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Visual Field Defects In Temporal Lobe Epilepsy Surgery

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Figure 1 ORIGINAL

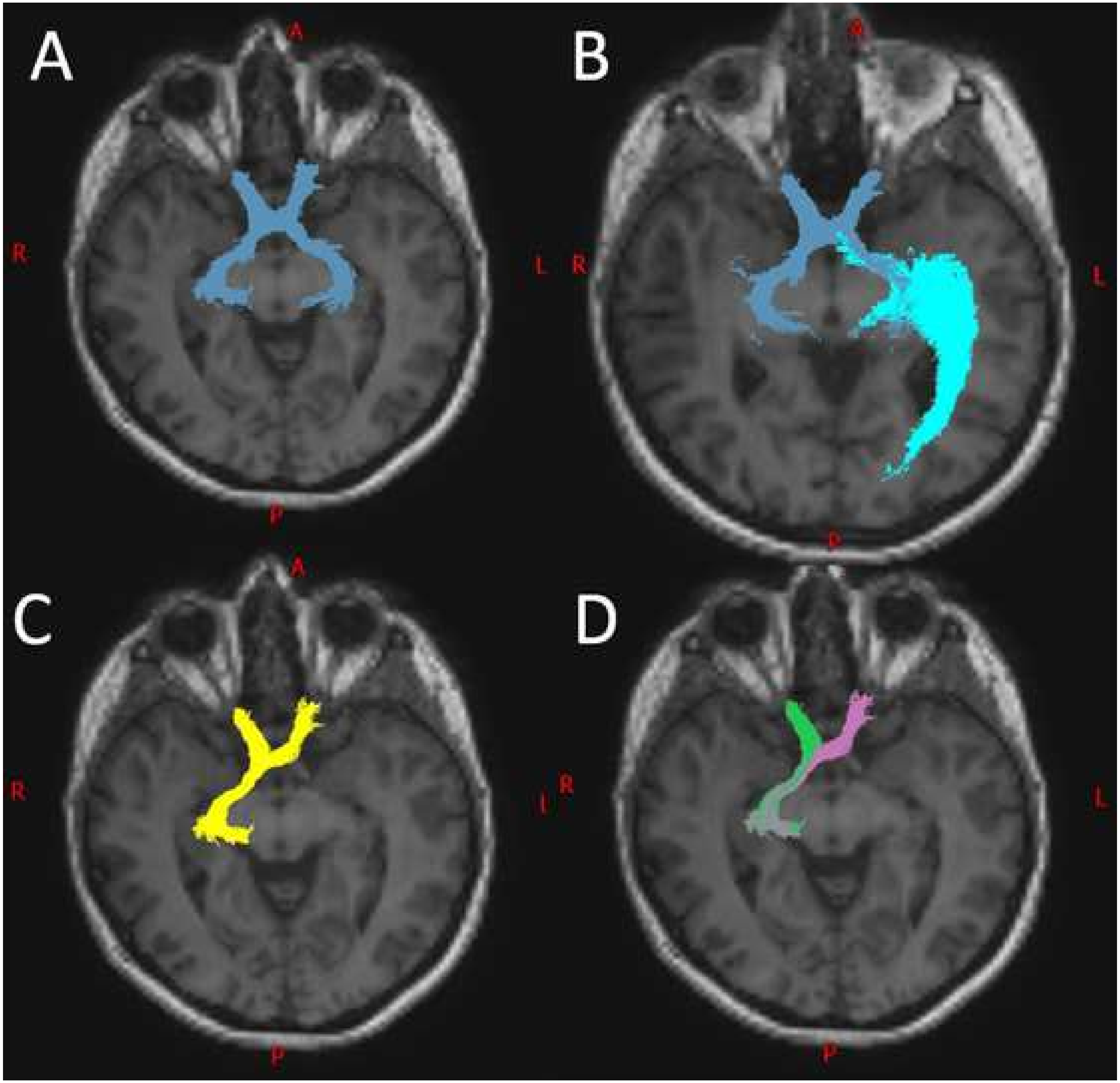

Figure 2 ORIGINAL

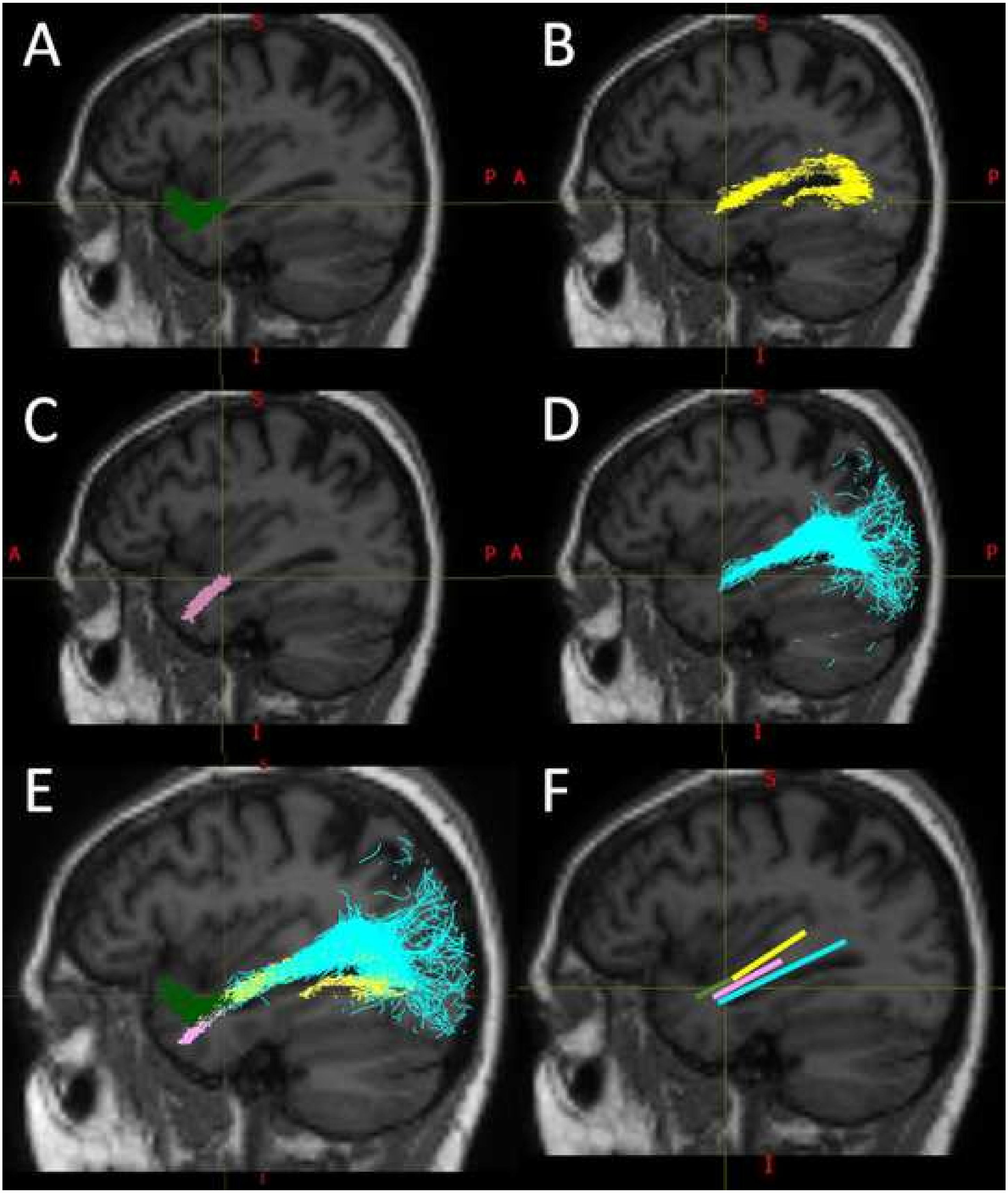

Figure 3 ORIGINAL

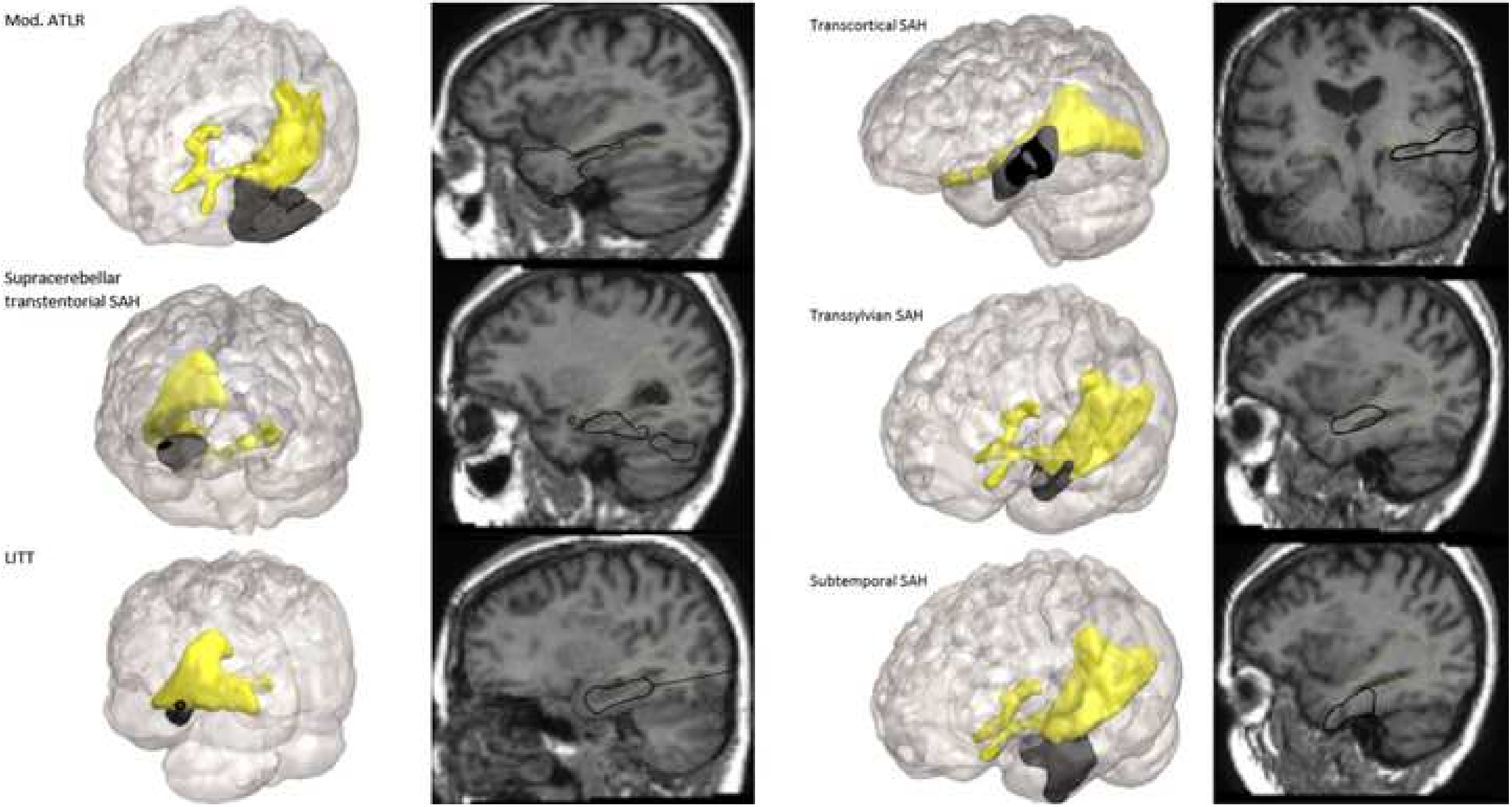

Table 1: Summary of visual field defects associated with different treatment modalities for mesial temporal lobe epilepsy

Author	Year	Treatment modality	VFD precluding driving (%)	Total VFD rate (%)
Mengesha et al.	2009	ATLR	Not specified	97
Quigg et al.	2018	ATLR	>23†	88
Cui et al.	2015	ATLR	Not specified	84
Cui et al.	2015	ATLR – with iMRI	Not specified	40
Jeelani et al.	2009	ATLR (modified with basal approach to ventricle)	4	15
Winston et al.	2014	ATLR with iMRI (modified with basal approach to ventricle)	0	89 (without brainshift correction) 67 (with brainshift correction)
Winston et al.	2014	ATLR (modified with basal approach to ventricle - historical cohort without iMRI)	13	Not specified
de Souza et al.	2020	tsSAH	Not specified	33
Yeni et al.	2008	tsSAH	Not specified	37
Delev et al.	2016	tsSAH	66%	88
Choi et al.	2006	tsSAH (modified transcisternal approach)		
Mengesha et al.	2009	tcSAH	Not specified	94
Delev et al.	2016	stSAH	33	54
Serra et al.	2020	scTT	0	0
Quigg et al.	2018	SRS	>19†	93
Jermakowicz et al.	2017	LITT	5.6	Not specified
Yin et al.	2017	LITT	20	20

