The field defects of anterior temporal lobectomy: a quantitative reassessment of Meyer’s loop

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Temporal lobectomy is often complicated by superior quadrantanopia. The relation of field loss to sagittal resection length can inform us about the functional anatomy of Meyer’s loop, with ramifications for surgical planning. However, the literature has produced highly variable results. We studied 29 patients with anterior temporal lobectomies using Goldmann perimetry. 24 patients had post-operating neuroimaging, with which we assessed resection length relative to each patient’s temporo-occipital dimensions. For the field defect we calculated the proportion of area lost for three isopters. We found a significant correlation between resection size and field loss for both nasal and temporal defects. Linear regressions suggested an anterior limit of Meyer’s loop at 24 to 28 mm from the anterior temporal pole, and involvement of the lower quadrant when resections reached 70 to 79 mm, with significant inter-subject variability. The nasal defect was 15% greater than the temporal defect for all degrees of quadrantanopia, with no difference between right and left hemispheres. Macular involvement began when field defects reached 61% of quadrant area, corresponding to a resection of about 58 mm. Patterns of field loss showed that the lower margins were most often horizontal or with a slight slope towards fixation, rather than true wedge defects. We conclude that field loss is related to resection length and that Meyer’s loop extends more anteriorly than estimated in traditional surgical studies, in agreement with modern MRI and dissection studies. The patterns of field loss support a revised retinotopic model in which the most anterior fibers of Meyer’s loop represent the superior field, not the vertical meridian as traditionally proposed.

Keywords: quadrantanopia; temporal lobectomy; Meyer’s loop; epilepsy; optic radiations

Abbreviations: AT-OP = anterior temporal–occipital pole


Meyer’s loop is the most anterior portion of the optic radiation (Meyer, 1907), projecting forward across the superior aspect of the anterior tip of the lateral ventricle’s temporal horn before turning to join the parietal fibres of the optic radiation in their course towards the striate cortex. It transmits visual information from the contralateral superior field of both eyes, and damage to its fibres is one cause of a homonymous superior quadrantanopia (Jacobson, 1997).

Knowledge about the anatomy of Meyer’s loop has been facilitated in the last 50 years by the development of anterior temporal lobectomy as a treatment for complex partial seizures. The size of the resection involved is tailored to available data concerning the location of seizure foci in the temporal lobe, and this variation in turn generates variability in the frequency and size of the field defects from associated damage to Meyer’s loop. Estimates of quadrantanopia complicating lobectomy range from 50–70% (Marino and Rasmussen, 1968; Katz et al., 1989; Tecoma et al., 1993) to 90–100% (Bjork and Kugelberg, 1957; Falconer and Wilson, 1958; Hughes et al., 1999). This variation has also allowed investigators to estimate the location, span and retinotopic anatomy of Meyer’s loop in humans. However, there has been considerable disagreement in the last 50 years on all of these points. For example, the anterior limit of Meyer’s loop has been estimated at anywhere from 20 to 60 mm posterior to the temporal pole, with a tendency to lower estimates in more recent studies (Krolak-Salmon et al., 2000; Nilsson et al., 2004). There is controversy on whether the size of resection...
correlates with the size of the field defect, as would be reasonable to expect, or if intersubject variability is so great as to obscure this relationship. Others argue about whether the defects are congruent or incongruent between the two eyes in their retinotopy, or whether there are hemispheric asymmetries in Meyer’s loop.

However, a review of the literature shows that many conclusions were based on qualitative or semiquantitative data. When stated, operative estimates of resection size were given to the nearest 0.5, 1.0 or even 2.0 cm (Wendland and Nerenberg, 1960; Marino and Rasmussen, 1968; Babb et al., 1982). Field defects on Goldmann perimetry were often only classified into broad categories, such as whether the defect was more or less than a quadrant (Marino and Rasmussen, 1968; Jensen and Seedorff, 1976; Babb et al., 1982). Since Meyer’s loop only represents the upper quadrant, such classifications state merely whether the loop was spared, partly involved or fully involved. While there are a few modern studies with MRI and/or automated perimetry, these have also tended to group either MRI or perimetric data into similarly broad categories (Hughes et al., 1999; Krolak-Salmon et al., 2000; Nilsson et al., 2004).

