The Modified Anterior Temporal Lobectomy plus Amygdalohippocampectomy: Guidelines and Lessons Learned

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Objective: The authors intend to demonstrate the currently used technique of anterior temporal lobectomy plus amygdalohippocampectomy for treating refractory temporal epilepsy as developed by the lead author (HTW). The anatomy based modifications presented in this paper have been gradually added to the original technique throughout a 13-year span to make these surgeries both safer and faster.

Material and methods: Three hundred and forty-six anterior temporal lobectomies plus amygdalohippocampectomies were performed by HTW from 1999 to 2011. The intraoperative observation of the difficulties encountered in each case motivated the search for modifications to overcome those difficulties.

Results: The major modifications are: patient positioning with less rotation of the head and more extension of the neck, interfascial dissection of the temporalis fascia, detachment of the temporalis muscle from the angle formed by the frontal and the temporal processes of the zygomatic bone, craniotomy below the superior temporal line, a 2.5 to 3.0 cm neocortical removal with subpial “peeling” technique, locating the temporal horn using the grey matter overlying the occipitotemporal sulcus, and resection of the amygdala based on a modified carotid-choroidal line. The modified sequence for the hippocampectomy is as follows: anterior disconnection, lateral disconnection, opening the choroidal fissure and the medial disconnection, and the posterior disconnection. Whenever possible, all the arachnoid membranes of the cisterns have to be kept intact during the intradural stage of the surgery. The overall seizure-free rate was 86%, and the complications were presented.

Conclusion: The careful intraoperative observation of the procedural difficulties, the anatomy-based modifications to overcome those challenges, and extensive practice of the microsurgical techniques helped the authors to design the above described technical modifications, making medial temporal resections safer and faster.

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Key words: epilepsy surgery, temporal lobe, microsurgical anatomy, hippocampus, amygdala, choroidal fissure, amygdalohippocampectomy, anterior temporal lobectomy


Introduction

Temporal lobectomies were first introduced in the mid 1940’s by Bailey and Gibbs⁴ and currently they are the most commonly performed procedures for treating refractory complex partial seizures arising from the medial temporal lobe.

Several different variations for the medial temporal resection have been described in general with good postoperative seizure control. Currently the most popular techniques are: the transsylvian selective amygdalohippocampectomy⁴¹, the anterior temporal lobectomy⁵ and the selective amygdalohippocampectomy via the middle temporal gyrus⁶. The main difference among these tech-
niques is the way in which they enter the temporal horn, whether via sylvian fissure, via middle temporal gyrus, or by removing the tip of the temporal lobe. Regardless the applied technique to enter the temporal horn, once inside the temporal horn, the structures that have to be removed are the same for all these techniques, namely the amygdala, hippocampus and part of the parahippocampal gyrus; however, the sequence for the amygdalohippocampectomy and the technical nuances might differ from surgeon to surgeon.

**Material and methods**

From 1999 to 2011, the first author (HTW) had the opportunity to perform 346 consecutive surgical resections involving the medial temporal region for epilepsy patients at the Hospital das Clínicas, College of Medicine, University of São Paulo, and at the Hospital Samaritano in São Paulo, Brazil. The modifications were introduced gradually to overcome the difficulties encountered in each case. In this paper the authors intend to display the currently used technique for the modified anterior temporal lobectomy plus amygdalohippocampectomy procedure.

These modifications have made this series of medial temporal operations safer and faster.

The anatomical aspects of the mesial temporal lobe were studied through dissections performed at the Laboratory of the Microneurosurgical Anatomy of the Department of Neurosurgery, University of Florida. The lessons learned therein were published earlier\(^6\)\(^{10}\)\(^{12}\)\(^{13}\).

**Results**

**The surgical technique**

The modified anterior temporal lobectomy plus amygdalohippocampectomy can be divided into the following steps: 1) the positioning of the patient; 2) the craniotomy; 3) the removal of the tip of the temporal lobe; 4) the...

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**Fig. 1** Patient positioning.

