SPINAL CORD TUMORS

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The main thrust of this discussion regards intramedullary spinal cord tumors about which a great deal of controversy exists regarding new surgical techniques and the role of radiation in the treatment of these lesions.

Tumors of the substance of the spinal cord are rare and account for about 10% of all spinal tumors (Table I). As a rule, intramedullary tumors are more common in children, while extramedullary tumors are more common in adults.

TABLE I

The Location of Spinal Tumor with Reference to the Spinal Cord and Its Covering

	No. of Cases	%
Extradural	141	25
Extramedullary	334	59
Intramedullary	62	11
Cauda Equina	30	5
TOTAL	567	100

Symptoms. The symptoms of intramedullary tumors result from direct interference with the intrinsic structures of the spinal cord.

The signs and symptoms of intramedullary tumors are more variable than those of extramedullary tumors. If the tumor is restricted to one or two segments of the cord, the syndrome is similar to that of an extramedullary tumor. However, the common scenario involves several segments, with patterns of disassociated sensory loss. Pain may be an early manifestation if the dorsal-root entry zone is affected. The involvement of the crossing pain fibers in the central portion of the cord may cause a pattern of pain and temperature loss only in the affected segments. As the tumor spreads peripherally, the spinothalamic tracts may be affected; in the thoracic and cervical areas, pain and temperature fibers from the sacral area lie near the external surface of the cord and may be spared (sacral sparing). Involvement of the central gray matter leads to destruction of the anterior horn cells, with weakness and atrophy in the appropriate segments; however, pyramidal fibers may be spared. The clinical picture may be identical to that of syringomyelia.

The diagnosis of an intraspinal tumor can be established before operation with absolute certainty by CT or myelography. Vascular malformations or vascular tumors may be visualized by spinal angiography. The recent widepsread use of MI has shown that this test of all tests is probably the most useful in diagnosing the location and the type of spinal cord tumors. It may well supplant previous basic diagnostic examinations.

Special Considerations. Attention of neurosurgeons was drawn to the entity of intramedullary tumors in the 1920's and 30's through the classic work of Charles Elsberg, who reported operation on 13 cases of intramedullary tumor with the successful removal of approximately one-third of these tumors and cure of the patient. Unfortunately, Elsberg's

surgical expertise was not heeded by the neurosurgical community and for many years, other than sporadic case reports of removal of these tumors, most tumors were subjected to surgical exploration, decompression, and radiotherapy, with mediocre results. In the 1960's, Greenwood's renewed interest in the surgical therapy of these tumors emphasized that ependymomas could be successfully removed in most cases without significant morbidity or mortality, whereas the astrocytomas did not generally lend themselves to total removal. Guidetti, Yasargil, and Malis subsequently reported a large series of intramedullary tumors operated by the microscope with a high degree of success, including total removal of many of these benign tumors.

In my series of 60 intramedullary tumors, the vast majority were astrocytoma and ependymoma, occurring with almost equal frequency. Other tumors included teratoma, hemagioblastoma, a rare cavernous malformation and a pigmented neurofibroma (Table II).

TABLE II

Tumor	Number
Astrocytoma	21
Resectable = 30%	
Glioblastoma	4
Ependymoma	18
Hemangioblastoma	7
Dermoid	4
Cavernous Malformation	3
Teratoma	2
Neurofibroma	1
TOTAL	60

Pathology. Intramedullary ependymomas have a distinct plane between the neoplasm and the normal spinal cord. These tumors are generally soft, moderately vascular, and have a pseudocapsule. Astrocytomas in my experience are 70% infiltrative with an ill-defined margin between tumor and spinal cord tissue. The other 30% have a well-defined plane, and even cysts between the neoplasm and spinal cord. Even in these there may be infiltration of the spinal cord in limited areas. The cysts associated with these common intramedullary tumors often contain yellow fluid with high protein content distinguishing them from the typical hydromyelia or syringomyelia. The teratomas and dermoid tumors have material within them of a heterogenous nature. The capsule of these tumors is often adherent to the surrounding spinal cord tissue.

Commonly, the astrocytoma and ependymoma produce a fusiform enlargement of the spinal cord and often leave no indication of their presence on the surface of the spinal cord, other than an occasional dilated vein at the caudal end of the tumor. In some cases, the dorsal surface of the cord will be so thin that it will be transparent and rarely an eccentric expansion of the tumor will be observed through the pia as a discoloration at the root entry zone. Teratomas, dermoids, and epidermoids are often associated with fibrous tracts bridging the dorsal surface of the cord to the dura, overlying bone and soft tissues. The glioblastomas produce a distinct discoloration of the spinal cord and appear to infiltrate along the pia. They may be highly vascular. The ependymomas of the conus or filum terminale can grow in an exophytic fashion, being both intramedullary and extramedullary.