The lack of consensus in the literature may reflect these limitations in methodology. We embarked on a re-evaluation of the functional anatomy of Meyer’s loop using quantitative measures of both resection length and field loss. With the advent of MRI, it is possible to achieve a more accurate assessment of the anterior–posterior dimensions of resection. While we used traditional Goldmann perimetry to map field loss, we calculated the area of visual loss rather than relying on broad categorizations. We applied quantitative analyses to these numerical data to address several questions raised in the older literature. First, is there a relation between field loss and resection size? Second, what are the anatomic limits of Meyer’s loop in the sagittal plane? Third, is there incongruity or hemispheric asymmetry in resection effects on the visual field? Fourth, where is the macula represented in Meyer’s loop? With the answers to these questions and additional observations on the patterns of partial quadrantanopias, we generated a revised model of the functional anatomy of Meyer’s loop.

**Methods**

**Subjects**

We recruited 29 patients who had previously had standard temporal lobectomies performed for idiopathic temporal lobe epilepsy, from patients seen consecutively over a 9-month period in the epilepsy clinic of Beth Israel Deaconess Medical Center. All patients were seen more than 6 months after surgery. We excluded patients with neoplastic lesions or other ophthalmic or neurological causes of visual loss. Of the 29 patients, 16 had left- and 13 right-sided resections. Of the 16 with left lobectomies, two declined postoperative research neuroimaging and one could not have MRI because of metallic objects from prior surgery elsewhere. Of the 13 with right lobectomies, two did not have postoperative imaging. The sample of patients with both imaging and visual fields was 11 patients with right and 13 patients with left temporal lobectomies. Average age of the patients in this sample was 45.5 years (SD 9.3, range 26–63), with no significant difference between right and left lobectomies. Average duration since surgery was 8.9 years (SD 5.6, range 1–19), also with no significant difference between right and left resections. The research protocol was approved by the hospital’s institutional review board and all patients gave informed consent for the study.

**Imaging**

Twenty-four patients had postoperative MRI (Fig. 1). MRI scans were obtained in standard fashion with axial slices aligned along the anterior commissure–posterior commissure line. Our standard protocol included axial and sagittal T1-weighted images [spin echo pulse sequence, TE (echo time) min full, TR (repetition time) 525], axial T2-weight images (fast spin echo pulse sequence, TE 85, TRed 5400) and axial FLAIR (fluid-attenuated inversion recovery) images (T2 flair pulse sequence, TE 120, TR 9000). Slice thickness was 5 mm and interslice spacing 1.5 mm. To measure the extent of resection, we first realigned each axial scan to eliminate head turn. We then estimated the anterior–posterior extent of the resection by measuring the distance from the anterior tip of the middle sphenoid fossa (which had contained the resected temporal pole) to the posterior margin of the resection, using images that intersected the midbrain. For

![Fig. 1 Axial MRIs of lesions. (Top row) Left temporal lobectomies. (Bottom row) Right temporal lobectomies.](image-url)
irregular margins we used the most posterior aspect of the resection in the periventricular white matter. Hyperintensities on FLAIR imaging, which presumably corresponded to scarring at the resection edge, were not included in the estimate. To compensate for variations in head size and possible metrical distortions introduced by MRI, the extent of resection was expressed as a fraction of the distance between the anterior tip of the middle sphenoid fossa to the occipital pole (anterior temporal–occipital pole, or AT-OP distance). To verify the accuracy of using the tip of the fossa as a surrogate for the temporal pole, measures of AT-OP distance were obtained in the non-resected hemisphere, using the existing temporal pole to mark the AT position. T-tests showed no significant bias in the AT-OP estimates between the intact and resected hemispheres, despite the difference in methods. The mean AT-OP distance was 135 mm (i.e. a 30% resection would correspond to a resection of about 40 mm). This estimate of 135 mm may seem slightly larger than the mean AT-OP distance of 125 mm (SD 4.7) in one study of 25 formalin-fixed brains (Ebeling and Reulen, 1988), but given the 10% degree of shrinkage induced by fixation these results are actually in close agreement.

