## Musculoskeletal Tumor Society Information Statement

# Use of radiolucent implants in surgery for musculoskeletal oncology

### *Novel Practice Assessment*

*In these occasional Novel Practice Assessments, the MSTS Guidelines and Evidence Based Medicine committee will assess the evidence underlying novel diagnostics and therapies entering clinical practice in musculoskeletal oncology. The goal is assist MSTS members make more informed decisions for their patients. As evidence is expected to change rapidly, articles will be rewritten or removed after one year.*

Author: Matthew W. Colman, Associate Professor, Spine Surgery and Musculoskeletal Oncology, Rush University Medical Center

Date: October 15, 2022

**Summary**

Pros

1. Radiolucency allows postoperative MRI and CT imaging for early detection of recurrence
2. Radiolucency allows accurate delivery of both photons and protons in the postoperative period without beam perturbation
3. Some carbon-fiber formats may offer fatigue strength which is superior to traditional metallic implants

Cons

1. Availability and cost may be barriers to widespread use
2. Workability of the implants may be more difficult due to inability to bend/contour, and instrumentation / user interface may be inferior to current implants
3. Implant position / failure / fracture may be difficult to visualize

## Background

The treatment of metastatic bone disease or primary tumors in the axial or appendicular skeleton frequently requires reconstruction or stabilization in order to maintain or restore functional capacity. Traditional metallic implants are the gold standard but may negatively impact postoperative imaging and radiotherapy plans. Additionally, patients requiring proton beam radiation frequently must have metallic implants removed in order to facilitate planning and delivery of accurate dosing.

## What is new ?

A variety of radiolucent carbon-fiber reinforced implants have emerged for the reconstruction and stabilization of defects in both the spine and extremities. The rationale for use of these implants involves the ability to obtain immediate postoperative imaging without reduction in image quality, the ability to deliver radiation accurately without beam perturbation, and an improved fatigue strength profile.

## What is the evidence in favor?

### Methods

A systematic literature review of PubMed and Medline through June 01, 2022 was conducted using the terms “radiolucent implant surgery,” “radiolucent implant tumor,” “carbon implant spine surgery,” “carbon implant tumor,” and “carbon extremity tumor” for studies published in English. The reference lists of retrieved articles were also manually searched for additional qualified studies that reported the use of radiolucent implants in musculoskeletal oncology. Only full text studies were included in this meta-analysis. After the initial search, titles and abstracts were reviewed. Then, each article that met criteria underwent full-text review. Articles that did not have full text available were excluded. Articles that did not evaluate the use of radiolucent implants for oncologic indications were excluded. We included all peer-reviewed studies focused on radiolucent screws and implants in the setting of spine and extremity pathology including clinical, radiation, and biomechanical studies.

For each included study, the following information was extracted using a standard data extraction form: 1) the first author’s name, 2) publication year and study type, 3) sample size, 4) clinical follow-up time, 5) clinical outcome metrics, 6) patient-reported outcome metrics, 7) location of tumor, 8) local recurrence, 9) instrumentation, 10) surgical challenges, 11) complications and 12) use of radiotherapy. Given the lack of larger studies and the heterogeneity of study design, quantitative analysis was not performed.

### Results: Spine

Eleven clinical studies have detailed the surgical efficacy, clinical outcomes and technical challenges of radiolucent implants in primary and metastatic *spinal* tumors. Generally speaking, the studies were small and underpowered to show non-inferiority. Nevertheless, most studies claim similar clinical outcomes and perioperative complications when comparing carbon implants to traditional titanium implants. Most studies highlight the anecdotal and non-quantified benefits of improved postoperative imaging and more easily facilitated radiation planning.

The study by Ringel quantified MRI scatter with titanium screw implants compared to carbon screws. They concluded that the carbon implants had better imaging characteristics but that the effect was mitigated by constructs greater than 4 levels due to the fact that the system they assessed had carbon screw shanks but titanium heads. Neal et al highlighted that in their series they detected three early recurrences out of a total 28 cases (4, 4, and 7 months) thanks to the imaging characteristics of the carbon system.

