INVITED REVIEW

Lasers in Spine Surgery: A Review

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Introduction

A Google search with the key words "spine surgery" results in a list of individuals and "institutes" emphasizing the use of laser technology. The words "laser" and "spine surgery" top the list of paid sponsors. A review of print media content in New York also reveals this strong association. Printed ads extolling the virtues of superior surgical outcomes with laser surgery have run for many years.

The combination of these two words clearly prompts patient interest. The substantial long-term costs of print ads would indicate that they also prompt patient response. The general notion is that laser surgery results in less blood loss, is less invasive and is more effective in treating a variety of spinal conditions, especially herniated discs.

This author polled 24 neurosurgeons and orthopedic spine surgeons in the New York City area. Interestingly, while two thirds use minimally invasive techniques, none use laser technology.

In the hope of providing some clarity, this review is intended to address:

1. The basic physics of lasers.
2. The general applicability of lasers in surgical practice.
3. The role of lasers in spinal surgery.
4. Review of pertinent literature with emphasis on outcomes.

In spinal surgery, the laser has been most widely applied to discectomy. The general concept of laser-assisted discectomy evolved from the development of percutaneous techniques.

Basic Physics of Lasers

Laser is an acronym for light amplification by stimulated emission of radiation. In this case, "light" refers to the ultraviolet (UV) (150 to 400 nm), visible (390 to 700 nm) and infrared (greater than 700 nm) portions of the electromagnetic spectrum produced by "stimulated emission," a process that imparts the monochromaticity and coherence of laser light.

When a molecule absorbs energy, a transition occurs in its energy state. The nature of this change depends on the amount of absorbed energy. High energy photons such as X-rays cause ionization events. Less energetic photons with wavelengths in the UV and visible portions of spectrum can cause electrons to change energy levels without ionization. Infrared photons cause nonionizing and nonelectronic changes in translational, vibrational and other molecular modes.

Sometime after an a molecule absorbs energy, it will spontaneously return to a lower energy state either in discrete intermediate steps or directly to the ground state, the state of minimal energy. If this decay is radiative, a photon with a wavelength proportionate to the difference in energy level is emitted at each step in this process; the shorter the wavelength, the greater the energy change and vice versa.

In the process of stimulated emission, a photon of the specific wavelength coincident on an atom in the excited state can cause that atom to decay to a lower energy state faster than would occur spontaneously. The incident and emitted photons then travel in the same direction (spatial coherence), are in phase (temporal coherence) and are of exactly the same wavelength (monochromatic). The word laser actually represents the principle but is nowadays used to describe the source of the laser beam.

The main components of the laser are the laser active light emitting medium and an optical resonator, which usually consists of two mirrors. The first laser was constructed in 1960 by Thomas Maiman.[1] It consisted of a ruby laser stimulated by a flash bulb and emitted light in the red spectral range of 694 nm.

Today the laser principle can be adapted to a wide range of spectra and power outputs.

Laser power is measured in watts (W), a derived unit of power in the International System of Units (SI). Watts measure the rate of energy conversion. One watt is equivalent to 1 joule (J) of energy per second. In mechanical energy terms, one watt is the rate at which work is done when an object is moved at a speed of one meter per second against a force of one newton. Laser power outputs vary between nanowatts (nW) (10^{-9} W) and terrawatts (TW) (10^{12} W).

Lasers are used in a wide variety of applications including CD players, CD-ROM drives, fiber optic cables, measurement and instrumentation, mining and tunnel survey, cutting, welding, surface treatments and surgery. Laser media can emit wavelengths from several hundred mm to a few nm in the soft X-ray range. The physical devices range from a few mm long to entire buildings in size. The wavelength and output power of any particular laser are defined by the application for which they are intended. The types of lasers most used in surgical applications are shown in **Table 1**.

Table 1. Lasers Used in Surgical Applications[2]

Type	State	Wavelength	Power	Operating Modus
Nd:YAG	Solid	1.06 μm	1 W to 3 KW	Continuous and pulsed
CO_2	Gas	10.6 μm	1 W to 40 KW	Continuous and pulsed
Argon-Ion	Gas	Approx. 500 nm	1 mW to 150 W	Continuous and pulsed

General Applicability of Lasers in Surgical Practice

As a surgical tool, the laser is capable of three basic functions[2]:

1. When transmitted through optical fibers, it behaves as a light source.
2. When focused on a point, it can cauterize deeply as it cuts, reducing the surgical trauma caused by a knife.
3. It can vaporize the surface of a tissue.

The first clinical uses of lasers involving the spine and spinal cord are reported by Ascher[3] and Takizawa[4] who used the CO_2 laser for the removal of small spinal cord tumors as well as meningiomas. The use of the CO_2 laser for the removal of extra-axial and intra-axial spinal tumors was more extensively reported by Edwards et al[5] in 1983. Advances in CO_2 laser technology allowed variable spot diameters and increased precision by internally aligning the visible aiming beam with the invisible CO_2 treating beam. Because of these characteristics, some have felt that in neurosurgical procedures, the CO_2 laser had greater applicability than the argon and the YAG (Nd:YAG (neodymium-doped yttrium aluminium garnet [Nd:Y3Al5O12]) lasers. However, Powers and Edwards et al[6] also reported the successful use of the argon laser in intra– and extra–axial spinal cord tumors, particularly medulloblastomas and ependymomas. They found that the argon laser was particularly well suited to excise moderately vascular lesions such as hemangioblastomas. The argon beam tended to coagulate rather than cut directly into the tumor bulk. Continuous application of a defocused beam with constant irrigation produced progressive vascular thrombosis and tumor shrinkage. This shrinkage developed a plane around the tumor and facilitated its removal. Other authors[7] have suggested that the Nd:YAG laser was also particularly suitable for this application.

Subsequent use of the lasers has been reported for the production of dorsal root entry zone (DREZ) lesions. The use of the laser in making DREZ lesions[8] produced longitudinal series of "craters." This technique is reported to be less traumatic, but equally effective as radiofrequency lesions. Somewhat similar use of lasers has been reported for the treatment of spasticity and chronic pain.[5] The use of lasers to fenestrate the dorsolateral columns with reconstruction without shunting of the arachnoid and dura for the treatment of syringomyelia has also been reported.[6]

The Role of Lasers in Spinal Surgery

In spinal surgery, the laser has been most widely applied to discectomy.[9] The general concept of laser-assisted discectomy evolved from the development of percutaneous techniques.

Percutaneous nucleotomy was first described by Hijikata[10] as a technique involving a partial resection of disc material via posterolateral approach under local anesthesia. In 1983, Kambin and Gellman[11] performed a dorsolateral discectomy by inserting a Craig needle and small forceps in the disc space, and in 1985, Onik and colleagues[12] introduced a nucleotomy for percutaneous lumbar discectomy. Subsequently in 1986, Kambin and Sampson[13] initiated the use of fluoroscopy for percutaneous discectomy. During this time period, Ascher and Heppner[14] used carbon dioxide and Nd lasers to treat lumbar disc disease. Their method involved measuring intradiscal pressure before and after laser discectomy by using a saline manometer placed within the center of the disc. These authors postulated that the removal of even a small volume of tissue from the disc caused a corresponding decrease in the intradiscal pressure, thus relieving pain and inflammation.