As a regional marker we also measured the distance from the tip of the lateral ventricle’s temporal horn from the temporal pole in the intact hemisphere, again expressed as a proportion of the AT-OP distance in that hemisphere.

Perimetry

All patients had Goldmann perimetry, using near refraction when necessary within 30° of eccentricity, and done by the same experienced examiner in 28 of the 29 patients (Figs 2 and 3). Perimetry was done in a standardized fashion for each eye separately, generating three isopters with the V4e, I4e and I2e targets, much like one prior study (Tecoma et al., 1993). Two subjects with right lobectomies had two isopters only because they could not see the I2e or I3e targets. Two subjects with left lobectomies had an additional 03e isopter because their I2e isopter lay peripheral to 30°.

An examiner blinded to the results of neuroimaging quantified the degree of visual loss in terms of area. Assessing area of loss on Goldmann perimetry can be complicated, particularly since the position of the outer margin of a quadrantic defect is unknown. Rather than estimating this outer margin, we decided to calculate the area lost within a circular region of field (much as automated static perimetry does), with radius equal to the height of the isopter in the intact field at the vertical meridian. We employed three different techniques, depending upon the nature of the inferolateral margin of the quadrantic defect. First, if the field loss in an isopter was wedge-shaped, estimating the fraction of sector loss is simply done by determining the angle of the inferolateral margin of the defect. However, in many partial quadrantanopias the lower margin of field loss...
was horizontal, a finding previously noted by others (van Buren and Baldwin, 1958). In these cases we used a second method. We approximated the area of a normal quadrant as the area of a quarter disc with radius \( r \) equivalent to the maximal vertical extent of the isopter in the intact field. By calculating the average height of the quadrantanopic margin from the horizontal meridian, we can integrate the function defining a circle, \( y = \sqrt{r^2 - x^2} \), to calculate the area spared:

\[
\int (y) = \frac{x}{2} \sqrt{r^2 - x^2} + \frac{r^2}{2} \arcsin \left( \frac{x}{r} \right)
\]

where \( x \) is the height of the spared region. Subtracting this from the normal quadrant area will give us an estimate of the amount of field lost for that isopter, which we then express as a proportion of the normal quadrant area for that isopter.

Third, for six fields with more complex borders we performed a manual calculation of the area affected. We used the same formula to determine the area of each 10° arc (i.e., 20–30° eccentricity, 30–40°) lying within a given isopter. For each arc we then estimated the percentage loss, using the radial degree markers as guidelines, and multiplied by arc area to give the area of loss in that arc. These areas were then summed for all arcs and divided by total quadrant area to give the proportionate area loss for that isopter.

After calculating the proportion of area loss for each isopter, we averaged these for all available isopters to yield the fraction of the upper quadrant lost in each eye. A value of 1 indicates complete quadrantanopia and a value greater than 1 occurs with loss extending into the lower quadrant.

These methods provided a very reasonable estimate of field loss in the superonasal quadrant, where isopters do approximate the shape of a quarter-circle. They are more approximate in their measure for the more oval-shaped superotemporal quadrant. However, by using the same methods for both nasal and temporal fields we could make quantitative comparisons between the two fields.

Because the central field is represented in all three isopters, whereas the periphery is covered by fewer isopters, these methods also weight the central field more than the peripheral field. This has the advantage of mimicking, though not precisely reproducing, the physiological central magnification present in optic nerve and striate cortex (Rovamo and Virsu, 1979; Tolhurst and Ling, 1988). Use of more than one isopter also allowed our area calculations to index the depth as well as the area of a scotoma, which is probably an important second factor in estimating the proportion of visual loss.

**Analysis**

Our chief aim was to determine the relation between field loss and resection length. We performed a linear regression analysis of field loss against resection length for each eye. From the intersections of

![Fig. 3 Goldmann perimetry of visual fields of 13 patients with right temporal lobectomies.](image-url)
Temporal lobectomy and Meyer’s loop

the regression line with field loss values of 0 and 1, we estimated the smallest resection that would lead to field loss and the size of resection at which inferior field involvement began. These essentially would be the anterior and posterior limits of Meyer’s loop.

