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## Case Series

# Preliminary Experience of Carbon Fiber Buttress Plating: A Case Series

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## Abstract

Metal has long been the basis for implants used in orthopedic surgery. The first metals used were stainless steel and cobalt-chrome based alloys with progression through the years to include titanium, nickel, and most recently, carbon fiber.[1] Multiple previous studies describe carbon fiber as a safe, biocompatible material that can be used in problematic fractures. [2-6] However to our knowledge, no study has examined the use of carbon fiber specifically in buttress plate application. Compared to conventional metal implants, carbon fiber offers several potential benefits. It provides a modulus of elasticity closer to that of bone, improved fatigue strength, and more complete imaging compatibility. [3-6] In addition, carbon fiber has a large elastic deformation phase with little to no plastic deformation, and it is this distinctive quality that would seem to make carbon fiber potentially ideal for buttress plate fracture fixation. The objective of this case series was to outline the preliminary experience of carbon fiber buttress plating in ankle fractures. This study was performed at a level II trauma center and includes four patients that underwent open reduction and internal fixation with carbon fiber buttress plating for either a bimalleolar equivalent fracture, bimalleolar ankle fracture, or trimalleolar ankle fracture. The main outcome measure included radiographic fracture visualization of healing, adverse tissue reaction, infection, subsequent fracture, or hardware failure. Overall, all patients achieved union with no adverse effects, drawing to the conclusion that carbon fiber is a safe and effective alternative when used in a buttress plate fashion,

**Keywords:** Ankle Fracture Treatment; Antiglide Plating; Butress Plating; Carbon Fiber; Carbon Fiber-Reinforced Polyetheretherketone (CFR-PEEK)

## Introduction

Metal has long been the mainstay for orthopedic implants. Metals offer the benefits of strength, malleability, corrosion resistance, and relatively low cost. Beginning in the twentieth century, the first metallic materials successfully used in orthopedic applications were stainless steel and cobalt chrome. Today, the stainless steel most widely used in clinical application is AISI 316L. This metal demonstrates good fatigue strength with a high elastic modulus and corrosion resistance. However, due to its relatively low wear resistance, the use of AISI 316L stainless steel in applications such as joint prosthetics has been limited in the past. This is one of the main reasons why cobalt chrome was introduced. Cobalt chrome-based alloys are widely used in joint prostheses due to their excellent mechanical and corrosion properties. This metal also offers superior fatigue strength with a modulus slightly higher than stainless steel (220-230 gigapascals compared to 200 gigapascals). Titanium and titanium alloys were brought forth in the 1940's. These became a material of great interest in the biomechanical field due to their modulus of elasticity much closer to that of cortical bone, low density, potential for osteointegration within the body, and good corrosion resistance. This corrosion resistance is due to the formation of a surface titanium oxide layer that forms when the metal is exposed to the corrosive environment of the human body. Nickel based implants first appeared in the 1960's though due to their unsolved allergic effects and potential for toxicity, their use has greatly been hindered [1].

Today, stainless steel and titanium remain a foundation for orthopedic trauma implants such as fracture plates, screws, and intramedullary nails. However, metal implants are not without their shortcomings. Disadvantages include limited fatigue life, corrosion, mismatch of modulus of elasticity, cold-welding seen with titanium locking screw constructs, generation of wear debris, and radiodensity that can prohibit accurate radiographic visualization of fracture reduction, healing, along with tumor or infection progression or resolution. [1] Although not new to orthopedic literature, carbon-fiber-reinforced composite implants have gained popularity in the past several years. Since their inception and first clinical use in the early 1980's, the utility of carbon fiber-based implants has indicated their unique biomechanical properties. [7] The material offers a modulus of elasticity far closer to that of cortical bone along with improved fatigue strength. In addition, carbon fiber has a large elastic deformation phase with little to no plastic deformation phase. Moreover, it is radiolucent and exhibits magnetic resonance imaging (MRI) compatibility, and it has shown lower wear debris volume when carbon fiber plates were compared to titanium plates. [8] Carbon-fiber-reinforced composite is a polymer material composed of continuous sheets of carbon fiber oriented in varying directions. [1] This carbon fiber material has shown unique biological, chemical, and physical characteristics when compared as a biological implant to metals. [9] The uniqueness of carbon fiber implants also lies in the fact that the material is radiolucent allowing for improved visualization of fracture reduction and healing along with tumor surveillance [10].

