Amygdalohippocampectomy (AH) is an accepted surgical option for treatment of medically refractory mesial temporal lobe epilepsy. Operative approaches to the amygdala and hippocampus that previously have been reported include: the sylvian fissure, the superior temporal sulcus, the middle temporal gyrus, and the fusiform gyrus. Regardless of the approach, AH permits not only extirpation of an epileptogenic focus in the amygdala and anterior hippocampus, but interruption of pathways of seizure spread via the entorhinal cortex and the parahippocampal gyrus. The authors report a modification of a surgical technique for AH via the parahippocampal gyrus, in which excision is limited to the anterior hippocampus, amygdala and parahippocampal gyrus while preserving the fusiform gyrus and the rest of the temporal lobe. Because transparahippocampal AH avoids injury to the fusiform gyrus and the lateral temporal lobe, it can be performed without intracarotid sodium amobarbital testing of language dominance and language mapping. Thus the operation would be particularly suitable for pediatric patients in whom intraoperative language mapping before resection is difficult.

Key Words * amygdalohippocampectomy * complex partial seizure * parahippocampal gyrus * subtemporal approach

Currently several different variations of temporal lobe resections are used for medically intractable complex partial seizures.[4,6,8,18,21,30,34] Among these operations is amygdalohippocampectomy (AH), first described in 1958 by Niemeyer,[16] who approached the amygdala and hippocampus through an incision on the middle temporal gyrus. Niemeyer and Bello[17] later used microsurgical techniques to refine the operation further. It was only in the late 1980s, however, that AH became an accepted surgical treatment for medically refractory mesial temporal lobe epilepsy. Yasargil and colleagues[34] popularized the procedure when they reported a favorable surgical outcome after transsylvian AH, which they had developed in the late 1970s. In keeping with the trend in epilepsy surgery to resect only the mesial temporal structures, Olivier[21] and Hori, et al.,[10] described AH approaches via the superior temporal sulcus and fusiform gyrus, respectively (Fig. 1 upper).
Fig. 1. Upper: Artist's rendering depicting previously reported surgical approaches to the hippocampus and amygdala and the technique described in this report: via the sylvian fissure, superior temporal sulcus, middle temporal gyrus, fusiform gyrus, and parahippocampal gyrus. Lower: Illustration depicting the extent of excision in transparahippocampal amygdala-hippocampectomy and an initial cortical incision to expose the temporal horn.

If the dominant temporal lobe is involved, language mapping before excision of epileptogenic areas is recommended.[20] In young children, however, precise language mapping is always challenging and
often impossible because of poor cooperation. For pediatric patients, a temporal lobe resection should ideally carry no risk of injury to the temporal language areas. Performed via a subtemporal approach, AH may be an operation that fulfills this requirement.[10] We report a variation of subtemporal AH in which excision is limited to the amygdala, hippocampus, and parahippocampal gyrus, leaving the temporal language areas intact (Fig. 1 lower).

SURGICAL TECHNIQUE

Before surgery, the location of the anterior margin of the temporal horn as it relates to the uncus is determined by magnetic resonance (MR) imaging. Typically, the temporal horn extends to the midportion of the uncus, approximately 3 cm posterior to the temporal pole. After the patient has been placed in the lateral position and a general anesthetic has been administered, a lumbar drain is placed and the patient's head is rotated away from the surgeon, with the vertex directed 30° downward. Intravenous mannitol (1 g/kg) is administered and the patient is hyperventilated. The scalp is incised to expose the zygoma and skull beneath the temporalis muscle. After the lumbar drain is opened, an 8 X 5-cm craniotomy flap is turned, extending to the sphenofrontal suture anteriorly and above the mastoid posteriorly. The sphenoid bone is removed down to the floor of the middle cranial fossa. After the dura is opened, an operating microscope is used. A brain retractor is inserted subtemporally under the anterior uncus and cerebrospinal fluid is gently suctioned from the ambient cistern. Then the anterior uncus is elevated using a brain retractor, which is later secured later to a self-retaining system, and the anatomical relations of the fusiform and parahippocampal gyri, uncus, tentorium, and ambient cistern are carefully inspected.

Fig. 2. Drawing showing that the oculomotor nerve can offer an anatomical landmark for a cortical incision, which is made on a midportion of the uncus 1 to 1.5 cm posterior to the point at which the oculomotor nerve crosses the tentorial edge. CNIII = third cranial nerve.

