38 mm Hg), but there was no significant difference at other points of the surgery, including nail insertion. Joist et al¹⁰ also used a sheep model to demonstrate that use of the RIA device compared to the AO reamer (Synthes) resulted in dramatically lower intramedullary pressures (P<.001). In addition, they found significantly less intravenous fat content, as well as lower pulmonary resistance, partial pressure of carbon dioxide, and pulmonary fat load. Husebye et al¹¹ also found that use of an RIA for intramedullary nailing in pigs resulted in significantly lower numbers of pulmonary emboli per area of lung compared with those treated with a standard reamer. Thus, aspiration in conjunction with reaming seems to reduce not only intramedullary pressure, but also the volume of marrow fat in the venous circulation and the lungs.

Our results demonstrate that using an RIA device during prophylactic femoral nailing allows for the retrieval of tumor material that otherwise would have been forced into the systemic circulation by a standard femoral reamer. The volume and mass of intramedullary contents retrieved varied greatly between cases, as did the estimated percent tumor content of the reamings. This was likely the result of factors specific to the individual patients (ie, length and diameter of the canal), as well as to the lesions themselves (ie, size, location, and lytic vs blastic composition). Diameter of the reamer did not seem to correlate with amount of reamings retrieved.

In oncologic patients undergoing prophylactic nailing, pulmonary and cerebral embolization carry the theoretical potential to transport tumor cells and lead to the development of new metastases. Although a correlation between tumor dispersal and increased metastases has not been proven, the general principles of oncologic surgery advocate the confinement of neoplastic cells to minimize this risk. Pharmacologic trials on oncology drugs are often considered successful if patient survival is increased by 1 or 2 months. Although difficult to prove, it is conceivable that preventing the intravascular spread of a mean 12 cc of tumor cells could have a similar effect on length of survival.

The only complication we observed related to the RIA was breakage of the drive shaft during the reaming process in 2 cases. To our knowledge, this problem has not been previously reported, and it remains unclear whether this was due to improper assembly, operative technique, or device malfunction. These seemed to occur when the RIA was pushed forcibly into the canal, and we speculate that it may have been related to the relatively large core diameter of the RIA. Of note, the core diameter of the RIA increases with the size of the reamer head, whereas it remains constant in the standard flexible reamer. This feature, designed to allow maximal inflow and outflow during reaming, creates a thinner head–neck junction compared with that of a standard reamer, and may lead to relative fragility. In our cases of failure, the tip was retrieved using the guidewire with minimal delay in operative time, and the case was completed using a standard reamer. These incidents resulted in no adverse consequences to the patient, and no canal perforations, clinically detectable intraoperative pulmonary emboli, or other complications were associated with use of the RIA.

There are several limitations to this study. The initial tumor content of the intramedullary canal preoperatively could not be measured; therefore, it was not possible to determine the extent to which the RIA extracted the original tumor load. Only a relatively small sample size was available for study, and no control group was formed because a mechanism to collect marrow contents with standard reamers does not exist. The estimated percent tumor of the samples was based on visual estimates of multiple representative samples by a single pathologist; although this is a standard means of histologic analysis, it remains subject to human and sampling error. In addition, the liquid aspirate from the RIA was not collected for cytologic analysis, although this would only result in the potential underestimation of salvaged tumor material.

Follow-up was limited, although not required to identify any complications related to the RIA, which would have occurred intraoperatively. Rates of metastases and survivorship would be ideal endpoints but were not feasible to evaluate for several reasons, including the large sample size, length of follow-up, and serial imaging studies that would be required. Even more prohibitive would be the multiple variables involved in the study population, such as medical comorbidities, type of cancer, stage at the time of surgery, and inherent aggressiveness of each individual malignancy. Finally, the significance of our conclusion relies on the data obtained in previous studies, which have shown the effectiveness of the RIA in preventing marrow invasation with greater certainty than would have been possible in our study population.

Conclusion
Although the percentage of the tumor itself that can be evacuated by the RIA remains unclear, the RIA retrieves a variable number of malignant cells that would otherwise be forced into the systemic circulation by a standard reamer. Our results sug-
gest that this technique decreases the potential for tumor embolization, thereby theoretically minimizing the risk of distant metastases and accelerated mortality of the underlying disease.

REFERENCES