Two studies used cadaveric or spine phantom laboratory setups to assess the quantifiable perturbation of radiation delivery for carbon implants in comparison to traditional titanium implants. Zhang et al showed up to 35% difference between plan and actual delivery in a cadaveric model using SBRT (photons) in the presence of metallic implants, in contrast to only 3% with carbon implants. Muller et al, whose study sought to compare photons to protons using carbon or metallic implants, showed nearly twice the deviation from plan with proton delivery around metallic implants in comparison to photons. This highlights the importance of taking care with the use of metallic implants with the use of protons specifically.

<u>Results: Extremity</u>

Two medium-size clinical studies have compared carbon intramedullary nails to titanium implants. These studies featured over 140 total patients with no complication or clinical outcome differences between the groups. No nail breakage events occurred, and Sachetti et al highlight the biomechanical strength of carbon implants.

Piccioli et al showed the absence of artifacts and optimal visualization of bone and soft tissues on postoperative CT and MRI. In a case of cephalomedullary nail fixation for a pathologic fracture, Vles et al illustrated that a deep infection was ruled out owing to the lack of metal artifact on MRI.

Use of carbon fiber plates or other implants in the extremities was limited to case reports or very small series.

### What is the evidence against?

The studies by Neal et al and Cofano et al both highlight the potential for difficulty reducing spinal rods and for longer OR times due to workability of the implants. Boriani and Ringel both mentioned occasional difficulty in assessing implant position and/or screw breakage with radiolucent implants.

Collis et al described difficulty inserting distal interlocking screws for a radiolucent humeral nail. They describe rotating and aligning radiopaque markers along the nail to make sure the hole is in adequate positioning for drilling and screwing.

Piccoli et al highlighted a 13% intraoperative and 7% postoperative complication rate using a carbon intramedullary nail, with radiographic union in only 14/53 patients.

**Future Directions**

Carbon implants may offer advantages over traditional implants in terms of postoperative MRI and CT imaging, as well as accurate delivery of radiation plans. While no clear inferiority has been established with regard to clinical outcomes and complications, concerns have been raised regarding implant visualization intraoperatively and implant system workability. Therefore, further clinical study and instrumentation evolution should occur before widespread adoption.

**Sources:**


1. Cofano F, Di Perna G, Monticelli M, Marengo N, Ajello M, Mammi M, Vercelli G, Petrone S, Tartara F, Zenga F, Lanotte M, Garbossa D. Carbon fiber reinforced vs titanium implants for fixation in spinal metastases: A comparative clinical study about safety and effectiveness of the new "carbon-strategy". J Clin Neurosci. 2020 May;75:106-111.
2. Kumar N, Lopez KG, Alathur Ramakrishnan S, Hallinan JTPD, Fuh JYH, Pandita N, Madhu S, Kumar A, Benneker LM, Vellayappan BA. Evolution of materials for implants in metastatic spine disease till date - Have we found an ideal material? Radiother Oncol. 2021 Oct;163:93-104.
3. Shen FH, Gasbarrini A, Lui DF, Reynolds J, Capua J, Boriani S. Integrated Custom Composite Polyetheretherketone/Carbon fiber (PEEK/CF) Vertebral Body Replacement (VBR) in the Treatment of Bone Tumors of the Spine: A Preliminary Report From a Multicenter Study. Spine (Phila Pa 1976). 2022 Feb 1;47(3):252-260. doi: 10.1097/BRS.0000000000004177. PMID: 34310537.
4. Cofano F, Di Perna G, Monticelli M, Marengo N, Ajello M, Mammi M, Vercelli G, Petrone S, Tartara F, Zenga F, Lanotte M, Garbossa D. Carbon fiber reinforced vs titanium implants for fixation in spinal metastases: A comparative clinical study about safety and effectiveness of the new "carbon-strategy". J Clin Neurosci. 2020 May;75:106-111. doi: 10.1016/j.jocn.2020.03.013. Epub 2020 Mar 12. PMID: 32173153.
5. Boriani S, Tedesco G, Ming L, Ghermandi R, Amichetti M, Fossati P, Krengli M, Mavilla L, Gasbarrini A. Carbon-fiber-reinforced PEEK fixation system in the treatment of spine tumors: a preliminary report. Eur Spine J. 2018 Apr;27(4):874-881. doi: 10.1007/s00586-017-5258-5. Epub 2017 Aug 16. PMID: 28815357.
6. Ringel F, Ryang YM, Kirschke JS, M√ºller BS, Wilkens JJ, Brodard J, Combs SE, Meyer B. Radiolucent Carbon Fiber-Reinforced Pedicle Screws for Treatment of Spinal Tumors: Advantages for Radiation Planning and Follow-Up Imaging. World Neurosurg. 2017 Sep;105:294-301. doi: 10.1016/j.wneu.2017.04.091. Epub 2017 May 3. PMID: 28478252.

