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CASE REPORT

Use of Carbon Fiber–Reinforced PEEK for Treatment of Femur Fractures: A Small Step for Implants, a Large Step in Fracture Care

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Summary: Composite carbon fiber–reinforced PEEK implants have now become cost-effective to use in fracture surgery. Since the use of metallic implants has dominated fracture treatment, there are sparse reports in the North American market regarding the efficacy of composite carbon fiber PEEK implants. In the present series of case reports, the authors present a case report from their many applications to demonstrate the utility of such implants. Because they are now cost-competitive, they may provide an advantageous benefit for certain fracture scenarios.

Key Words: carbon fiber, composite, PEEK, trauma, fracture, fixation, value, biomechanics

INTRODUCTION

Since the latter part of the 20th century, intramedullary fixation of the femoral shaft and meta-diaphyseal fractures has been the standard of care. The evolution of implants has gone through several iterations of design and material. Early on, solid stainless steel nails were used, but technical innovations led to the use of open section hollow nails that provided the ability to perform nailing with "closed" methods. Then, closed section nails with interlocking capability allowed the use of smaller nail profiles for unstable fracture patterns. Since that time, smaller diameter, closed section, statically locked, nailing of the femur has been the accepted method for most femoral fractures. More recently, retrograde nailing and lateral entry nails have been introduced that have expanded and facilitated nailing in unique circumstances such as obesity, need for supine positioning, and more proximal/distal fracture patterns. As such, the available femoral nail technology has been rather standardized. However, there remain some aspects of metal (titanium or steel) that continue to present some challenges. Issues with postnailing imaging using computed tomography or magnetic resonance imaging (MRI) result in scatter and image resolution around the nail. Stiffness of the nail in brittle bone or near arthroplasty may present biomechanical issues of stress risers. Oncologic cases requiring therapeutic radiation may result in scatter of the radiation to surrounding tissues and imaging challenges to follow tumor progress. And in anecdotal but notable circumstances, metal allergy and barometric pain have all been described. Over the past decade, material technology has advanced wherein polymeric materials have become available for fracture care. In particular, carbon fiber-reinforced PEEK has been used for fracture treatment. Impediments to mainstream the use of carbon fiber PEEK have traditionally been cost and unfamiliarity of the technology. Metal implants have over a century of use, and carbon fiber PEEK is only decades old in fracture care. Recent advances in material, manufacturing and design have made carbon fiber PEEK cost effective and and more familiar to surgeons. Like any new technology, there are always concerns about performance, but there is ample literature both clinical and laboratory that support the feasibility of carbon fiber PEEK in orthopaedics.[1–8] In the present report, we describe a case where a carbon fiber PEEK composite is used for bilateral femur fractures with the need for advance imaging.

PATIENT INFORMATION

A 32-year-old woman was involved in an automobile accident sustaining bilateral femur fractures (Fig. 1). She underwent retrograde femoral nailing of both femur fractures on a vascular table in the supine position without incident (Fig. 2). Clinical examination after surgery did not demonstrate any hip or knee abnormalities.

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SURGICAL TECHNIQUE

The carbon fiber PEEK nail is radiolucent and thus requires radio-opaque markers to identify its in vitro position radiographically. This is achieved by the use of tantalum wires or markers along its length, its proximal and distal tips, and with a set of 4 markers for each interlocking hole (Fig. 3). The technique of insertion for a femoral nail is essentially the same as that of standard metallic nails but differs in 2 ways mentioned below. The patient was positioned supine on a radiolucent table with a triangle and small bump under the fracture to correct apex posterior sagging of the fracture. A transpatellar approach was used, and the author visualized the notch under direct vision to ensure proper positioning. After entry guide wire insertion, a rigid reamer was used to access the medullary canal. Next, a ball tipped guide wire was passed across the fracture to the level of the proximal femur. The nail length is chosen to be at the level of lesser trochanter so that if there is a clandestine femoral neck fracture or a postoperative femoral neck fracture identified, there will be adequate space above the nail tip to allow for placement of fixation devices (screws or compression hip screw). Although rare, this occurrence of such fractures is well documented. If the nail is placed too proximal, such a fracture would be more difficult to treat. The nails were placed as noted and statically locked. The authors will usually use an 11-m diameter nail in all cases. The ball tip guide wire is exchanged for a smaller diameter nitinol wire using a cannulated plastic tube (historically called a chest tube) because the inner lumen diameter of the nail is smaller than the standard ball tip guide wire. Alternatively, the nail can be placed without the use of a nitinol guide wire, and the author routinely passed the nail without its use, as had historically be done for unreamed nails in the past. The nail is generally easy to pass across the fracture using a few radiographic images to assist. Once situated, the interlocking method is the second variation of the standard nailing technique.

