Intraoperative subcortical electrical mapping of optic radiations in awake surgery for glioma involving visual pathways

Clinical article

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Object. Preservation of the visual field in glioma surgery, especially avoidance of hemianopia, is crucial for patients’ quality of life, particularly for driving. Recent studies used tractography or cortical occipital stimulation to try to avoid visual deficit. However, optic radiations have not been directly mapped intraoperatively. The authors present, for the first time to their knowledge, a consecutive series of awake surgeries for cerebral glioma with intrasurgical identification and preservation of visual pathways using subcortical electrical mapping.

Methods. Fourteen patients underwent awake resection of a glioma (1 WHO Grade I, 11 WHO Grade II, 2 WHO Grade III) involving the optic radiations. The patients had no presurgical visual field deficit. Intraoperatively, a picture-naming task was used, with presentation of 2 objects situated diagonally on a screen divided into 4 quadrants. An image was presented in the quadrant to be saved and another image was presented in the opposite quadrant. Direct subcortical electrostimulation was repeatedly performed without the patient’s knowledge, until optic radiations were identified (transient visual disturbances). All patients underwent an objective visual field assessment 3 months after surgery.

Results. All patients experienced visual symptoms during stimulation. These disturbances led the authors to stop the tumor resection at that level. Postoperatively, only 1 patient had a permanent hemianopia, despite an expected quadrantanopia in 12 cases. The mean extent of resection was 93.6% (range 85%–100%).

Conclusions. Online identification of optic radiations by direct subcortical electrostimulation is a reliable and effective method to avoid permanent hemianopia in surgery for gliomas involving visual pathways.

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Key Words • direct electrical stimulation • subcortical mapping • optic radiations • visual field • oncology

In brain tumor surgery, real-time identification of functional networks (for example, sensorimotor or language structures) by direct electrical stimulation has been extensively demonstrated as improving both functional and oncological outcomes.15,34 Indeed, the neurosurgeon’s goal is now not only to optimize the extent of resection but also to preserve the quality of life, to optimize the “onco-functional” balance.20

To date, however, visual pathways have received little attention. The challenge with respect to surgery within the posterior part of the temporal lobe and within the temporoparietooccipital junction is to avoid permanent homonymous hemianopia. Indeed, quadrantanopia is usually asymptomatic and in most countries, authorities consider that superior quadrantanopia is not a contraindication for driving.26,32 In the last 2 decades, works proposed the use of tractography,25,37,40 direct cortical occipital stimulation,24,29 functional MRI,20,21 and cadaver dissection,28,33,36 to try to better understand functional anatomy and 3D relationships of the optic radiation and to avoid visual deficit, but in none of these studies were the optic radiations directly mapped intraoperatively.

Of note, Duffau et al.17 reported, in 2004, the first case with direct intraoperative detection and preservation of...
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the optic radiations in a patient undergoing awake craniotomy for a diffuse glioma invading the tempororo-occipital junction. Here, we present the first series of intrasurgical mapping of optic radiations using subcortical electrical stimulation in awake patients with a glioma involving the visual pathways. The optic radiations constituted the deep functional boundary of the resection. This boundary was chosen with the aim of preventing the induction of a persistent homonymous hemianopia. In the light of our original results, we propose to consider more systematically the realization of subcortical visual electrical mapping for surgery within the tempororo-occipital junction.

Methods

Patients

Fourteen patients with a corticosubcortical glioma involving visual pathways underwent awake surgery, performed by the senior author (H.D.), between March and October 2010. This consecutive series consisted of 10 men (8 right handed, 1 ambidextrous, 1 left handed) and 4 women (all right handed), ranging in age from 22 to 47 years (mean age 38 years). The initial manifestation of the tumor was seizure in all cases. The results of the preoperative neurological examination were normal in all 14 patients. No patient had any presurgical visual field deficit.

The topography of the tumor was carefully analyzed on preoperative MR images. The tumors were located within the tempororo-occipital junction in 10 cases (5 right, 5 left), in the right posterior temporal lobe in 2 cases, in the left precuneus in 1 case, and in the right cuneus in 1 case.