Intramedullary tumors receive their blood supply from perforating branches of the anterior spinal artery which enter the ventral aspect of the tumor. Even so, the tumors are not highly vascular, unless malignant. The tumors appear to arise in the central portion of the cord and grow toward the dorsal columns. Cysts may occur at either pole of any of these tumors. It is not uncommon to find these cysts, and this immeasurably facilitates the removal of the tumor.

In my series, 70% of the tumors were divided almost equally between astrocytoma and ependymoma. Fortunately, only four of the astrocytomas were glioblastomas. There were seven cases of hemangioblastoma, a relatively rare intramedullary tumor. Four of these hemangioblastomas involved the cervical-thoracic region, while one involved the thoracolumbar region. Teratomas generally occurred in the lumbosacral region. A cavernous malformation occupied the lumbar region and gave rise to a 21-year history. A rare intramedullary pigmented neurofibroma, extending from the mid-cervical region to the obex of the medulla in an elderly patient, was successfully removed.

A point should be made about the anatomic changes that appear to be unique to the hemangioblastoma. We have observed in six cases of hemangioblastoma, extensive widening of the spinal cord in either direction from the primary lesion, which in these cases has been discrete and confined to one or two spinal segments. At operation, we have not been able to define the cause of this enlargement. It is not due to a cyst extending from the tumor or to multiple hemangioblastomas. We have been perplexed as to the nature of the widening, and assume it is due to congestion and edema of adjacent spinal cord because of the high vascularity of these lesions. This theory is substantiated by follow-up diagnostic studies done in a number of these cases in which the entire spinal cord has returned to normal size following removal of the primary lesion. This suggests that this change is a temporary phenomenon related solely to the presence of the tumor.

Surgical Technique. Surgery is a primary treatment for intramedullary tumors. Radiotherapy has little to offer, even for malignant tumors. In timing surgery, the sooner the better in terms of tumor growth. There is nothing to be gained by allowing the tumor growth to devastate the patient while withholding surgery. The surgical results are generally predicated on the preoperative condition of the patient, no matter how large the tumor; if the patient preoperatively has minimal neurological findings, then the postoperative course should be gratifying, especially if the tumor can be resected in toto. Those patients that arrive for surgery in a wheelchair or with severe paralysis may regain little function, even after a successful operation.

I prefer to operate on all of these patients in the prone position. This allows the surgeon and the assistant to work vis-a-vis across the operating table. The operation microscope is utilized with a binocular side arm for the assistant. All operations are carried out with evoked potential monitoring of dorsal column function. This has been of some use in guiding the surgery, although we prefer to rely on observations through the operation microscope as to the extent of dissection. In the future, we hope to utilize with greater efficiency recordings from the corticospinal tract. General anesthesia with endotracheal intubation is always used, and the endotracheal tube is frequently left in place for 24 to 48 hours after surgery on more extensive cervical intramedullary tumors.

A broad laminectomy is performed over the entire extent of the spinal cord widening in order to visualize the pathology. The dura is opened through the entire laminectomy and sutured tightly to the surrounding tissue, affording the best exposure of the spinal cord. As previously noted, many of these tumors afford little definition of their position and extent as the surgeon views the dorsal surface of the spinal cord. It will appear uniformly widened and usually without discoloration. There may be prominent or distended veins at the caudal aspect of the tumor. Cysts are generally not revealed, except by ultrasonic scanning of the spinal cord when it is exposed, or by anticipation from MRI scan.

A longitudinal straight myelotomy must be made over the entire extent of the cord widening. Generally, the spinal cord tumor interface will be observed 2 to 3 mm below the pial surface. The depth varies according to the extent of the tumor. At the polar regions of the tumor, the interface is usually deeper within the spinal cord and may be associated with a cyst. In those tumors which are infiltrating, no definite plane is observed, and in some cases it may be difficult to tell normal from abnormal. This is the situation in the case of infiltrating low-grade astrocytomas, in which the tumor tissue histologically is little different from the supporting tissue of the spinal cord, leading to poor definition. Once the