**Fig. 2** The large arrow indicates the surgeon’s line of view; the star indicates the posterior limit of the medial temporal resection; the white double arrow indicates the size of the neocortical removal necessary to achieve the posterior limit of the medial temporal resection (indicated by the star); the yellow double arrow indicates the desired size of the neocortical removal to achieve the “star”.

A thirty-degree rotation allows a straight resection tunnel down to the posterior limit of the medial temporal resection, with small neocortical removal. A ninety-degree rotation requires larger neocortical removal to achieve the posterior limit of the medial temporal resection; if a small neocortical removal is preferred in a ninety-degree rotation, the surgeon has to work in a rather uncomfortable angle, almost parallel to the ground and against gravity (as the lateral temporal lobe will fall over medial temporal lobe).
removal of the amygdala; 5) the removal of the hippocampus and the parahippocampal gyrus.

1) Patient positioning

The patient is placed in the supine position (Fig. 1), with a cushion under the ipsilateral shoulder; the head is elevated, slightly rotated to the contralateral side (Fig. 2), and the neck is extended to bring the malar eminence as the highest point of the head. The incision is similar to that used for the pterional approach with a slight posterior curve to keep the incision far behind the hairline for cosmetic reasons.

2) Craniotomy

After interfascial dissection to expose the angle formed by the frontal and the temporal processes of the zygomatic bone (Fig. 3), the temporalis muscle is detached from that angle, along the superior temporal line (Fig. 4). The burr holes are distributed and a fronto–temporo–sphenoidal craniotomy within the limits of the superior temporal line is performed. There is no need for extensive drilling of the sphenoid wing or removal of the orbital roof. The dura mater is anchored along the edge of the craniotomy and it is opened in “C” fashion (Fig. 5). It is adequate to expose at least the sylvian fissure, the superior and the middle temporal gyri.

3) Temporal lobe tip removal

The surface of the temporal lobe is inspected: the resection of the temporal neocortical cortex is planned to be performed at the superior temporal gyrus, approximately 2.5 cm behind the tip of the temporal lobe (Fig. 6). However, if there is a large cortical artery within this limit and it is coursing posteriorly to supply the remaining temporal lobe, it usually is dissected and relocated.
posteriorly. The same consideration can be extended to the presence of large cortical veins, as they usually are preserved (Fig. 7).

Before performing the neocortical resection, the arachnoid membrane covering the arterial branches is opened and the arterial branches are coagulated and sectioned. The veins usually are preserved and when necessary, they are sacrificed only in the last stage of the neocortical removal to avoid venous congestion.

The neocortical removal starts at the superior temporal gyrus, and it is directed perpendicularly to the sylvian fissure and towards the base of the middle fossa. The grey matter overlying the occipitotemporal sulcus has been a reliable anatomical landmark for locating the temporal horn; the temporal horn can be located medially to the tip of the grey matter overlying the occipitotempo-
Fig. 10  The right temporal lobe. The superior temporal gyrus has been "peeled" off the arachnoid membrane of the sylvian fissure down to the inferior limiting sulcus of the insula (yellow arrowheads). Please note the middle cerebral artery and branches underneath the arachnoid membrane of the sylvian fissure (blue arrowheads). 1- temporal pole; 2-uncus; 3-frontal lobe; 4-superficial sylvian vein.

Fig. 11  A coronal section of the MRI displaying the direction of the right temporal neocortex removal (yellow dotted line).

Fig. 12  The uncus has been peeled off the arachnoid membrane of the carotid, crural and the interpeduncular cisterns to display the internal carotid, P2A segment of the posterior cerebral artery and the oculomotor nerve. 1-internal carotid artery, 2-oculomotor nerve and the free edge of the tentorium, 3-frontal lobe, 4-P2A segment of the posterior cerebral artery, 5-uncus.

Fig. 13  The right temporal horn has been exposed. The inferior choroidal point is displayed by the tip of the suction tube. 1-amygdala, 2-head of the hippocampus, 3-choroid plexus, 4-body of the hippocampus.
ral sulcus (Fig. 8, 9).

Once opened, the temporal horn can serve as a landmark for neocortical removal: the removal of the temporal lobe tip is performed above and laterally to the temporal horn.