7. Zimel MN, Hwang S, Riedel ER, Healey JH. Carbon fiber intramedullary nails reduce artifact in postoperative advanced imaging. Skeletal Radiol. 2015 Sep;44(9):1317-25. doi: 10.1007/s00256-015-2158-9. Epub 2015 May 17. PMID: 25982252.
8. Piccioli A, Piana R, Lisanti M, Di Martino A, Rossi B, Camnasio F, Gatti M, Maniscalco P, Gherlinzoni F, Spinelli MS, Donati DM, Biagini R, Capanna R, Denaro V; Italian Orthopaedic Society (SIOT) Bone Metastasis Study Group. Carbon-fiber reinforced intramedullary nailing in musculoskeletal tumor surgery: a national multicentric experience of the Italian Orthopaedic Society (SIOT) Bone Metastasis Study Group. Injury. 2017 Oct;48 Suppl 3:S55-S59. doi: 10.1016/S0020-1383(17)30659-9. PMID: 29025611.
9. Vles GF, Brodermann MH, Roussot MA, Youngman J. Carbon-Fiber-Reinforced PEEK Intramedullary Nails Defining the Niche. Case Rep Orthop. 2019 Jul 30;2019:1538158. doi: 10.1155/2019/1538158. PMID: 31467753; PMCID: PMC6701391.
10. Collis PN, Clegg TE, Seligson D. The invisible nail: a technique report of treatment of a pathological humerus fracture with a radiolucent intramedullary nail. Injury. 2011 Apr;42(4):424-6. doi: 10.1016/j.injury.2010.10.012. Epub 2010 Dec 4. PMID: 21130437.
11. Goudriaan WA, Tordoir RL, Broekhuis D, van der Wal RJP. Early Failure of a Carbon-Fiber-Reinforced Polyetheretherketone Distal Femur Plate: A Case Report. JBJS Case Connect. 2020 Jul-Sep;10(3):e20.00041. doi: 10.2106/JBJS.CC.20.00041. PMID: 32910577.
12. Sacchetti F, Andreani L, Palazzuolo M, Cherix S, Bonicoli E, Neri E, Capanna R. Carbon/PEEK nails: a case-control study of 22 cases. Eur J Orthop Surg Traumatol. 2020 May;30(4):643-651. doi: 10.1007/s00590-019-02602-4. Epub 2019 Dec 21. PMID: 31865455.
13. Neal MT, Richards AE, Curley KL, Patel NP, Ashman JB, Vora SA, Kalani MA. Carbon fiber-reinforced PEEK instrumentation in the spinal oncology population: a retrospective series demonstrating technique, feasibility, and clinical outcomes. Neurosurg Focus. 2021 May;50(5):E13. doi: 10.3171/2021.2.FOCUS20995. PMID: 33932921.
14. Disch AC, Schaser KD, Melcher I, Feraboli F, Schmoelz W, Druschel C, Luzzati A. Oncosurgical results of multilevel thoracolumbar en-bloc spondylectomy and reconstruction with a carbon composite vertebral body replacement system. Spine (Phila Pa 1976). 2011 May 1;36(10):E647-55. doi: 10.1097/BRS.0b013e3181f8cb4e. PMID: 21217423.
15. Laux CJ, Villefort C, Ehrbar S, Wilke L, Guckenberger M, M√ºller DA. Carbon Fiber/Polyether Ether Ketone (CF/PEEK) Implants Allow for More Effective Radiation in Long Bones. Materials (Basel). 2020 Apr 9;13(7):1754. doi: 10.3390/ma13071754. PMID: 32283675; PMCID: PMC7178689.
16. Zhang C, Wang S, Mansi A, Katzir M. In Situ Real-Time Dosimetric Studies for Spine Stereotactic Body Radiation Therapy in a Cadaver Implanted with Carbon-Fiber and Titanium Instrumentation. World Neurosurg. 2022 May 18:S1878-8750(22)00673-8. doi: 10.1016/j.wneu.2022.05.043. Epub ahead of print. PMID: 35595045.
17. Poel R, Belosi F, Albertini F, Walser M, Gisep A, Lomax AJ, Weber DC. Assessing the advantages of CFR-PEEK over titanium spinal stabilization implants in proton therapy-a phantom study. Phys Med Biol. 2020 Dec 11;65(24):245031. doi: 10.1088/1361-6560/ab8ba0. PMID: 32315991.
18. Trungu S, Ricciardi L, Forcato S, Scollato A, Minniti G, Miscusi M, Raco A. Anterior Corpectomy and Plating with Carbon-PEEK Instrumentation for Cervical Spinal Metastases: Clinical and Radiological Outcomes. J Clin Med. 2021 Dec 16;10(24):5910. doi: 10.3390/jcm10245910. PMID: 34945214; PMCID: PMC8706248.

