rary implants is the delivery of constant low-rate radiation that may enhance biologic effects on malignant cells.

During the past decade, the development of image-directed stereotactic systems has resulted in the ability to treat tumor volumes with radioactive sources (iodine 125 or iridium 192) with a high degree of accuracy and safety. Results from early trials of interstitial radiotherapy in selected patients have been encouraging, with quality survival as long as five years in a number of patients. Many neurosurgical centers are currently using this approach to treat malignant brain tumors (primary as well as metastatic) in conjunction with external-beam radiotherapy. Several groups have reported benefits of such treatment when compared with historical controls, but such effects in controlled studies remain to be quantified. Complication rates, both short and long term, also need to be better defined. Preliminary data suggest that short-term morbidity is less than 5%, but a number of patients require subsequent operations for recurrent masses. Posttreatment masses may include large volumes of necrotic tissue thought to result from the radiation implants. Because this is a relatively new form of treatment, long-term efficacy and complication rates also require further definition.

To summarize, interstitial radiotherapy is a logical adjuvant therapy in the management of malignant brain tumors. Initial data suggest efficacy in selected patients. Whether such therapy will become the standard of care will depend on the results of ongoing phase III investigations such as those of the Brain Tumor Cooperative Group. Randomized, controlled studies such as those of the Brain Tumor Cooperative Group hold the promise that the indications for and efficacy of interstitial radiotherapy will be determined.

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## Management of Prolactin-Secreting Pituitary Adenomas

PROLACTIN-SECRETING ADENOMAS are the most common functioning pituitary tumors that present to clinicians. The successful integration of medical and surgical therapy provides an extremely high potential for the effective treatment of such tumors in terms of resolving endocrine symptoms and intracranial mass effects.

The medical treatment of prolactin-secreting pituitary tumors is based on the physiology of prolactin release—prolactin being the only hormone of the anterior pituitary to be regulated exclusively by a mechanism of tonic inhibition effected by neurotransmitter release from the hypothalamus. The neurotransmitter regulating the release of prolactin has dopaminergic characteristics, but whether it is dopamine is unknown. Bromocriptine, an ergot derivative with dopaminergic characteristics, effectively suppresses prolactin secretion and restores prolactin levels to normal in greater than 95% of patients with prolactin-secreting adenomas. It also significantly reduces the size of large prolactin-secreting tumors in at least 50% of patients and usually precludes further tumor growth once therapy is instituted. Bromocriptine therapy represents an acceptable alternative to surgical therapy, but the drug is not curative and not all patients tolerate its use. Furthermore, cessation of the drug results in a rapid return of hyperprolactinemia and the tumor reverts to at least its original size. Therefore, bromocriptine therapy is required for the lifetime of a patient when used alone.

Approaches to treatment involve a consideration of the stage of the tumor. Stage I lesions (less than 1 cm in diameter and confined to the intradural sella) are most amenable to surgical cure. The main indication for the treatment of such small lesions is patients' desire for pregnancy. The possible genesis of premature osteoporosis in women who are amenorrheic and hypoestrogenemic as a consequence of systemic hyperprolactinemia is a hypothetical concern that awaits clinical confirmation. In our experience, surgical resection of stage I lesions has an 84% chemical cure rate a year after resection, with morbidity less than 1% and mortality 0%. Serum prolactin levels measured six weeks postoperatively are used to determine whether further intervention is necessary. Bromocriptine therapy, on the other hand, restores normal serum prolactin levels in virtually 100% of patients who tolerate the drug, thus allowing normal pregnancy. Care must be taken with this approach, however, because tumor regrowth may necessitate reinstituting bromocriptine therapy during pregnancy. For stage I lesions, therefore, either surgical resection or bromocriptine therapy can effectively maximize the potential for pregnancy. The choice of therapy should depend on the patient's preference, taking into account the need for long-term medical management should an operation be deferred.

Stage II tumors (greater than 1 cm in size, with or without supraseller extension but without invasion of the dura or bone of the sella turcica) present similar treatment options, although the chemical cure rate of surgical treatment is only 50%, compared with 90% with bromocriptine use. Some stage II tumors, such as those that are cystic or of low density on a computed tomographic scan, generally do not shrink with bromocriptine therapy. This underlines the advantage of surgical resection in such cases—the reduction of tumor size.

Stage III tumors (local invasion of dura and sella) and stage IV tumors (diffuse sellar invasion with or without extension into the anterior, middle, or posterior fossa) defy cure by any single means. Surgical therapy alone achieves only a 25% physiologic cure of stage III lesions, and the physiologic cure of stage IV lesions approaches 0%. On the other hand, high doses of bromocriptine, with resulting increases in side effects, are required to have an effect on such large tumors. Therefore, we use combined therapy in stage III and IV tumors. The patient is initially placed on a regimen of increasing bromocriptine doses until a serum prolactin level of less than 20 ng per ml is established. If, after six weeks of normal prolactin levels, no reduction in tumor mass is observed on serial imaging studies, surgical resection is attempted. Imaging studies are done at three and nine months postoperatively and yearly thereafter. If postoperative imaging fails to show tumor progression and the prolactin level remains normal, no radiation therapy is given. Should the tumor progress despite bromocriptine therapy, radiation therapy is usually given. One indication for more urgent surgical intervention is progressive visual compromise despite bromocriptine therapy. Should significant reductions in tumor size be achieved with bromocriptine use, continued medical management becomes an op-

tion. In this case, yearly follow-up imaging studies are done to assess tumor status.