Surgical Procedure

All patients underwent surgery in the lateral position under local anesthesia so that functional cortical and subcortical mapping could be carried out using direct brain stimulation. This method, including the electrical parameters, was previously described by the authors. A bipolar electrode with 5-mm-spaced tips delivering a biphasic current (pulse frequency of 60 Hz, single pulse phase duration of 1 msec, amplitude from 2 to 4 mA; Nimbus, Hemodia) was applied to the brain of the awake patients. The current intensity used for individual patients was determined by progressively increasing the amplitude in 1-mA increments (from a baseline of 2 mA) until a functional response was elicited. In a first stage, tumor boundaries were also identified using ultrasonography. Then, before starting with the resection, cortical mapping was performed. In all cases, sensorimotor mapping was performed first (to elicit transient movement and/or paresthesia). When resection was performed in the dominant hemisphere, the patient was also asked to count until speech arrest was induced at the level of the premotor cortex. This allowed definition of the optimal threshold of stimulation (mean 2.7 mA in this series). Cortical mapping was also performed during a picture-naming task in the dominant hemisphere, using the DO 80, which consists of 80 black and white pictures selected according to variables such as frequency, familiarity, age of acquisi-
Within the left precuneus, we started the corticectomy at the level of the mesial parietal cortex just above the primary visual area. Before this resection, we identified the primary visual cortex by eliciting a blurred vision sensation using cortical stimulation (intensity of 4 mA). In the other cases, surgery approaches were far from the primary visual area. Before this resection, we identified the primary visual area. Before this resection, we identified the primary visual area.

At the subcortical level, all patients experienced visual symptoms within the contralateral visual hemifield when the optic radiations were stimulated. We used the same electrical parameters (especially the same threshold) at the subcortical level as at the cortical level. The main symptoms were blurred vision (in 11 [78.6%] of 14 patients), phosphenes (in 4 [28.6%] of 14 patients), and impression of “shadow” (in 2 [14.3%] of 14 patients). Interestingly, 1 patient with a tumor located within the right cuneus complained of visual hallucinations such as zoopsia during subcortical stimulation. The visual disturbances, especially blurring, can be attributed to subcortical stimulation because they lasted for the entire duration of the stimulation and stopped immediately after the stimulation. Moreover, these symptoms were reproduced by at least 3 stimulations.

In addition, all patients with tumors located within the left temporocippitoparietal junction and the left-handed patient in Case 4, with tumor involving the right temporal lobe, also had speech disturbances (semantic and/or phonemic paraphasia) induced by stimulation of language pathways. Finally, the patient in Case 14 experienced alexia with stimulation of the left inferior longitudinal fasciculus, more basally located. As mentioned, these bundles constituted the deep functional boundary of resection in all cases.

**Postoperative Course**

There was no mortality. Six patients who had speech disturbances during subcortical stimulation experienced immediate postoperative language disturbances. They completely recovered within 3 months following surgery, thanks to specific language rehabilitation.

Concerning visual outcome, postoperative homonymous hemianopia was avoided in 13 (93%) of 14 patients; the patient in Case 14 had homonymous hemianopia. The patient in Case 1, who had a precuneus tumor, had no visual field deficit. As expected, the other patients had quadrantanopia. Two patients with a temporal lobe tumor experienced a left superior quadrantanopia. Among the 10 patients with a tumor located within the temporocippitoparietal junction, 2 patients (Cases 5 and 6) had an inferior quadrantanopia, while the 8 other patients had a superior quadrantanopia (Fig. 1). The patient with homonymous hemianopia had partial improvement in her visual field within 6 months after surgery (Fig. 2). As of this writing, she has no limitation in her daily life and is working full time. Moreover, she passed the official driving examination successfully despite her persistent visual field deficit.