We compared the nasal and temporal field loss in each patient. Because this analysis was done without regard to MRI, we also included the fields from four of the five patients who did not have postoperative imaging, to give a sample of 28 patients. (One of the five was excluded because she had complete hemianopia in one eye, and hence was an extreme outlier.) We used an analysis of variance (ANOVA) with main factors of side of surgery (right versus left) and side of field loss (nasal versus temporal) to determine if field loss was greater in the nasal or the temporal field. We also performed a linear regression analysis of temporal against nasal field loss, to see if asymmetries tend to increase or decrease with the amount of field loss.

Goldmann perimetry is less accurate in quantifying loss in the central 5°; therefore we devised a semiquantitative 6-point scale to characterize macular involvement. For each eye, a point was awarded for each isopter in which part or all of the central 5° was affected. Thus, an eye in which all three isopters showed macular loss was awarded 3 points, and one in which only the I2e isopter showed macular loss was awarded 1 point. The scores from both eyes were summed to give a total score out of 6, which was then divided by 6 to give a range from 0 to 1. This was plotted as a function of both the proportion of quadrant field loss and the resection length, to determine at what point the macular field was compromised. A linear regression analysis was performed using the non-zero values of macular involvement to demonstrate the relation between these variables. The intersection of this linear regression line with a macular involvement value of zero was taken as indicating the point at which the fibres representing the macula became involved.

Last, we also made some qualitative observations on the shape of partial quadrantanopias, particularly in reference to the course of the inferolateral margin of the field defects. These margins are particularly relevant to issues of the retinotopic map of Meyer’s loop.

Results

Right temporal lobectomies averaged 46% (SD 6) of the AT-OP distance (about 61 mm, range 52–76 mm), compared with 40% (SD 6, about 54 mm, range 41–68 mm) for left lobectomies, a difference that was close to statistical significance by t-test (P = 0.12).

All patients had an abnormal visual field in at least one eye. The linear regression analyses showed significant correlations of field loss with lesion length for both fields [nasal field, r = 0.75, F(1,21) = 24.6, P < 0.0001; temporal field, r = 0.69, F(1,21) = 26.1, P < 0.0001] (Fig. 4, top). From the intercepts of the lines with a field loss value of zero, the estimates of the anterior limit of the optic radiation were 18% (24 mm) for the nasal field and 21% (28 mm) for the temporal field. For comparison, our measure of the anterior tip of the temporal horn of the lateral ventricle in the contralateral hemisphere was 24% (SD 2), or about 32 mm from the temporal pole.

From the intercept of the lines with a field loss value of one, the estimate of the point at which the inferior quadrant began to be involved was 54% (72 mm) for the nasal field and 58% (79 mm) for the temporal field. Within this range, with every additional 10 mm of resection about 20–22% of vision in the superior quadrant was lost.

We also confirmed the observations of mild incongruity with greater nasal than temporal loss after lobectomy. ANOVA showed no significant effect of side of resection, but a significant main effect of side of field [F(1,26) = 66.5, P < 0.0001]. The average field loss in the nasal quadrant was 0.70, compared with 0.55 in the temporal quadrant. We also repeated the ANOVA with isopter as an additional factor. This analysis showed no significant interaction between side of field and isopter [F(1,26) = 0.16, P = n.s.], indicating that the presence of the nasal/temporal asymmetry was similar in all isopters. Linear contrasts confirmed that all three isopters showed significant differences between nasal and temporal fields at the P < 0.001 level: the absolute difference between percentage quadrant loss in nasal versus temporal fields was 13% for the I2e, 13% for the I4e, and 16% for the V4e isopter. Regression analysis of the nasal versus temporal field loss showed that the slope was not significantly different from 1 (Fig. 4, bottom). Thus the absolute nasal/temporal asymmetry of 15% in field loss was present for all degrees of resection. To express the nasal/temporal asymmetry in another way, Fig. 4 (top) shows that the regression lines for nasal and temporal field loss are offset by a mean value of 6 mm between field loss values of 0 and 1.