The superior temporal gyrus can be “peeled” off the pia mater and arachnoid membrane of the sylvian fissure, the inferior limit of the arachnoid membrane overlying the branches of the middle cerebral artery indicates that the inferior limiting sulcus of the insula has been reached, and the interposing white matter between the inferior limiting sulcus of the insula and the temporal horn is the temporal stem. This “peeling” process of the superior temporal gyrus can be continued anteriorly and medially until the uncus is reached (Fig. 10).

The tip of the temporal lobe is removed superiorly and laterally to the temporal horn: the contents of the temporal horn are not violated at this stage (Fig. 11).

The lateral wall of the temporal horn is removed as far back as possible for a better exposure of the temporal horn up to the atrium.

4) Amygdala removal

The “peeling” process of the superior temporal gyrus is continued anteriorly towards the uncus. At this stage, when the anteromedial surface of the uncus is “peeled off”, the middle cerebral artery (MCA), the anterior choroidal artery (ACHA), and the supracalnoid internal carotid artery can be visualized through the arachnoidal membrane. When the apex of the uncus is removed, the oculomotor nerve comes to the view. Then, when the posteromedial surface of the uncus is “peeled off, the P2A segment of the posterior cerebral artery (PCA) can be visualized through the arachnoidal membrane (Fig. 12).

The amygdala forms the anterior wall of the temporal horn and it also is located on top of the head of the hippocampus. To remove the amygdala, it is important to establish the superior limit of the resection, as the amygdala blends superiorly with the globus pallidus. For establishing the upper limit of the amygdala resection, HTW has used a “modified carotid–choroidal line” wherein the most superior and posterior point of the uncus is the inferior choroidal point (Fig. 13). The anteromedial surface of the uncus is peeled off the arachnoidal membrane as posteriorly and as superiorly as possible, then when the arachnoid plane is over, the surgeon has reached the most superior and anterior point of the uncus. Once those 2 points are established (the highest anterior and the highest posterior points of the uncus), the modified “carotid choroidal line” is then traced between them and the superior limit of the uncal resection is established (Fig. 14). As the arachnoid membrane is kept intact throughout the process, all the vascular and neural structures related to

Fig. 14 The dotted line indicates the modified “carotid–choroidal line”. M1: M1 segment of the middle cerebral artery.

Fig. 15 The amygdala has been separated from the head of the hippocampus. AM: amygdala, 1: head of the hippocampus, 2: the site where amygdala was adherent to the head of the hippocampus.
the uncus are preserved (optic tract, anterior choroidal artery [AChA], M1 segment of the middle cerebral artery [MCA], oculomotor nerve, P2A segment of the posterior cerebral artery [PCA]).

The amygdala is located anteriorly and superiorly to the head of the hippocampus. Frequently the amygdala is attached to the head of the hippocampus, and it has to be separated from the head of the hippocampus (Fig. 15).

5) Hippocampus and partial parahippocampal gyrus removal

The hippocampus and partial parahippocampal gyrus removal consists of 4 steps: a) anterior disconnection - separating the head of the hippocampus from the brainstem; b) lateral disconnection - separating the hippocampus from the rest of the temporal lobe through the collateral eminence; c) splitting the choroidal fissure through the taenia fimbriae; d) removing the parahippocampal gyrus; e) posterior disconnection - separating the body from the tail of the hippocampus;

a) The anterior disconnection

After the amygdala is removed, the part of the head of the hippocampus that constitutes the medial wall of the temporal horn ahead of the inferior choroidal point has to be removed. At this point, the head of the hippocampus is usually very adherent to the underneath arachnoid membrane and it usually is removed by gentle suction; it is very important to keep that membrane intact as that arachnoid membrane separates the head of the hippocampus from the AChA, basal vein and the crus cerebri. The disconnection of the head of the hippocampus is complete when it reaches the inferior choroidal point (Fig. 16, 22).