## Materials and Methods

After Institutional Review Board (IRB) approval, a retrospective review was completed of all cases performed at one level-2 trauma center, where carbon fiber buttress plating technique was used in the treatment of distal tibia and distal fibula fractures. Over a 12-month period between May 2015 to May 2016, a total of five plates were implanted in four patients for AO/OTA classification type B fractures of the distal tibia and distal fibula. The data collected for the patients included age, sex, injury mechanism, fracture type, postoperative weight bearing status, radiographic visualization of fracture healing, possible adverse tissue reactions, possible infection, possible subsequent fracture, or hardware failure. These data points are included in Table 1 located at the end of the case reports. Patients were followed 6 to 14 months postoperatively depending on fracture type and functional status before made pro re nata (PRN).

| Patient No. | Age (years) | Sex | Injury Mechanism | Fracture Type (AO/OTA) | Post-Operative Weight Bearing Status | Radiographic Visualization of Fracture Healing | Adverse Tissue Reaction | Infection | Subsequent fracture | Hardware Failure |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 36 | F | Twisting Fall | Type B Lateral Malleolar Ankle Fracture (Bimalleolar Equivalent) | NWB 8 Weeks | Yes | No | No | No | No |
| 2 | 26 | F | Running/ Twisting Ankle | Type B Lateral Malleolar Ankle Fracture (Bimalleolar Equivalent) | NWB 8 Weeks | Yes | No | No | No | No |
| 3 | 44 | F | Slip/Twisting Fall | Type B Distal Tibia and Distal Fibula Trimalleolar Ankle Fracture | NWB 12 weeks | Yes | No | No | No | No |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 57 | F | Reported Insidious Onset | Type B Bimalleolar Ankle Fracture | NWB 12 weeks | Yes | No | No | No | No |

**Table 1:** Demographic Data for the Four Patients with Ankle Fractures.

## Case Presentations

### Case 1

The patient was a 36-year-old female who presented with a right ankle pain after a twisting mechanical fall. She had lateral ankle tenderness to palpation and stress films revealed increased medial clear space widening with an AO/OTA type B distal fibula fracture (Figure 1A,B). Through a standard lateral approach to the ankle, the fibular fracture was reduced anatomically and fixed using one-1.5mm fully threaded lag screw. Next, a 5-hole 1/3 tubular CarboFix plate was used in a buttress fashion on the lateral surface of the fibula with three-3.5mm fully threaded cortical screws placed into the proximal fragment (Figure 2A, 2B). Syndesmosis was stable with a cotton test and no syndesmotic screws were placed. The postoperative plan included non-weight bearing to the operative extremity for 8 weeks.