The left femur had the use of a Poller or "blocking" screw to help avoid varus malalignment. This technique is well described in the literature and typically is placed on the "concavity" of the deformity to be avoided. In this case, the screw was placed just medial to the nail path (Fig. 4).

Distal interlocking is done using a drill guide similar to standard nails. Because the nail is radiolucent, proximal interlocking is not done using the "perfect circle" technique.

FIGURE 1. The initial fractures of the patient as they presented to the operating room. Figure 1A is an AP image and figure 1B is a lateral image of the contralateral leg.

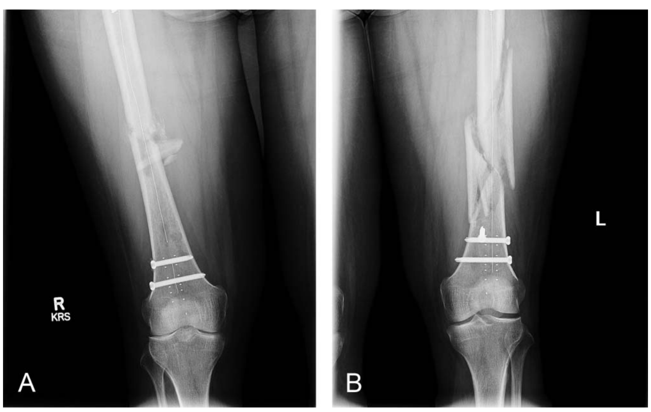

FIGURE 2. A and B, Postoperative images of the fractures after fixation.