ATLR – Anteromesial temporal lobe resection; iMRI – intraoperative MRI; tsSAH – transsylvian selective amygdalohippocampectomy; tcSAH – transcortical selective amygdalohippocampectomy; stSAH – subtemporal selective amygdalohippocampectomy; scTT – supracerebellar transtentorial approach; SRS – stereotactic radiosurgery; LITT – laser interstitial thermal therapy.

†Likely an under-estimate as reported as rate of macular involvement.

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Abstract

Purpose of review

Surgery can provide a robust long-standing seizure remission in drug-refractory mesial temporal lobe epilepsy (MTLE). Despite this, a significant proportion of post-operative patients are ineligible to gain a driving licence due to the size of the subsequent visual field defect (VFD). The amygdala and hippocampus are intimately related to several important white fibre association tracts and damage to the optic radiation results in a contralateral superior quadrantanopia. For this reason, several different modifications to established surgical approaches and novel techniques have recently been applied to mitigate or prevent damage to the optic radiation. There is still no consensus on which operative technique results in optimal outcomes regarding seizure remission, neuropsychological sequelae and VFD rates. We explore contemporary surgical approaches to the mesial temporal lobe and describe the intraoperative use of tractography and iMRI in preventing VFDs.

Recent findings

Established approaches for the surgical treatment of MTLE include standardised approaches in the form of anterior temporal lobectomies, selective approaches and various modifications thereof. Recent advancements in microsurgical techniques have seen numerous modifications to these approaches to spare the optic radiation as well as the introduction of minimally invasive alternatives such as laser interstitial thermal therapy (LITT) and stereotactic radiosurgery (SRS). The intraoperative use of optic radiation tractography through overlays in the operative microscope and interventional MRI suites to correct for brain shift have been shown to reduce VFDs.

Summary

VFDs following the surgical treatment of drug-refractory MTLE can have a significant impact on the quality of life. Each of the surgical techniques carries a risk to the visual pathways but the use of minimally invasive techniques as well as surgical adjuncts may reduce or prevent acquired VFDs.

Keywords: Optic radiation, Tractography, Epilepsy Surgery, Visual Field Defect

Introduction

Epilepsy affects 1% of the population and it is estimated that 30% of these patients fail to achieve seizure remission with best medical therapy alone. Surgical treatment for drug-resistant mesial temporal lobe epilepsy, following the failure of two or more adequate drug trials, results in a 58% absolute increase in seizure freedom compared to best medical therapy[1]. This improves to 73% when surgical intervention is undertaken within 2 years of the onset of disabling seizures[2]. As the benefit of surgical resections for drug-refractory mesial temporal lobe epilepsy became more apparent an increasing number of patients became seizure-free but were not eligible for a driving licence due to the magnitude of the resulting VFD[3]. In many countries, VFDs along the horizontal meridian within an area subtending 120 degrees or a significant defect within the central +/- 20 degrees during binocular Esterman protocol assessment would preclude eligibility for a driving licence. An increasing focus has, therefore, been placed on minimising VFDs, as well as neuropsychological sequelae, which are integral to post-operative cognition and social integration[4]. An understanding of the anatomy of the optic radiation and other white fibre tracts is fundamental in achieving this.