Inspection of Fig. 4 also shows that, for any given magnitude of resection, the average amount of visual loss does not differ for left versus right resections. This was confirmed with analysis of covariance analyses using MRI resection size as the covariate and resection side as the main factor. For neither nasal nor temporal field defects was there a significant main effect or interaction from the side of resection.

Macular involvement was not seen until substantial field loss had occurred. Figure 5 shows that macular involvement began when about 60% of the quadrant’s field was affected, which, given the linear regressions of Fig. 4, would correspond to a resection of 40% of the AT-OP distance, or about 54 mm. This agreed quite well with the independent analysis of the relation of macular involvement to resection length, which suggested onset of macular involvement at a resection length of 42%. After this point the degree of macular depression correlated with the degree of additional field loss. The regression line intersected a macular loss value of 1 (indicating macular loss of the V4e isopter in both eyes), when the degree of quadrant loss was also 1 (indicating complete quadrantanopia).

Inspection of the maps of partial quadrantanopic defects showed that the majority of the inferolateral margins followed either a horizontal course or a slightly downward sloping course towards the vertical meridian (Figs 2 and 3). However, in no case was the inferolateral margin aligned on a radial line pointing towards fixation. That is, we did not observe pie-shaped wedge defects corresponding to a radial sector of the visual field. Rather, what we termed ‘pseudo-wedge’ defects were frequent, in which there is a more
moderate downward deflection of the margin near the vertical meridian.

Discussion
To summarize our findings, there is a significant quantitative correlation between field loss and the degree of temporal lobe resection. The linear regression analysis estimates the anterior extent of Meyer’s loop at 24 mm, and its posterior limit at 79 mm. For every 10 mm of resection, about 20% of vision in the quadrant is lost. There is considerable inter-subject variance, which must be kept in mind with surgical planning and prognostication. Analysis of incongruity shows 15% greater visual loss in the nasal than in the temporal field. Linear regression lines (solid lines) and equations are shown, using data from all patients regardless of the side of lobectomy. There is a consistent 16% greater loss in the nasal field than in the temporal field.

Fig. 4 Proportionate field loss as a function of resection length. (Top left) Nasal field loss (ipsilateral eye). (Top right) Temporal field loss (contralateral eye). Linear regressions including both left and right temporal lobectomies are shown, with equations in the upper left corners of the graphs. Dashed lines indicate the estimate of the posterior border of Meyer’s loop, when the linear regressions intersect a field loss value of 1, indicating complete quadrantanopia. (Bottom) Nasal versus temporal field loss. For each patient the proportion of temporal quadrantal loss is plotted as a function of the proportion of nasal quadrantal loss. The dashed diagonal line indicates where nasal field loss equals temporal field loss. Linear regression lines (solid lines) and equations are shown, using data from all patients regardless of the side of lobectomy. There is a consistent 16% greater loss in the nasal field than in the temporal field.

lost, or at about a resection length of 54 mm. We also confirmed the observation that the most frequent forms of the inferolateral margins of partial quadrantanopias were horizontal or pseudo-wedge margins, with a slight downward slope as the margin approached the vertical meridian.

Where is the anterior extent of Meyer’s loop? Penfield first stated that lesions of less than 60 mm from the temporal tip were not likely to produce a field defect (Penfield, 1954). Since then a series of reports has gradually shifted this location anteriorly. Falconer suggested a location at 45 mm (Falconer and Wilson, 1958), while Marino found that the smallest defect occurred with a resection of 40 mm (Marino and Rasmussen, 1968), and Bjork estimated that the anterior limit lay between 30 and 40 mm (Bjork and Kugelberg, 1957). All of these older studies used intraoperative estimates of resection size. More recently a study with MRI and automated perimetry moved the estimate of the anterior limit...
of Meyer’s loop to between 20 and 30 mm (Krolak-Salmon et al., 2000). Another study that used coronal MRI to assess different compartments of the temporal lobe concluded that involvement of the superior temporal gyrus between 18 and 36 mm from the pole was correlated with the presence of field defects (Nilsson et al., 2004). A pathological dissection of 25 brains found a mean value of 27 mm (SD 3.5) but emphasized the variability between subjects (Ebeling and Reulen, 1988). Using MRI data, our estimates from linear regression of the mean anterior limits of Meyer’s loop are 24 mm for the nasal field and 28 mm for the temporal field. These are more consistent with the modern dissection and MRI reports than with the older reports based on intraoperative material. Our findings on the relation of the anterior limit of Meyer’s loop to the tip of the lateral ventricle also agree with the dissection study (Ebeling and Reulen, 1988). We found a mean position of the lateral ventricle’s tip at 32 mm from the temporal pole, implying that Meyer’s loop extends 4–8 mm beyond the ventricle on average. This is similar to the dissection report’s value of a mean 5 mm extension (range –5 to +10 mm), but contrary to older assertions that Meyer’s loop does not ‘cap’ the ventricle’s temporal horn (van Buren and Baldwin, 1958).