In 1990 Yonezawa[15] used an Nd:YAG laser to transmit energy through a double lumen needle with a bare quartz fiber. Their tip-type pressure transducer was similarly able to record intradiscal pressure. The KTP laser uses a beam generated by a Nd:YAG laser directed through a potassium-titanyl-phosphate (KTP) crystal to produce a beam in the green visible spectrum. Use of the KTP laser for lumbar disc ablation was first reported in 1992.[16] Side-firing probes, which provide better directional control and visualization, were subsequently developed. The side-firing probe reduces the risk to anterior structures such as the vena cava, aorta, and iliac vessels. Yeung[17] recommended injecting the disc with indocyanine green to act as a chromophobe, thus maximizing delivery and minimizing the chance of injury to adjacent structures. The holmium-YAG (Hol:YAG) system uses a unique pulsed laser that enables pulse width and frequency adjustment to cause disc cavitation and reduce intradiscal pressure while minimizing injury to adjacent structures.

Review of Pertinent Literature

There are no reported prospective controlled studies reporting percutaneous laser discectomy. Choy and colleagues[18] reported the use of the Nd:YAG laser to treat lumbar disc disease in 1987. Inclusion criteria were based on the presence of a documented nonsequestered disc herniation in patients with radicular pain corresponding to the level of disc involvement. Exclusion criteria included a previous surgery at the level of the disc to be treated, as well as absence of spinal stenosis, facet impingement, lateral recess stenosis, advanced degenerative disc disease or spondylolisthesis. Patients with active litigation and Workers' Compensation were also excluded. Choy employed MacNab criteria[19] for response to treatment At 26-month follow-up, 78.4% of patients rated good to fair relief of pain. Notably, all of the failures (21.6%) had subsequent open surgical treatment.

Yeung[17] reported an 84% rate of good or excellent results with a KTP/532 laser. Sherk,[20] however, observed no difference between treated and controlled groups in an analysis of response to pain questionnaire or the presence of physical signs.

Ohnmeiss et al[21] collected 204 patients who had undergone KTP laser disc decompression by a nonspecified number of surgeons at three surgical centers. Only 41 of the patients selected by two independent reviewers fit the inclusion criteria similar to those used by Choy. Using similar outcome measurements, 70.7% had "successful results." Ohnmeiss' review noted that the surgeons in this retrospective study concluded that laser disc decompression was appropriate for "that type of disc which does not correspond to conservative measurements and is not bad enough to operate on." She stressed that failure stretching the inclusion criteria resulted in clinical failure.

More recently Ahn[22] describes the role of lasers in percutaneous lumbar discectomy for recurrent disc herniation. In this retrospective study using the MacNab criteria, 81.4% of the patients had good or fair outcomes. It should be stressed that the laser in these cases was applied through posterolateral approach and not through the original incision thereby avoiding the possible complications of operating through a scarred area.

One of the largest series was reported by Savitz in 1998.[23] Over a six-year period, 300 percutaneous laser discectomies were performed with a YAG laser in a community hospital. The outcome data are difficult to interpret. Savitz reports fewer than 2% required a second surgery. The only postoperative sequelae recorded were one psoas hematoma which resolved, and sympathetic mediated pain which occurred in 5% of patients. Savitz attributes the apparent safety of this procedure to his ability to visualize, via the cannula, the area of the annulus to be fenestrated, verify the status of the nerve root and monitor laser hemostasis and vaporization.

To increase further the safety of percutaneous laser discectomy Jako and Cselik[24] are developing a high-intensity diode laser at 980 nm wavelength to be used with a stereotactic computer-assisted navigation system. Navigation system accuracy was reported better than 2% when tracking the instruments from pre-acquired formatted CT reconstructed images in a porcine model. They also reported that tracking of the instrument from pre-acquired CT with reconstructed images reduced overall radiation exposure by limiting the need for continuous intra-operative C-arm fluoroscopy. The application of this technique to humans has yet to be reported.

Ahn[25] and his colleagues used a sophisticated side-firing Hol:YAG laser for posterolateral percutaneous endoscopic foraminotomy. In essence, Ahn utilized the laser and endoscopic forceps to undercut hypertrophy of the superior facet in L5-S1 foraminal or exit zone stenosis. Limited efficacy information is reported, but this technique attempts to apply laser technology to spine procedures other than discectomy.

Conclusion

Evidence-based data regarding application of laser technologies to the spine are limited. Challenging variables include patient selection, operative indications and the types of laser used. There are no prospective studies comparing percutaneous discectomy with conventional microlumbar discectomy or minimally invasive procedures, eg, the METRx. These shortcomings make analysis difficult. To date, laser discectomy may be more effective in attracting patients than in treating them.

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J Stern: nothing to disclose.

COMMENTARY

Lasers in Spine Surgery... and Other Controversial Topics

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Introduction

In the spirit of balanced reporting, Dr. Eeric Truumees asked me to comment on the use of lasers in spine surgery. From our days together at the Cleveland Clinic, he was aware of my experience in developing the holmium laser since the early 1990s. As I embraced the task, I quickly realized the depth, complexity and controversy of the issues surrounding its use, and more significantly, its marketing.

First, the laser is a tool used in certain types of surgical procedures by delivering a focused amount of high energy to a specific tissue thereby altering its molecular and structural characteristics. For example, as we'll see later, the laser can shrink or remove the tissue compressing a nerve.

Second, it is not the laser that determines clinical outcomes but the surgeon using it. Having been involved in the development of pedicle screw fixation in the 1980s, I experienced the backlash and condemnation firsthand. Some claimed "those damn screws are dangerous and hurting patients." (It led to a national class action law suit!) Today, pedicle screw fixation is a standard part of lumbar fusion surgery. They remain just as "dangerous" in the hands of the wrong person.

Third, in spine care, 90% of what we treat—pain—is subjective. The degenerative condition underlying this pain does not have a "cure" and will increase in prevalence in coming years. Multiple specialties each provide a variety of alternate approaches devoted to treating this epidemic. This spectrum of treatment options implies that no one solution answers the challenges of spine care.

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Medical Marketing

Airline magazines, newspapers and the internet often carry advertisements for laser spine surgery, robotic prostate and heart surgery, endoscopic hand surgery, same-day dental reconstruction centers, cosmetic and eye surgery, and other minimally invasive approaches to a variety of conditions. Further observation reveals individual practitioners, group practices and large well known, respected academic medical centers are engaging in similar marketing schemes to do one thing: attract patients. This phenomenon extends beyond the United States to practices worldwide.

Decreasing reimbursements, consolidation of small single specialty practices into large multiperson, multilocation practices and Medicare and health insurance uncertainties are pressuring stakeholders to increase business and ensure survival in a very competitive and unsure economic environment. Very few physicians have received training in these marketing activities or their formal, ethical guidelines. Especially as it relates to Internet marketing, even our professional organizations offer little guidance. "Medical marketing and advertising" firms are emerging with little real experience in medicine. They simply apply traditional, nonmedical paradigms to sell medical and surgical procedures as they would any other product. The medical community is spending significant sums of money pursuing these services at great risk to its credibility. It is not in our nature.

The Internet has also opened a new world to inquisitive persons seeking the latest and greatest procedures available. These individuals represent all age groups, geographic locations and economic backgrounds. In order to engage these "contacts," the medical community has embraced this technology through WebMD, Spine Universe and other sites. To grow their businesses, this technology has allowed everyone from the single practitioner to pharmaceutical companies to become active players in this increasingly effective medium.

Almost every physician has a Web site. But that is only the beginning. To effectively attract patients, expensive search engine optimization, pay-per-click ads, social networking and paid Internet advertising services (those pop-up ads) are required. In this increasingly harsh marketplace, collegiality and evidence-based medicine are the first to suffer. Then again, outcomes research bores the general public. Level I evidence doesn't sell and marketing firms seek only to sell their client.