FLAIR-weighted MRI obtained immediately (within 48 hours) and at 3 months after surgery showed that complete resection (no signal abnormality) was achieved in 3 cases, subtotal resection (less than 10 cm³ residual tu-

### TABLE 1: Clinical, radiological, and surgical characteristics of the 14 patients with glioma invading subcortical visual pathways

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Handedness</th>
<th>Tumor Location</th>
<th>Tumor Dx†</th>
<th>Intraop Sx at Subcortical Level</th>
<th>Intensity of Stim (mA)</th>
<th>Tumor Vol (cm³)</th>
<th>Extent of Tumor Resection (%)</th>
<th>Postop VFD (3 mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42, M</td>
<td>R</td>
<td></td>
<td>L, precuneus</td>
<td>oligo II</td>
<td>blurred vision (LHF)</td>
<td>4</td>
<td>11</td>
<td>100</td>
<td>no deficit</td>
</tr>
<tr>
<td>2</td>
<td>22, F</td>
<td>R</td>
<td></td>
<td>R, cuneus</td>
<td>ACG I</td>
<td>hallucination, phosphenes (LHF)</td>
<td>3</td>
<td>7</td>
<td>100</td>
<td>pLSQ</td>
</tr>
<tr>
<td>3</td>
<td>41, F</td>
<td>R</td>
<td></td>
<td>R, TI</td>
<td>oligo II</td>
<td>shadow (LHF)</td>
<td>2.5</td>
<td>132</td>
<td>15</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>38, M</td>
<td>L</td>
<td></td>
<td>R, T</td>
<td>oligo III</td>
<td>blurred vision (LHF), SD</td>
<td>2.5</td>
<td>48</td>
<td>3</td>
<td>94</td>
</tr>
<tr>
<td>5</td>
<td>47, M</td>
<td>R</td>
<td></td>
<td>R, TPJ</td>
<td>oligo II</td>
<td>blurred vision (LHF)</td>
<td>2.5</td>
<td>145</td>
<td>25</td>
<td>85</td>
</tr>
<tr>
<td>6</td>
<td>33, M</td>
<td>R</td>
<td></td>
<td>R, TOPJ</td>
<td>oligo II</td>
<td>blurred vision, phosphenes (LHF)</td>
<td>2.5</td>
<td>34</td>
<td>1</td>
<td>97</td>
</tr>
<tr>
<td>7</td>
<td>34, F</td>
<td>R</td>
<td></td>
<td>R, T+TOPJ</td>
<td>oligo II</td>
<td>blurred vision (LHF)</td>
<td>2.5</td>
<td>120</td>
<td>7</td>
<td>94</td>
</tr>
<tr>
<td>8</td>
<td>39, M</td>
<td>R</td>
<td></td>
<td>R, T+TOPJ</td>
<td>oligo II</td>
<td>blurred vision (LHF)</td>
<td>3</td>
<td>91</td>
<td>8</td>
<td>91</td>
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<tr>
<td>9</td>
<td>38, M</td>
<td>R</td>
<td></td>
<td>R, T+TOJ</td>
<td>oligo II</td>
<td>blurred vision, phosphenes (LHF)</td>
<td>2.5</td>
<td>73</td>
<td>12</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>34, M</td>
<td>A</td>
<td></td>
<td>L, T+TOJ</td>
<td>oligo II</td>
<td>blurred vision, shadow (RHF), SD</td>
<td>2.5</td>
<td>75</td>
<td>3.5</td>
<td>95</td>
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<tr>
<td>11</td>
<td>44, M</td>
<td>R</td>
<td></td>
<td>L, TOJ</td>
<td>oligo III</td>
<td>blurred vision, shadow (RHF), SD</td>
<td>2.5</td>
<td>17</td>
<td>1</td>
<td>95</td>
</tr>
<tr>
<td>12</td>
<td>42, M</td>
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<td>L, TOJ</td>
<td>oligo II</td>
<td>phosphenes (RHF), SD</td>
<td>2.25</td>
<td>26</td>
<td>1</td>
<td>95</td>
</tr>
<tr>
<td>13</td>
<td>27, M</td>
<td>L</td>
<td></td>
<td>L, TOJ</td>
<td>oligo II</td>
<td>blurred vision (RHF), SD</td>
<td>2</td>
<td>13</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>47, F</td>
<td>R</td>
<td></td>
<td>L, TOJ</td>
<td>oligo II</td>
<td>blurred vision (RHF), SD</td>
<td>3</td>
<td>10</td>
<td>0.5</td>
<td>95</td>
</tr>
</tbody>
</table>

