CyberKnife rhizotomy for facetogenic back pain: a pilot study

GORDON LI, M.D.,¹ CHIRAG PATIL, M.D.,¹ JOHN R. ADLER, M.D.,¹ SHIVANAND P. LAD, M.D., PH.D.,¹ SCOTT G. SOLVYS, M.D.,² IRIS C. GIBBS, M.D.,² LAURIE TUPPER, N.P.,² AND MAXWELL BOAKYE, M.D.¹

Departments of ¹Neurosurgery and ²Radiation Oncology, Stanford University School of Medicine, Stanford, California

Object. By targeting the medial branches of the dorsal rami, radiofrequency ablation and facet joint injections can provide temporary amelioration of facet joint–producing (or facetogenic) back pain. The authors used CyberKnife radiosurgery to denervate affected facet joints with the goal of obtaining a less invasive yet more thorough and durable antinociceptive rhizotomy.

Methods. Patients with refractory low-back pain, in whom symptoms are temporarily resolved by facet joint injections, were eligible. The patients were required to exhibit positron emission tomography–positive findings at the affected levels. Radiosurgical rhizotomy, targeting the facet joint, was performed in a single session with a marginal prescription dose of 40 Gy and a maximal dose of 60 Gy.

Results. Seven facet joints in 5 patients with presumptive facetogenic back pain underwent CyberKnife lesioning. The median follow-up was 9.8 months (range 3–16 months). The mean planning target volume was 1.7 cm³ (range 0.9–2.7 cm³). A dose of 40 Gy was prescribed to a mean isodose line of 79% (range 75–80%). Within 1 month of radiosurgery, improvement in pain was observed in 3 of the 5 patients with durable responses at 16, 12, and 6 months, respectively, of follow-up. Two patients, after 12 and 3 months of follow-up, have neither improved nor worsened. No patient has experienced acute or late-onset toxicity.

Conclusions. These preliminary results suggest that CyberKnife radiosurgery could be a safe, effective, and noninvasive alternative to radiofrequency ablation for managing facetogenic back pain. No patient suffered recurrent symptoms after radiosurgery. It is not yet known whether pain relief due to such lesions will be more durable than that produced by alternative procedures. A larger series of patients with long-term follow-up is ongoing.

(DOI: 10.3171/FOC-07/12/E2)

Key Words • CyberKnife • facetogenic back pain • low-back pain • radiosurgery

Low-back pain is a major public health problem with significant socioeconomic impact that costs society upwards of $50 billion annually.¹²,¹³,⁴⁴ About 80% of people will experience at least one episode of low-back pain in their lifetimes, and their pain will recur at rates of 20–44% annually, 80% over 10 years, and 85% over their lifetimes.¹²,¹³,⁴⁴ For most patients, back pain has no clear, identifiable cause. In a significant number of patients there is evidence of degenerative spinal changes, but such changes may also be present in asymptomatic individuals.⁶,¹¹ In only 1–2% of patients with back pain is there a clear underlying cause such as tumor, infection, or trauma.

Increasing attention has recently been focused on the role of facet joints in the pathogenesis of back pain. Goldthwait was the first to propose the concept of facet joint–producing (facetogenic) back pain in 1911, but the term “facet syndrome” was not coined until 1933 when Ghormley used it to describe back pain starting in the midback and spreading laterally to proximal limbs in a sclerodermal fashion, often aggravated by hyperextension.²² The authors of several studies have confirmed the involvement of the facet joints in a significant number of patients with back pain. Schwarzer et al.⁴⁴ estimated the prevalence of facetogenic back pain at 15–40%.

Medial branches of the lumbar dorsal rami supply the facet joints, with each joint receiving innervation from medial branches of two rostral dorsal rami. The medial branches of the dorsal rami relay pain impulses from the facet joint through their nociceptive terminal endings.⁵ Facetogenic pain may result from mechanical stresses in the joint due to joint degeneration or from inflammation in the joint. Back pain may also result from segmental instability due to incompetent facets. Reducing joint inflammation or destroying the nociceptive nerve fibers that supply the joint may lessen facetogenic pain.

Abbreviations used in this paper: ODI = Oswestry Disability Index; PET = positron emission tomography; RF = radiofrequency; SF-36 = 36-Item Short Form Health Survey; VAS = visual analog scale.
Shealy first reported on the efficacy of RF ablation of the nerve to the facet joint for facetogenic back pain. Radiofrequency ablation of the medial branch to the facet joint has become a mainstay of the treatment of facetogenic back pain,2,4,13,21,22,26,29,35,42 but the results have been mixed.17,22,43 Many centers have not adopted the recommended guidelines for RF ablation, a situation that may have led to variable outcomes. Moreover, RF ablation has a reported complication rate of 1%, including a 0.5% incidence of new neuritic pain probably resulting from errors of placement of the needle electrodes. Finally, pain relief after RF ablation is usually not durable, and patients often require multiple RF ablation procedures.