The term laser surgery, whether in eye, ENT, urological, dermatological, neurosurgical, orthopedic or spine surgery attracts potential patients looking for less invasive "high tech" alternatives to more traditional open procedures. Potential problems arise from the claims made about what this technology can or cannot do. Similar enthusiasm regarding stem cell therapies as the ultimate minimally invasive procedure is emerging. The *New York Times* recently reported on the hundreds of thousands of US citizens going abroad each year for stem cell therapies not currently available in the USA.

The public has become acutely aware of the absence of "curative" treatments for spinal degeneration. When the few well-designed, controlled studies are publicized, patients actively question our recommendations. More frequently, patients seek second and third opinions. They are increasingly willing to travel to get information. For example, for single-level symptomatic lumbar spinal stenosis, advertised treatment options include chiropractic, decompression machines, acupuncture, interventional pain procedures, physical therapy and, of course, surgery. Consider further the surgical options; laminectomy alone, laminectomy and fusion, interspinous spacers, microdecompression and endoscopic decompression. In the right hands, any of these procedures could be effective in properly indicated patients.

The problem lies in the small percentage of surgeons with experience in even some of the more than 36 surgical procedures for degenerative spine conditions. When innovative procedures are developed, those surgeons not familiar with it often react with skepticism, criticism and condemnation.

Applications of the Holmium:YAG Laser in Spine Surgery

The laser is a tool like any other and is not a "miracle maker." Lasers are powerful and versatile devices allowing surgeons to do a significant amount of work in a very small space. Applications include percutaneous, endoscopic, microscopic and traditional open and revision procedures. A variety of lasers are used in spine surgery, but I will restrict my comments here to the Holmium:YAG laser (Coherent, Trimedyne). The Hol:YAG laser can only cut, shrink or vaporize soft tissue, especially tissues with high water content such as nucleus pulposus, joint cartilage, and ligaments. While the Hol:YAG works very well on fibrous scar tissue, IT WILL NOT CUT BONE SAFELY. When this laser contacts bone and calcium, it creates an instant flash or spark that can damage surrounding tissues. Of course, the greater the laser's power, the greater the danger.

The Hol:YAG laser is fiber optically delivered through a small-head hand piece making it suitable for a variety of procedures. Straight, angled and side-firing versions are available as is a version effective through endoscopic working channels.

This laser is intermittent or pulsed. User settings allow a change of pulse rate per second (rate) and pulse power (watts). These factors multiplied yield the energy delivered (pulse rate/sec x watts = joules), ranging from a few hundred to several thousand joules. Most spine procedures use a power setting of 5 to 20 watts/sec and average 1,000 to 3,000 joules of laser energy delivered. As energy delivered increases, excessive tissue heating can occur.

The Hol:YAG laser is also appealing because the heat penetration into tissue is minimal, typically 0.5 mm per pulse. This limited penetration renders it very safe around nerve roots, the dura and other soft tissue structures. In contrast, the Nd:YAG laser penetrates up to 3 to 4 mm. With the Hol:YAG, what you see is what you get. Under magnification, I have removed scar tissue and cysts directly on the dura under magnification without nerve injury.

These characteristics foster routine Hol:YAG laser use routinely by otolaryngologists, urologists, arthroscopic surgeons, cranial neurosurgeons, percutaneous discectomy and nerve ablation proceduralists and, of course, spine surgeons. Beginning in 1991, I have trained hundreds of surgeons to use the Hol:YAG in spine surgery including staff surgeons, residents and fellows at the Cleveland Clinic. More than a dozen of my spine colleagues, surgeons and pain management specialists in southeast Florida, use it on a routine basis.

Spine Applications of the Hol:YAG Laser

Percutaneous Discectomy. Percutaneous discectomy has been performed since the early 1980s. A side-firing Hol:YAG laser delivered through a fiber optic endoscope (Lase™ System, Clarus Medical) is available for this technique. Other options include coblation (ArthroCare), endoscopic manual percutaneous discectomy (Kamdin/Stortz), automated suction percutaneous discectomy (Nucleotome, Clarus) and the IDET coil (Smith & Nephew). All procedures require the use of image intensification and the use of at least local and monitored anesthesia control or IV sedation. It can usually be performed safely in an outpatient facility. The efficacy of percutaneous disc surgery continues to be debated. Advocates claim that, in the management of disc bulges and contained herniations, percutaneous techniques are equally effective to microdiscectomy. The laser simply represents another way to perform the procedure.

Microdiscectomy and Microdecompression Surgery. Those of us who perform open microdiscectomy, microdecompression and microendoscopic decompression (MED) through small incisions understand the challenges conventional instruments pose in very small spaces. Oftentimes, a curette, pituitary rongeur, Kerrison rongeur, scalpel or osteotome can fill the entire field of view. In this setting, the Hol:YAG laser is particularly useful in vaporizing offending disc with little need for conventional instruments. The laser acts like an air-paint brush to resculpt the degenerative bulging annulus. Direct visualization, copious irrigation, constant suction/aspiration, and low power settings are the key to safe use. The laser also effectively ablates synovial cysts, especially at their point of origin on the facet joint. In this microsurgical application, the laser is simply a helpful tool. No studies evaluate the laser specifically in this application.

Epidural Endoscopic Laser Surgery. Epidural endoscopy has emerged within the past decade. Building on the success of endoscopic surgeries in other specialties, spine physicians used early small spine endoscopes in epiduroscopy to visualize the spinal canal and associated pathology. This procedure has been popular among interventional pain specialists. High flow normal saline, epidural steroids and pain medications have been injected through a working channel in the 2.7 mm endoscope. Criticisms of epiduroscopy center on the physician's inability to recognize the anatomy. The small endoscopic camera has limited clarity and resolution. The fiber optic cable's quality and the display monitor's resolution are also questioned. Today's high definition video cameras, monitors and computer image enhancement provide an impressive view through a tiny 2.7 mm endoscope. Now, a laser fiber passed through this endoscope can perform an ablation. A small group of advocates claim they can visualize and diagnose problems not seen on MR, CT or conventional X-ray images, ie, diagnostic spine endoscopy much like colonoscopy. An interactive component is also available where the endoscope actually "bumps" or probes a nerve or pathological structure and reproduces the patient's pain. Ostensibly, the problem anatomy is then vaporized and the pain resolves. Some published reports showing good clinical results describe transforaminal endoscopic decompression with the side-firing Hol:YAG laser under direct visualization.

Facet Nerve Ablation. Many believe facet degeneration is a major source of low back pain. As in the appendicular skeleton, the thinking holds that capsular tearing along with cartilage degeneration causes joint pain and inflammation of the surrounding tissue. Efforts to diagnose and treat this condition include diagnostic facet blocks, thermal, cryo and radiofrequency nerve ablation, prolotherapy, percutaneous facet screws, facet arthroplasty and laser facet nerve ablation. Most of these procedures are performed by interventional pain specialists. The laser shrinks the capsule and ablates the facet nociceptors along with the sensory branch of the posterior primary ramus. One or multiple joints can be treated in this fashion. Most reports suggest good, but temporary improvement.

Revision Spine Surgery. Perhaps one of the most challenging areas of spinal surgery involves managing patients who have had previous spinal surgery. The previous intervention ranges from percutaneous procedures to major reconstruction surgery. The role that scar tissue plays in the genesis of persistent pain remains controversial. In addition to oral and transdermal pain medication and injection therapy, other options including spine endoscopy, lysis of adhesions, dorsal column stimulators, intrathecal pain pumps and, more recently, peripheral nerve stimulators. The Hol:YAG laser has been used to release scar tissue. Outcomes of laser use in this patient population have not been reported.

Who is Doing these Procedures and What Does the Future Hold?

