Update

Surgical anatomy of the hippocampus

Anatomie chirurgicale de l'hippocampe

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Abstract

Background and purpose. – Hippocampectomy is an efficient procedure for medial temporal lobe epilepsy. Nevertheless, hippocampus anatomy is complex, due to a deep location, and a complex structure. In this didactic paper, we propose a description of the hippocampus that should help neurosurgeons to feel at ease in this region.

Methods. – Embryological data was obtained from the literature, whereas adult anatomy was described after dissecting 8 human hemispheres (with and without vascular injection) and slicing 3 additional ones.

Results. – The hippocampus is C-shaped and made of 2 rolled-up laminae, the cornu Ammonis and the gyrus dentatus. Its ventricular aspect is covered by the choroid plexus of the inferior horn excepted at the head level. Its cisternal aspect faces the mesencephalon from which it is limited by the transverse fissure. Its rostral part (head) curves dorso-caudally to form the uncus, located at the medial aspect of the temporal lobe. Its caudal part (tail) splits into the fimbria and the gyrus fasciolaris that respectively run ventral and dorsal to the corpus callosum, to become the fornix and indusium griseum.

Conclusion. – Consequences of this complex anatomy are presented, and the authors stress the need for a subpial resection. Important landmarks are provided to avoid lesions of the surrounding structures.

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Résumé


Méthode. – Les données embryologiques sont issues de la seule littérature, alors que les données anatomiques adultes ont été obtenues après dissection de 8 hémisphères humains injectés ou non et la réalisation de coupes pour 3 autres.

Résultats. – L’hippocampe a une forme de « C » et est constitué de 2 lames enroulées, la corne d’Ammon et le gyrus dentatus. Sa portion ventriculaire est recouverte par le plexus choroidien de la partie ventriculaire inférieure sauf au niveau de la tête. Sa portion cisternale fait face au mésencéphale dont il est séparé par la fissure transverse. Sa partie rostrale (tête) s’incurve dorso-caudalement pour former l’uncus. Sa partie caudale (queue) se divise en fimbria et gyrus fasciolaris qui cheminent respectivement aux faces ventrale et dorsale du corps calleux, pour devenir la jambe du fornix et l’indusium griseum.

Conclusion. – Les conséquences pratiques de cette anatomie sont présentées et les auteurs soulignent l’importance de la dissection sous pia et du respect de repères anatomiques lors de la chirurgie de cette région.

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1. Introduction

Most of the epileptic patients suffering an hippocampal sclerosis can be efficiently treated by resection of the hippocampus more or less including the surrounding structures, especially amygdaloid...
complex and parahippocampal gyrus: after such a surgery, more than 80% of them are seizure free [Engel Class I] [1–4]. Nevertheless, hippocampus anatomy has the reputation to be very complex and difficult to understand for non-specialized neurosurgeons or neurologists. Hippocampus is indeed a deep structure, hidden between the mesencephalon and medial aspect of the temporal lobe, its main aspect being only visible inside the inferior horn of the lateral ventricle. This anatomical challenge is increased by a complexity in the used terminology, a same structure being differently named in different part of the hippocampus.

The goal of this didactic paper is to provide the reader with a comprehensive and practical anatomy of the hippocampal region and the practical consequences of this anatomy for neurosurgical procedures. We first present a summarized and highly simplified embryological view of this region, in order to give the reader the keys that are mandatory to understand the adult anatomy. We then describe the surface and sectional anatomy of the hippocampus, and finally present influence this anatomy should have in surgical planning. This paper does not aim at a complete description of the hippocampus morphology and function that can be found elsewhere [5,6], nor in an original description of this region. For this reasons, we only used a limited number of specimens, without any attention paid to inter-subjects variability.

2. Material and method

For the description of adult anatomy, 11 human brain hemispheres (5 left and 6 right) were obtained from the body donation program of our laboratory. For surface anatomy, we studied 4 hemispheres (2 right 2 left) that were extracted, fixed in a 10% commercial formalin solution for 3 months and then whitened in a 10% commercial hydrogen peroxide solution. To study hippocampus vasculization, two brains were injected with colored latex: after severing the head, red neoprene latex (neoprene latex #671, E. I. Du Pont de Nemours–Dow Elastomers, Wilmington, DE) was injected into the primitive carotid and vertebral arteries, and blue neoprene latex was injected into the jugular veins. Brain was extracted after latex polymerization and fixed as previously described. Dissections were performed under optical magnification and important steps of the dissections were photographed. Relationships of the hippocampus were studied on these dissections but also slices. One additional right hemisphere was sliced following a coronal plane after being fixed, whereas another brain was sliced after carotid and vertebral injection of a mixture of gelatin and india ink.