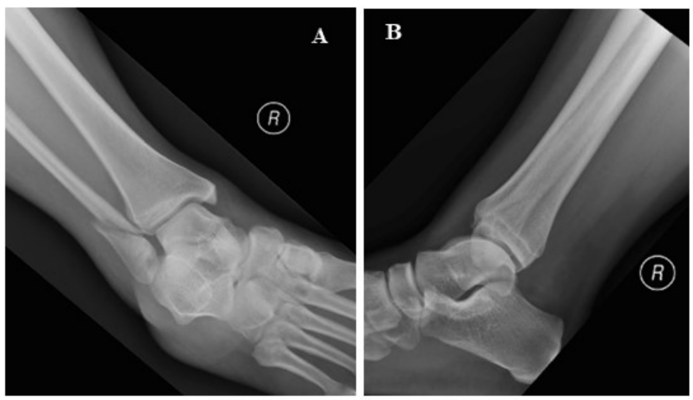


**Figure 1:** A &B: showing an AO/OTA type B distal fibula fracture.

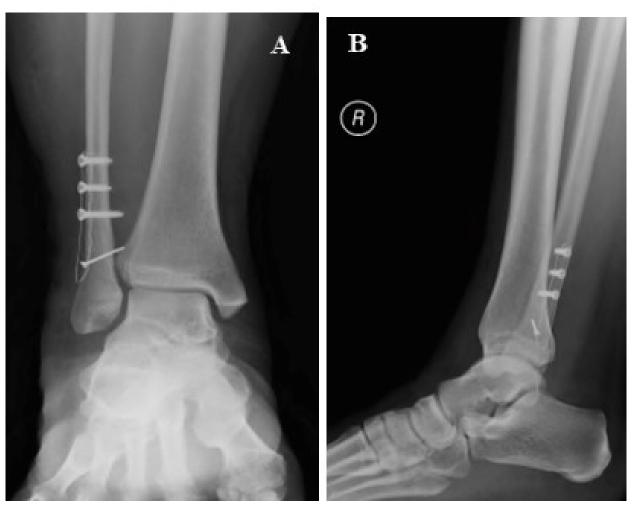


**Figure 2:** A &B: Shows a Carbofix plate used in a buttress fashion with assosicated lag screw in the distal fibula.

### Case 2

The patient was a 26-year-old female who presented after running and twisting her ankle, She reported diffuse ankle pain. Plain film radiographs including gravity stress views revealed an AO/OTA type B distal fibular fracture along with medial clear space widening (Figure 3A,3B), Through a standard lateral approach to the ankle, the fibular fracture was anatomically reduced and fixed using two-1.5mm fully threaded lag screws. Next, a 5-hole 1/3 tubular CarboFix plate was applied to the posterolateral surface of the fibula, directly over the axilla of the fracture thus providing maximal buttress effect. A cotton test revealed syndesmotic instability; therefore, the two proximal screws previously placed in the plate were replaced with longer 3.5mm fully threaded syndesmotic screws (Figure 4A-C). The most proximal screw length size was not optimal as the longer option screw size penetrated the tibial cortex and was prominent/palpable on the skin over the medial tibia while the shorter option screw was too short to grab the fourth cortex. Therefore, the screw was cut to an optimal length and inserted. The postoperative plan included non-weight bearing to the operative extremity for 8 weeks.

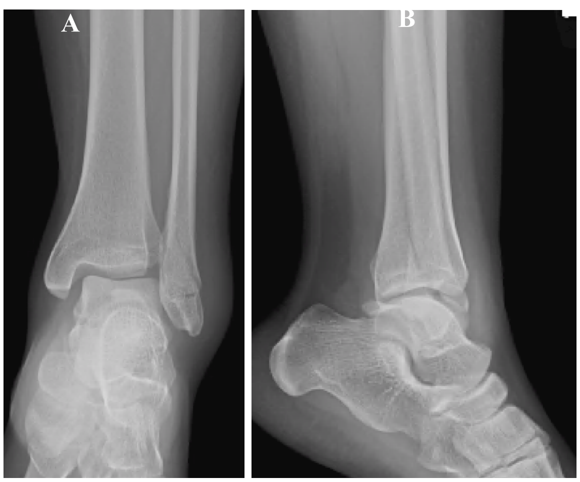


**Figure 3:** A &B: Showing an AO/OTA type B distal fibular fracture along with medial clear space widening.

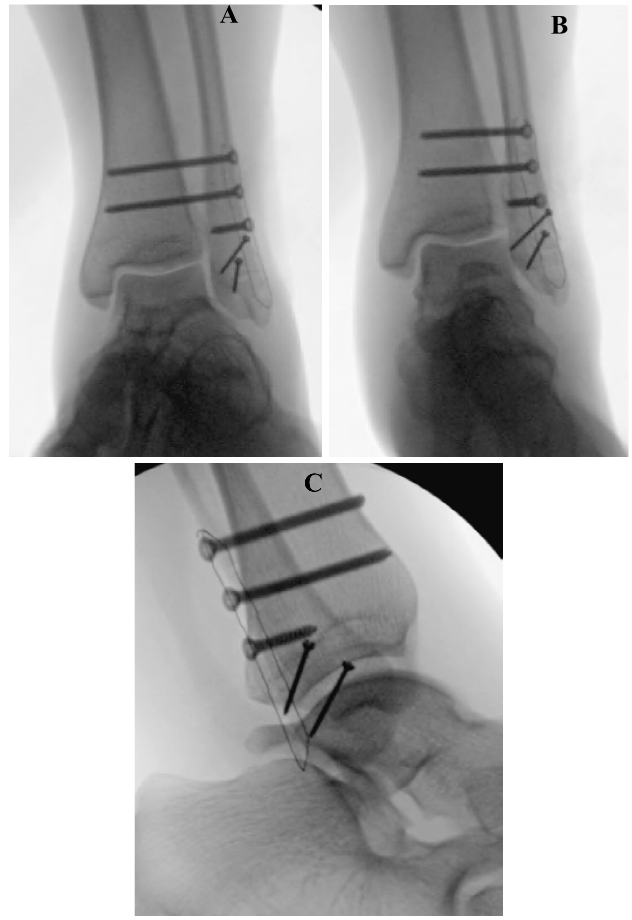


**Figure 4:** A-C: Shows a Carbofix plate used in a buttress fashion with assosicated lag and syndesmotyic screws in the distal fibula.