The laser is just another option for performing current, sometimes longstanding, procedures. A great and powerful tool, the laser's suitability depends on the experience and training of the surgeon. How this tool is presented to patients, on the other hand, has more to do with our ethics. Having transitioned from an academic to a private practice setting, I see stiff competition among doctors and even between large medical centers. Everyone waits for the annual *US News and World Report* "rankings." We must not stretch the truth to attract patients. More importantly, we have to acknowledge the public's increasing demand for alternatives to conventional spine care. Everyone knows someone who has had back surgery and is now worse! The population is becoming more informed and savvy. The Internet is proving to be a powerful vehicle to facilitate this process. Our Web sites are becoming our "storefronts" to the world. We say who we are, what we do and how we do it. How we use this technology is a personal choice. Our performance is constantly being evaluated and reported on more and more by our patients themselves through such Internet sites as DoctorScorecard, HealthGrades, RateMDs, Vitals, PhysicianReports, Facebook, MySpace, Twitter, YouTube, and other social or posting locations. Just Google your name! Patients tell me all the time: "You won't believe what is written about you on the Internet."

Through technology development and personal ingenuity, minimally invasive spine surgery is evolving daily. In addition to neurosurgeons and orthopedic spine surgeons, interventional pain specialists, neurologists, rheumatologists, physiatrists, radiologists, primary care and sports medicine doctors are beginning to perform these procedures. How do we address and support this growth? How do we train, credential and monitor these physicians and procedures if at all?

Is the timing right for NASS to take a leadership role in better organizing the spine care world? Is this the domain of our specialty organizations and certifying boards? Or should we let it go as free-for-all?

Perhaps a new Spinal Medicine and Surgery specialty complete with ACGME certification could arise. Even spine fellowship training programs lack comprehensive exposure to all interventional and surgical spine procedures. A physician with that training could provide any type of care necessary. We would not be trying to stuff the proverbial square peg into the round hole.

Author Disclosure

R Biscup: Consultant & Royalties, Depuy, Medtronic. Level F.

RADIOLOGY ROUNDS

Vertebral Hemangiomas

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Case Presentation: L4 Hemangioma with Radiculopathy

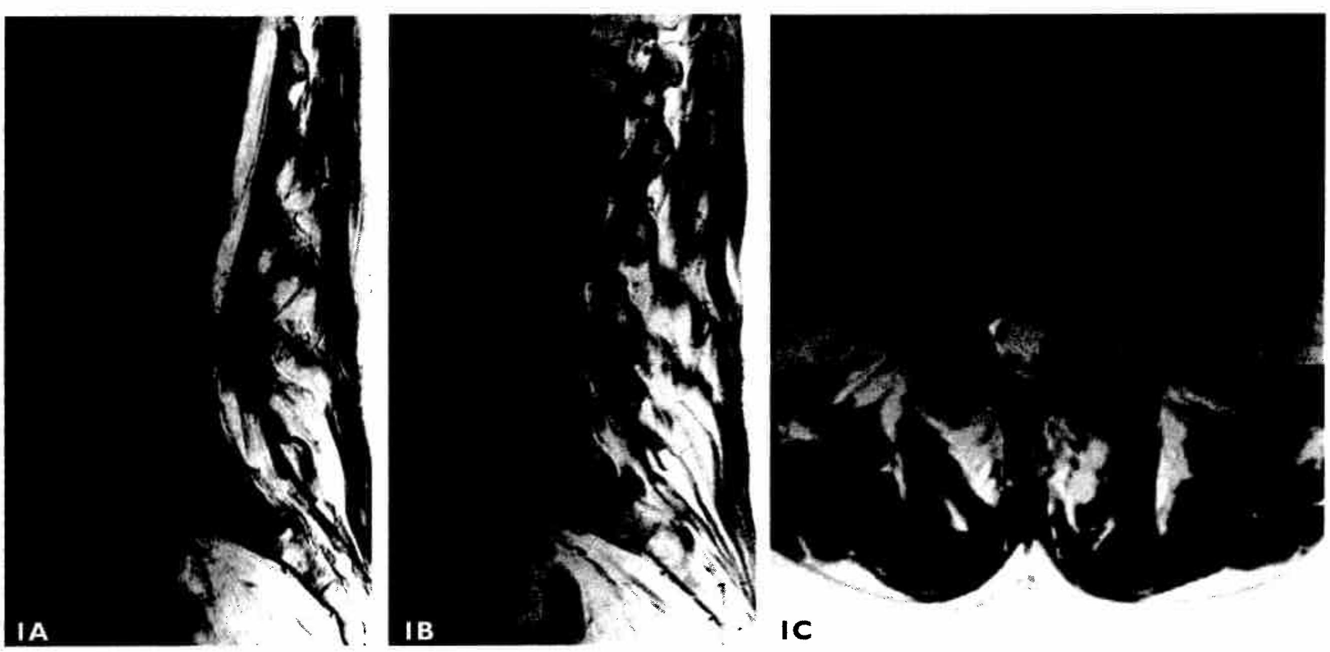
This patient is a previously healthy 54-year-old female who presented to an outside institution complaining of lumbar radiculopathy. She ultimately underwent a hemilaminotomy with attempted decompression after an MRI demonstrated a "soft disc." No plain films had been ordered prior to surgery. At surgery, the procedure was aborted when she experienced 4 liters of blood loss.

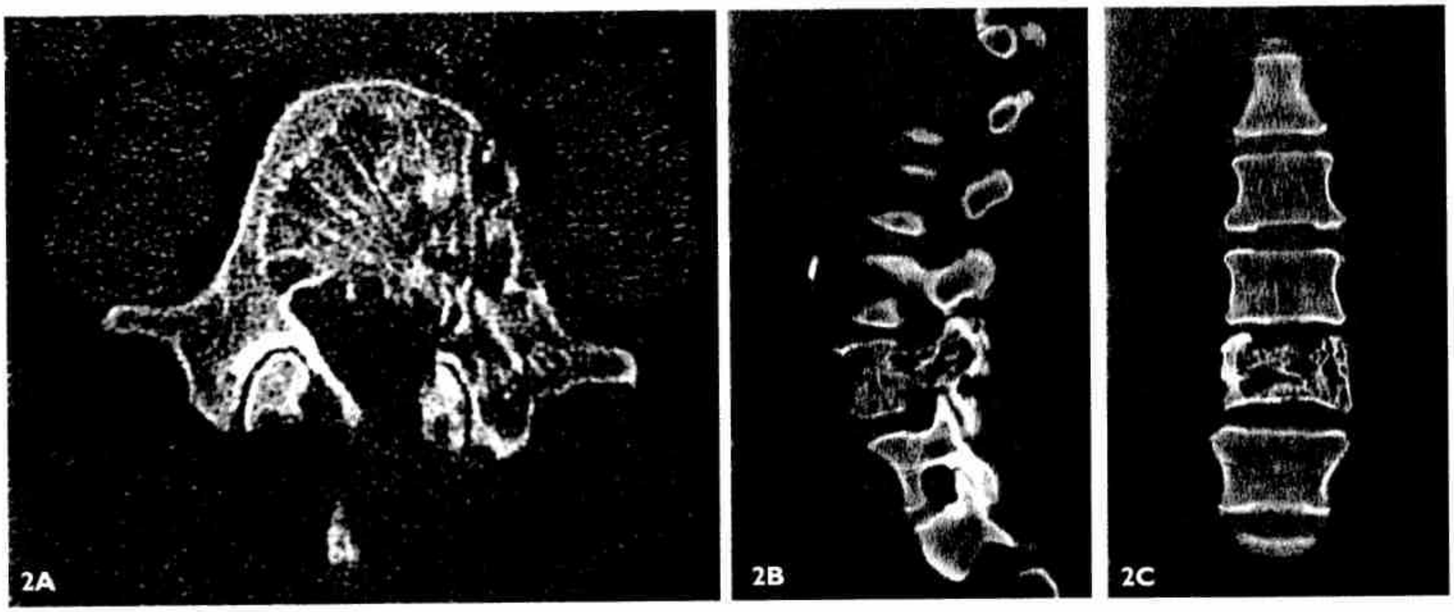
Later, she was referred to Radiation Oncology at our institution for a presumed metastasis. No clear tissue diagnosis was available. Radiation Oncology transferred the patient to Interventional Neuroradiology for possible biopsy and vertebroplasty. Repeat imaging included an MRI (**Figures 1 A-C,** below) demonstrating diffuse involvement of the vertebral body with apparent preservation of the disc space and some collapse of the superior end plate as well as some expansion of the cortex. Significant spillage of tumor into the canal is demonstrated with stenosis.