Anatomy of the fibre pathways within the temporal lobe

The optic radiation (OR), also known as the geniculocalcarine tract, emerges from the lateral geniculate nucleus (LGN) in three distinct bundles as anterolateral, lateral and posterior streams projecting to the inferior bank of the calcarine sulcus[5]. The anterolateral stream is termed 'Meyer's loop' and is most at risk during anteromesial temporal resections for drug-refractory focal epilepsy. Meyer's loop displays a retinotopic distribution with the anterior-most projecting fibres representing the superior-most temporal aspect of the contralateral visual field. Damage to fibres within Meyer's loop, therefore, results in a contralateral superior homonymous quadrantanopia, the severity of which is dependent on how far posteriorly the damage extends. It has been estimated that each mm of optic radiation that is damaged causes an additional loss of 5% from the contralateral superior quadrant[6]. The anterior projection of Meyer's loop is variable between patients and between the language-dominant and non-dominant hemispheres as defined by functional MRI (fMRI) derived language lateralisation indices[7]. Previous studies, utilising Klingler's white fibre dissection techniques in cadaveric specimens, estimate the anterior projection of Meyer's loop varies between 22 and 37 mm from the temporal pole[8]. Relative to the temporal horn the fibres were found to extend between 10 mm anterior and 5 mm posterior to the tip of the ventricle (see Figure 1).

Figure 1 – Anatomy of the visual pathway

The temporal stem has a complex anatomical configuration and lies immediately inferior to the inferior limiting sulcus of the insula[9] extending from the limen insulae anteriorly to the LGN posteriorly. It contains fibre tracts attributable to the uncinate fasciculus (UF), inferior fronto-occipital fasciculus (IFOF), anterior commissure (AC) and OR. The topography of the white fibre tracts within the temporal stem is of critical importance to understanding the relative neurological and neuropsychological deficits associated with different surgical approaches to the mesial temporal regions, which will be discussed subsequently. The anterior-most aspect of the temporal stem, that which lies deep to the limen insula, is comprised of the UF connecting the anterior frontal and temporal lobes. Transection of the uncinate fasciculus may be beneficial in preventing the spread of epileptogenic activity from the temporal lobe to the orbitofrontal and medial frontal regions. Continuous posteriorly with the UF the white fibre tracts transition into the long association fibres of the IFOF connecting the frontal and the parieto-occipital lobes. The IFOF is thought to be a critical part of the ventral language stream. Lesions of IFOF in the language dominant hemisphere can result in semantic paraphasias and should be avoided[10]. Inferior to the IFOF are fibres that belong to the lateral extension of the anterior commissure as they emerge from the canal of Gratiolet and terminate in the temporal pole as well as the middle and inferior temporal gyri[11]. The OR constitutes the deepest fibre bundle within the temporal stem and lies immediately above the roof of the temporal horn of the lateral ventricle (See Figure 2). For completeness, the other white fibre tracts within the temporal lobe include the middle longitudinal fasciculus (MLF), inferior longitudinal fasciculus (ILF) and arcuate fasciculus (AF).

Figure 2 – White matter fibre tracts of the temporal stem

Contemporary surgical approaches for anteromedial temporal lobe epilepsy

A range of different surgical approaches for the treatment of mesial temporal lobe epilepsy have been utilised including standardised approaches, such as the anterior temporal lobe resections (ATLR) with various modifications[12,13], selective approaches (transsylvian (tsSAH)[14], transcortical (tcSAH)[15], subtemporal (stSAH)[16] and supracerebellar transtentorial (scTT)[17]), stereotactic radiosurgery (SRS)[18] and laser interstitial thermal therapy (LITT)[19]. The surgical approaches each carry different risks to the adjacent white matter fibre tracts and are, therefore, associated with varying postoperative VFD rates (see Figure 3 and Table 1).

Figure 3 – Surgical resection associated with different approaches for amygdalohippocampectomy

Anterior temporal lobe resections

Early series of ATLRs reported dominant and non-dominant lateral neocortical resections of 4.5cm and 6 cm from the temporal pole, respectively. In these reports, VFDs were considered an expected outcome and no attempt was made to prevent damage to the optic radiation fibres. As microsurgical approaches became more sophisticated it became possible to undertake amygdalohippocampectomies through smaller lateral neocortical resection utilising a 3.5 cm neocortical resection and transventricular approach to the mesial temporal structures. Concurrently, a selective transsylvian approach through the inferior limiting sulcus of the insula had been described to avoid the need for any lateral neocortical resection[14]. Before this, selective approaches via a transcortical approach through the middle temporal gyrus to the temporal horn of the lateral ventricle were favoured[15].