19. Boriani S, Pipola V, Cecchinato R, Ghermandi R, Tedesco G, Fiore MR, Dionisi F, Gasbarrini A. Composite PEEK/carbon fiber rods in the treatment for bone tumors of the cervical spine: a case series. Eur Spine J. 2020 Dec;29(12):3229-3236. doi: 10.1007/s00586-020-06534-0. Epub 2020 Jul 20. PMID: 32691220.
20. M√ºller BS, Ryang YM, Oechsner M, D√ºsberg M, Meyer B, Combs SE, Wilkens JJ. The dosimetric impact of stabilizing spinal implants in radiotherapy treatment planning with protons and photons: standard titanium alloy vs. radiolucent carbon-fiber-reinforced PEEK systems. J Appl Clin Med Phys. 2020 Aug;21(8):6-14. doi: 10.1002/acm2.12905. Epub 2020 May 31. PMID: 32476247; PMCID: PMC7484848.
21. Mosher ZA, Patel H, Ewing MA, Niemeier TE, Hess MC, Wilkinson EB, McGwin G Jr, Ponce BA, Patt JC. Early Clinical and Economic Outcomes of Prophylactic and Acute Pathologic Fracture Treatment. J Oncol Pract. 2019 Feb;15(2):e132-e140. doi: 10.1200/JOP.18.00431. Epub 2018 Dec 4. PMID: 30523763.
22. Loeb AE, Mitchell SL, Osgood GM, Shafiq B. Catastrophic Failure of a Carbon-Fiber-Reinforced Polyetheretherketone Tibial Intramedullary Nail: A Case Report. JBJS Case Connect. 2018 Oct-Dec;8(4):e83. doi: 10.2106/JBJS.CC.18.00096. PMID: 30601766.
23. Zavras AG, Schoenfeld AJ, Patt JC, Munim MA, Goodwin CR, Goodwin ML, Lo SL, Redmond KJ, Tobert DG, Shin JH, Ferrone ML, Laufer I, Saifi C, Buchowski JM, Jennings JW, Ozturk AK, Huang-Wright C, Mesfin A, Steyn C, Hsu W, Soliman HM, Krishnaney AA, Sciubba DM, Schwab JH, Colman MW. Attitudes and trends in the use of radiolucent spinal implants: A survey of the North American Spine Society section of spinal oncology. N Am Spine Soc J. 2022 Feb 23;10:100105. doi: 10.1016/j.xnsj.2022.100105. PMID: 35368717; PMCID: PMC8967730.
24. McDonnell JM, Nagassima Rodrigues Dos Reis K, Ahern DP, Mahon J, Butler JS. Are Carbon-fiber Implants More Efficacious Than Traditional Metallic Implants for Spine Tumor Surgery? Clin Spine Surg. 2020 May 15. doi: 10.1097/BSD.0000000000001007. Epub ahead of print. PMID: 32427719.
