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Comparison of Carbon Fiber and Titanium Intramedullary Nails In Orthopaedic Oncology

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Background
Carbon fiber implants offer numerous benefits in the orthopaedic oncologic population. In addition to favorable mechanical characteristics, the radiolucency of carbon fiber implants offer immense imaging advantages over titanium implants due to minimal scatter or susceptibility artifact on CT or MRI, respectively. This is especially relevant in orthopaedic oncology as radiolucency allows for improved visualization of bone healing, post-operative surveillance for local disease recurrence or progression, and improved capability for radiation planning. Carbon fiber can be applied to the treatment of sarcomas of the bone or soft tissue for use in allograft reconstruction or for prophylactic protection of bone adjacent to irradiated soft tissue sarcomas, respectively. At present, there is currently a paucity of literature describing the use of carbon fiber-based implants for pathologic fracture fixation.

Purpose
This study investigated the surgical characteristics and short-term results of a cohort of sarcoma and metastatic bone disease patients with primary tumors of different origin at our institution who underwent either prophylactic or therapeutic fixation with a carbon-fiber implant for treatment of pathologic fracture.

Methods
This tertiary institutional, retrospectively matched case-control study included patients who underwent prophylactic or therapeutic fixation for pathological humeral, femoral, or tibial fracture with either a titanium (n=36) or carbon fiber (n=36) intramedullary nail between 2016-2020 by one of three surgeons. Patients were 18 years of age or and were matched for demographic characteristics, histologic diagnosis, and fracture location. Patients were excluded if intramedullary fixation was combined with any other surgical procedure/fixation method. Outcomes included operative time, blood loss, fluoroscopic time, and complications. Fisher exact and Mann-Whitney U analyses were used for categorical and continuous outcomes, respectively.

Results
72 patients were included with 36 patients each in the carbon fiber nail and titanium nail group. Patients with a carbon fiber nail had a lower median BMI (24 [IQR:22-26] vs. 27 [23-30]) (Table 1). No other baseline differences were noted between both groups. Median follow-up in months was 14 (IQR:2.3-38) in the titanium group and 9.5 (2.4-18.8) in the carbon fiber group. Patients receiving carbon fiber nails compared to titanium nails sustained higher blood loss (150ml [IQR:100-250]) vs. 100ml [50-150]; p=0.042) and longer fluoroscopic time (150 seconds [114-182)] vs. 94 seconds [58-124]; p=0.001). No differences in operative time was noted. There were no differences between groups with regard to implant rejection, fatigue, exchange, or complication, surgical wound infection, and mortality. Implant exchange was required in 4 patients in the titanium group (2 for non-union; 2 for local disease progression leading to conversion to endoprosthetic reconstruction) as compared with 0 in the carbon fiber group (p=0.115). Complications with implants neared statistical significance with 7 patients (19%) in the titanium group, including 4 periprosthetic complications, versus 1 patient (3%) in the carbon fiber group (p=0.055) (Table 2).

Conclusions
Use of carbon fiber nails for fixation of pathologic long bone fractures was non-inferior to titanium nails with respect to radiographic union, implant failure, or complications. Carbon fiber has a favorable surgical profile for intramedullary nailing in both the upper and lower extremities with a low overall complication rate as demonstrated in this study. This study was well-matched with regard to patient population demographics and tissue histology and

demonstrated a low rate of complications in both groups without statistically significant difference. This represents the largest cohort to date in the United States assessing oncologic applications of carbon fiber implants, with similar or more extensive follow-up duration and tracked patient metrics. In contrast to prior case series, this study matched patients who received carbon fiber nails to those who received titanium nails including by tissue histology which can lead to unique surgical and radiation oncologic treatment considerations. Limitations include relatively short term follow-up given the nascency of this implant and subjectivity of blood loss, operative time, and duration of fluoroscopy which may be confounded by the nature/size of the specific oncologic lesion and technical expertise with carbon fiber nails (though performed by a small group of three experienced oncologic surgeons). Functional outcome metrics and longer term follow-up data are currently being collected for future update to this study. Altogether, this cohort's surgical results support further consideration of carbon fiber as a suitable material for intramedullary pathologic fracture fixation in orthopaedic oncology, particularly given the favorable mechanical and imaging properties of carbon fiber relevant to the oncologic population.

Table 1. Characteristics of patients treated with titanium (n=36) and carbon fiber nails (n=36) for impending or completed pathological fractures.

Variables	**Titanium Nail (n=36)**	**Carbon Fiber Nail (n=36)**	***p-value***
	Median (IQR) or % (n)		
Age (years)	67 (62-72)	69 (63-75)	0.332
Body mass index (in kg/m^2)	27 (23-30)	24 (22-26)	**0.046**
Preoperative white blood cell count	7.9 (5.7-11.6)	7.3 (4.7-9.6)	0.199
Men	50% (18)	39% (14)	0.477
Other Modified Charlson Comorbidity^	25% (9)	33% (12)	0.605
Pathological fracture			0.227
Impending	53% (19)	69% (25)	
Completed	47% (17)	31% (11)	
Tumor location			0.704
Femur	61% (22)	67% (24)	
Humerus	36% (13)	28% (10)	
Tibia	3% (1)	6% (2)	
Extremity			0.614
Lower extremity	64% (23)	72% (26)	
Upper extremity	36% (13)	28% (10)	
Preoperative radiation	19% (7)	14% (5)	0.753
Postoperative radiation	31% (11)	50% (18)	0.149
Follow-up time in months*	14 (2.3-38)	9.5 (2.4-18.8)	0.055

IQR=interquartile range; min=minutes; ml=milliliters. Bold p-value indicates p<0.05.

^These values were based on any additional comorbidity on top of the metastatic disease score according to the modified Charlson Comorbidity Index.

****One patient in the carbon fiber nail group was lost to follow-up after 3 days of discharge due to return to hometown that was out of the country; no special circumstances were noted during surgery or at discharge. The other 71 patients had at least 1-year follow-up.***

#Estimated blood was available in 32 patients (89%) in the titanium group and 34 patients (94%) in the carbon fiber group. No other missing values were recorded.

Table 2. Outcomes of patients treated with titanium (n=36) and carbon fiber nails (n=36) for impending or completed pathological fractures.

Outcomes	Titanium Nail (n=36)	Carbon Fiber Nail (n=36)	*p-value*
	Median (IQR) or % (n)		
Operation time (min)	90 (65-120)	80 (68-120)	0.686
Estimated blood loss (ml)#	100 (50-150)	150 (100-250)	**0.042**
Fluoroscopic time (seconds)	94 (58-124)	150 (114-182)	**0.001**
Implant			
Rejection	0	0	-
Fatigue	0	0	-
Exchange	11% (4)	0	0.115
Complication with implant			0.055
None	81% (29)	97% (35)	
Non-union	6% (2)	3% (1)	
Periprosthetic fracture	11% (4)	0	
Chronic pain	3% (1)	0	
Surgical wound infection	3% (1)	8% (3)	0.614
Mortality			
90-day	28% (10)	26% (9)	0.999
1-year	44% (16)	51% (18)	0.638
Overall	69% (25)	67% (24)	0.999

IQR=interquartile range; min=minutes; ml=milliliters. Bold p-value indicates p<0.05.
#Estimated blood was available in 32 patients (89%) in the titanium group and 34 patients (94%) in the carbon fiber group. No other missing values were recorded.