plane is detected, the pial margins of the spinal cord are held open by fine traction sutures. This significantly assists the dissection around the margin of the tumor. The easiest and best-defined plane is sought. This may not always be at the equator of the tumor, but may be at either end of the tumor, especially in relation to a cyst. Gradually the tumor is circumscribed with interruption of the penetrating vessels which are generally found at the ventral aspect of the tumor. Thse are interrupted by bipolar cautery and cut with fine scissors. Dissection including myelotomy may be carried out with scissors or fine arachnoidal knives. Dissection and removal of the tumor is facilitated by the neurosurgical assistant, who works from the opposite side of the operating table using both hands either to irrgate, suction, or cauterize and sometimes to incise the adhesions. In the instance of large tumors, we prefer to use the Cavitron to debulk the tumor, thereby facilitating dissection around its capsule and its removal. This has a minor disadvantage of spilling the contents of the tumor into the dissection plane or obscuring the dissection plane by bleeding. In most cases, however, the tumors are relatively avascular and bleeding is not a major problem, even with the use of the Cavitron. Gradually, the entire tumor may be removed. For those tumors (usually astrocytoma) which are infiltrating, a debulking procedure is valuable, especially in children. One does not attempt to remove all of the tumor, but it would appear that the remaining tumor may remain quiescent for many years and not change nature. Malignant tumors such as the glioblastoma cannot be removed and do not appear to respond to radiation therapy. These are usually hopeless cases.

Special attention is given to the removal of hemangioblastomas. These are highly vascular tumors, and if they are decompressed or cut into, the bleeding will not only obscure the anatomical planes, but may result in catastrophic problems. Therefore, even in large hemangioblastomas it pays to work around the margin of the tumor interrupting the feeding arteries and finally the primary draining vein as the tumor is rolled out on the last venous pedicle. Often these tumors are associated with a cyst, facilitating their removal. They are identified by their characteristic orange-red appearance, and in almost all cases extrude from the pial surface. Their presence is also identified by large dilated arterialized veins that often surround them. This will mimic an AVM on the myelogram and occasionally on spinal angiography. In some instances, these hemangioblastomas may be multiple and additional tumors may be removed if they are accessible. In rare instances they will be associated with cranial tumors or the von Hippel-Lindau syndrome.

The intramedullary teratomas and dermoids often have fibrous tracts leading from the spinal cord to overlying tissue, and these must be removed as well as the tumor. The tumor capsule may be adherent to the cord tissue and virtually irremovable. In these instances, long-term follow-up would indicate that residual small diaphenous portions of the capsule do not lead to recurrence.

Cavernous malformations have been seen twice; in only one was a subtotal removal accomplished. In one case of a pigmented intramedullary neurofibroma, the tumor was removed including its extension to the obex of the medulla. In all other cases, the tumors rarely extended beyond the cervical medullary junction and when they did, usually represented an intermediate grade or malignant astroctyoma and could not be successfully removed from the medulla. There were no ependymomas that extended above the cervical medullary junction.

In children, the syndrome of holo spinal cord widening is caused by extensive astrocytomas or localized astrocytomas and extensive cysts. Here, it pays to localize the tumor either through clinical or radiological evaluation and remove it while only draining the cyst. A subtotal radical removal with the Cavitron or laser in these children is satisfactory, with long-term remission of the disease process. Although these astrocytomas are histologically identical to those in adults, they may have different growth behavior related to the child's age rather than to the histological appearance.

Following the tumor surgery, the pial traction sutures are released and the attenuated dorsal columns allowed to fall back into the cavity. No attempt has been made to resuture the pia for fear of creating an intramedullary cyst. The rest of the incision is closed in the

usual fashion and postoperative steroids are utilized.

In cases which have had prior surgery with the dura left open and/or radiotherapy, intense scarring has been noted between the overlying tissues and spinal cord. This scarring can compromise a definitive surgical endeavor. If total removal of an intramedullary tumor seems unfeasible, the dura should be reconstructed, preferably with a graft and gelfoam over the spinal cord. In cases in which radiation has been given following a biopsy, we have noted intense intramedullary gliosis by biopsy, separate from the margin of the tumor, usually at the caudal or rostral interface. It is assumed that this is an adverse effect of the radiation.

Results. In all cases of ependymoma, the tumor was totally removed and follow-up to date indicates a cure. No postoperative radiotherapy was given in these cases. In the patients with astrocytoma, approximately half of these underwent gross total removal. Follow-up would indicate no regrowth in the latter cases, but in cases in which considerable amount of tumor or most of the tumor had to be left in place, the course has generally been progressive in spite of a decompressive laminectomy and radiation. In those cases of glioblastoma, the result has been extremely discouraging from either surgical decompression or radiotherapy.

The results in the hemangioblastoma cases depend upon the multiplicity of tumors. Teratomas and dermoids have responded very well to surgery with good results on long-term follow-up.

In this series, no patient was made worse by the surgery, and those patients with marked neurological deficits prior to surgery were rarely improved. Those with mild to moderate neurological deficit prior to surgery did extremely well when the tumor was removed and in most cases returned to normal activity.

On the basis of this experience, our recommendation is that all intramedullary tumors be operated with the expectation that a high percentage will lend to total removal and thereby cure. In those cases in which total removal cannot be accomplished, we would prefer to watch and reoperative, withholding radiotherapy until there is no other course of action possible. This is especially the case in children.