The patient's increasing leg pain and weakness led the neuroradiologist to refer her to spine surgery for consideration of decompression and stabilization. Based on the soft tissue spill seen on the MRI, a CT scan was requested to further assess bone and soft tissue detail. A lytic lesion involving a large portion of the vertebral body with extension into the left pedicle and posterior elements was noted. Some early collapse of the end plates was noted as was ongoing spill of soft tissue into the spinal canal. A needle biopsy confirmed a highly vascular lesion consistent with hemangioma (**Figures 2 A-C,** next page).

Except for its lumbar location, this lesion meets all of the criteria for an aggressive hemangioma, including involvement of the entire vertebral body, indistinct cortical margins, irregular honeycomb pattern, soft tissue spill, extension into posterior neural arch and a stromal pattern of decreased fat and increased vascular content (low T1, high T2).

We discussed treatment options with the patient. In this young patient, evidence seems to be lacking for the long-term efficacy of embolization alone. Ethanol injection did not

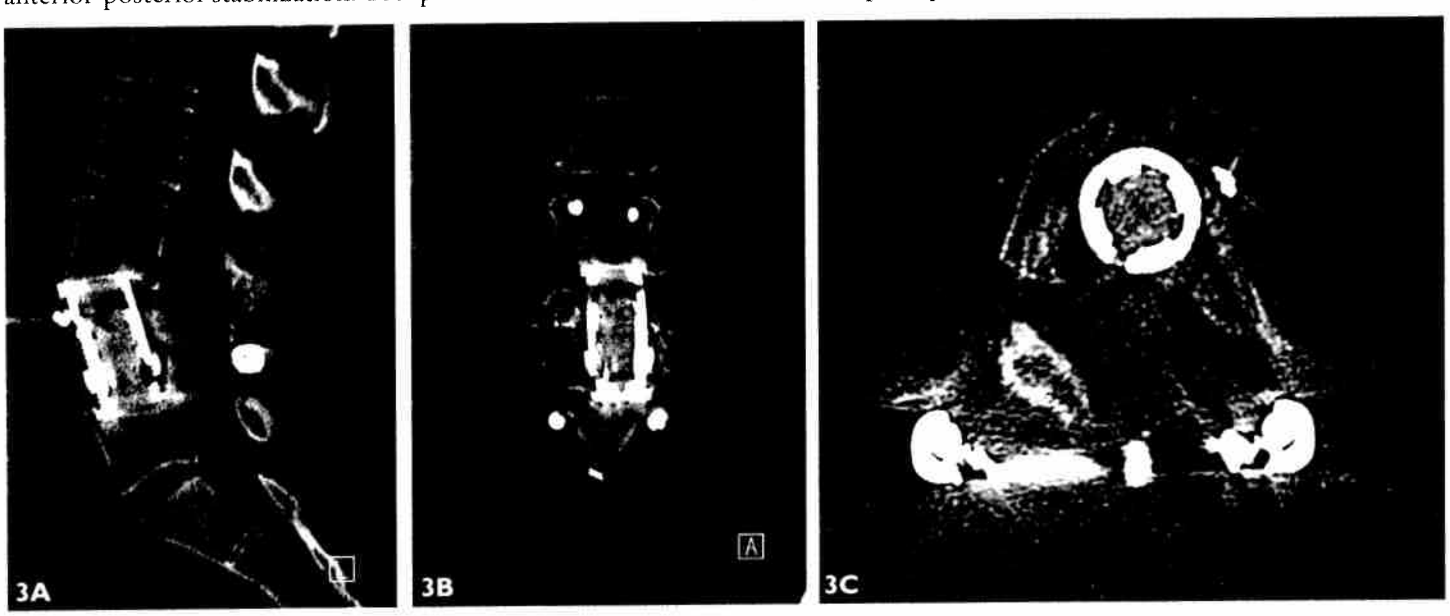


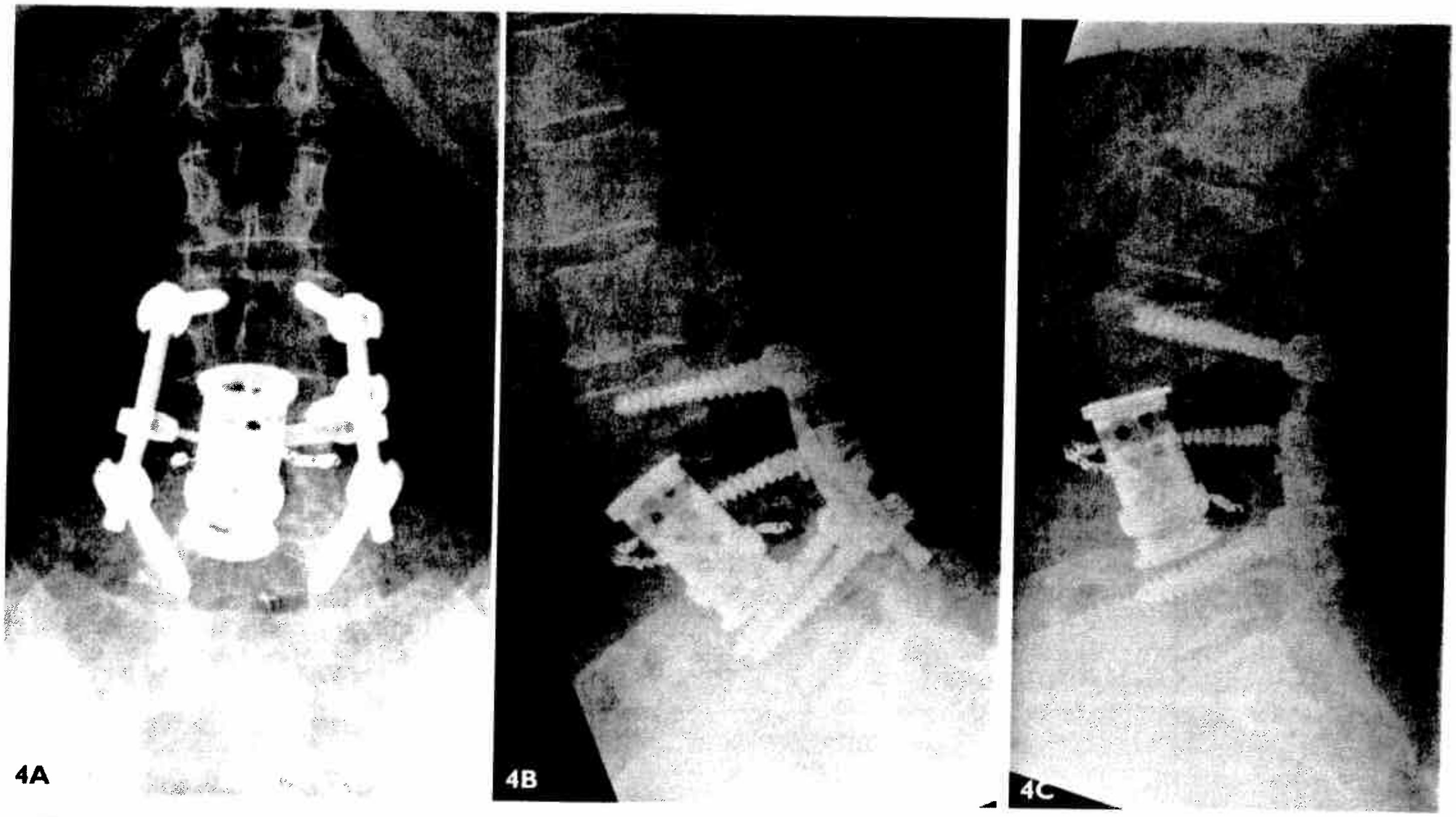


address the structural deficiencies caused by the three-column spinal involvement. While we have extensive experience with vertebral augmentation procedures (vertebroplasty and kyphoplasty) in contained hemangiomas, a percutaneous approach would not address the patient's neurologic compromise. At this point, the ability of PMMA to control an aggressive hemangioma over the long term remains questionable. Finally, the risk of PMMA leakage was felt to be high given the marked cortical destruction. In older and sicker patients, a hybrid open approach utilizing PMMA for the anterior column stabilization and embolization is considered.

Given the aggressiveness of the lesion, the patients relatively young age, previous failed surgery, and neurologic complaints, we recommended a wide resection for decompression and anterior-posterior stabilization. Preoperative embolization was performed in the neuroradiology department. A two-incision approach was undertaken, beginning with a retroperitoneal approach to the L4 level. With the patient in a semi-lateral position, we used an O-Arm to plan and then assess the vertebral resection. The patient was then positioned prone for posterior stabilization and resection of the affected posterior elements, including the right L4 pedicle. Cancellous, autogenous bone graft was harvested through a small cortical window from the posterior iliac crest.

Postoperative imaging includes a 4-month postop CT scan, **Figure 3,** including sagittal (A), coronal (B) and axial (C) images. Excellent early through-growth of the bone graft is noted. The slight subsidence of the expandable cage in the inferior L3 end plate was noted immediately after surgery and has remained stable. No postoperative external brace was employed.





This patient did extremely well after her surgery. Despite the size of the surgery, she had less pain immediately in the post-operative period than she did preoperatively. A total of 300cc of blood loss was recorded. Subsequently, at six months, plain films (**Figure 4,** above) were obtained, including AP (A), flexion (B) and extension (C) lateral views. Additional incorporation of the posterolateral bone graft is noted. There is no excessive motion with flexion-extension. The patient is essentially symptom free, but will undergo yearly surveillance.

What do you think? What would you have done differently?

Vertebral Hemangiomas Review

In the spine, vertebral hemangiomas may involve the epidural space or the vertebral body.[1] These lesions may be small, benign, incidental findings or larger, more aggressive lesions causing cord compression. Some have pathognomonic imaging findings. Others may be difficult to differentiate from malignant neoplasms. We will examine the incidence, pathophysiology, evaluation and treatment options of spinal hemangiomas.

Incidence

Asymptomatic vertebral hemangiomas are common benign vascular tumors identified in 10% to 27% of specimens in autopsy series.[2-6] In population-wide plain radiographic surveys, the estimated incidence falls to 10% to 12%, while reported MRI studies have ranged from 2.3% to 26.9% depending on the levels investigated.[7,8] Although they can be seen from the upper cervical to the sacral spine, they are most commonly found in the lower thoracic and upper lumbar spine.[9-11] These lesions are most often solitary, but up to a third occur as contiguous or noncontiguous multiples, especially in the thoracic spine. Symptomatic or treated hemangiomas account for only 2% to 3% of spinal tumors. Less commonly, patients may present with a syndrome of multiple hemangiomas and may carry an increased risk of progression and are therefore more likely to become symptomatic.[12]