The CyberKnife consists of a linear accelerator mounted on a robotic arm that can be manipulated through 6 degrees of freedom using image guidance technology. It employs real-time imaging that allows tracking of and adjustment for patient movements, ensuring submillimetric accuracy of targeting.8 It provides conformal radiosurgery capability to cranial as well as spinal and paraspinal targets.7,15 It has been used safely and successfully in the treatment of benign and malignant lesions of the spine,15,33 as well as trigeminal neuralgia.21

In this study, we report preliminary results using CyberKnife (Accuray, Inc.) radiosurgical facetectomy for the treatment of facetogenic pain. The CyberKnife may overcome most of the disadvantages associated with an RF ablation procedure: compared with RF ablation, the CyberKnife system is inherently more amenable to the development and adoption of a standardized protocol established by primary investigators, and much more accurate through its image guidance capability. None of the complications associated with RF ablation, such as erroneous placement of the needle electrodes and secondary neuritis pain, would be relevant. The CyberKnife is also more capable of lesioning the entire joint, thereby perhaps ensuring a more comprehensive rhizotomy. We hypothesize that CyberKnife-induced denervation of the facet joint may be as effective as RF ablation and yield fewer complications.

**Clinical Material and Methods**

Patients were prospectively enrolled in an internal review board–approved protocol in which CyberKnife radiosurgery was used to treat facetogenic back pain. Patients were eligible if they had low-back pain refractory to nonsurgical management and, at least temporarily, pain that was resolvable by the injection of a local anesthetic into 1 or 2 lumbar facet joints. Additionally, we required PET-documented hypermetabolism at the facet joint in which the pain was believed to originate (Fig. 1). Patients were excluded if they had 1) gross spinal instability, 2) nerve root compression, or 3) a history of radiotherapy involving the lumbar spine. Five male patients (age range 53–82 years) underwent radiosurgical lesioning. The lesions were treated with a marginal prescription dose of 40 Gy in a single session as detailed below. Pain was measured using a VAS, and function was evaluated using the ODI and SF-36 questionnaire prior to treatment and at follow-up.14,36

**Radiosurgical Treatment Planning**

In the days prior to the procedure, a custom-made alpha cradle mold was constructed for each patient to ensure relative immobilization throughout preradiosurgical imaging and CyberKnife radiosurgery. Prone computed tomography scans with 1.25-mm contiguous slices were obtained to identify the target facet joint. The intraarticular surfaces of the facet were identified, and standard contouring tools were used to delineate the facet joint as shown in Fig. 2. The thecal sac and exiting nerve roots adjacent to the target facet were considered critical structures so that their dose was minimized.

**Radiation Dosimetry**

The treatment plan was developed using an inverse planning algorithm. All patients were treated in a single session with a median maximum dose of 50.6 Gy (range 50–53.55 Gy). The median marginal dose was 40 Gy prescribed to a mean isodose line of 79% (range 75–80%).

**Treatment Delivery**

All but one of the patients was positioned prone on the treatment couch and immobilized in their customized alpha cradle mold. One of the patients was positioned supine. The Xsight target tracking software (Accuray, Inc.) was used to localize the target at the start of treatment and throughout radiosurgery by moving the treatment table. Once the patient’s position was optimized, the facet joint rhizotomy was conducted in accordance with the treatment plan. Upon completion, patients received 4 mg of dexamethasone and 8 mg of ondansetron.

**Results**

As of October 2007, 7 facet joints in 5 male patients (mean age 64 years) with presumptive facetogenic back pain underwent CyberKnife lesioning (Table 1). The duration of follow-up was 16 months for the first patient, 12 months for the subsequent 2 patients, 6 months for the fourth, and 3 months for the fifth. The mean planning target volume was 1.7 cm³ (range 0.9–2.7 cm³). A 40-Gy radiation dose was prescribed to a mean isodose line of 79% (range 75–80%). The mean maximum dose was 50.6 Gy (range 50–53.55 Gy).