Summary. The most common intramedullary tumors are ependymomas and astroctyomas. In almost all ependymomas, the tumor can be resected following a myelotomy and microsurgical approach; radiotherapy is not indicated after total removal, and is rarely indicated after partial removal; the patient should be observed for recurrent mass effect. Additional operative procedures should be considered if they are indicated. Perhaps half of all intramedullary astrocytyomas are resectable by microsurgical technique; again, postoperative radiotherapy is not indicated. When radiotherapy is given after incomplete removal of an astrocytoma, the results are discouraging. In the uncommon presence of other intramedullary tumors such as hemangioblastomas, teratomas, or dermoids, complete removal without adjuvant radiotherapy is the rule.

After radical and extensive surgery for these tumors, spinal deformities (which may have been present postoperatively) may appear or increase, requiring fixation. These deformities, if allowed to progress, may in turn create neurologic syndromes due to spinal cord compression. This is especially pertinent in children. Some surgeons have advocated replacement of the lamina after definitive surgery, rather than the standard laminectomy. The additional use of radiotherapy for intraspinal tumors in children may affect the growth of the spine, leading to or increasing pre-existing deformities of the spine.

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SURGICAL MANAGEMENT OF SPINAL CORD ASTROCYTOMAS IN CHILDHOOD

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Introduction

Intramedullary spinal cord astrocytoma is a relatively uncommon neoplasm accounting for only 4% of central nervous system tumors in childhood. Over the past four years the author has operated on 100 young patients with very extensive astrocytomas, many of which involve the entire length of the spinal cord. This unusual series has provided us with a unique opportunity to study the biology of the tumor, the response to conventional surgical and radiation therapy, and to develop a surgical technique that permits gross resection of the neoplasms.

Clinical presentation

Clinical symptoms are often present for months to years prior to neurosurgical consultation. In some cases, the course may be punctuated by exacerbations and remissions possibly related to varying degrees of peritumoral edema. Spinal pain caused by distention of the dura by a spinal cord expanded by tumor is the most common pain syndrome. It has a dull, aching quality and is localized in bony segment adjacent to the tumor. Radiculopathy is present 20% of the time, is usually limited to one or two dermatomes, and is similar to root pain from a variety of disease processes. A sharp sensory level occurs less frequently than with extramedullary tumors.

Older children often present with an insiduously progressive scoliosis and seek neurosurgical attention only when there is the onset of a mild paraparesis. In infants and yound children, pain from a distended dural tube with secondary rigidity and paravertebral spasm may be the presenting symptom complex.

With cervical tumors, mild weakness of the upper extremities, often without atrophy, and a "waistcoat" type of sensory loss is frequently present. Weakness of the lower extremities is variable and sphincter function is well preserved until late in the course of the disease (unless the conus is involved) in contrast to extramedullary tumors.

Neurodiagnostic studies

Plain spine x-rays frequently demonstrate some degree of scoliosis varying from mild to severe and a widened canal often

extending from the cervical to the lower thoracic or lumbar levels. Erosion and flattening of pedicles and scalloping of vertebral bodies are a common finding and invariably correspond to the segments of the spinal cord that are spanned by solid tumor as compared to diffuse widening of the spinal canal which is usually secondary to associated cysts. Since "holocord" widening is common, it is essential that the entire extent of the lesion be documented. Metrizamide myelography-CT scan is routinely performed to help delineate the degree of cord widening. CT scan is especially helpful in the presence of a complete subarachnoid block on myelography. In addition, we routinely perform a delayed CT scan 24 hours after the myelogram to document a delayed appearance of intrathecal contrast meterial within the cyst cavity. Occasionally intravenous contrast has supplemented the spinal CT scan and demonstrated an enhancing neoplasm.

In those patients who have had previous laminectomy real time ultrasound is performed over the laminectomy defect and has been extremely helpful in delineating the extent of solid tumor versus associated cyst. In patients with "holocord" widening, large rostral and caudal cysts are frequently associated with a relatively focal solid timor of six to ten segments; laminectomy needs only to be carried out over the region of solid tumor.

Surgical technique

In the first patients that we operated on for what was presumed to be a holocord neoplasm, a total laminectomy was carried out from C2 to L1. We subsequently recognized that much of the cord widening was secondary to associated rostral and caudal cysts whose walls were non-neoplastic. Therefore it was only necessary to perform a limited laminectomy over the solid component of the neoplasm as documented by our neurodiagnostic studies.

After the laminectomy is performed the wound is filled with saline to allow intraoperative ultrasound. With the transducer set at a frequency of 7.5 MHz, the head of the probe (previously covered with a sterile sheath) is gently immersed without touching the dura. The area of solid tumor is localized as well as associated cysts. Intratumoral cysts are small, eccentrically located and have irregular margins. In contrast, the sonographic appearance of the non-neoplastic rostral and caudal cysts is smooth walled, large and centrally located.