Vertebral hemangiomas range in size from subcentimeter lesions to those replacing the entire vertebral body. In survey studies, most (65%) were less than 10 mm in diameter.[7] While most are confined to the vertebral centrum, 10% to 15% reach the posterior cortex. Less frequently, the lesions extend into the surrounding soft tissues, including the spinal canal, or into the posterior arch. Rarely, hemangiomas can exclusively affect the posterior elements.

No clear racial or ethnic propensity has been identified, but these lesions are more common in women.[7] Other studies have found that women are more likely to be symptomatic. Osseous hemangiomas can be encountered in any age group, but the peak incidence lies in the fifth decade. Unlike their cutaneous counterparts, they are rare in children.[13]

Pathophysiology

Vertebral hemangiomas usually arise from the medullary cavity. Uncommonly, surface-based hemangiomas are encountered in the cortex, periosteum and subperiosteal regions.[14] Grossly, these lesions are well-demarcated, with unencapsulated cystic cavities.[15] Microscopic examination reveals hamartomatous proliferations of vascular tissue within endothelium-lined spaces.[16] The angiomatous tissue consists of consists of thin-walled vessels and sinuses interspersed among sparse longitudinally oriented trabeculae and mixed matrix consisting of nonvascular tissues such as fat, smooth muscle and fibrous tissue.[4,16,17] Based on the predominant type of vascular channel present, four histologic variants have been described, ie, cavernous, capillary, arteriovenous and venous types, and these subgroups can coexist. In the vertebral column, the capillary hemangiomas predominate.

Natural History

The growth rates and natural history of vertebral hemangiomas are not very well known. Typically these lesions are termed "slow growing."[4,16] More likely vertebral hemangiomas have a variable natural history. Many stay stable over time, while others grow quickly.[13,18] Although locally aggressive growth patterns can radiographically mimic malignant lesions, malignant degeneration is uncommon. Although unclear, reported risk factors for progression include female gender and posterior element involvement. After asymptomatic lesions have been identified, there are no clear rules for further follow-up. Certainly small lesions with pathognomic findings may require no further evaluation. However, larger lesions may benefit from serial scanning. The interval should inversely relate to lesion size, pedicular involvement and cortical disruption.

Clinical Evaluation

Vertebral hemangiomas are typically evaluated in one of two settings. Most commonly these lesions are seen incidentally during the evaluation for other spinal or thoracoabdominal complaints.[4] In that setting, the goals of evaluation include: identification of the source of symptoms, ruling out malignant or other unfavorable lesions, and the identification of aggressive hemangiomas.[4,11,16,19] The differential diagnosis should include spinal meningioma, Paget's disease, multiple myeloma, aneurismal bone cyst and spinal metastases. A separate evaluation pathway arises from the less common symptomatic hemagiona.[3,20] Identified early, aggressive lesions may benefit from less invasive management options.[13] [**Table I**] More typically, these lesions can become symptomatic either by weakening the vertebral body resulting in pathologic fracture, or from neurologic compression from fracture fragments or direct compression from the hemangioma itself.[5,21-25] Hemangiomas can also become symptomatic because of spontaneous hemorrhaging, often without a precipitating event.[3,20,26]

Radiographic evaluation begins with plain films, which may demonstrate the classic findings of vertically oriented vertebral lucencies separated by thickened trabecular bone ("honeycombing"). These changes, while variably apparent on plain films, are seen in nearly all cases.[27] This preferential resorption of horizontal trabeculae with reinforcement of the vertical has also been described as "Irish lace," lattice-like, accordion-like, or corduroy in appearance and is the result of reinforcement of the osseous network resorbed by the adjacent vascular channels. This can be distinguished from Paget's disease, where the trabecular pattern has been termed "picture framing" due to prominent horizontal vertebral trabeculae. In osteoporosis, the horizontal trabeculae are lost before the vertical as well.[28]