Contemporary standardised mesial temporal resections limit the lateral neocortical resection to <3.5 cm from the temporal pole. Following a lateral neocortical and temporal pole resection, the mesial temporal structures are subsequently resected through the temporal horn of the lateral ventricle. This results in transection of the UF and the anterior aspect of the ILF. In this procedure, Meyer's loop is most at risk during the approach to the temporal horn of the lateral ventricle as the anterior-most projection ranges from 22-37 mm in anatomical studies[8] and 24-47 mm in tractography studies[20] from the temporal pole. Nevertheless, simply limiting the neocortical resection to 3.5 cm and approaching the temporal horn of the lateral ventricle from the basal surface through the collateral sulcus can reduce the significant VFD rate to as low as 4-13%[21,22].

Transsylvian selective amygdalohippocampectomy

The tsSAH enters the temporal horn of the lateral ventricle through the inferior limiting sulcus of the insula through an aperture of 12-20 mm and transgresses the anterior portion of the temporal stem. Consequently, this transgresses the uncinate and inferior fronto-occipital fasciculi[23] but spares any lateral neocortical resection. Given that Meyer's loop extends to the anterior border of the temporal horn and in some cases beyond this, access to the temporal horn from a superior approach through the temporal stem conveys a significant risk of VFD. Reported series of patients undergoing tsSAH, describe significant VFDs that would prevent driving in around 30%-90% of cases[13,24,25]. Modified approaches utilising a transsylvian-transcisternal approach through the uncus[26] with a temporal stem transgression limited to the anterior 5 mm[27] have been described and may spare Meyer's loop fibres but are technically more demanding and limit access to the posterior hippocampus. Post-operative MRI studies of patients undergoing both standard tsSAH and the modified transsylvian-transcisternal techniques reveal high rates of secondary temporal pole atrophy suggesting that these approaches are not as selective as once thought[23]. Further considerations regarding the tsSAH are the branches of the middle cerebral artery as vasospasm of these vessels, through their manipulation, can result in unintended ischaemic complications.[28].

Transcortical selective amygdalohippocampectomy

The tcSAH involves entry into the temporal horn of the lateral ventricle through a 2-3 cm corticotomy in the middle temporal gyrus. The intervening white matter within the lateral temporal lobe that is transgressed from lateral to medial includes the short association fibres, ventral and dorsal segments of the AF, IFOF, posterior projections of the AC and the optic radiation fibres. A study of VFDs following tcSAH reported severe VFD rates in 89% (16/18)[29].

Subtemporal selective amygdalohippocampectomy

The stSAH potentially avoids the neocortical resection required with an ATLR, prevents transgression of the temporal stem as with tsSAH and does not transect the optic radiation during the approach to the temporal horn as with the tcSAH. Similar to the modified ATLRs described previously the stSAH entails entry into the temporal horn through the collateral sulcus or a 2 cm corticotomy in the fusiform gyrus[16]. This approach, however, necessitates elevation of the temporal lobe to enter the temporal horn through the basal surface and consequently carries a risk of venous injury. In such cases where the basal temporal draining veins preclude elevation of the temporal lobe a modified transcortical approach utilising the inferior temporal gyrus is required[30]. A randomised control trial comparing outcomes following stSAH with a tsSAH revealed a similar seizure-free outcome rate. The extent of the VFD, however, prevented driving in 33% (5/15) of the stSAH group compared with 67% (10/15) following tsSAH[25]. Of note, although the overall frequency of patients developing a VFD was lower with the stSAH, when deficits did occur they were more likely to impact driving eligibility. The implication being that VFDs during stSAH tend to be more posterior in the course of the optic radiation and hence damage a greater extent of the fibre tract.

Supracerebellar transtentorial selective amygdalohippocampectomy

The original descriptions of the scTT approach for mesial temporal resections involved the use of the semi-sitting position[17] but due to concerns over the venous air embolism risk, the lateral or park-bench positions have also been used[31]. A craniotomy is performed extending over the transverse sinus and a supracerebellar dissection is performed. After visualisation and protection of the trochlear nerve at the tentorial incisura, the tentorium is incised to allow access to the mesial basal temporal lobe. The mesial temporal lobe structures including the parahippocampal gyrus are then resected[32]. This technique uniquely has the benefit of preventing any unnecessary brain resection or retraction and recent series have reported no VFD rates with seizure freedom rates comparable to the other surgical techniques[33]. It should be noted that the position of the torcula and consequently the angle of the tentorium in some patients may preclude this technique. Furthermore, the exposure entails long working distances and is technically challenging.