The dura is opened in the routine fashion over the entire extent of solid tumor as documented by ultrasound. An attempt is made to identify the anatomical midline of the spinal cord, however the anatomy is often unclear and surface landmarks may be distorted. Careful inspection of the cord surface may identify subpial tumor. Utilizing the operating microscope and the carbon dioxide laser on low wattage (six to eight watts) a midline myelotomy is performed. Myelotomy must extend over the entire length of the tumor. The rostral and caudal margins of the tumor will sometimes be demarcated by smooth white-walled cyst contaning xanthochromic fluid.

6-0 pial traction sutures are placed and facilitate tumor exposure, obviating the need to retract normal cord. Attenuated white matter overlying the tumor is removed with either the laser or microdissectors and fine suction. Utilizing the cavitron ultrasonic surgical aspirator (CUSA) tumor removal is initiated at either rostral or daudal pole of the solid tumor. The excision proceeds from within the center of the tumor laterally and anteriorly until a glial-tumor interface is identified. Small remaining fragments of tumor are vaporized with the carbon dioxide laser. In all of the patients, a gross total removal of the tumor with exposure of rostral and caudal cysts (when present) was accomplished. In those patients who did not have the cystic dilatations of the spinal cord, a glial-tumor interface was obtained at both poles of the neoplasm. The dura was closed primarily in all patients unless it had been left open at a previous procedure. In these cases a dural patch was utilized.

Somatosensory evoked potentials are monitored throughout the majority of the operative procedures. Although in some cases there were improvements in the wave form we are not able to document that this had any clinical relevance. At present this type of monitoring is desirable in terms of accumulating information, but whether or not it will prove a mandatory adjunct to spinal cord surgery remains to be seen.

Discussion

Holocord astrocytoma forms a large subgroup (60%) among the spinal cord astrocytomas and in our series as a more common occurrence than the more limited neoplasm. Although this has been described in occasional case reports the prevalence has not been previously recognized as a result of the earlier tendency not to carry out complete neurodiagnostic studies when a complete intramedullary block was observed on myelography.

There are a number of important observations that are clearly relevant in terms of understanding the biology of this group of neoplasms as well as recommending proper surgical mangement. It has been a consistent observation that the solid component of the astrocytoma is often not as extensive as myelography alone suggests, and indeed the actual location of the neoplasm may be in those segments of the spinal cord that correspond to neuorlogical dysfunction. Demonstration of the rostral and caudal cysts by delayed metrizamide CT scan and ultrasonography is helpful. The lack of significant neurological dysfuntion relating to the spinal segment that is distended with fluid is probably directly related to the anatomical location of the cyst within the center of the cord as compared to the solid component of the neoplasm which was relatively more diffuse. It was only necessary to expose and extirpate the solid partion of the neoplasm and drain the rostral and caudal cysts in order to obtain a satisfactory surgical result. Therefore a limited lamincetomy over the solid portion of the neoplasm was

sufficient. The extent of the laminectomy was defined by the combination of neurological deficit, eroded pedicles, scalloped vertebral bodies and area of maximal spinal cord widening on plain films and myelography and confirmed intraoperatively with ultrasound.

The presence of cysts which were similar in appearance to those associated with the cystic astrocytomas of the cerebellum, suggests that these neoplasms are congenital tumors that had their inception sometime during gestation. The fluid produced by the tumor extends up and down the spinal cord in the region of least resistance, that is the central canal. It is our perspective that the presence of a widened spinal cord from the cervicomedullary junction to the conus, which is associated with a relatively slowly evolving neurological deficit, is indicative of a very slowly growing and perhaps even hamartomatous type of lesion which has a good long term prognosis and should be treated aggressively. The rare malignant astrocytoma in the population presents with a different clincial picture: the development of neurological deficits occurs rapidly and the prognosis parallels that of glioblastomas elsewhere in the central nervous system.

Benign astrocytomas are often firm, contain calcium deposits and have no obvious cleavage plane to delineate them from normal neural tissue. Traditional surgical technique of suction and blunt dissection is relatively inefficient and may cause considerable traction on normal adjacent structures, accounting for the high incidence of neurological deficit in older series. The use of the CUSA and the surgical laser has been an indispensable surgical adjunt in the radical resection of theses tumors. The CUSA and the surgical laser has been an indispensable surgical adjunt in the radical resection of these tumors. The CUSA and the surgical laser permit fragmentation, emulsification, vaporization, and aspiration of the firmest tissue without any movement of adjacent normal spinal cord.