Due to the didactic aim of this paper, and to the limited number of subjects that does not allow study of variations, photographs of right specimens were presented in their original orientation, whereas those from left specimens were right-left flipped.

The embryologic considerations were obtained from the literature [6–8].

3. General situation

The hippocampus is located between the medial aspect of the temporal lobe and the temporal horn of the ventricle. It is part of the limbic lobe (or rhinencephalon), a complex puzzle of various anatomical structures located at the medial aspect of the hemisphere [9]. The limbic lobe (Fig. 1A) is limited from the surrounding cortex by the limbic fissure, and is divided into 2 concentric circles, the limbic and intralimbic gyrri.

The discontinuous limbic fissure includes:

- the cingulate sulcus, between the anterior and middle parts of the cingulate gyrus and the superior frontal gyrus;
- the subparietal sulcus that limits the posterior part of the cingulate gyrus from the precuneus;
- the anterior segment of the calcarine sulcus, running between the isthmus of the cingulate gyrus and the lingual gyrus (or OS);

![Fig. 1. Development and adult anatomy of the limbic system.](image-url)
the temporal, anterior part of the collateral or medial temporo-occipital or T4-T5 sulcus that limits the lateral temporo-occipital gyrus (or fusiform gyrus) from the medial temporo-occipital gyrus. The later includes a temporal part (parahippocampal gyrus or T5) and an occipital part (lingual gyrus or O5);

• and the rhinal sulcus, located between the limbic lobe and temporal pole.

The limbic gyrus forms the peripheral circle of the limbic lobe, its outer limit being the limbic fissure; it contains:

• the subcallosal gyrus located below the rostrum of the corpus callosum;
• the cingulate gyrus including its isthmus;
• and the parahippocampal, or T5, or temporal part of the medial occipito-temporal gyrus.

Finally the intralimbic gyrus, which is the inner circle of the limbic lobe, corresponds to the adult hippocampus and its embryological remnants:

• the prehippocampal rudiment or precommissural hippocampus, located in the depth of the paraterminal gyrus;
• the indusium griseum or supracommissural hippocampus that follows the cingulate gyrus around the rostral, dorsal, and caudal aspects of the corpus callosum;
• and the hippocampus proper or retrocommissural hippocampus that lies at the superior aspect of the parahippocampal gyrus.

4. Embryology and compared anatomy

This complex organization of the hippocampus and related structures is nicely explained by embryology and compared anatomy. During its development the hippocampus experiences 3 important changes from which its complex shape derives.

4.1. Rotation around the developing basal ganglia and thalamus

As they develop, the lateral parts of the telencephalon – or telencephalic vesicles – rotate dorso-caudally, then ventrally and finally rostrally to give the adult frontal, parietal, occipital and temporal lobes. The small part of the telencephalon located on the midline (telencephalon impar), just dorsal to the optic chiasm, thickens to give the commissural plate, which is the precursor for the anterior, callosal and hippocampal commissures (Fig. 1B). The Hippocampal commissure first follows the telencephalic rotation and extends from the supra optic to the temporal regions. The callosal commissure then also develops from the commissural plate and progressively splits the hippocampal commissure in a ventral and a dorsal parts (Fig. 1B):

• the part of the hippocampal commissure ventral to the callosal commissure or subcallosal part, gives the adult fornix;
• its dorsal part can be subdivided in precommissural and supra commissural, the respective precursors for the prehippocampal rudiment and indusium griseum;
• finally, in the temporal region (retrocommissural part), the hippocampal commissure is not divided by the callosal commissure and becomes the hippocampus proper.

As a consequence, in the adult (Fig. 1A), the indusium griseum continues the tail of hippocampus dorsal to the corpus callosum, whereas the fornix is the expansion of the hippocampal fimbria, ventral to the corpus callosum.