We caution, though, that our estimate of the anterior limit of Meyer’s loop might be slightly liberal, since we had no patients with normal fields in both eyes and the regression assumes that an approximate linearity holds to the anterior limit of Meyer’s loop, which may not be the case. For example, in Fig. 4 a value of 0.25 (about 34 mm) could be a potential anterior limit if the most anterior part of the loop was more compressed than its posterior aspect.

On the other hand, our estimates of the point at which the posterior optic radiation becomes affected by temporal lobe resection are consistent with the older literature. Our linear regressions indicated that this happened when resections reached about 70 mm for the nasal and 79 mm for the temporal field. Two studies have suggested a value of 80 mm (Falconer and Wilson, 1958; Wendland and Nerenberg, 1960), and Penfield stated that lesions of 80 mm or more resulted in hemianopia (Penfield, 1954). Another study found that lesions of 70 mm or more were associated with complete quadrantanopia or extension into the inferior field (Marino and Rasmussen, 1968).

Within the anterior and posterior limits of Meyer’s loop we found that the proportion of field lost correlated with resection length, a point of inconsistency in the literature. Many authors cite a lack of correlation but this is based mainly on studies with cruder intraoperative measures of resection size and field loss assessments (Falconer and Wilson, 1958; Babb et al., 1982; Tecoma et al., 1993). One quantitative approach to field loss used linear measures of the eccentricity and the lower radial limit of the field defect for a single isopter (Katz et al., 1989) but such one-dimensional measures do not capture aspects of field loss such as area and depth. A few older studies did report approximate correlations of field loss with resection length (Bjork and Kugelberg, 1957; Wendland and Nerenberg, 1960; Marino and Rasmussen, 1968) but are subject to the same criticisms. A newer study with MRI and automated static perimetry reported a correlation but again subdivided both MRI and field data into broad categories (Krolak-Salmon et al., 2000). One other study with
MRI and automated static perimetry did use quantitative field data but simply binned lesions into those less than 50 mm or more than 60 mm (Hughes et al., 1999); nevertheless, it did conclude that greater field loss occurred with larger resections.

We believe that two critical factors allowed us to show a quantitative correlation between field loss and resection length. First, our resection assessments were based on neuroimaging. This allowed a more fine-grained measure of resection length than intraoperative estimates. Axial imaging allowed us to determine the most posterior aspect of each resection in white matter, which may be the most functionally relevant measure for a field defect. Also, we could use imaging to calculate lesion size as a proportion of each subject's brain size, as measured by the AT-OP distance, thus reducing one source of intersubject variability.

Second, our assessments of visual fields may have produced a more realistic estimate of the amount of visual loss. We calculated area involved and used several isopters to both gauge the depth of loss and provide some degree of central magnification. Our method for doing this was relatively simple. More sophisticated calculations that better approximate physiological central magnification and more precise perimeter assessments of the depth of field loss might further improve the correlation, but at least some of the variance in our results in Fig. 4 is due to intersubject anatomical variability rather than methodological issues (Ebeling and Reulen, 1988).