In most cases of holocord tumor the initial complaint was a weak arm or a mildly weak leg and associated pain somewhere along the spinal axis. The signs and symptoms were consistently relatively minor when compared to the apparently diffuse nature of the pathological process. It is perfectly understandable why a neurosurgeon, faced with this clinical dilemma, has been most concerned about inflicting a greater neurological deficit as a result of extensive dissection within a rather well-functioning spinal cord. This rationale has been used for a temporising surgical approach consisting of a limited laminectomy and biopsy and relying on radiation therapy to control tumor growth. Unfortunately, the natural history of these tumors with radiation therapy is slow deterioration and eventual severe neurological disability or death.

The outcome following radical resection of these tumors is directly related to the preoperative neurological status. Although a transient increase in weakness or sensory loss was sometimes seen in the immediate postoperative period, only one

patient had a significant permanent increase in neurological deficit following operation. Patients with paraparesis or quadriparesis who were ambulatory before surgery had stabilization of their deterioration and usually had neurological and functional improvement over several weeks. The group of patients with severe deficits preoperatively rarely made any significant improvement although their downhill course abated.

There is no evidence that radiation will cure benign astrocytomas of the spinal cord and there is abundant evidence that it has a deleterious effect on the immature, developing nervous system. Spinal cord astrocytomas should be recognized as excisable lesions with radiation therapy reserved for possible adjunctive use if there is a recurrence. At that time, it might be employed following a second radical surgical resection.

Children who have undergone extensive laminectomy and, in addition, have denervation of the paravertebral muscels from tumor as well as operative muscel retraction, are at risk for developing severe spinal deformities as they pass through periods of rapid growth. They may need to be treated with body braces for several years after surgery. Close collaboration with a pediatric orthopedic surgeon experienced with kyphoscoliosis is helpful in managing these patients. To date, very few of our patients have required Harrington rods and fusion for progressive deformity.

RADIATION THERAPY FOR SPINAL CORD TUMORS

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Since many neoplasms that arise within the spinal cord or from its meninges cannot be totally resected, the value of radiation therapy in their treatment must be considered. Surgery is necessary to establish the pathological diagnosis, to provide rapid decompression of the cord if necessary and to remove the bulk of tumor. If the tumor can be totally resected without undue morbidity or neurological deficit, such resection should be performed, in which case radiotherapy is not indicated. The basic principles for treating incompletely resected primary tumors of the spinal cord depend on the histological type of tumor, the extent of resection, whether or not metastases have occurred or are likely to, and the radiation tolerance of the cord. Control of the tumor will stabilize the patient's disease and may lead to neurological improvement, whereas failure may mean death or severe neurologic disability. Most of these tumors require aggressive radiotherapy to a radiation dose that carries some risk to the normal spinal cord.

Modern radiation therapy given with curative intent is largely limited to megavoltage irradiation, i.e., employs a source with an energy greater than one million electron volts. Megavoltage irradiation has the advantage of greater penetration, less absorption in bone, less side scatter of the radiation, and reduced dosage to skin and subcutaneous tissues. Linear accelerators in common use today produce x-rays ranging from 4-25 MeV.

The biological basis of radiation therapy is complex. The intent is control of tumor with a dose that is tolerated by the normal tissue within the radiation volume. The success of treatment depends upon many interrelated factors: 1) careful treatment planning designed in so far as possible to restrict the high dose volume to the tumor and to noncritical normal structures; 2) the inherent radiosensitivity of the normal and tumor cells; 3) the total number of various cell types present; 4) the ability of normal cells to migrate into and tumor cells to metastasize out of the irradiation volume; 5) the repopulation capability of normal cells in proportion to that of tumor cells; 6) redistribution of normal and tumor cells in the cell cycle between radiation fractions; 7) the relative ability of tumor and normal cells to repair sublethal radiation damage between treatment fractions; 8) tissue oxygen tension; and 9) time

required for reoxygenation of hypoxic tumor cells (as hypoxia may decrease radiosensitivity by threefold). In practice, the radiation therapist, after selecting the approach that gives the best physical distribution of absorbed radiation dose, tends to apply the maximum dose consistent with an acceptable risk for critical and normal structures, in this case the spinal cord. Since any neoplasm can be controlled locally by irradiation, if there were no limitations on radiation dose the dose limiting factor is the tolerance of normal tissues that cannot be excluded from the high dose volume; therefore, a brief review of CNS tolerance follows.