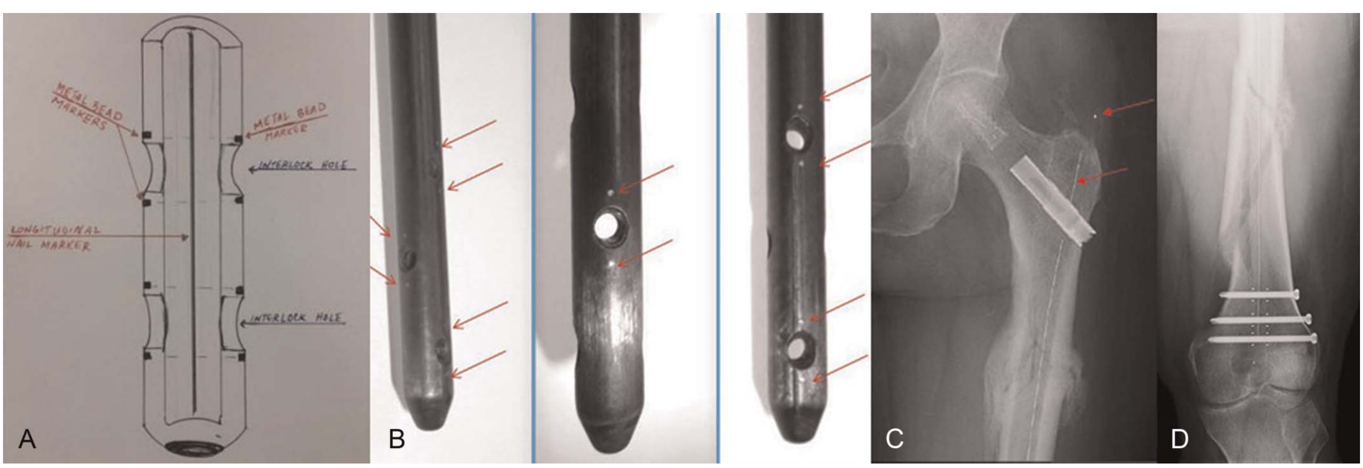

FIGURE 3. A–D, Images of the tantalum markers along the nail to identify its location radiographically. A, Cross-section schematic of a nail showing the longitudinal marker and 4 markers identifying the interlocking holes. B, Actual image of the nail and markers around the interlocking holes. C, Radiographic appearance of the nail with a single dot proximally identifying the top of the nail and the longitudinal marker of the nail shaft. The compression screw is outlined by a thin metallic sheath that allows identification of the thread areas and the shaft of the screw. D, Radiographic image of a retrograde femoral nail showing the interlocking screws and markers.

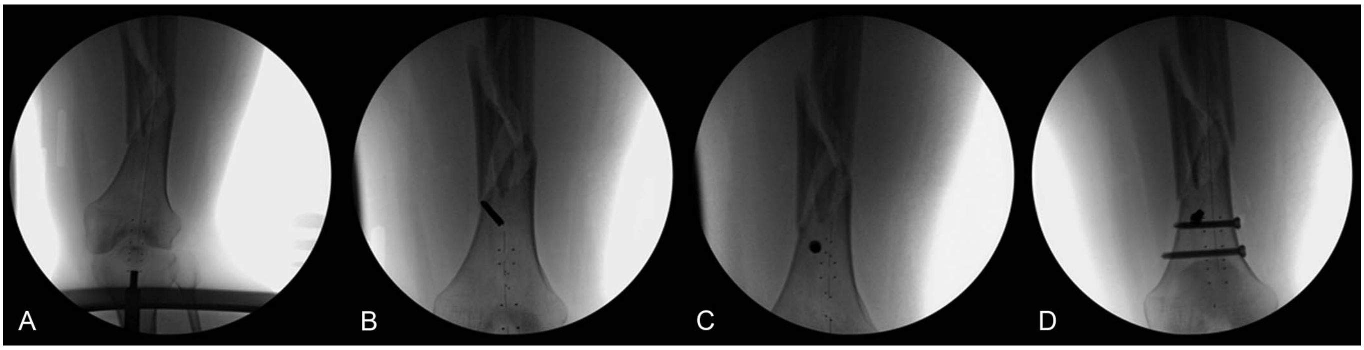

FIGURE 4. A–D, Intraoperative images demonstrating the placement of the Poller screw. A, Varus deformity. B, Placement of the drill bit. C, Tip of the nail passing the screw. Note the tantalum markers showing the tip of the nail and the proximal interlocking holes. D, Nail fully seated with distal interlocking and with varus deformity corrected.

The carbon fiber PEEK nail's interlocking holes have 4 tantalum markers placed in a planar configuration (2 on each side of the interlocking hole). When imaged perpendicular to the interlocking hole, 4 markers appear, but when imaging is exactly parallel to the hole, 2 markers will superimpose to make a 2-marker image. This image determines the location and direction of the interlocking hole and screw trajectory. Although it may seem difficult, the authors have found this technique to be as easy if not easier than the traditional "perfect circle" technique (Fig. 5).

POSTOPERATIVE COURSE

After surgery, she was allowed to be weight bearing as tolerated. At her first follow-up, the patient reported feeling a pop and block to motion during a therapy session. Clinical examination demonstrated significant pain and inability to extend beyond 20 degrees of flexion or flex past 45 degrees of flexion. An MRI was ordered of bilateral knees. Imaging revealed bilateral bucket handle tears of the medial meniscus (Figs. 6, 7). The MRI images did not require any special software processing to reduce artifact and were easily interpreted by the radiologists, who in fact commented to the requesting surgeon that the carbon fiber PEEK greatly facilitated their interpretive ability. Subsequently, in this patient, the meniscal injuries were addressed by arthroscopic repair. Her recovery from the meniscal repairs was uneventful, and at final follow-up, both fractures were healed and her range of motion was 0–125 degrees without pain (Figs. 8, 9).