Previous examinations of incongruity have also produced mixed results. Several Goldmann studies reported congruous defects, though methods of assessment were often not described (Bjork and Kugelberg, 1957; Falconer and Wilson, 1958; Wendland and Nerenberg, 1960) or stated to be ‘inspection’ (Tecoma et al., 1993). Reports of incongruity have usually found more severe loss in the nasal field (van Buren and Baldwin, 1958; Jensen and Seedorff, 1976; Babb et al., 1982) with exceptions (Marino and Rasmussen, 1968). While some have claimed that incongruity is more likely with smaller defects (Marino and Rasmussen, 1968), we found that the absolute degree of incongruity was independent of the size of the field defect, in agreement with another study (Katz et al., 1989). The magnitude of incongruity has been expressed both as a percentage of field loss and a spatial estimate. One study estimated a 5% greater loss in the nasal field, though the method of calculation was not stated (Jensen and Seedorff, 1976). Our figure of 15% is larger. On the other hand, another study estimated that the nasal field’s projections may extend as much as 10–15 mm anterior to those of the temporal field (Babb et al., 1982). Our linear regressions suggest a more modest displacement of 6 mm.

A potential asymmetry between right and left optic radiations has also been reported. In an early study the few patients with field defects extending to the lower field were more likely to have had a right than a left resection, attributed to more generous right-sided resections (Jensen and Seedorff, 1976). Other studies reported slightly larger right-sided resections by 5–15 mm (Tecoma et al., 1993; Hughes et al., 1999), similar to our finding of 7 mm, but found no difference between left and right quadrantanopias (Tecoma et al., 1993; Hughes et al., 1999). These studies did not control for resection size, though, and one might argue that a difference in resection length but not in field defect could indicate a more anterior optic radiation on the left. However, when we control for the magnitude of resection there is no difference in the amount of superior field loss between the right and left hemispheres.

Macular involvement has been variable in prior studies. One study using only the I4e target found no compromise of the central 5° (Egan et al., 2000). A larger study with Goldmann perimetry found macular involvement in 14% of 74 patients (Jensen and Seedorff, 1976), and another with automated perimetry noted loss in the central 3° in 25% (Hughes et al., 1999). Older studies have claimed that macular involvement does not occur until field loss affects the lower quadrant (Marino and Rasmussen, 1968; Babb et al., 1982). While our results agree with claims that the macula is represented posteriorly (Hughes et al., 1999; Egan et al., 2000), they also show that relative loss within the central 5° begins earlier, with partial quadrantanopias of about 60%. Hence our results more precisely specify that the representation of the superior macula is in the posterior aspect of Meyer’s loop, but not posterior to all other fibres of the loop, as some models depict (Hughes et al., 1999).

The most common form of the inferolateral border of partial quadrant defects in our study was a horizontal margin, usually shallow, sometimes with increasing downward slope as the vertical meridian was approached. Others have noted a similar preponderance of these types of defects (van Buren and Baldwin, 1958). Also, we suspect that the ‘convex’ borders noted by others are probably equivalent to a horizontal margin sloping down near the vertical meridian (Bjork and Kugelberg, 1957; Egan et al., 2000). Of note, we did not find true wedge defects, in which the inferolateral margin points to fixation. Only one prior study found such defects in a few patients (Wendland and Nerenberg, 1960). Close inspection reveals that the ‘wedges’ reported by others are a subtler downward deflection of the margin near the vertical meridian.

These deflections or pseudo-wedges have been interpreted as evidence for locating the vertical meridian in the most anterior portion of Meyer’s loop (van Buren and Baldwin, 1958). The resulting traditional models often show a radial retinotopy, in which the radial degrees proceed from vertical to horizontal during the transition from the anterior to the posterior portion of the loop (Hughes et al., 1999; Egan et al., 2000). However, if that were the case, vertical resections should always create true wedge defects, and the mildest defect should be a slice adjacent to the vertical meridian. Our data and the illustrations in prior reports (Bjork and Kugelberg, 1957; Hughes et al., 1999; Krolak-Salmon et al., 2000)—in particular and ironically those of van Buren and Baldwin (1958)—suggest that partial quadrantanopias have a different form, with horizontal or sloping pseudo-wedge margins.