Progressive radiation myelopathy was first described by Ahlbom in 1941 in a report of the results of radiation therapy for hypopharyngeal cancer at the Radiumhemmet in Stockholm.[1] Since then, numerous reports of its occurrence in the cervical, thoracic, and lumbar areas have appeared.[2,3,4,5] The actual incidence of radiation myelopathy as a function of radiation dose and number of fractions, however, is difficult to determine; most reports of injury have failed to state the size of the population at risk and most patients who have received large doses of radiation to the spinal cord have had types of cancer for which and survival is too short injury to the spinal cord to develop. Radiation myelopathy may appear as a transient syndrome (Lhermitte's syndrome) or as a more serious, usually progressive, late reaction. Transient radiation myelopathy generally is characterized by momentary electrical shock-like paresthesias radiating from the neck into the extremities. It is precipitated by neck flexion. The paresthesias may only radiate down the legs or involve the upper extremities as well. The symptoms are symmetrical and do not conform with the distribution of a specific dermatome. There are no other associated abnormal neurological findings. As a rule, the syndrome develops after a latent period of 1-4 months following irradiation and gradually rebates over the next 2-9 months. Jones attributed this syndrome to transient demylination of the ascending sensory neurons most probably in the posterior columns, lateral spinal thalamic tracks, or both.[2] The induction of symptoms by neck flexion is thought to arise from elongation or stretching of the posterior fibers of the cord made hypersensitive by demyelination. In most instances the syndrome is spontaneously reversible and requires no specific therapy. In clinical radiotherapy, delayed radiation myelopathy occurs several months to years after irradiation. The latent period tends to decrease with increasing dose. The neurological changes associated with radiation myelopathy are often irreversible but not always progressive, and about 1/2 of patients so afflicted die from secondary complications. The primary site of radiation myelopathy is the white matter. The pathogenesis has been attributed to either direct affect on oligodendroglial cells or vascular damage. Because of the long latent period, vascular injuries are considered the primary cause of radiation myelopathy. Phillips and Buschke have estimated that the tolerance of the spinal cord increases rapidly with the number of individual radiation fractions.[6] A review by van der Kogal suggests that not only is tolerance is highly influenced by

the number of daily fractions but, at least up to 6 weeks, is relatively unaffected by overall treatment time.[7] A review of cases of thoracic cord injury at UCSF and in the literature indicates that 2000 rad in 5 fractions in 1 week, 3000 in 10 fractions in 2 weeks, and 5000 in 25 fractions 5 weeks approaches the tolerance level of the thoracic cord and, even these regimens occasionally may cause some degree of injury.[8,9] Although not well documented, the cervical cord generally is thought to be more tolerant than the thoracic cord. Hypertension, spinal cord pathology and concurrent chemotherapy have been reported to decrease the tolerance of the normal cord. If injury should occur, it may result in any level of injury up to complete transverse necrosis with loss of both sensory and motor function below the level of injury. Presently, the only effective treatment is prevention.

Primary intraspinal tumors are relatively uncommon constituting only about 15% of tumors arising within the central nervous system. Schwannomas, meningiomas, and gliomas occur with about equal frequency and together account for 3/4 of spinal tumors. Approximately 2/3 of the gliomas are ependymomas, the majority of which arise in the lumbosacral region. In general, if total operative removal is possible without excessive neurologic complications it should be performed. If removal is complete, operation alone constitutes adequate treatment. Depending upon tumor type, radiation therapy may extend the recurrence free interval or be curative.

Table 1 shows reported results of treatment of ependymomas of the spinal cord.[9,10,11,12,13,14,15,16,17,18] The extent of operative resection in the patients of Wood et. al. and of Schuman et. al.[10,11] was not stated but probably was incomplete. The remainder of the data in this table relate to patients in whom only a biopsy or an incomplete resection was performed. All seven of the non-irradiated patients of Schuman and associates and of Barone and Elvidge had recurrence of ependymoma. For these patients with non-irradiated tumors Schuman's group reported a median symptom-free interval of three years; and Barone and Elvidge,[12] an average survival of two and a half years. With irradiation, Schuman and co-workers reported, three of three patients were without recurrence at five years, and Barone and Elvidge had four of eight alive (time after treatment unstated) with an average survival of nine and a half years. Slooff and colleagues had a survival rate for irradiated patients (time post-treatment unstated) nearly double that for unirradiated patients.[13] Combining the data in Table I, the five-year recurrence-free survival for irradiated patients was 82 per cent. Recurrences may appear later than 5 years, e.g. Shaw et. al.[14] although having a 95% 10 year overall survival for irradiated patients, reported a decrease in disease free survival from 81 to 71% between 5 and 10 years. Twelve of the patients reported by of Wood et. al. and Scott et. al.[10,15] who had received radiation treatment were without recurrence for 12 or more years. These data suggest that postoperative radiation therapy for incompletely resected ependymomas increases the recurrence-free

survival time and that at least long-term control, possibly cure, can be achieved in the large majority with such lesions.