* A = ambidextrous; ACG = angiocentric glioma; Dx = diagnosis; FLAIR = fluid-attenuated inversion recovery; HA = homonymous alexia; HS = homonymous sensory loss; HZ = homonymous motor palsy; I = oligodendroglioma; II = oligo; III = oligo III; IQ = inferior quadrantanopia; LSQ = left superior quadrantanopia; LHF = left hemifield; LIQ = left inferior quadrantanopia; LSQ = left superior quadrantanopia; LSH = left hemispherectomy; pLSQ = partial left superior quadrantanopia; pLIQ = partial left inferior quadrantanopia; RH = right hemianopia; RHF = right hemifield; RSH = right hemispherectomy; RSQ = right superior quadrantanopia; SD = speech disturbances; Stim = Stimulation; Sx = symptoms; T = temporal; TI = temporoinsular; TOJ = temporocippitoparietal junction; TPJ = temporooccipital junction; VFD = Visual Field Deficit.

† The Roman numerals refer to WHO grade.
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Fig. 1. Case 6, involving a 33-year-old right-handed man who underwent resection of a WHO Grade II oligodendroglioma in the right temporocippitoparietal junction and had left inferior quadrantopia postoperatively.  a: Intraoperative view before resection. The letter Tags A–G mark the tumor boundaries identified using ultrasonography. The number tags correspond to eloquent sites: Tag 1, within the ventral premotor cortex, and Tag 2, within the retrocentral part of the rolandic operculum, both eliciting speech arrest; Tags 3, 4, and 6, within the primary somatosensory cortex, eliciting left superior lip, left superior limb thumb, and left hand dysesthesia, respectively; Tag 5, within the primary motor cortex of the left hand, eliciting left finger movement; Tag 11, within the anterosuperior part of the supramarginal gyrus, and more posteriorly, Tag 12, within the junction between the middle temporal gyrus and angular gyrus, both eliciting transient spatial cognition impairment during electrical stimulation.  b: Preoperative axial FLAIR-weighted and coronal T1-weighted enhanced MR images showing a right-hemisphere diffuse glioma (arrows) involving the temporocippitoparietal junction, in a patient without any visual defect.  c: Intraoperative view after resection. The subcortical mapping allowed the detection of thalamocortical fibers, with induction of dysesthesia of the left hemibody (Tags 48, 49, and 50). More ventrally and lateral to the ventricle, stimulation elicited transient left phosphenes and blurred vision: Tag 46 marks the subcortical optic radiations.  d: Postoperative axial FLAIR-weighted and sagittal T1-weighted enhanced MR images obtained 3 months after the surgery, showing the ventrolateral deep edge of the cavity—that is, at the level of the direct bundle of the optic radiations, which were identified and then preserved using intraoperative stimulation (arrow).  e: The 4-screen naming task used with the goal of preserving the left upper quadrant. The sacrificed left inferior quadrant is here symbolized by a gray quadrant, and visual symptoms (phosphenes, blurred vision) by black stars.  f: Postoperative Octopus perimetric evaluation performed 3 months after surgery, showing a left inferior quadrantopia. A = anterior; D = dorsal; P = posterior; V = ventral.

mor) was achieved in 8, and partial resection (more than 10 cm³ residual tumor, range 12–25 cm³) was achieved in 3 patients. The average extent of tumor resection was 93.6% (range 85%–100%).

Neuropathological examination revealed 1 WHO Grade I, 11 WHO Grade II, and 2 WHO Grade III gliomas.