### Case 3

The patient was a 44-year-old female with history of a slip and fall with associated twisting mechanism who presented with left ankle pain and deformity. Plain films revealed a left trimalleolar ankle fracture dislocation (Figures 5A,5B). Closed reduction of the ankle was performed in the Emergency Room and a CT scan was obtained for further assessment of the posterior malleolar component. Treatment included a staged approach due to soft tissue swelling and fracture blisters. The initial stage included a posterolateral approach to the ankle, whereby the lateral and posterior malleoli were plated in a buttress fashion using 7-hole and 5-hole 1/3 tubular CarboFix plates respectively with an ankle-spanning external fixator applied for added stability (Figures 6A, 6B). Once the soft tissues allowed, the medial malleolus fracture was fixed using two-3.5mm fully threaded cortical screws with washers to obtain bicortical purchase (Figures 7A,7B). The post-operative restrictions included non-weight bearing on the operative extremity for 12 weeks following the last surgery.

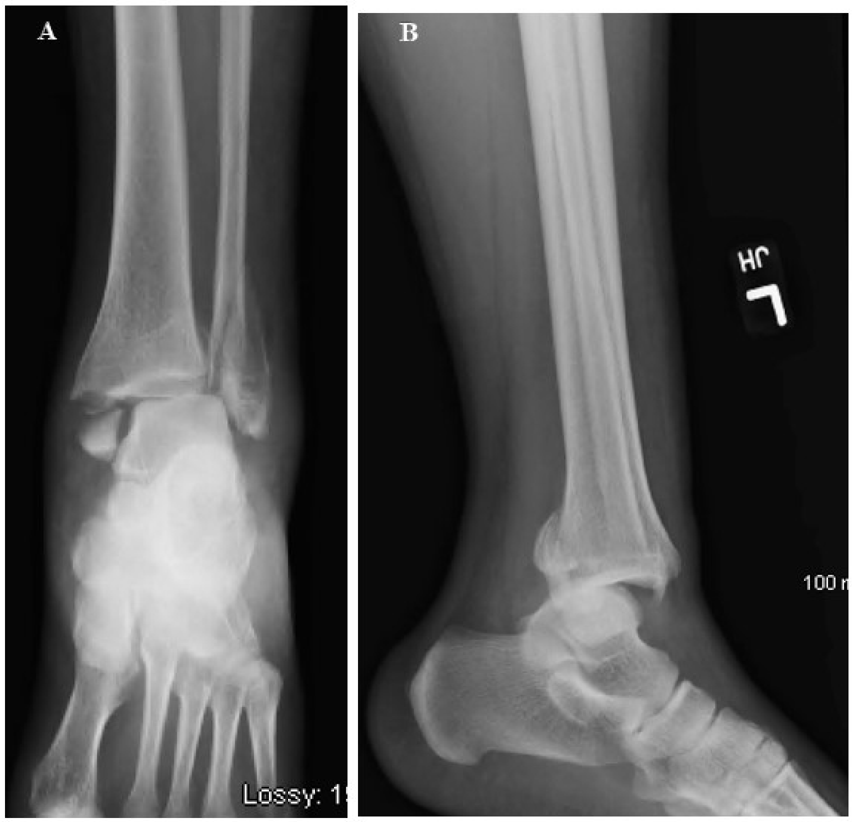


**Figure 5:** A &B: Showing a trimalleolar ankle fracture dislocation.

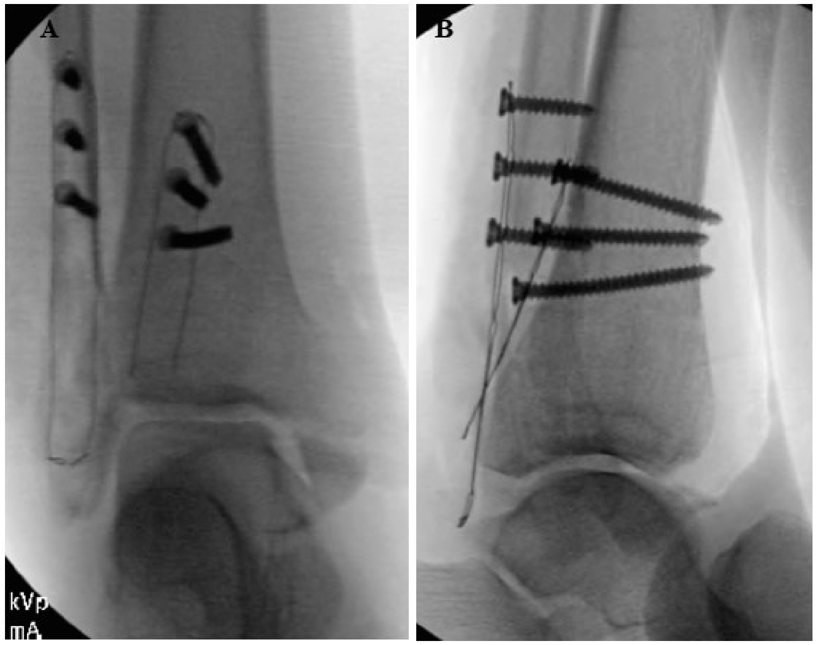


**Figure 6:** A &B: Showing Carbofix plate used in a buttress fashion in the posterior tibia and distal fibula.

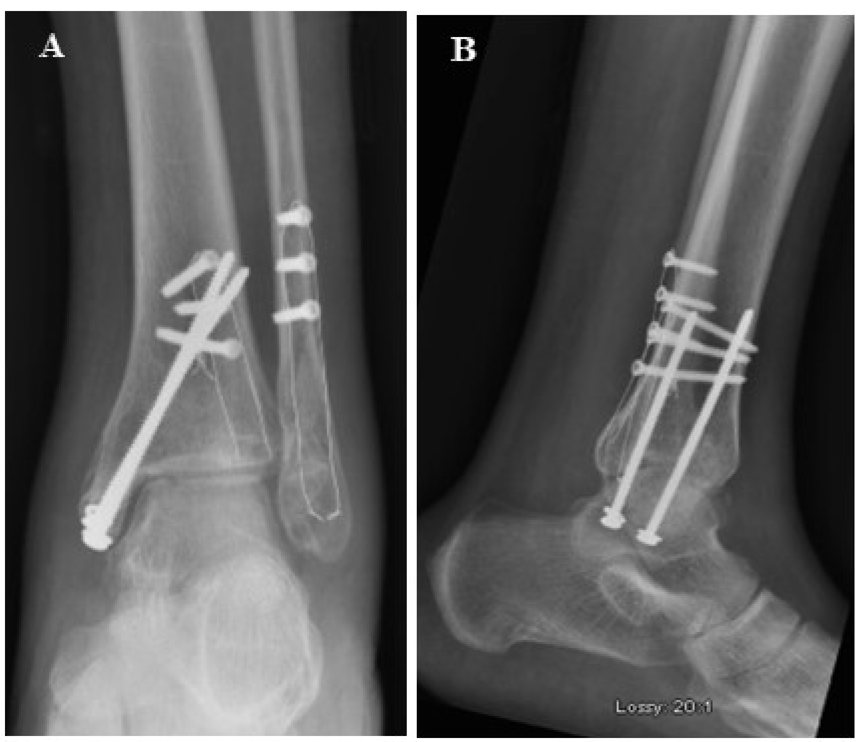