4.2. Invagination into the medial temporal lobe

In acallosal mammals (such as ornithorhynchus anatinus), the hippocampus is organized around a longitudinal hippocampal sulcus that invaginates at the medial wall of the hemisphere and remains clearly visible in the adult. In Humans, such a hippocampal sulcus - although less visible -also exists at the medial aspect of the temporal lobe and ventrally limits the hippocampus from the underlying parahippocampal gyrus (Fig. 2).

4.3. Rotation along the hippocampus longitudinal axis

In human, the apparition of the hippocampal sulcus is accompanied by a rotation along the longitudinal axis of the hippocampus, which gets a complex rolled structure (Fig. 2B). Afterwards, the hippocampal sulcus involutes deeply and remains only visible at surface of the medial aspect of the temporal lobe. Due to this rotation and to an increasing volume, the resulting adult human hippocampus bulges in the ventricle.

5. Descriptive anatomy and structure

Seen from above (Fig. 3) the hippocampus resembles a “C” medially concave around the mesencephalon. Three parts can be described: the body (middle part) running sagittally, the head which is longer and runs rostro-medially, and the tail, the thinner part, coursing caudo-medially and dorsally. These 3 parts are made of a 3-layered allocortex.

5.1. Body of the hippocampus

The complex anatomy of the hippocampus body is better understood after a simultaneous description of its structure (Fig. 2) and surface anatomy (Fig. 3).

5.1.1. Structure

It is nicely depicted on a coronal slice (Fig. 2). The hippocampus is made of 2 cortical laminae rolled-up inside the other: the cornu Ammonis and the gyrus dentatus:

• the cornu Ammonis laterally continues the subiculum, which is the flat superior aspect of the parahippocampal or T5 gyrus. The cornu Ammonis can be subdivided in 4 different fields regarding the cyrochitectonics of its the pyramidal layer, namely CA1 (close to the subiculum) to CA4 (within the concavity of the gyrus dentatus). A thin white layer, the alveus, covers the cornu Ammonis and medially ends as the fimbria;
• the gyrus dentatus is a dorso-medially concave groove that contains the CA4 field. Its medial aspect faces the transverse fissure and is limited from the fimbria by the fimbrio-dentate sulcus located dorsally, and from the subiculum, located ventrally, by the hippocampal sulcus. Due to its location, this part of the gyrus dentatus (known as the margo denticulate) is only visible at the medial, extraventricular aspect of the hippocampal body.

5.1.2. Intraventricular aspect of the hippocampus body

The hippocampus forms the major part of the floor of the inferior (or temporal) horn of the lateral ventricle. It appears (Fig. 2B, Fig. 3, Fig. 4A) as a bulge that mainly corresponds to CA1 to CA3 covered by the alveus. The floor of the inferior horn is laterally continued by the collateral eminence, a less marked bump facing the depth of the bottom of the collateral or T4-T5 sulcus. Medially the floor of the inferior horn is limited by the fimbria, posteriorly continued by the crus of the fornix.
The hippocampus faces the roof of the inferior horn of the lateral ventricle. This roof is made (Fig. 2):

- deeply, of the temporal stem that contains several white matter tracts including the temporal (or Meyer’s) loop of the optic radiations [10,11];
- and superficially of the tail of the caudate nucleus laterally, and of the stria terminalis medially. The latter is an association path between the amygdala and the septal area.

Medially, the inferior horn of the lateral ventricle is closed by the tela choroidea (Fig. 3C). The later is a juxtaposition of pia mater and ependyma attached between thickenings of the ventricles walls, the taenias. The tela choroidea is attached between the taenias of the habenulas in the 3rd ventricle; between the taenia of the thalamus and the taenia of the fornix in the body of the lateral ventricle; and between the taenia of the stria terminalis and the taenia of the fimbria in the inferior horn. The choroid plexus is an intraventricular expansion of the tela choroidea that covers most of the hippocampus body.

5.1.3. Extraventricular (or cisternal) aspect of the hippocampus body

Only a narrow part of the hippocampus is visible at the medial aspect of the temporal lobe (Fig. 3B and Fig. 4B). It is made of several structures, namely from dorsal to ventral: the fimbria; the fibriodentate sulcus; the margo denticulatus that is the tooth-shaped visible part of the gyrus dentatus; finally, the hippocampal sulcus that limits the margo denticulatus from the subiculum.