If the oculomotor nerve within the ambient cistern that courses anteriorly along the tentorium is identified, it offers an anatomical landmark for an initial cortical incision in the uncus. A location 10 to 15 mm posterior to the point at which the oculomotor nerve crosses the tentorial edge, as it courses toward the cavernous sinus, is the site for the initial cortical incision in the uncus and corresponds to the middle one-third of the uncus (Fig. 2). The temporal horn is exposed by suction excision of the cortex and underlying white matter (Fig. 3A). To avoid veering away from the temporal horn, it is critical that the suction dissection be performed through the white matter perpendicular to the inferior surface of the uncus. Otherwise, the dissection tends to proceed toward the medial parahippocampal gyrus near the tentorial edge. Frameless stereotactic techniques might be of help at this point in the operation, although we have not yet used them in our patients.
Fig. 3. Drawings showing the temporal horn as it is initially exposed after the uncal white matter is removed with suction (A). The cortical incision is extended to visualize the pes hippocampi (superior) and amygdala (inferior) covered partly by a cotton patty (B). The parahippocampal gyrus parallel to the hippocampus is removed by suction to gain space to remove the hippocampus en bloc (C).

Once the temporal horn is opened, the amygdala, which forms the anterosuperior wall of the temporal horn, comes into view as a distinct grayish structure (Fig. 3B). The head of the hippocampus is distinguished from the amygdala by its appearance and location. The temporal horn and the anterior hippocampus are now exposed posteriorly by incising the parahippocampal gyrus up to 3 to 4 cm from the uncus. The choroidal fissure along the medial aspect of the hippocampus is visualized by gently elevating the body of the hippocampus and the choroid plexus to expose the teniae choroidea (Fig. 3B). Anteriorly, the hippocampus blends with the amygdala through a thin layer of neural tissue where the choroidal fissure is no longer present. The thin layer connecting the two structures is divided by subpial aspiration.
Fig. 4. Artist's drawings depicting the transverse division of the anterior 2 to 3 cm of hippocampus directed toward the tentorium (A). The hippocampus is separated subpially from the brainstem and amygdala and is removed en bloc (B and C) and, when needed, additional hippocampus is suctioned following the en bloc excision. Finally, the superomedial amygdala is removed subpially with the ultrasonic aspirator (D).

Next, the parahippocampal gyrus overlying the inferolateral portion of the hippocampus is removed subpially to make room so that later in the dissection the hippocampus can be rolled laterally (Figs. 3C and 4A). The anterior 2 cm of the hippocampus is divided transversely in the direction of the tentorial edge (Fig. 4B and C). As the truncated hippocampus is separated from the arachnoid overlying the ambient cistern, a few hippocampal arteries arising from the anterior choroidal and posterior cerebral arteries are seen to penetrate the hippocampus; these are coagulated and divided immediately adjacent to the hippocampus. This allows complete separation of the hippocampus from the arachnoid membrane and its removal en bloc. After this, an additional 1-cm portion of the hippocampus is removed using a suction and bipolar cautery. Finally the amygdala facing the temporal horn is excised with an ultrasonic aspirator (Cavitron, Valley Laboratory, Inc., Boulder, CO). The excision extends anteriorly to the level of the horizontal segment of the middle cerebral artery (Fig. 4D). The superomedial amygdala is contiguous with the basal ganglia and, therefore, radical resection of the amygdala is not attempted.

We have performed this operation in eight patients, seven of whom underwent the operation in the dominant temporal lobe. Postoperative MR imaging confirmed in all patients that the excision extended to the hippocampus, part of the amygdala, the parahippocampal gyrus, and the uncus (Fig. 5). During a brief follow-up period, lasting 2 to 19 months, seven patients were free of seizures and one patient had more than a 90% reduction in seizures. Operative morbidity consisted of contralateral homonymous quadrant visual defect in one patient and memory impairment in another.
Fig. 5. Postoperative magnetic resonance images showing excision of the hippocampus, parahippocampal gyrus, and uncus.