In summary, no single therapeutic modality is either ideal or unacceptable in the management of prolactin-secreting pituitary tumors. Fortunately, stage I and II tumors lend themselves to surgical cure, which avoids the need for a lifelong commitment to a medical regimen. The role of bromocriptine therapy adds a useful alternative to surgical intervention in some patients and also plays a crucial role in the combined management of more invasive lesions. The net result of this complementary set of therapeutic options is the reduction or elimination of tumor mass and the restoration of normal endocrine function.

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## Surgical Treatment of Petroclival Meningiomas

THERE HAS BEEN A dramatically increased interest in more aggressive surgical treatment of tumors at the base of the skull. New approaches are being developed, and old ones are being revitalized. Because of the complexity of the anatomy at the skull base, surgical approaches to this region are now frequently multidisciplinary, involving most often a neurosurgeon and an otolaryngologist. The team approach has provided tumor management that is more powerful than the sum of its parts, and nowhere is this more apparent than in the surgical treatment of meningiomas of the petrous bone and clivus, histologically benign lesions rendered malignant solely because of their relative surgical inaccessibility.

Petroclival meningiomas have been resected most commonly by the suboccipital (posterior fossa) retromastoid approach, and for most lesions this has been adequate. Surgical access to more complex lesions, however, such as those that extend to the prepontine cistern, middle fossa, or craniovertebral junction, require novel techniques often involving removing portions of the cranial base. Modern thinking stresses an approach that, while fundamentally a posterior fossa craniotomy, is different in that the sigmoid sinus is no longer the lateral limit to bone removal, such that a more direct line of vision along the petrous bone and in front of the cerebellum to the petrous apex and clivus is available to microsurgeons. This "petrosal" approach is now possible because the neurosurgery-neuro-otology team is not reluctant to drill anteriorly into the temporal bone.

There are three types of transpetrosal posterior fossa craniotomy: retrolabyrinthine, translabyrinthine, and transcochlear. In the retrolabyrinthine approach, bone removal anterior to the sigmoid sinus is halted at the level of the semicircular canals. Although this approach spares auditory function, it affords only a slightly improved access to the posterior fossa. In the translabyrinthine procedure, anterosigmoid bone is removed to the level of the internal auditory canal. This provides excellent visualization of the lateral aspect of the pons and upper medulla with only minimal retraction of the cerebellar hemisphere. Because the semicircular canals are removed, unilateral hearing loss is inevitable. In the transcochlear approach, the entire otic capsule is removed along with the middle ear and external auditory canal. By anteriorly rerouting the facial nerve from its intratemporal canal and then resecting both the petrous apex and lateral aspect of the clivus, an unimpeded view of the ventral aspect of the pons and clivus is obtained without the need for brain retraction. Hearing loss and transient facial palsy are acceptable deficits only with an otherwise inaccessible and potentially lethal tumor.

For tumors that arise high on the petrous bone and clivus, surgeons are adding a low temporal craniotomy to the petrosal approach with ligation of either the transverse or, more frequently, the superior petrosal sinus to allow splitting of the tentorium for additional superior exposure through the supratentorial space. For lesions arising from or extending to the low clivus or anterior rim of the foramen magnum, the lateral accentuation of the approach angle is gained by isolating and protecting the vertebral artery and drilling off the lateral aspect of the foramen magnum and occipital condyle. Because the sigmoid sinus sweeps anterosuperiorly at this level, drilling can be safely carried forward all the way to the hypoglossal canal. For these same low clival or anterior foramen magnum meningiomas, some surgeons are attempting an anterior (transoral, transclival) approach. Despite the development of fibrin glues for dural repair, however, the specter of postoperative cerebrospinal fluid leak into the oropharynx makes most surgeons reluctant to remove intradural lesions by this route.

Certain petroclival meningiomas will not be completely resectable despite the aforementioned advances in surgical access. For them, external radiation therapy, brachytherapy, and radiosurgery will be useful treatment adjuncts.

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## Intraoperative Digital Subtraction Angiography for Neurosurgery

HIGH-RESOLUTION, REAL-TIME, digital subtraction angiography (DSA) facilitates the intraoperative management of complex intracranial vascular disorders. Portable DSA equipment is now available that provides angiographic images virtually equivalent to conventional angiography. A mobile "C" arm fluoroscopy unit with high-resolution video is fitted with frame-averaging, catheter road mapping and automatic peak opacification capability. These features reduce the volume of contrast material necessary for adequate images. The system is powered by standard 115-volt, 20-ampere lines and requires no special shielding. The software package can be modified to allow for stereoscopic visualization of intracranial vascular lesions. Angiographic pictures accrue immediately, with the advantage of overlying bony and relatively radiopaque instrument subtraction. Carbon-fiber head holders can be subtracted, but ordinary metal instruments cannot. Draping, scalp hemostasis, and retraction require modification to avoid metallic artifacts. Technical considerations involved in intraoperative transfemoral or direct arterial catheterization have been described.

Indications for intraoperative neurosurgical DSA are di-