DISCUSSION

The advantages of this composite material are several. It has superior fatigue properties compared with metal. Although metallic implants often fail within 50,000–100,000 cycles of physiologic load, the carbon fiber PEEK composite implants have withstood over 1,000,000 cycles with cessation of testing.[9] The modulus of elasticity is less than that of titanium and closer to that of bone and thus provides theoretical advantages of a more flexible but more durable (fatigue) implant that might potentially enhance fracture healing. Although difficult to elucidate with high-level evidence data, the authors note that in their experience, there seems to be an enhanced callus response at an earlier time postoperatively,

FIGURE 5. Sequence of images demonstrating the imaging of interlocking screw placement and marker visualization. As the image intensifier is moved, the 4 markers around the interlocking hole will gradually become superimposed to appear as 2 dots instead of 4. The interlocking hole is still faintly visible and located between the 2 dots. The 4 dots to the left and right of those within the red circle represent the interlocking holes perpendicular to that demonstrated. To properly achieve the needed image, more than 1 plane of image correction may be necessary. This method is identical to the standard "perfect circle" technique, but instead of achieving a circle, the goal is to convert 4 dots into 2 dots.

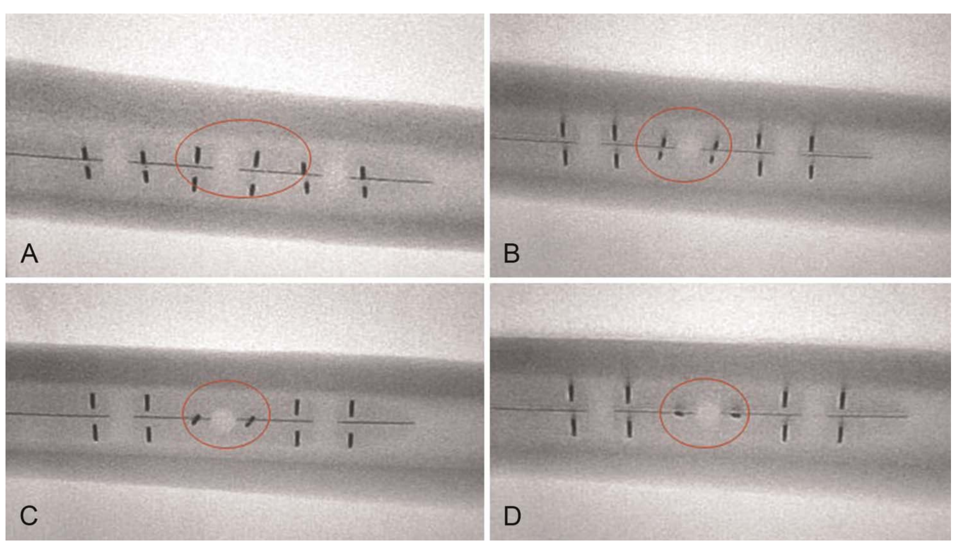

FIGURE 6. A–C, Magnetic resonance imaging of the left knee showing bucket handle tear on the coronal image (A) and an absent meniscus on the sagittal image (B). C, Meniscus in the notch and excellent visualization of other soft tissue structures, especially the posterior cruciate ligament, with little to no artifact from the nail that is seen in the medullary canal.

which may likely be due to the mechanical benefits of a lower modulus of elasticity. In addition, with a lower modulus and lack of metal alloy compounds, there may also be less issues with barometric pain, which is another anecdotal finding by the authors.

There is a further advantage in the oncological specialty where therapeutic radiation is required. With metallic implants, the scatter of the radiation can potentially injure adjacent tissues, whereas with carbon fiber PEEK, there is less scatter and the ability to monitor treatment progress with enhanced imaging. In the current case report, the main advantage was the need for ancillary imaging around the composite fracture implant. Before the use of a composite implant, MRI imaging of the knee after retrograde femoral nailing was limited by artifact, which precluded detailed visualization of subtle soft tissue injuries. With metallic implants, the radiologists would often state that the examination is "limited" because of such artifact. However, with the composite implant, there has been a consistently accurate and detailed reading of the knee and surrounding soft tissue structures.