25. Wagner A, Haag E, Joerger AK, Gempt J, Krieg SM, Wostrack M, Meyer B. Cement-Augmented Carbon Fiber-Reinforced Pedicle Screw Instrumentation for Spinal Metastases: Safety and Efficacy. World Neurosurg. 2021 Oct;154:e536-e546. doi: 10.1016/j.wneu.2021.07.092. Epub 2021 Jul 30. PMID: 34339894.
26. M√ºther M, L√ºthge S, Gerwing M, Stummer W, Schwake M. Management of Spinal Dumbbell Tumors via a Minimally Invasive Posterolateral Approach and Carbon Fiber-Reinforced Polyether Ether Ketone Instrumentation: Technical Note and Surgical Case Series. World Neurosurg. 2021 Jul;151:277-283.e1. doi: 10.1016/j.wneu.2021.04.068. Epub 2021 Apr 27. PMID: 33915306.
27. Ho D, Phan THT, Mobbs RJ, Reddy R. The use of radiolucent (carbon fibre-reinforced polymer) pedicle screw fixation for serial monitoring of clear cell meningioma: a case report. J Surg Case Rep. 2020 Dec 18;2020(12):rjaa510. doi: 10.1093/jscr/rjaa510. PMID: 33365123; PMCID: PMC7748253.
28. Herzog LN, Traven SA, Walton ZJ, Leddy LR. The Use of Carbon Fiber Implants for Impending or Existing Pathologic Fractures. J Orthop Trauma. 2022 Jul 1;36(7):e260-e264. doi: 10.1097/BOT.0000000000002320. PMID: 35727005.
29. "Intensity-Modulated Radiation Therapy (IMRT).",ÄØMayo Clinic, Mayo Foundation for Medical Education and Research, 16 Apr. 2020, https://www.mayoclinic.org/tests-procedures/intensity-modulated-radiation-therapy/about/pac-20385147.,ÄØ

30. Kumar N, Lopez KG, Alathur Ramakrishnan S, Hallinan JTPD, Fuh JYH, Pandita N, Madhu S, Kumar A, Benneker LM, Vellayappan BA. Evolution of materials for implants in metastatic spine disease till date - Have we found an ideal material? Radiother Oncol. 2021 Oct;163:93-104. doi: 10.1016/j.radonc.2021.08.007. Epub 2021 Aug 19. PMID: 34419506.
31. Goodloe JB, Toner S, Althoff A, Herzog L, Rothwell S, Reid K. Bilateral Atypical Femur Fractures Complicated by Carbon Fiber Cephalomedullary Nail Fracture: A Case Report. JBJS Case Connect. 2020 Jul-Sep;10(3):e2000182. doi: 10.2106/JBJS.CC.20.00182. PMID: 32960020.