Discussion

Gliomas and Quality of Life: an “Onco-Functional” Challenge

In recent decades, functional outcomes have been dramatically improved in glioma surgery, thanks to the use of intraoperative electrical mapping of sensorimotor and language networks. Mapping of nonlanguage functions has, however, received less attention, despite the possible consequences of deficits other than aphasia on daily life. Recently, some authors have proposed performing intrasurgical mapping of nonlanguage networks, such as spatial cognition, memory, or calculation. Nevertheless, visual function is still neglected in brain tumor surgery, possibly because homonymous hemianopia is considered an acceptable neurological deficit in comparison with the oncological risk of leaving residual tumor. This is particularly true in cases of occipi-
tal glioma, when an extensive lobectomy can be achieved with a significant impact on long-term median survival. 38

On the other hand, in young patients harboring non-occipital (low-grade) gliomas near or within the optic radiations, with no or only slight symptoms that do not prevent them from enjoying a normal social and professional life, avoiding homonymous hemianopia is important for preserving quality of life. Indeed, in most countries, although authorities consider that superior contralateral quadrantanopia is usually asymptomatic, 23 surgery actually becomes challenging when the resection is close to the temporooccipitoparietal junction, where the 3 bundles of visual fibers (Meyer loop, direct, and central) emerge from the lateral geniculate body. At this level, there is a high interindividual variation in the shape of the optic radiations. 18, 22, 33

Surgical Challenge Around the Temporooccipitoparietal Junction: Preservation of Visual Pathways

Interestingly, in epilepsy surgery, neurosurgeons have already tried to find the best surgical approach to removing anterior and mesiotemporal structures while avoiding postoperative visual field deficit. 16, 19, 39 However, while these techniques based on pure anatomical criteria can be applied to a tailored anterior temporal lobectomy, the risk of inducing homonymous hemianopia is higher in cases of diffuse glioma involving more posterior brain regions. Indeed, considering that superior contralateral quadrantanopia is usually asymptomatic, 23 surgery actually becomes challenging when the resection is close to the temporooccipitoparietal junction, where the 3 bundles of visual fibers (Meyer loop, direct, and central) emerge from the lateral geniculate body. At this level, there is a high interindividual variation in the shape of the optic radiations. 18, 22, 33

Fig. 2. Case 14, involving a 47-year-old right-handed woman who underwent resection of a WHO Grade II oligodendroglioma in the left temporooccipital junction and had right hemianopia postoperatively.  a: Intraoperative view before resection. The letter Tags A and B mark the tumor boundaries identified using ultrasonography. The number tags correspond to eloquent sites: Tag 1, within the posterior part of the superior temporal gyrus, and Tag 3, within the junction between the posterior part of the middle temporal gyrus and the occipital lobe, eliciting anomia and semantic paraphasia, respectively; Tag 2, within the posterior part of the inferior temporal gyrus, eliciting transient pure alexia during stimulation. b: Preoperative axial FLAIR-weighted MR image, showing a left diffuse glioma (arrows) involving the temporooccipital junction in a patient without any visual defect. c: Intraoperative view after resection. The subcortical mapping allowed the detection of the inferior frontooccipital fasciculus (Tag 42, eliciting reproducible transient complete anoma during stimulation). Immediately above, laterally and posteriorly, stimulation elicited transient right phosphens and blurred vision: Tags 10 and 11 mark the subcortical visual pathways. d: Postoperative axial FLAIR-weighted and coronal T2-weighted MRI performed 3 months following the surgery, showing the dorsomesial deep edge of the cavity—that is, at the level of the visual pathways (arrow), which were identified intraoperatively. e: The 4-screen naming task used in this case with the goal of preserving the right lower quadrant. The sacrificed right superior quadrant is symbolized by a gray quadrant, and visual symptoms (phosphens, blurred vision) by black stars. f: Postoperative Octopus perimetric evaluation performed 3 months after the surgery showing a right incomplete hemianopia.
Intraoperative mapping of optic radiations

Recently, tracking of visual pathways using diffusion tensor imaging was suggested in order to study the relationships between the optic radiations and the tumor location as well as to integrate these data into a neuro-navigational system. However, limitations of the tractography itself, especially due to the fact that this method provides only anatomical and not functional information, associated with intraoperative brain shift, explain why this technique is not yet reliable enough to optimize the extent of resection while minimizing the risk of permanent deficit. Moreover, for gliomas located within the left dominant temporooccipitoparietal junction, there is an additional risk of damaging language pathways running in the stratum sagittale near the optic radiations, especially the inferior frontooccipital fascicle.