5.1.4. Relationships of the hippocampus body

The Ambient cistern is located between the mesencephalon and the medial aspect of the temporal lobe (Fig. 2B, Fig. 5A). This cistern contains, from cranial to caudal, the P2 segment of the posterior cerebral artery and basal vein, the posterolateral choroidal arteries, the collicular arteries and the superior cerebellar artery.
The transverse fissure (Fig. 2) is a lateral expansion of the ambient cistern. It invaginates between the subiculum, located ventrally, the optic tract, lateral geniculate body and pulvinar dorsally, and the extraventricular part of the hippocampus and tela choroidea laterally. It contains vessels for the hippocampus and subiculum.

5.2. Head of the hippocampus

Several changes occur in the head of the hippocampus both intra- (Fig. 4A) and extraventricularly (Fig. 4B).

5.2.1. Intraventricular aspect of the hippocampus head

The fimbria ends at the tip of the uncus (see below).

Since the taenia fimbria and the taenia stria terminalis join, the tela choroidea, which runs between them, disappears. This junction, also known as velum terminale or inferior choroid point, is located at the junction between the head and body of the hippocampus. As an important consequence, the head of the hippocampus is free of choroid plexus (Fig. 3).

The cornu Ammonis takes an undulated shape that induces digitations at the surface of the head (Fig. 4A).

The superior aspect of the hippocampal head is covered by the amygdala that bumps into the ventricle.

5.2.2. Extraventricular (or cisternal) aspect of the hippocampus head

The piriform lobe is the rostral part of the parahippocampal gyrus. It is subdivided in the entorhinal area, located caudally that continues the subiculum, and in an uncal part.

The uncal part of the piriform lobe and the rostral part of the hippocampus curve dorso-caudally to form a hook known as the uncus (Fig. 4B and C). This organization of the uncus has two
consequences: firstly, its ventral aspect faces the dorsal one of the subiculum (parahippocampal gyrus) from which it is limited by the uncus sulcus; and secondly, the uncus contains 2 parts of different origin:

- the rostral part of the uncus has a parahippocampal origin, since it belongs to the piriform lobe. The uncal part of the piriform lobe may be subdivided into: the ambient gyrus that directly continues the entorhinal area, and the semilunar gyrus that medially covers the amygdaloid complex;
- the posterior part of the uncus belongs to the hippocampus and ends as the uncinal apex, a region having the shape of a cone, on the top of which the fimbria is attached. Two regions are described rostral to the uncinal apex:
  - the medial band of Giacomini that corresponds to the terminal part of the gyrus dentatus: the margo denticulatus, originally follows a caudo-rostral horizontal direction at the medial aspect of the hippocampus. It then takes a latero-medial course at the ventral aspect of the uncus. As it reaches the medial aspect of the uncus, its direction changes again to become vertical,
  - the uncinate gyrus, which corresponds to CA1, is rostral to the medial band of Giacomini, and immediately caudal to the ambient gyrus.

5.2.3. Relationships of the hippocampus head

The uncus is located just bellow the amygdaloid complex (Fig. 4). The rostral segment of the uncus is the lateral limit of the anterior perforated substance. It thus has close relationships with the oculomotor nerve, M1 segment of the middle cerebral artery and its lenticulostriate arteries (Fig. 5B). The anterior choroidal artery runs at the medial and then superior aspects of the uncus, between the ambient and semilunar gyri. It finally reaches the ventricle and choroid plexus after giving perforating arteries to its deep territory. The caudal part of the head (Fig. 5A) faces the crus cerebri and crural cistern, and is in relationships with the P2 segment of the posterior cerebral artery and basal vein.
5.3. Tail of the hippocampus

Major changes also occur in the hippocampal tail as compared to its body:

- the tail runs caudally but also medially and dorsally (Figs. 3 and 4);
- as explained by embryology (Fig. 1), the different components of the hippocampus, originally packed in the body, split to run dorsal or ventral to the splenium of the corpus callosum.