Table 2 summarizes some reported treatment results for irradiated astrocytomas and for intrinsic tumors of the spinal cord not subjected to biopsy.[9,10,19,20,21] The 4 year recurrence-free survival was 64 per cent for 14 patients with astrocytoma. The 3 to 5 year rate was 70 per cent for the 20 patients in whom biopsy was omitted.

In order to gain further insight into the management of these tumors we have retrospectively reviewed the records of 42 patients who completed radiation therapy for primary spinal cord tumors at the University of California, San Francisco from 1957 to 1986. Initial diagnosis included 21 patients with ependymoma, 15 patients with astrocytomas, and 6 patients with nondiagnostic or no biopsy. Irradiation was given with megavoltage equipment with a usual tumor dose of 5040 rad given in daily 180 rad fractions.

The 5, 10, and 15 year relapse-free survival rates for astrocytomas were 52%, 41%, and 41%, respectively. The 5, 10, and 15 year relapse-free survival for ependymomas were 77%, 55%, and 27%, respectively. Ten patients failed in the local tumor volume and three metastized throughout the craniospinal axis.

The above data are obviously inconclusive regarding the value of radiotherapy for primary neoplasms of the spinal cord. There has been no controlled trial nor is there likely to be one in the foreseeable future. Reports to date generally fail to detail, or even address, selection factors, radiation doses, local recurrence rates and prognostic factors. In all probability patients irradiated had had incomplete resections but there are no series of nonirradiated, but otherwise comparable patients, against which results may be compared. It is evident that long term survival may be achieved after incomplete resection with irradiation of low grade ependymomas and astrocytomas but not with glioblastomas.

While more definitive data regarding the efficacy of radiation therapy are desirable, until they are available treatment decisions must be based on evidence at hand. The current policy of the authors is to operatively decompress, biopsy and remove as much tumor as possible without significantly increasing the neurological deficit. In case of a nonresectable or incompletely resected tumor, regardless of histological type, we advocate postoperative radiation therapy beginning after the incision is well healed. Megavoltage radiation is used. A total dose of about 5000 rads is given as a single course with daily fractions of 180 to 200 rads. With rapidly progressive lesions or those of aggressive histology, it is thought reasonable to accept a greater radiation risk and carry the total dose to 5500 or 6000 rad. Doses to the region of the cauda equina, i.e. below the level of the true cord, also may be as high as 6000 rad. For recurrence after irradiation, repeat operation may be useful,

depending upon the location and extent of the tumor and the patient's willingness to accept the additional morbidity that may accrue.

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Table I EPENDYMOMAS OF THE SPINAL CORD

Author	RT	NED	"Alive"
		(Local control)	
Kopelson, et. al.	2700-5500 rad	7 of 8-5 yrs	8 of 8 5 yrs 73% - 10 yrs
Marks, et. al.	3000-5000 rad	cauda equina 7 of 8-5 yrs	7 of 8 5 yrs
		spinal cord 3 of 7-5 yrs	4 of 7 5 yrs
Peschel, et. al.	4500-5200 rad	4 of 4-5 yrs	
Shaw, et. al.	3600-5700 rad (5000 median)	22 patients 81% 5 yrs 71% 10 yrs	95% - 10 yrs
	≤ 5000 rad > 5000 rad	11 of 17 4 of 5	
Read	3500-5000 rad		22 patients
Wood, et. al.	Multiple courses 1000-3000 R Multiple courses 1000-3000 R	12 of 15 5 yr 9 of 9 5 yr	70% @ 5 years
Schuman e. al.	None	0 of 4 "Median symptom-free interval" 3 yr	
	1700-3700 R	3 of 3 5 yr	
Scott	2500-5000 R	3 of 3 12-21 yr	
Sloff et. al	Spinal cord None Some Filum terminale None Some		9 of 23 (39%) 16 of 26 (61%) 4 of 11 (36%) 11 of 17 (65%)
Barone and Elvidge	None		0 of 3 (Avg. surv. 2.5 yr)
	Some		4 of 8 (Avg. surv. 9.5 yr)

Table II OTHER GLIOMAS AND HISTOLOGICALLY UNIFENTIFIED TUMORS OF THE SPINAL CORD

Author	Histology	Radiotherapy	"Alive"
Kopelson & Linggood 3500-4300 rad			
Astrocytoma (9 pts.)			89% 5 yrs
Glioblastoma (5 pts.)			0% 3 yrs
DeSousa et. al.			86% 6 yrs
Wood et. al.	Astrocytoma	Multiple courses of 1700-2000 R	4 of 7 5 yr
	Unknown	Multiple courses of 1000-1800 R	9 of 11 5 yr
Schwade et. al.	Astrocytoma	~5000 R	5 of 7 yr
	Unknown	~5000 R	5 of 9 yr
Marsa et. al.	Glioma	~5000 R	5 of 9 2 yr