According to the results of the VAS, ODI, and SF-36, significant improvement in pain was achieved in 3 of the 5 patients. The improvement persisted at 16-, 12-, and 6-month follow-up sessions for the 3 responsive patients, respectively. The first patient complained of constant axial back pain (VAS score of 6), which improved temporarily after right L3–4 facet joint injections prior to CyberKnife treatment. Prior to facet injection, PET scanning demonstrated increased uptake at the right L3–4 facet joint. By 2
weeks after L3–4 CyberKnife radiosurgery, his pain decreased (VAS score of 4), and it remained at this level at 3-, 6-, 12-, and 16-month follow-up visits. On his follow-up SF-36 questionnaire, the patient answered that his activities were only limited “a little” by his pain in contrast to being limited “a lot” on his pretreatment questionnaire. In response to the follow-up ODI, the patient stated that he could sleep without difficulty, travel without pain, and walk long distances without pain, whereas before treatment, he had answered that he could only sleep with pain medication, pain restricted his travel to < 2 hours at a time, and he could only walk with crutches or a cane.

The patient in Case 2 complained of continuous chronic midback pain (a VAS score of 6) that was also temporarily relieved with facet injection, as directed by PET findings. Positron emission tomography scanning demonstrated an increased uptake at the right L4–5 and left L5–S1 facet joints. After CyberKnife radiosurgical facetectomy at those levels, pain decreased to a VAS score of 3 at the 2-week and 3-month follow-up visits and to a VAS score of 2 at 6 and 12 months. His responses to the SF-36 questionnaire indicated no limitations to activity after treatment in contrast to being limited “a lot” before CyberKnife treatment. In his response to the pretreatment ODI, the patient answered that pain limited him to walking < 0.05 miles, standing for < 30 minutes, and sleeping < 6 hours without large amounts of pain medications. Posttreatment he answered “no limitations” to the same ODI categories at 3, 6, and 12 months.

The patient in Case 4 had chronic back pain (a VAS score of 6), and PET scanning revealed increased uptake at the right L4–5 facet joint (Fig. 1). His symptoms were temporarily ameliorated by facet injection, and he underwent CyberKnife rhizotomy at that affected level (Fig. 2). At 2 weeks and 3 months posttreatment his VAS pain score was 2 and at 6 months it was 1. As with the other patients prior to CyberKnife treatment, he reported “a lot” of limitation of activity on the SF-36, and this improved to no limitations at the 6-month follow-up visit. His pain, as described on the ODI, prevented him from lifting weights, standing for > 30 minutes, or sleeping > 4 hours without pain medications. After radiosurgical treatment, the ODI indicated that he experienced no difficulty with any of these activities.

There was no improvement of symptoms in 2 of the 5 patients (Cases 3 and 5) after 12 and 3 months of follow-up, respectively. These patients also complained of chronic low-back pain that responded temporarily to facet joint injections, and PET findings were positive. The lack of improvement in these patients’ pain may have been due to poor patient selection: the patient in Case 5 had an ongoing disability application and the other had undergone 2 previous lumbar operations and had failed–back surgery syndrome. These two patients did not worsen after their treatment. To date, no patient has experienced complications from the radiosurgical treatment. Of note, the PET scans in 2 of the 3 patients with improved pain were repeated 1 year after treatment, and there was no significant change compared with pretreatment images. More data regarding postoperative PET scans are needed and are being gathered.

Discussion

Chronic axial back pain is a modern epidemic that carries significant socioeconomic impact. The incidence of
disability due to back pain has risen faster than that associated with any other medical condition. Although most episodes of back pain eventually resolve, 29% of patients report a poor outcome at 1 year, and 5% continue to suffer chronic pain and disability. Back pain is the second-most frequent reason for patients to seek medical care.

Recently, the facet joints have been determined to be the pain generator in many cases. There is often radiographic evidence of osteoarthritic changes in facet joints in patients with back pain, and inspection of facet joint specimens obtained in patients with back pain undergoing surgery for degenerative spinal disorders shows unusually high levels of inflammatory cytokines. Stimulation of facet joints or the nerve supply to these joints causes pain similar to that described in the facet joint syndrome. 

Radiofrequency ablation of the medial branch to the facet joint has become the mainstay of treatment for facetogenic pain since Shealy described the procedure in 1976. There have been 3 randomized controlled studies evaluating the efficacy of RF ablation for low-back pain. In their 2005 review article, Hooten et al. recommended procedural guidelines for performing RF ablation and for conducting future trials, including the use of Revel’s clinical screening criteria for patient selection, the use of single and comparative blocks for diagnosis, and proper RF technique and outcome measures. A study by Dreyfuss et al. applied most of these recommendations, and the authors were able to demonstrate efficacy of this technique. There are many concerns regarding RF ablation. A complication rate of 1%, including a 0.5% incidence of new neuritic pain, has been reported. It is likely that most of the neuritic complications result from erroneous placement of the needle electrodes. Additionally, many centers have not adopted the recommended guidelines, a fact that may lead to a continued variability of outcomes. Furthermore, RF ablation is not always durable and often needs to be repeated.