Stereotactic radiosurgery

SRS is delivered at a single outpatient session in which 24-Gy is delivered to a 50% isodose to the amygdala, anterior 2 cm of the hippocampus and the adjacent parahippocampal gyrus[18]. An evaluation of VFDs following SRS delivered as part of the multicenter ROSE trial revealed an overall rate of 91%[34]. Driving eligibility was not formally assessed in this study but macular involvement was similar to the ATLR cohort and this would likely preclude driving in 19%. More sclerotic hippocampi preoperatively were also predictive of greater VFDs following SRS, presumably due to greater collateral damage to the surrounding white matter. Additionally, the extent of cerebral oedema following SRS can be extensive and in some cases required prolonged steroid administration[18].

Laser interstitial thermal therapy

LITT is a novel minimally invasive thermal ablation technique that is performed through a small incision in the scalp. A 3.2 mm burr hole is then placed in the occipital bone and a bolt is stereotactically implanted into the skull to guide the insertion of a1.65 mm catheter. The trajectory of the catheter is critical in the determination of the ablation zone and consequently the seizure freedom and VFD rate[35–37]. Studies reporting VFDs following laser ablation contain small patient numbers but estimates range from 5-20%[37,38]. Visual field defects range from homonymous superior quadrantanopias to complete hemianopias. The latter is thought to occur due to heat transmission across the choroid fissure to the LGN. Surprisingly, visual field defects were more common when the tissue diffusivity within the LGN was abnormal pre-operatively, suggesting it may be more vulnerable to damage in these cases[39]. Low CSF volume within the choroid fissure, and hence reduced heat sink effect, has also been shown to be a risk factor[37]. Similarly, thermal injury to Meyer's loop is less likely to be a cause of visual field defects as the temporal horn of the lateral ventricle prevents heat transmission. Damage to the optic radiation is more likely to occur when extensive ablations are carried out at the posterior body of the hippocampus and heat is transmitted to the adjacent stratum sagittale[39].

Surgical adjuncts to minimise VFDs

MRI fibre tractography is a method of reconstructing the optic pathway based on the diffusivity of water molecules. Early methods of undertaking fibre tractography were based on resolving diffusion tensors within each voxel of the brain. Streamlines were then propagated between the adjacent voxels utilising deterministic algorithms based on the principal eigenvector. Such methods were unable to reliably reconstruct Meyer's loop and mainly represented fibres projecting posteriorly. Improvements in the number of gradients (multi-shell acquisitions), diffusion directions and field strengths (b-values), combined with mathematical models to resolve different fibre populations within a voxel and use of probabilistic algorithms, have resulted in more sophisticated methods that can delineate kissing and crossing fibre populations. Tractography has several limitations, chief of which is the lack of an in vivo gold-standard. When generating streamlines a proportion of these may propagate spuriously to regions that are not connected (false-positives) or may fail to reconstruct connections (false-negatives) that are present in vivo. False-positives are more common with probabilistic algorithms whilst false-negatives are more common with deterministic algorithms. Additional user variability exists based on the placement of seed, inclusion and exclusion regions of interest. Despite these pitfalls, clinical studies have reported on the predictive ability and intraoperative use of optic radiation tractography to guide mesial temporal resections[40,41]. This requires the use of intraoperative neuronavigation software, which can be integrated with the neurosurgical microscope to provide overlays of the tractography during surgery. Brainshift is a common problem affecting the accuracy of neuronavigation systems, especially during procedures involving large resections or significant CSF loss such as with transcisternal or transventricular approaches. To overcome this, intraoperative MRI suites have been utilised to perform a repeat MRI scan following resection of the lateral neocortex in ATLR procedures[42,43]. The position of the tracts can then be re-registered to the intraoperative MRI scan to correct for brain shift. The interim scan added on average an additional one hour to the total operative time. In one such study, the degree of brain shift after resection of the lateral neocortex was 6.5 mm on average but was underpowered to detect a significant difference between the two methods[22]. Additionally, this study showed that the use of intraoperative MRI significantly reduced the size of the post-operative VFD. None of the 21 patients that underwent intraoperative MRI-guided anteromesial temporal resections was prevented from driving post-operatively, but this study was underpowered to detect driving eligibility when compared to a historical cohort where tractography was not used.