The main obstacle to the use of such a composite has been 2-fold. First, the manufacturing and costs were historically challenging in the current economic climate, and second, variations of technique and "visualization" were considered unconventional to surgeons accustomed to a technique in place for over 50 years. These small but notable obstacles have now been overcome with cost structures that are comparable or less than metallic implants, and the technique of insertion has been facilitated to make their use rather similar and simple as compared with the metallic standard in place. The instrumentation and appearance of the composite implants are very similar to conventional metallic implants, and the minor adjustments to technique are easily accomplished. In fact, we have noted no change in surgical planning or operative times with the conversion to composite implant use.

Since the authors have begun using composite intramedullary implants (in several hundred cases), we have not noticed any issues related to healing or implant performance. We also note an enhanced ability to visualize fracture healing because there is no radio-opaque obscuration of the fracture region. We have not seen

FIGURE 7. A–C, Magnetic resonance imaging of the right knee showing bucket handle tear on the coronal image (A) and an absent meniscus on the sagittal image (B). C, Meniscus in the notch and excellent visualization of other soft tissue structures with little to no artifact from the nail that is seen in the medullary canal.

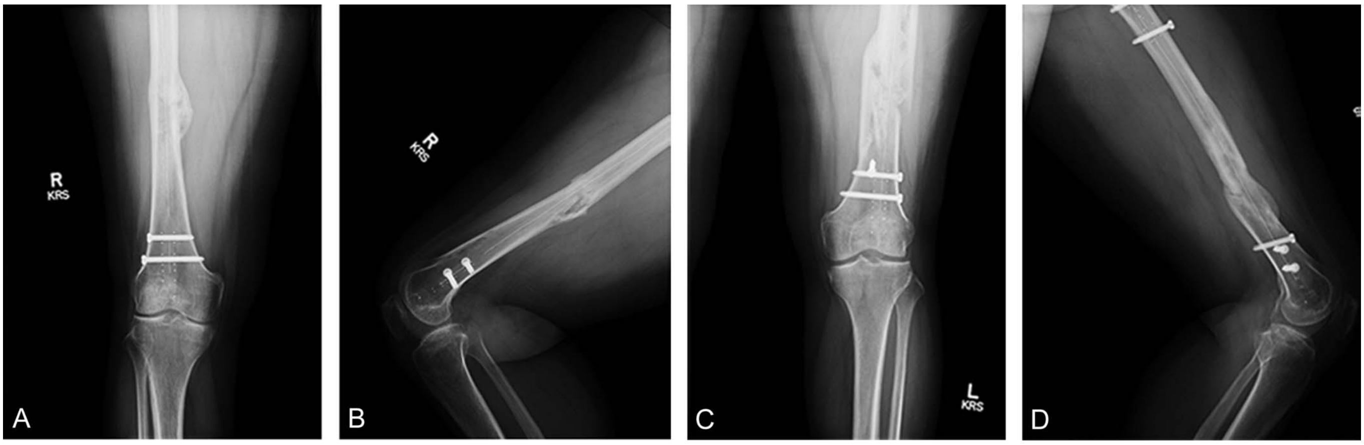

FIGURE 8. A–D, Final images of the healed fractures at 4 months. A and B, Right femur. C and D, Left femur.

any issues with particulate debris or inflammatory reaction, which is supported by studies comparing the biologic reactions between metal and carbon fiber. In short, we have had a very favorable experience with composite carbon fiber PEEK implants in fracture care.

FIGURE 9. A, Represents extension of the legs. B and C, Represent flexion of the knee after healing and meniscal repair.

CONCLUSION

In summary, since technology and manufacturing processes have advanced to allow the use of more modern composite implants, their use has become increasingly noted, and our experience with carbon fiber PEEK nails has been very favorable for a number of reasons noted. Its use is safe and effective and may offer some advantages over standard metallic implants.

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