**Figure 7:** A &B: showing addition of two medial malleous screws with washers to previous construct seen in Figure 6A, 6B.

**Case 4**

The patient was a 57-year-old female who presented with ankle pain that reportedly started insidiously 3 days prior. Plain films revealed a bimalleolar ankle fracture (Figure 8). With the amount of fibrous tissue formation present at the fracture sites, the patient's fracture likely occurred prior to the reported injury date. The patient also had significant osteoporosis that affected the planned surgical procedure. An indirect reduction technique was performed during surgery whereby a 6-hole 1/3 tubular CarboFix plate was applied to the lateral surface of the fibula and was provisionally affixed loosely in two of the holes one proximal and one distal using 1.6mm threaded K-wires thus allowing for axial alignment, but not preventing lengthening, Next, a 3.5mm fully threaded syndesmotic screw was placed at the apex of this fracture incorporating four cortices to gain extra purchase due to the poor bone quality of the patient, The indirect reduction technique was captured in Figures 9A-C, Next, two-3.5mm fully threaded bicortical screws were placed proximally in the fibula followed by two-3.5mm fully threaded bicortical screws that were placed in a divergent pattern into the medial malleolus following open reduction through a standard medial approach (Figures 10A-C). Post-operative plan included non-weight bearing for 12 weeks following surgery.