Table I: Findings of an Aggressive Hemangioma[13,92,93]

- More aggressive lesions get harder and harder to distinguish from malignant lesions
- Body enlargement
- Occur between T3 and T9
- Entire body involved
- Indistinct cortical margins
- Irregular honeycomb pattern
- Soft tissue spill
- Extension into posterior neural arch
- Decreased fat and increased vascular content (low T1, high T2)

The complex vertebral anatomy renders computed tomography (CT) more useful than conventional radiography for evaluating location and differentiating hemangiomas from other bony destructive lesions.[29] [**Figures 5A and 5B**] On the axial view, the thickened trabeculae are seen in cross section as small punctate areas of high attenuation and have therefore been referred to as the "polka dot sign" due to their appearance.[30] The axial view may be useful for identifying regional spread.[31,32]

MRI can be used to characterize hemangioma aggressiveness, degree of soft tissue extension and for evidence of neurologic compression. Lesion aggressiveness relates to its proportion of fat and vascularity.[33] On T1 sequences, high fat areas confer a high signal, while highly vascular areas demonstrate high signal on T2 with low T1 signal. MRI is the best imaging study for identifying extraosseous spill,[34] which can take on different appearances. Typically, the epidural component is isointense to cord on both T1 and T2 sequences and with gadolinium enhances avidly and homogenously.

Spinal angiography is typically utilized for preoperative planning and embolization of symptomatic spinal hemangiomas. In some areas, angiography results are used to select among the various treatment options or to confirm the diagnosis by its defining vascular pattern.[35,36] Hemangiomas are typically seen as cold spots on scintigraphy. Occasionally, they light up, especially in the context of trabecular collapse, remodeling or pathologic fracture. Even benign hemangiomas can occasionally light up[37] and act as false positives during metastatic work-ups. While the increasing use of SPECT and nontechnetium labeling improves sensitive and specificity[38] and allows better differentiation between aggressive hemangiomas and metastatic lesions,[39] they can also be seen as vertebral "cold spots" on PET Scanning for metastatic work-up.[40]

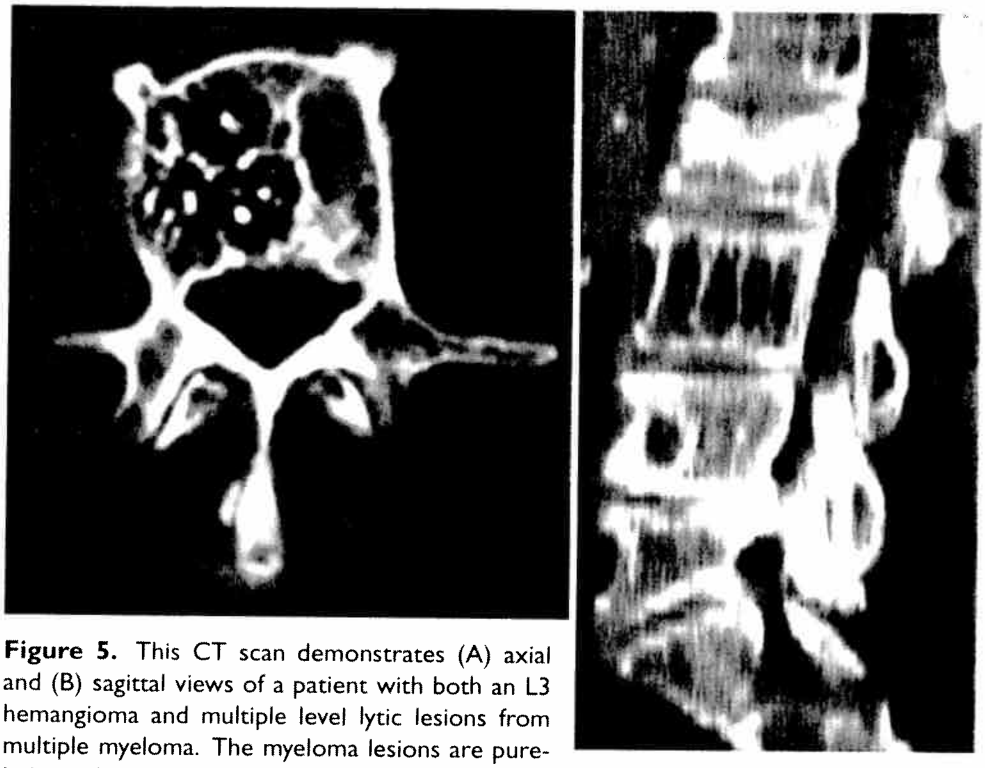


Figure 5. This CT scan demonstrates (A) axial and (B) sagittal views of a patient with both an L3 hemangioma and multiple level lytic lesions from multiple myeloma. The myeloma lesions are purely lytic, the hemangioma demonstrates classic erosions of the horizontal trabeculae with thickening of the vertical trabeculae. On the axial view, this appearance (on the right side of the body) is termed the "polka dot" sign. On the lateral a corduroy appearance or jailhouse striations are noted.

Treatment Options

Most vertebral hemangiomas are asymptomatic and require no treatment. However, in a small subset of patients, symptoms can arise from either vertebral body or neural arch expansion or from direct epidural soft tissue invasion. Traditionally, direct surgical resection of these highly vascular tumors was avoided because of potential complications arising from massive hemorrhaging.[4,5,16,25,41-44] As a result, radiation therapy or limited decompressive surgery with postoperative irradiation was typically recommended. More recently, however, the use of preoperative transarterial embolization combined with modern reconstructive techniques has made surgical interventions a more practical option.[11,45-49] These options range from percutaneous minimally invasive procedures such as ethanol injection, isolated transarterial embolization and cement augmentation (vertebroplasty and kyphoplasty) to open surgery. [**Figure 6**]

Ethanol Injection

Percutaneous or open ethanol injection is used as a primary and adjunctive treatment for vertebral hemangiomas. In 1994, Heiss et al[50] reported relief of spinal cord compression after percutaneous ethanol injection in two patients. Since then, reports of ethanol vertebroplasty effectively treating both pain and neurological deficits have multiplied.[51-54]

Transarterial Embolization

In addition to its use as a preoperative technique to reduce the risk for blood loss,[4,24,42,46,47,55] transarterial embolization has also been employed as sole therapy.[56-60] Others recommend that embolization be followed by radiation to improve durability of relief. Unfortunately, long-term studies on any of these approaches are limited. Although controversial, some studies have shown that embolization alone can reduce hemangioma size, provide pain relief, and relieve subarachnoid canal compromise.[58,60-62] In the Acosta series, 3 of 4 patients who underwent technically successful embolization had symptom resolution without further treatment. The authors reported that embolization was effective as a sole therapy for patients with pain and without neurologic symptoms.[27] However, in a study by Smith et al on two patients with neurological symptoms embolization alone failed to provide clinical improvement.[60]

Radiotherapy

Historically, because hemangiomas are typically radiosensitive, low-dose radiotherapy (30 to 40 Gy) has been utilized for the treatment of treatment of symptomatic lesions.[4,63,64] It is believed that interval radiotherapy can diminish lesional vascularity and aggressiveness.[65] Patients with multiple symptomatic hemangiomas may be particularly well suited for treatment with radiotherapy. Although its use is typically limited to patients with low back pain, reports of successful reversal of neurological deficits have been described, but this still remains controversial.[4,25,62,63,66,67] In these cases, most authors recommend surgical decompression.[4,25,62,67] However, in the case of a subtotal resection postoperative irradiation can be considered.[4,11,24,41,45, 46,55,64,68-70] Reported complications include radionecrosis, skin ulceration, osteonecrosis, malignant sarcomatous degeneration, and neurologic deterioration, which can all occur as delayed complications particularly in young patients.[25,66,71]