5.3.1. Intraventricular part of the tail

The organization of the intraventricular part of the tail (Fig. 4A) is similar to the one of the body: medially, the floor of the atrium is made of the tail, and laterally of the collateral trigone, an enlargement of the collateral eminence. The calcar avis is a marked relief facing the bottom of the calcarine sulcus that bumps into the floor of the atrium. Medially, the tail is limited by the fimbria that ascends and becomes the crus of the fornix.

5.3.2. Extraventricular part of the tail

The tail (Fig. 6) experiences 2 major changes:

- the superficial relief of the gyrus dentatus, or margo denticulatus becomes completely smooth and is called fasciola cinerea in the tail. As it runs caudally towards the splenium of the corpus callosum, it narrows and finally disappears. Similarly to the

Fig. 5. Cisternal relationships and Vascularization of the hippocampus. A. Superior view of the right hippocampus and mesencephalon. The inferior horn was opened to show the hippocampus head (H head), fimbria (fi), and collateral eminence (col em). Most of the hippocampus is hidden by the choroid plexus (Cho pl). Extraventricularly, the subiculum (subic) and margo denticulatus (md) are covered by an arterial network arising from the posterior cerebral artery (PCA) or temporal arteries by several hippocampal arteries (HA). This network is especially dense along the hippocampal sulcus (Hs). The P1 segment of the posterior cerebral artery runs in the intercisternal cistern (ic cst), whereas its P2 segment runs in the cranial cistern (cruc cst) and then in the ambient cistern, along the margin of the parahippocampal gyrus. The ambient cistern (amb cst) is located between the mesencephalon and the hippocampus body and also contains: the baséal vein (bv), the posterolateral choroidal arteries, the collicular arteries and the superior cerebellar artery. At the tail level, the ambient cistern is continued by the quadrigeminal cistern (qua cst) that contains the venous confluence of the basilar veins, cerebral and great cerebral veins (vc), P2, and the postero medial choroidal arteries (pmChoA) for the roof of the third ventricle. B. Inferior view of the brain. The left temporal lobe was partially resected to show the ventricle and the relationships of the uncus and anterior choroidal artery (AchoA). This artery originates from the internal carotid artery (ICA), just dorsal to the origin of the posterior communicating artery (PComA). It runs at the medial and then superior aspect of the uncus to reach the choroid plexus (Cho pl). On the way it gives perforators (P) for its deep territory that usually includes the internal capsule. In the anterior perforated substance (APS), these perforators are in close relationships with those of the middle cerebral artery (MCA), and vascular balances between AchoA and MCA occur for these deep territories. On this specimen, the left P1 is atrophic, and P2 directly arise from the PComA (fetal type). II: optic nerve; III: oculomotor nerve; ACA: anterior cerebral artery; BA: basilar artery; AIC: antero-inferior cerebellar artery; SCA: superior cerebellar artery.
margo denticulatus it continues, the fasciola cinerea is also ventrally limited by the hippocampal sulcus;
• as a consequence to the ascending direction of the fimbria and crus of the fornix, the distance between the fimbria/fornix and margo denticulatus/fasciola cinerea increases. An additional gyrus, the gyrus fasicollaris, appears in between, and replaces the fibro-dentine sulcus, which was originally present in the hippocampus body. The gyrus fasicollaris then courses ventral to the splenium and is therefore renamed subhisprenial gyrus. It then follows the course of the cingulum and becomes the indusium griseum or supra commissural hippocampus that runs caudal and then dorsal to the corpus callosum to finally reach the subcallosal region (prehippocampal rudiment).

5.3.3. Tail relationships
As for the body, the tail is the lateral limit of the transverse fissure (Fig. 7) that contains the medial atrial vein. Posteriorly, the transverse fissure communicates with the quadrigeminal cistern that contains: P2, the posteromedial choroidal arteries for the roof of the 3D ventricule, and the terminal segments of the internal cerebral and basilar veins into the great cerebral vein.

The lateral wall of the atrium contains the posterior genu of the caudate nucleus tail, and, more laterally the optical radiations.

6. Vascularization

6.1. Hippocampal arteries

The hippocampal arteries mainly arise from the posterior cerebral artery (PCA), and at a lower extend, from the anterior choiroideal artery.

Along its course at the medial aspect of the uncus, the anterior choiroideal artery gives an uncal branch that descends at the medial aspect of the cus to reach the uncal sulcus. It also gives perforators to a variable deep territory often including the internal capsule (Fig. 5).