It is important to remember that at this stage, not only the head of the hippocampus is removed, but the posteromedial and the inferior surfaces of the uncus are also removed. When we visualize the P2A segment of the posterior cerebral artery, it indicates that the posterior segment of the uncus also has been removed. It is important to remember that the head of the hippocampus occupies the posteromedial surface of the posterior segment of the uncus, above the hippocampal sulcus.

b) The lateral disconnection

The collateral eminence is removed by suction all the way from its most anterior part to the collateral trigone (Fig. 17). This maneuver creates more room laterally to the hippocampus, allowing the hippocampus to be pushed laterally when the opening of the choroidal fissure (located on the medial side of the hippocampus) is performed. It is important to keep the arachnoid mem-
Fig. 18 The right hippocampus before the splitting of the choroidal fissure. 1—head of the hippocampus, 2—body of the hippocampus, 3—choroid plexus of the temporal horn, 4—inferior choroidal point, *: tenia fimbriae.

Fig. 19 The choroidal fissure has been split through the tenia fimbriae. 1—fimbria of the fornix, 2—body of the hippocampus, 3—arachnoid membrane of the hippocampal sulcus, 4—head of the hippocampus (in this case it has not been removed yet), 5—thalamus, 6—inferior choroidal point.

Fig. 20 The choroidal fissure has been split through the tenia fimbriae. 1—head of the hippocampus, 2—the arachnoid membrane of the hippocampal sulcus, 3—transverse hippocampal vein, 4—parahippocampal gyrus (beneath the arachnoid membrane of the hippocampal sulcus, 5—superficial sylvian vein.

Fig. 21 Splitting the choroidal fissure toward the atrium. 1—body of the hippocampus, 2—fimbria of the fornix, 3—basal vein, 4—choroid plexus, 5—thalamus, 6—anterior choroidal artery inside the choroid plexus.
brane of the basal surface of the temporal lobe intact to preserve the inferior temporal arteries that course on the basal surface of the temporal lobe.

c) Splitting the choroidal fissure

The choroidal fissure is split through the tenia fimbriae (the ependymal covering that attaches the choroid plexus to the fimbria of the fornix) (Fig. 18, 19). As soon as the choroidal fissure is split close to the inferior choroidal point, the usually thick arachnoid membrane comes to view. This arachnoid membrane enters the hippocampal sulcus carrying the hippocampal vessels (Fig. 20). The arachnoid membrane of the hippocampal sulcus is the continuation of the arachnoid membrane that covers the brainstem.

As we proceed posteriorly with the splitting of the choroidal fissure, the arachnoid membrane is usually very thin, and splitting the choroidal fissure will display the parahippocampal gyrus laterally and the thalamus medially (Fig. 21).

The hippocampal arteries (Uchimura’s arteries) and the transverse hippocampal veins (Fig. 22, 23) are coagulated and cut.

d) Removing part of the parahippocampal gyrus

After cutting the hippocampal vessels, the parahippocampal gyrus is removed by gentle suction, keeping intact the arachnoid membrane that protects the posterior aspect of the crus cerebri and the tegmentum of the midbrain (Fig. 24).

e) The posterior disconnection

After the parahippocampal gyrus is removed, it becomes easier to reach the posterior part of the body of the hippocampus and disconnect it from the tail of the hippocampus (Fig. 25). As the tail of the hippocampus is directed medially toward the medial wall of the atrium, it is impossible to reach it through a small neocortical removal such as performed in this technique.

The final aspect of the right modified anterior temporal lobectomy plus amygdalohippocampectomy can be seen in Fig. 26 and 27, and the corresponding postoperative MR can be seen in Fig. 28.

The average intradural operating time was 2 hours.

The overall seizure-free rate of this series was 86%. The visual field study was performed in the first 100 cases: in 60% the result was normal; forty percent of the cases presented a partial, small superior temporal
quadrantanopia.

The postoperative complications of this series were: one case of transient hemiparesis (in 1999), 2 cases of meningitis (in 1999 and 2000), 4 cases of wound infection (respectively in 2001, 2005, 2007, and 2008), 1 case of CSF leakage (due to frontal sinus opening, in 2002), 1 case of cerebral contusion (in 2001, during craniotomy, with full recovery), 2 cases of epidural hematoma (in 2005, and 2007), 2 cases of intraparenchymal hematoma (both in 2007), 1 case of small but scattered bilateral thalamic infarction (in 2008, a patient with severe chronic arterial hypertension previous to the surgery who was...
kept intraoperatively at a very low arterial pressure; he only returned to his previous neurological status approximately 2 years after the surgery.