Cement Augmentation (Vertebroplasty and Kyphoplasty)

The use of vertebroplasty for the treatment of symptomatic hemangioma was first reported by Depriester and Deramond for a C2 lesion.[72] Since then, vertebroplasty and kyphoplasty have been used throughout the cervical, thoracic and lumbar spine.[11,47,73-78] In these techniques, injection of acrylic cement into the vertebral body has lead to consistent pain relief and may

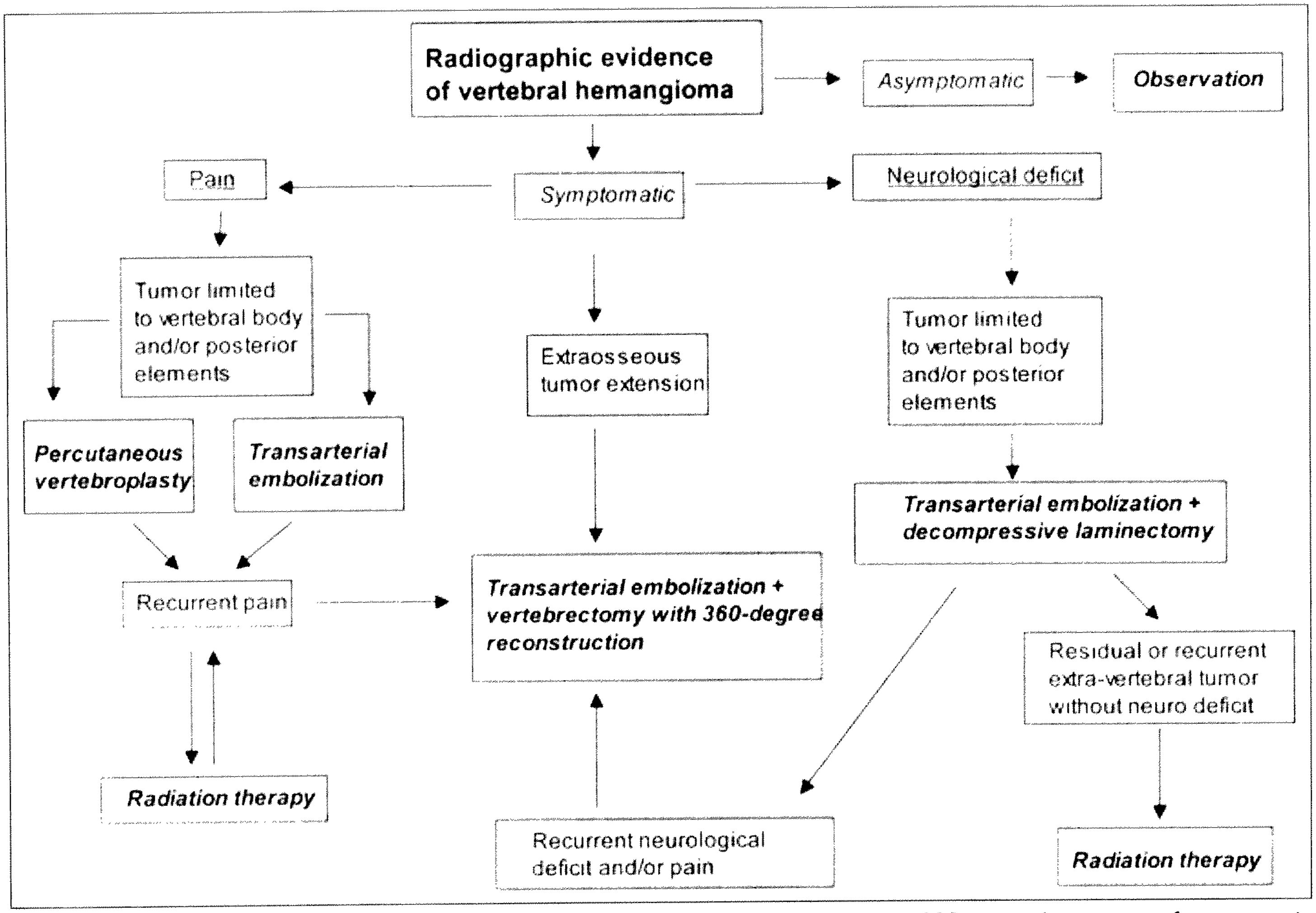


Figure 6. This algorithm was developed by Acosta and coworkers from their assessment of 20 years of treatment of symptomatic hemangiomas. Reprinted from Acosta FL Jr., Sanai N, Chi JH, et al. Comprehensive management of symptomatic and aggressive vertebral hemangiomas. *Neurosurg Clin N Am.* 2008;19(1):17-29. Copyright 2008, with permission from Elsevier.

prevent further collapse.[72-74,76,78-80] Interestingly, the mechanism for this relief remains unclear and restoration of end plate stiffness or chemical ablation of pain-sensitive nerve endings have been proposed.[74,81-83]

It has been shown, that in cases where the toxic monomer and heat of polymerization from the cement do not completely obliterate the hemangioma, recurrence of the hemangioma with expansion into spinal canal can cause recurrent cord compression.[26] Other reported complications include neural compression from direct extrusion of the cement itself.[72,82] Currently, the role of cement augmentation for the management of patients with neurological deficits remains unclear and is typically not indicated. Advantages of vertebroplasty over kyphoplasty and vice versa remain under considerable debate. Furthermore, long-term efficacy for both procedures remains unknown and is currently under considerable investigation.

Open Surgery

Open surgical decompression continues to be the procedure of choice for patients who present with neurologic compromise.[4,25,69] The specific surgical approach is determined by the hemangiomas' location, degree of compression and rate of neurologic decline.[4,24,25,84,85] Emergency laminectomy is favored in cases of rapid and progressive neurological deficit.[4,11,24,69] Laminectomy alone is associated with 70% to 80% success rates when treating isolated posterior element lesions.[3-5,24,67,69,86] Posterior decompressive laminectomy for anterior lesions are at high risk for recurrence.[1] Therefore, in patients with significant vertebral body and anterior spinal canal involvement, a more radical surgical resection including corpectomy or vertebrectomy is typically recommended.[4,42,45,47,87-89] In these cases, anterior spinal weight-bearing column is reconstructed with anterior strut grafts or cages combined with either anterior or posterior stabilization should be considered.[4,55,27,90,91]

Conclusions

Hemangiomas of the spinal column are extremely common and are most often solitary lesions; however, up to a third may occur as contiguous or noncontiguous multiples. Evaluation includes a thorough history and examination. Radiographic evaluation begins with plain films which may demonstrate the presence of trabecular thickening. The use of CT, MRI and other imaging techniques can provide additional information and help characterize the aggressiveness of the hemangioma, degree of soft tissue extension and evidence of neurologic compression. Fortunately, most are asymptomatic and found incidentally. In symptomatic patients, the cause can be from the presence of a pathologic fracture, direct neurologic compression from the hemangioma itself or from spontaneous hemorrhage.

Treatment options for symptomatic hemangiomas continue to evolve. At this time, there is limited information as to which option will confer the best long term outcomes for patients. Most often, it's useful to consider the individual patient's lesion characteristics and select those treatments that address these characteristics.

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