Accounting for these patterns of partial quadrantanopia would be difficult with the traditional model. Rather,
horizontal margins are more compatible with a model in which the superior field occupies the most anterior portion of Meyer’s loop, due to a 90° rotation of the visual field. Furthermore, pseudo-wedge defects are a natural consequence of a linear resection through the superior field when the retinotopy incorporates the effects of central magnification (Fig. 6). In such a model, slight angulations of the line of resection can create either a horizontal margin or margins with varying degrees of downward slope to the vertical meridian.

Central magnification may also explain why the results of Fig. 4 show an empirically good linear fit between field area and resection length, even though there is no a priori reason to indicate that this relation is necessarily linear. As in all models of field loss following temporal lobectomy, the guiding assumption is that with resections in an approximately coronal plane, the effect on the visual field is determined by the intersection of this resection plane with the most anterior projection of the loop. This corresponds to the point where Meyer’s loop turns from an anterior to a posterior course, with its axons momentarily projecting perpendicular to the sagittal plane, and arraying the retinotopic map in the sagittal plane. In our model of retinotopy the chief effect of the sagittal position of the resection on this map is to determine how much of the superior aspect of the quadrant is lost. In a quadrant without central magnification, the area of field above a horizontal margin is a non-linear function of the vertical position of that margin. Thus at the top of the quadrant, moving the margin down a small amount only removes a small sliver of field, whereas a similar movement of the margin when it is already close to the horizontal meridian results in a large loss of area. However, central magnification offsets this effect, since increases in resection at the superior periphery would move the vertical position of the margin much further than similar increases in resection near the horizontal meridian. The combination of these two opposing non-linear effects may generate the approximately linear relation between resection length and area of field loss that we observed, even if the underlying relation is probably not truly linear.

Figure 7 incorporates all our findings into a new model of Meyer’s loop. The anterior margin may extend about 5 mm on average beyond the tip of the lateral ventricle’s temporal horn, as others have also found (Ebeling and Reulen, 1988), though this will vary between subjects. The loop measures about 50 mm in the sagittal plane. The nasal field is offset about 6 mm anterior of the temporal field, in its entirety not just its most anterior portion. The retinotopy of the radiation is a 90° rotation of the field, with the superior field most anterior, with the lines of eccentricity appropriate for central magnification, and with the macula occupying its natural position in this map at the posterior aspect of the loop. This retinotopic organization not only better accounts for the form of partial quadrantanopias after temporal lobectomy, but is also more consistent with retinotopic maps of the lateral geniculate nucleus, optic radiations, striate cortex and pulvinar (Spalding, 1952; Bender, 1981; Horton and Hoyt, 1991). A downward rotation of our map of Meyer’s loop as the radiation completes its course over the roof of the lateral ventricle and turns to project towards the occipital pole would precisely match our retinotopy with that of the more distal optic radiation in the coronal plane (Spalding, 1952). Thus, not only is this new retinotopic model more consistent with the data, but more plausible and logical given the retinotopy of other visual structures. We believe that the traditional model is predicated upon the confusion of pseudo-wedge defects with true wedge defects, and the failure to appreciate the role of central magnification in generating pseudo-wedge defects.
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References


Fig. 7 A proposed model of Meyer’s loop. A right visual quadrant is shown at top left (M = macula). At top right is a lateral view of the left cerebral hemisphere showing the lateral ventricle and optic radiations. Distances perpendicular to the coronal plane are shown. Meyer’s loop extends to about 24 mm from the temporal pole, just anterior to the termination of the temporal horn of the lateral ventricle at about 32 mm, and is about 50 mm in length. The middle left panel shows a proposed retinotopy of Meyer’s loop in the sagittal plane. An exponential central magnification is estimated beginning with the allocation of 40% of the length of the radiation to the central 5°. The entire nasal field is offset anterior to the temporal field (the nasal field is shown superimposed semitransparently on the temporal field). Resections parallel to lines A and B generate the two possible field defects illustrated at bottom right. Because of central magnification, a purely vertical resection creates a horizontal margin with a slight upward slope. Tilt of the resection towards line A would create a truly horizontal margin of the field defect. A tilt in the other direction would accentuate the slope of the defect. The box shows the retinotopy required if vertical resections led to true wedge defects, corresponding to traditional models of Meyer’s loop.


Temporal lobectomy and Meyer’s loop