**Figure 8:** Showing a bimalleolar ankle fracture.

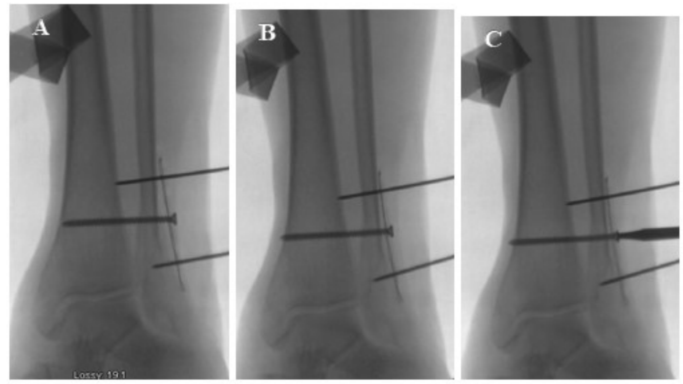


**Figure 9:** A-C: Showing indirect reduction technique of the distal fibula wth a Carbofix plate and associated K-wires.

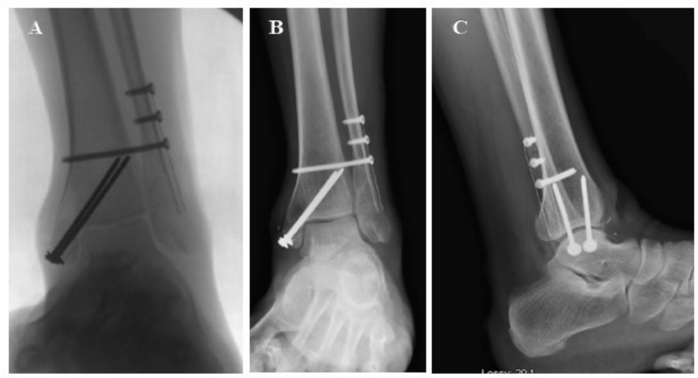


**Figure 10:** A-C: Showing final fixation of bimalleolar ankle fracture.

## Results

Of the four cases investigated, two involved distal fibula lateral buttress plate applications after anatomic reduction and lag screw fixation, which was performed for bimalleolar equivalent fracture types; another included buttressing of the posterior aspects of both the tibia and fibula followed by medial malleolus fixation in a trimalleolar ankle fracture dislocation; and the final case incorporated an indirect fracture reduction technique using a lateral buttress plate for a distal fibula fracture in a patient with poor bone quality followed by medial malleolus fixation in a bimalleolar ankle fracture. All patients went on to union, while no patients showed evidence of adverse tissue reaction, infection, subsequent hardware complication, or recurrent fracture. Case 1 and Case 2 were followed for 6 and 7 months respectively postoperatively. Case 2 was followed for approximately 14 months and case 4 was unfortunately lost to long term follow-up.

## Discussion

The prior four cases represent buttress plate application of carbon fiber plates. To our knowledge, no other study has reported on results of the use of carbon fiber plates in this capacity, Carbon fiber has several unique properties that potentially give it superiority when compared to traditional metal implants. Carbon fiber has a large elastic deformation phase with little to no plastic deformation phase. This means that when a force is applied to carbon fiber plates they will deform, however once the force is removed, the plate will return to its original shape thus it is reversible or elastic. This contrasts with metal plates that are ductile and have a smaller elastic deformation phase and larger plastic deformation phase. Once a force large enough to deform the metallic material is applied, the material will remain deformed even after the external force is removed thus it is irreversible or plastic. (11) It is this important characteristic of carbon fiber that is of specific interest in this paper, and it is our thought that this is what allows for its optimal buttressing effect. In addition, carbon fiber offers greater fatigue strength and a modulus of elasticity far closer to that of cortical bone; it is radiolucent and exhibits Magnetic Resonance Imaging (MRI) compatibility and has shown lower wear debris volume when carbon fiber plates were compared to titanium plates. [12] Carbon fiber implants can also be engineered to affect their biomechanical properties. Depending on the number and orientation of carbon fiber layers, the material can have varying degrees of strength and stiffness. This allows for an implant that can be more compliant than metal and better match the elastic modulus of bone. [1] As reported by Golish, the modulus of elasticity of carbon fiber-reinforced polyetheretherketone (CFR-PEEK) is 3.5 gigapascals (GPa), compared with 230 GPa for stainless steel, 210 GPa for cobalt chrome, 106 to 155 GPa for titanium alloy, 12 to 20 GPa for cortical bone, and 1 GPa for cancellous bone, Mismatch of modulus between implant and bone can lead to difficulties like altered loading, stress shielding, and detrimental periprosthetic bone remodeling [13].