The P1 segment of the PCA runs in the intercercular cistern, whereas its P2 segment run in the crural cistern (close to the medial aspect of the uncus) and then in the ambient cistern, along the margin of the parahippocampal gyrus. The PCA usually gives rise to 3 groups of hippocampal arteries:

• anterior for the head and the uncus. They arise from the main trunk or from collaterals (inferior temporal arteries) of P2 and anastomose to the uncal branch of the anterior choiroideal artery;
• middle for the body and tail. They also arise from P2 main trunk or inferior temporal arteries;
• and posterior for the body and tail that come from the splenial artery.

These feeders to the hippocampus then longitudinally connect along the superior aspect of the hippocampal sulcus as a pial network.

6.2. Hippocampal veins

The superficial hippocampal veins run at the surface of the hippocampal and fibro-dentine sulci where they form 2 arches. These arches join at their anterior and posterior extremities. The anterior end reaches the inferior ventricular vein, whereas the posterior one connects to the medial atrial vein. They finally drain into the basilar vein.
7. Discussion

The anatomy of the hippocampus is relatively complex, but a few rules may help for surgical practice:

- the hippocampus is a C-shape structure comprising a head, a body and a tail;
- it is made of 2 rolled-up laminae, the corru Ammonis (CA1 to CA4) and the gyrus dentatus;
- the hippocampus has 2 aspects, ventricular and cisternal:
  - the floor of the inferior horn of the lateral ventricle is mostly occupied by the hippocampus, laterally bordered by the collateral eminence (rostral) and trigone (caudal);
  - the cisternal aspect of the hippocampus faces the lateral one of the mesencephalon from which it is limited by the transverse fissure;
- major changes occur at both ends of the hippocampus:
  - rostrally, it enlarges to become the hippocampus head. The rostral part of the hippocampus and parahippocampal gyrus (piriform gyrus) curve dorso-caudally to form the uncs.
  - caudally, the hippocampus tail is thin and splits into 2 elements: the fimbria that ascends and runs ventral to the corpus callosum where it joins the crus of the fornix; and the gyrus fasciolaris that corresponds to the posterior part of the cornu Ammonis that runs ventral to the splenium (subpialen gyrus) and then dorsal to the corpus callosum where it is known as the indusium griseum.

Part of this complexity comes from the fact that a same structure can have different names, depending of the part of the hippocampus. For instance, the gyrus dentatus appears as the “margo denticulatus” at the body level, as the “medial band of Giacomini” at the medial aspect of the uncus, and as the “fasciola cinerea” at the tail level.

Important hippocampal relationships has to be stressed for a safe surgical practice.

First the dissection should be conduced subpially not to injure the elements contained in the transverse fissure, ambient and quadrigeminal cisterns; as a rule, the pia mater covering the medial surface of the hippocampus has to be preserved and the content of the cisterns should not be dissected. Despite a rich pial vascularization, the hippocampus can be safely removed without any pial coagulation that would certainly induce pial opening and may lead to damages of the elements contained in the underlying cisterns. Instead, cottonoid packing is sufficient to stop most of bleeding.

Second, the choroid plexus mainly covers the hippocampus and may be gently retracted during the procedure. One should avoid dissecating it, since branches to the optic tract, lateral geniculate body and thalamus may arise from the intraplexual segment of the anterior choroidal artery.

Finally, the extend of the temporal lobectomy associated to the hippocampus removal is a matter of debate. The volume of resected tissue varies a lot from a procedure to another one, as damages induced to the surrounding structures (Fig. 8). For instance, limited transsylvian resection [12] was proposed to limit the extent of cortical resection, but is potentially more invasive for branches of the middle cerebral artery and induces a proximal lesion of the temporal stem. Such a lesion may induce visual field abnormalities, since the temporal stem contains the temporal loop of the optic radiations. A limited transcortical approach may be preferred to limit lesions of the temporal stem but is associated to more or less extensive lesion of the temporal neocortex. In the dominant hemisphere,
it implies posteriorly limited approaches that may make difficult removal of the tail of the hippocampus. As a rule, during such a transcortical approaches, the axial plane containing the choroid plexus is an important surgical landmark that has to be respected to avoid lesions of structures located above: optical tract, lateral geniculate body, temporal stem.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

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