DISCUSSION

It appears that the hippocampus and amygdala can be safely resected through the parahippocampal gyrus in patients with intractable complex partial seizures of mesial temporal lobe origin. The rationale for choosing transparahippocampal AH is based on the observation that intractable complex partial seizures most often originate in the hippocampus and/or the amygdala and propagate to the temporal neocortex through the entorhinal cortex and the parahippocampal gyrus.[6,29,31] In particular, the entorhinal cortex is critical in seizure propagation because it receives afferents from the association of the cerebral cortex and cingulate cortex and then sends efferents to the hippocampus; efferents from the hippocampus project backward to the entorhinal cortex to reach the cerebral cortex.[1,11,33] Thus excision of the hippocampus, amygdala, uncus and parahippocampal gyrus (which harbors the entorhinal cortex) not only extirpates the epileptogenic focus, but interrupts afferent circuitry for seizure spread in patients with temporal lobe seizures.[6]

Historically, Penfield and associates[24,25] tailored excision of the temporal lobe to interictal spikes on electrocorticography and excised anterior hippocampus only if it appeared to be abnormal grossly or electrocorticographically. The limited anterior temporal lobectomy, however, failed to control seizures in a significant number of patients;[22,32] this failure led in later years to the development of a temporal lobectomy that routinely includes 2 to 4 cm of the anterior hippocampus in excision. For adequate excision of the hippocampus for seizure control, several different operative approaches have been developed.[4,5,9,15,23,26,30,32] A notable exception in the literature is a report by Hardiman, et al.,[8] who limited excision to the lateral temporal cortex, sparing the entire mesial temporal lobe structures, yet achieving a surgical result equal to that of other temporal lobe resections. Microdysgenesis, consisting of neuronal ectopia in the white matter, and neuronal clustering within the cortical layers were the pathological abnormalities seen in their patients.

Although the first report of AH dates back to 1958,[16] only during the last decade has the operation been used widely for treatment of temporal lobe epilepsy. In a response to worldwide surveys of epilepsy centers for the Palm Desert Conferences, no case of AH was recorded prior to 1985; however, AH cases increased between 1986 and 1990 to constitute nearly 10% of the 5430 temporal lobe resections reported.[2] Moreover, the surveys demonstrated that AH resulted in cessation of, or improvement in,
seizures in nearly 90% of patients, as did anterior temporal lobe resections. Recently, Yasargil and colleagues documented similar results: 78% of 78 patients, followed for at least 2 years, showed cessation of, or significant improvements in, their seizures. Because of the documented favorable surgical outcome, an increasing number of patients with mesial temporal lobe epilepsy will likely undergo AH and, hence, refinements of surgical techniques for AH are important.

Until now, the transsylvian AH has been the most popular AH approach. The transsylvian AH is certainly an ingenious operation, but it is technically demanding because of a severely limited cortical incision and the presence of major blood vessels in the sylvian fissure. Yasargil and colleagues have warned that "besides skillful microsurgical techniques, the exact knowledge of the vascular supply and of the surgical anatomy is essential." In the transsylvian approach, a cortical incision is limited to 2 to 2.5 cm. Consequently no brain retractor can be inserted through the corticectomy and the mesial temporal structures are removed using suction and bipolar forceps, which must simultaneously serve as retractors. In addition, "there is inevitably some injury to the superior temporal, inferior temporal and fusiform gyri," and 20% of the anterior temporal stem of the superior temporal gyrus is transected in the transsylvian AH. The transcortical AH proposed by Niemeyer is technically easier than the transsylvian approach, but damages the lateral temporal cortex.

The term "selective transsylvian amygdalohippocampectomy" implies removal of the amygdala and hippocampus without incurring a significant injury to the remaining temporal lobe. However, a recent report contained a description of surprisingly extensive damage to the remaining temporal lobe structures on MR imaging obtained after transsylvian and transcortical AH. The transsylvian AH resulted in changes consistent with wallerian degeneration throughout the temporal stem; the transcortical AH caused damage to the lateral temporal neocortex and the temporal stem. Although the lateral temporal cortex is known to possess important higher cortical functions, such as verbal memory recorded in the dominant superior and middle temporal gyri, significant neuropsychological benefits after transsylvian AH were not demonstrable in a previous study. Extensive but unrecognized temporal stem injury following the transsylvian approach may be the underlying cause of these negative results. At any rate, the demonstrated damage to the remaining temporal lobe caused by the transsylvian and transcortical approaches clearly indicates the need for further refinement in the surgical technique of AH.

In contrast to the transsylvian approach, the transparahippocampal AH provides wide access to the hippocampus, amygdala, parahippocampal gyrus, and uncus, allowing the surgeon to remove the structures under direct visualization throughout the operation. An important advantage is that the operation spares the temporal stem and the remaining temporal gyri, although some retraction injury may occur to the anterior fusiform gyrus and the inferior temporal gyrus. We have observed that MR T2-weighted images, obtained shortly after operation, reveal increased signal intensity in the white matter of the fusiform and inferior temporal gyri. However, follow-up images obtained 6 months later demonstrated no injury to the temporal stem like that seen after transsylvian AH--a result that requires further investigation.