Moreover, carbon fiber implants offer greater fatigue strength when compared to metal implants. Commercially available carbon fiber plates and nails have been biomechanically tested to 1 million fatigue cycles without failure. [12] When looking at bending strength, carbon fiber plates and nails also exceed their metal counterparts. The average bending strength for a 4.5mm CFR-PEEK plate is 19.1 Newton meters (Nm), while the bending strength for a comparable 4.5mm stainless steel locking compression plate is 16.7 Nm. The average bending strength for a 10mm CFR-PEEK intramedullary tibial nail is 80.3 Nm, while the bending strength of a 11mm titanium tibial nail is 43 Nm. [12] Furthermore, carbon fiber implants offer distinct advantages over metal implants when looking at their radiographic imaging differences. Carbon fiber is radiolucent thus allowing for improved visualization of fracture reduction and healing with standard radiographs. In addition, the significant decrease of artifact on both magnetic resonance imaging and computed tomography allows for improved visualization and thus possible advantages in such applications as trauma, spine, infection, and oncologic cases [9,14-16].

With all the discussed advantages of carbon fiber implants, they are not without their own shortcomings. Carbon fiber implants cannot be pre-contoured intra-operatively with current available techniques, thus their use in some fracture fixation applications can be limited because of this. Moreover, even though the increased strength of carbon fiber compared to metal implants decreases its risk of fatigue failure, the radiolucency of the material can potentially preclude the visualization of carbon fiber plate failure radiographically [1]. Carbon fiber implants are manufactured today with a variety of plate and nail applications. It was our interest to specifically focus on the buttressing capability of carbon fiber plates. Buttress plating, or antiglide function plating, is typically seen in articular fractures such as malleolar fractures (as observed in our study), tibial plateau fractures, or distal radius fractures, where shearing forces can displace a large fragment. In order to counteract these forces and keep the reduced fragment in its proper place, a plate is best applied in a position that locks the spike of the fragment into place preventing any further gliding or shearing of the fragment. [8] The plate location that provides the optimal buttress effect is at the apex of the fracture where an axilla can be created between the fracture and plate and thus locking the distal fracture fragment in a reduced position. [17] Buttress plates exert their influence by reducing and stabilizing vertical shear fractures through this antiglide effect. [18] This is not only seen in partial intra-articular fractures (AO/OTA type B fractures), but also in vertical or oblique extra-articular fractures that have a significant deforming force creating a shearing moment across the fracture site [17,19-29].

Main limitation of this study was small sample size and may not represent the overall general population. The average age seen in this study was 40.75 years of age with a large number of ankle fractures happening in ages over sixty years old. Three out of the four patients were released between 6-14 months with remaining lost to follow-up resulting in minimal long-term data collected. Overall, in our retrospective review we saw great results with no adverse post operative complications indicating carbon fiber plating in a buttress fashion a premium option when indicated in ankle fractures. Future study suggestions would include: 1. Head-to-head prospective study comparing carbon fiber plating vs traditional metallic plating of ankle fractures with long term follow-up. 2. Carbon fiber plate applications as a buttress in different anatomic locations.

## Conclusions

Carbon fiber is a safe and effective alternative when used in a buttress plate fashion. In our case series, all ankle fractures went on to union, and all patients tolerated the plates without an increased rate of adverse tissue reaction, infection, or complication. The carbon fiber material is unique in its biomechanical properties and behaves differently compared to conventional metal plates. The effectiveness of this implant used in a buttress fashion likely lies in its inherent lack of plastic deformation. Thus, the plate is able to constantly counteract the deforming forces allowing for a more robust buttress effect. Ultimately the use of carbon fiber requires an understanding of the properties that make it unique and the appropriate application to the specific fracture pattern that one is treating.

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