As a consequence, on the basis of our first case report, in patients with diffuse glioma within or near optic radiations, and who experienced no presurgical visual deficit, we proposed performing an intraoperative electrical mapping of the subcortical visual pathway to prevent homonymous hemianopia.

Contribution of Subcortical Stimulation of Optic Radiations

To the best of our knowledge, this is the first series that describes the use of intraoperative direct stimulation of visual pathways during glioma surgery. Nguyen et al. recently mapped the visual cortex during an awake craniotomy in a patient harboring an anaplastic glioma located within the left precuneus and successfully avoided postoperative visual field deficits. However, no mention was made of visual tracts. In the present study, we demonstrated that direct stimulation of the optic radiations in awake patients is a reliable method of avoiding homonymous hemianopia, since only 1 patient (7%) experienced this deficit after resection—and that patient’s condition partially improved within months after surgery, demonstrating that even if the resection appears to have approached the ventricular wall, some visual pathways have nonetheless been preserved. It is worth noting that we were able to identify the visual pathways in 100% of cases intraoperatively, and that such real-time feedback provided by the patient allowed us to maximize the extent of resection by generating a voluntary quadrantanopia in 10 cases. However, we have to acknowledge that “blurred visual fields” is subjective, and that other perceptual distortions outside of the primary visual system could give similar findings. On the other hand, this high rate of quadrantanopia confirms that we were actually in contact with the optic radiations at the end of surgery, demonstrating that it is highly unlikely that we left tumor unnecessarily. It also shows the accuracy of the mapping technique, because it was possible to cut a part of the visual pathways without eliciting homonymous hemianopia. In contrast, diffusion tensor imaging incorporated in neuronavigation is currently unable to differentiate with reliability the subcomponents of optic radiations that can be removed from those that should be preserved in order to produce quadrantanopia and optimize the extent of resection without producing homonymous hemianopia.

Such accuracy was made possible thanks to the improvement of the intraoperative testing in comparison with the purely subjective patient evaluation used in our previous case. Our present task is based on a combined procedure, using the naming task (DO 80) and a visual field assessment (4-quadrant screen). Thanks to strong cooperation with the speech therapist and the patients during the awake stage, we prevented postoperative homonymous hemianopia by interrupting the resection when the patients experienced visual symptoms during subcortical stimulation. Interestingly, this task allowed us to map both visual and language pathways, mainly within the temporooccipitoparietal junction in the dominant left hemisphere, where language tracts and optic radiations are very close. Indeed, optic radiations are located just medially and above the inferior longitudinal fasciculus, which is involved in reading, whereas the inferior frontooccipital fasciculus, which is involved in semantic language processing, runs medially and above them. Of note, using a picture-naming task modified in quadrants, optic radiations cannot be confounded by language interruption and vice versa. Indeed, if language pathways are stimulated, the same kind of naming disturbances (for example, semantic paraphasia) involve both items (the 2 diagonally placed pictures), without any subjective visual complaint. In contrast, if visual pathways are stimulated, the patient experiences subjective transient visual disturbances (as blurred vision, phosphenes, shadow) only within the contralateral visual hemifield, thus preventing him from objectively naming the picture situated in the contralateral quadrant, but not the picture situated in the ipsilateral quadrant, demonstrating a visual field deficit and not a language disorder.

Conclusions

Subcortical mapping of visual pathways using intraoperative direct electrical stimulation represents a reliable and reproducible method of identifying and thus preserving optic radiations in surgery for glioma within or near visual tracts. Thanks to visual tasks adapted to awake procedures, this technique allowed us to avoid homonymous hemianopia in 93% of cases. However, it still needs to be improved by developing more sensitive tasks, and by combining the online functional feedback provided by the patient with monitoring of visual evoked potentials, as well as multimodal neuroimaging. Interestingly, beyond the field of glioma surgery, such a method could also be useful in epilepsy surgery involving the posterior brain areas, such as the temporooccipitoparietal junction.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. Author contributions to the study and manuscript preparation include the following. Conception and design: Duffau. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Duffau, Gras-Combe. Critically revising the
article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Duffau. Administrative/technical/material support: Duffau. Study supervision: Duffau.

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