In this study, we present an alternative treatment of facetogenic pain: CyberKnife radiosurgery is used to lesion the nerves that innervate the facet joint. Radiosurgical facetectomy is a straightforward extension of the current techniques and protocols used in the treatment of paraspinal targets, which involves noninvasive irradiation of the joint with minimal risk to surrounding critical structures. When trained in a standardized protocol, users of the CyberKnife can generate accurate facet joint rhizotomies that cover the entire joint and avoid potential problems associated with the use of needle electrodes, including neuritic complications and skin burns. No patients experienced acute or late-onset toxicity. There is no radiation delivered to the spinal cord itself, given the levels that are being treated. The dose to the thecal sac and nerve roots, which have greater tolerance to radiation than the spinal cord, is minimized by delineating them as critical structures. Secondary malignancies after stereotactic spinal radiosurgery have not been reported. There have been case reports of secondary malignancies found intracranially after radiosurgery, but the largest retrospective cohort study evaluating ~5000 patients and 30,000 patient-years of follow-up showed no increased risk of malignancy after stereotactic Gamma Knife surgery.

We believe that the effectiveness of the CyberKnife for facetogenic pain is mediated acutely through an anti-inflammatory effect with a durable response due to ablation of the nerve supply to the joint. Many centers in Europe have used low-dose radiotherapy to treat osteoarthritic joints. Low-dose radiotherapy has significant anti-inflammatory effects, perhaps in part because it reduces the adherence of monocytes to endothelial cells or decreases neutrophil function. Between 1994 and 1996, ~13,000 patients underwent low-dose radiotherapy for inflammatory osteoarthritic disorders, and between 2001 and 2002, this number nearly doubled. Centers in Europe generally follow published consensus guidelines for treatment of osteoarthritis and inflammatory conditions with low-dose radiotherapy. Although there are no reported studies in which authors have used radiosurgery to treat facet joint arthritis, we hypothesize, based on these studies on osteoarthritis, that CyberKnife radiosurgery, in the acute and subacute period, could relieve facetogenic pain by an anti-inflammatory mechanism.

A second possible mechanism by which the CyberKnife may act is the radiosurgical ablation of the nerve supply to the joint. As we discussed, small terminal fibers of the medial branches of the dorsal rami supply the joint. Previously published studies have demonstrated the efficacy of CyberKnife radiosurgical neurectomy in patients with trigeminal neuralgia. The proposed protocol would involve doses similar to those used in our previous protocols for treatment of trigeminal neuralgia. In previous studies in patients with trigeminal neuralgia, we found that doses between 50 and 80 Gy were quite effective for relief of facial pain. We hypothesize that radiosurgical rhizotomy of these fibers will denervate the facet joint and prevent transmission of nociceptive stimuli from the joint, akin to the effect achieved by the RF ablation.
CyberKnife rhizotomy for facetogenic back pain

In our study, 3 of the 5 patients experienced significant relief of chronic back pain within 2 weeks of CyberKnife treatment. The pain relief was sustained over the follow-up intervals of 16, 12, and 6 months during which these 3 patients were each observed. Two of the 5 patients did not have any symptom relief, although this may be due to poor patient selection. One of these patients had a pending disability claim, whereas the other had persistent leg and back pain despite 2 surgeries prior to radiosurgery. He was included because his PET study was positive despite the fact that he was not an ideal candidate. Patient selection is critical for this study, and the inclusion and exclusion criteria for future patients will be changed to exclude patients with pending disability claims or patients who have previously undergone surgery. The inclusion criteria chosen included clinical and radiographic criteria as well as a positive response to facet joint injections in an attempt to specifically select patients with facetogenic back pain. There have been no complications due to the CyberKnife treatment in these patients. This study is a pilot study and the treatment dose was extrapolated from the trigeminal neuralgia experience. However, neither the dose nor the treatment volume has been optimized. With further experience and investigation, a more optimal treatment protocol will be established.

Conclusions

There is evidence that facet joints cause back pain in 15–40% of patients.19 Intraarticular facet joint injections or medial branch blocks can help in the selection of a group of patients who may benefit from RF ablation. Our very preliminary results suggest that CyberKnife radiosurgery may be a safe, effective, and noninvasive alternative to RF ablation for the treatment of facetogenic back pain. Although no patient suffered recurrent symptoms after radiosurgery, it is not yet certain that such lesions will be more durable than alternative procedures. A study with a much larger series of patients and long-term follow-up data is required and currently ongoing. Moreover, the unique nature of radiosurgery could make it possible to conduct the first randomized sham-controlled trial of facet rhizotomy.

Disclosure

Dr. Adler sits on the board of directors of Accuray, Inc. Drs. Adler and Chang are each shareholders of Accuray, Inc.

References

29. North RB, Han M, Zahrak M, Kidd DH: Radiofrequency lumbar...