The operation described here differs from previously reported subtemporal approaches to the mesial temporal lobe. Hori, et al., cut the tentorium in an effort to reduce retraction on the temporal lobe, emphasized measures to avoid damage to the vein of Labbé, and advocated en bloc excision of the fusiform gyrus to open the temporal horn. With respect to the tentorial incision, we found that the fusiform gyrus and the lateral temporal lobe can be spared from excessive retraction, even without a
tentorial incision. The temporal horn is approached after aspiration of cerebrospinal fluid from the ambient cistern and administration of mannitol and induced hyperventilation. The uncus is then retracted, rather than the posterior parahippocampal and fusiform gyri. The wide basal surface of the uncus allows elevation of the structure with only slight retraction of the fusiform gyrus. The uncus inevitably is subject to retraction injury at this point, but in AH the uncus is eventually resected, which makes retraction injury inconsequential. As regards the vein of Labbé, we begin resection from the medial uncus far more anterior to the vein of Labbé. The vein is not seen in the operative field initially and is visualized only after the anterior parahippocampal gyrus is removed. By this stage of the operation, there is already sufficient space for retraction and the vein is not subjected to undue traction, rendering the chance of venous injury remote. Third, as to excision of the fusiform gyrus, the sole purpose of resecting it in the operation described by Hori, et al.,[14] appears to be to open the temporal horn easily because there is no evidence that excision of the fusiform gyrus in AH improves seizure outcome. As we have demonstrated, the temporal horn can be easily reached through the uncus and parahippocampal gyrus. Moreover, studies of direct electrocortical stimulation have demonstrated the existence of basal language areas in the fusiform gyrus of the dominant temporal lobe. This may account for the dysphasia that sometimes occurs after dominant temporal lobe resection in some cases.[14] Thus it would be desirable to preserve the fusiform gyrus if possible. Other surgeons have reported a zygomatic approach that involves detachment of the zygomatic arch, removal of the sphenoid ridge and the basal temporal bone, and excision of the inferior temporal and fusiform gyri as well as other mesial temporal lobe structures.[28] Clearly, this operation differs from the transparahippocampal AH, but it may provide better exposure of the inferior temporal lobe and minimize the retraction injury to the fusiform and inferior gyri.

The presurgical evaluation for AH must include MR imaging to ascertain not only the degree of hippocampal atrophy but also the presence of other lesions such as gliomas and developmental malformations that might involve mesial temporal structures.[12,13] If more than one pathology (for example, cortical dysplasia) is found, the standard temporal lobe resection may prove more effective than AH. Most of our patients were evaluated using invasive subdural electrodes; such invasive monitoring may not be indicated in patients whose noninvasive tests all point to an epileptogenic area in the mesial temporal lobe. At present, however, we do not have sufficient knowledge about the reliability of noninvasive methods to localize accurately the area of epileptogenic foci in the mesial temporal lobe. Until we know more about this, invasive monitoring will be needed to evaluate most potential candidates for AH. The sodium amobarbital test may not be an essential adjunct to transparahippocampal AH because the operation requires no language mapping and the test may not reliably lateralize the hemisphere that supports memory, particularly in children. Further investigations are needed, however, before the sodium amobarbital test can be safely omitted from a presurgical evaluation for AH.

Some neurosurgeons perform temporal lobe resections with the patient awake, partly because this form of craniotomy allows intraoperative stimulation mapping of language areas.[20] However, many children, especially those with labile emotion or cognitive impairments, cannot cooperate fully with a surgical team, making intraoperative language mapping impossible. This poses a special problem in cases of children with dominant temporal lobe involvement because a dominant anterior temporal lobectomy, performed while the patient is anesthetized, without language mapping carries a risk of postoperative dysnomia.[9] Because transparahippocampal AH requires no language mapping, the operation offers an excellent option for children who require dominant temporal lobe resection.

In conclusion, the amygdala and hippocampus can be safely resected through the parahippocampal gyrus and this modification of subtemporal AH may offer several important advantages over other AH
approaches previously documented in the literature. Further experience is required to determine not only the surgical outcome but also the neuropsychological benefits resulting from preservation of the lateral temporal cortex and temporal stem.

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