There were no complications from 2009 to 2011 (83 consecutive cases).

Discussion

The ultimate goal of any treatment is to achieve good results with a low rate of complications. When a surgical approach for resecting the medial portion of the temporal lobe is presented, there will always be a great deal of discussion about which is the best approach (best results with lowest complication rates).

Nowadays, as long as the patients are adequately investigated and selected, and as long as the medial temporal structures are adequately removed, the overall seizure–free rate among the various surgical approaches is about the same, as they all can achieve good results. As far as complications are concerned, the 2 most frequently evaluated postoperative issues are a visual field deficit, and the neuropsychological outcome.

It is well known that in approaching the temporal horn, the usual visual field deficit is caused by damaging the Meyer’s loop of the optic radiation. The more anterior the approach to the temporal horn, the less the probability of injuring the fibers of the optic radiation.

The medial temporal lobe region (especially the posterior portion of it) also can be approached from below, as the fibers of the optic radiation do not cover the inferior aspect of the temporal horn. This has led some authors to approach the posterior medial temporal region using the infratentorial supracerebellar approach, with the patient in a semi sitting position, in which the tentorium cerebelli is cut, and the medial temporal region is approached from below and from posterior to anterior.

This is an elegant approach and avoids the optic radiation, but it implies sacrificing the veins binding the tentorial surface of the cerebellum to the tentorium cerebelli, sacrificing the tentorial sinus of that side, and opening the tentorium with venous channels, in a semi sitting position with the risk of air embolism.

Hori et al described the subtemporal amygdalohippocampectomy, it certainly spares the optic radiation, but implies in superiorly retracting the temporal lobe; that this superior retraction might be limited by the anatomical variation of the vein of Labbé complex.

As far as the neuropsychological outcome is concerned, the general concept is that if the resection is restricted to the medial temporal region, more lateral neocortical removal means poorer neuropsychological outcome. This has led several authors to perform a more “selective” amygdalohippocampectomy with less neocortical removal.

The gold standard for any surgical approach to the medial temporal region is to remove the medial temporal structures, sparing the lateral neocortex and the optic radiation. The only drawback is that, sometimes in order to spare the lateral neocortex, one tends to make a too small neocortical removal and tries to achieve the medial temporal removal through that small gap; sometimes it can lead to excessive retraction, poor intraoperative visualization of the important structures and in the end, may cause higher risk of cerebral contusion, injury to important medial temporal structures, or inadequate medial temporal removal.
It is absolutely important to keep the arachnoid membrane intact over the following structures: sylvian fissure, carotid artery and branches, oculomotor nerve, brainstem and vessels surrounding it. This maneuver will prevent injuring those important structures, making the surgery safer and faster. It is obvious that the main concern of each surgery is the safety and to a lesser extent, the length of it, but it is nice to have both, making our surgery attractive as it is safer and faster.

Probably the best surgical approach for the medial temporal region is the one that the surgeon is most familiar with.

The complications of the present series can be divided into the intradural and the extradural complications: the 3 intradural complications (one transient hemiparesis in 1999 and two postoperative hematomas in 2007) imply directly to the main surgeon (HTW). As the transient hemiparesis occurred in the first year of the series, it was probably due to a lack of experience. However, since the latter two complications occurred after 8 years; it is difficult to pinpoint the cause, whether it was the over confidence of the surgeon or the local coagulation factors. The extradural complications occurred throughout the series until 2008. The extradural stage of the surgery is performed by the residents (and they rotate every 3 months), so it also is difficult to pinpoint the cause here, whether it was related to the skill of the particular resident or local coagulation factor of the patient, or a less than optimal vigilance or supervision by the senior surgeon (HTW) during the extradural stage of the surgery or a combination of factors, but the complication rate has dropped since 2009.

Conclusion

In this paper, the authors presented anatomy based technical modifications of the anterior temporal lobectomy plus amygdalohippocampectomy with good postoperative results and a relatively low complication rate. Those modifications were introduced gradually over a period of 13 years until the current status, and have made medial temporal region resections safer.

Reference