Conclusion

We summarise the contemporary surgical treatment modalities for drug-refractory mesial temporal lobe epilepsy. The surgical armamentarium has expanded beyond the traditional open surgical approaches to encompass new treatment modalities including SRS and LITT. We demonstrate the surgical resections associated with each approach, the three-dimensional anatomical course of the optic radiation and the corresponding risk of VFD. Finally, we summarise the pertinent literature regarding the use of modern operative adjuncts such as intraoperative MRI and tractography.

Key points

- The choice of surgical approach and knowledge of white fibre tract anatomy is critical to preventing post-operative visual field defects (VFDs) and neuropsychological sequelae in patients undergoing epilepsy surgery.
- Variability in the anterior extent of Meyer's loop between patients and between hemispheres in the same patient necessitates an individualised approach to mesial temporal lobe resections.
- Novel surgical techniques, such as the supracerebellar transtentorial approach, as well as minimally invasive technologies, may reduce the incidence of VFDs that prevent driving post-operatively when long-term seizure remission is achieved.
- The use of intraoperative adjuncts, including tractography and interventional MRI suites, yield promising results but there is significant variability in their implementation and availability.

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Figure 1 Legend: A: Tractography reconstruction (dark blue) of the anterior visual pathway from the optic nerves to the LGN and tectum to mediate the pupillary response. B: Addition of fibre tracts (cyan) emanating from the LGN and travelling to the primary visual cortex. C: Connectivity of both of the optic nerves (yellow) to the right LGN. D: Differential connectivity of the right (green) and left (pink) optic nerves to the right LGN outlining why a unilateral lesion of the LGN results in homonymous hemianopia.

Figure 2 Legend: Tractographic representation of the unicate fasciculus (A - green), inferior longitudinal fasciculus (B – yellow), anterior commissure (C - pink) and optic radiation (D – cyan) at the level of the temporal horn of the lateral ventricle. Superimposition of all of the fibre tracts within the temporal stem (E) and schematic representation of their relative positions (F).

Figure 3 Legend: Three-dimensional cortical representations of the visual pathways (yellow) and surgical resection cavity (black) with corresponding MRI image associated with the different surgical approaches to the left mesial temporal lobe structures. Three-dimensional model projections: Transcortical SAH – lateral view, Transylvian SAH - Superior lateral view, Subtemporal SAH - Superior lateral view, Mod. ATLR - Superior lateral view, Supracerebellar transtentorial SAH – Inferior posterior view, LITT – Posterior lateral view.

Table 1: Summary of studies reporting visual field deficit rates based on the operative approach employed:

Author	Year	Technique	Overall VFD rate	VFD rate preventing driving
Mengesha et al.	2009	ATLR	90.9%	
Quigg et al.	2018	ATLR	88%	
Cui et al.	2015	ATLR	84.4%	
Cui et al.	2015	ATLR – with iMRI	40%	
Jeelani et al.	2009	ATLR (modified with basal approach to ventricle)	4.0%	

Winston et al.	2014	ATLR with iMRI (modified with basal approach to ventricle)	0%	
Winston et al.	2014	ATLR (modified with basal approach to ventricle - historical cohort without iMRI)	12.5%	
de Souza et al.	2020	tsSAH	32.5%	
Yeni et al.	2008	tsSAH	36.6%	
Delev et al.	2016	tsSAH	87.5%	
Choi et al.	2006	tsSAH (modified transcisternal approach)		
Mengesha et al.	2009	tcSAH	89%	
Delev et al.	2016	stSAH	54%	
Serra et al.	2020	scTT	0%	
Quigg et al.	2018	SRS	93%	
Jermakowicz et al.	2017	LITT	5.6%	
Yin et al.	2017	LITT	20%	

ATLR – Anterior temporal lobe resection, iMRI – interventional MRI, tsSAH – transsylvian amygdalohippocampectomy, tcSAH – transcortical amygdalohippocampectomy, stSAH – subtemporal selective amygdalohippocampectomy, scTT – supracerebellar transtentorial approach, SRS – stereotactic radiosurgery, LITT – Laser interstitial thermal therapy.

We thank the reviewers for their kind comments regarding the manuscript. As recommended, we have now included the table summarising the visual field defect rates associated with the different treatment modalities described in the manuscript. We have also amended the typographical error. We hope the manuscript is now suitable for publication.

Kind Regards,

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