·数智神经外科学·

智能化水分离技术在岛叶胶质瘤手术壳核外侧面分离中的应用

吴东东 束旭俊 赵恺 丛小均 周星宇 夏鹰 孙国臣

【摘要】 **研究背景** 岛叶胶质瘤手术中精准把控壳核外侧面位置是一项挑战，常未达到壳核外侧面或侵入壳核。本研究旨在探索一种基于水分离技术的岛叶胶质瘤手术中壳核外侧面分离方法。**方法与结果** 纳入2020年1月至2024年12月在解放军总医院第一医学中心经额峡部入路切除岛叶胶质瘤的17例患者，均未累及壳核，术中采用自行组建的低压水流系统水分离肿瘤底面与壳核外侧面，包括Sanai-Berger分区Ⅰ区2例、Ⅰ区+Ⅳ区6例、Ⅰ区+Ⅳ区+Ⅲ区+Ⅱ区9例，均较易分离，未损伤豆纹动脉；术后24 h内经MRI证实精准分离肿瘤与壳核外侧面，肿瘤均近全切除，壳核外侧面锐利规整，分离效果良好；无一例发生水分离相关并发症。术后3个月随访，失语商均>93.80分，手术相关侧别肌力均>4$^+$级，Karnofsky功能状态评分90(90,100)分。**结论** 对于存在壳核外侧面“泾渭分明征”的低级别岛叶胶质瘤，水分离技术可以精准分离肿瘤底面与壳核外侧面界限，降低手术难度、缩短手术学习曲线、提高手术效率和安全性。

【关键词】 神经胶质瘤； 水分离(非*MeSH*词)； 神经外科手术

Application of intelligent water dissection technology in sculpting the lateral surface of putamen during insular glioma surgery

WU Dong-dong[1], SHU Xu-jun[2], ZHAO Kai[1], CONG Xiao-jun[1], ZHOU Xing-yu[1], XIA Ying[3], SUN Guo-chen[1]

[1]*Department of Neurosurgery, The First Medical Center of Chinese PLA General Hospital, Beijing 100853, China*

[2]*Department of Neurosurgery, General Hospital of Eastern Theater Command, Nanjing 210002, Jiangsu, China*

[3]*Department of Neurosurgery, Xiangya School of Medicine, Haikou Affiliated Hospital of Central South University, Haikou 570208, Hainan, China*

Corresponding author: SUN Guo-chen (Email: sgc3130@126.com)

【**Abstract**】 **Background** In insular glioma surgery, accurately localizing the lateral surface of putamen remains challenging. This study aimed to explore a water dissection-based technique for sculpting the lateral surface of putamen during insular glioma surgery. **Methods and Results** Total 17 patients with insular glioma hospitalized in the Department of Neurosurgery, The First Medical Center of Chinese PLA General Hospital from January 2020 to December 2024, all of the tumor were not involved in the putamen and the tumor was resected by trans-frontal isthmus approach. A self-constructed low-pressure water flow system was used to separate the Sanai-Berger zone Ⅰ (2 cases), Ⅰ+Ⅳ (6 cases), and Ⅰ+Ⅳ+Ⅲ+Ⅱ (9 cases). The bottom of the tumor was easily separated from the lateral surface of the putamen, and the lenticulostriate artery exposed on the lateral surface of the putamen was not damaged during the operation, and the separation process was smooth. Within 24 h after surgery, MRI showed the separation of the lateral surface of the putamen from the tumor was appropriate, the lateral surface of the putamen was sharp and regular, and the tumors were nearly completely removed, and the separation effect was good. No complications related to water dissection occurred. At 3 months follow-up, aphasia quotient (AQ) was > 93.80, the operative related side muscle strength was > 4$^+$, and Karnofsky Performance Status (KPS) median

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作者单位：100853 北京，解放军总医院第一医学中心神经外科医学部(吴东东，赵恺，丛小均，周星宇，孙国臣)；210002 南京，东部战区总医院神经外科(束旭俊)；570208 中南大学湘雅医学院附属海口医院神经外科(夏鹰)

通讯作者：孙国臣，Email：sgc3130@126.com

score was 90 (90, 100). **Conclusions** For low-grade insular gliomas without putamen involvement characterized by "Jing-Wei River sign", water dissection effectively delineates the tumor-putamen surface, reduces surgical difficulty, shortens the learning curve, and enhances safety and efficiency.

【Key words】 Glioma; Water dissection (not in *MeSH*); Neurosurgical procedures

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岛叶胶质瘤手术常因肿瘤与壳核边界处理难度较大而具有较高的挑战性[1-7]。如何精准判断肿瘤底面与壳核外侧面界限，成为降低学习曲线、提高手术效率的关键。我们课题组在前期研究中提出一种新的岛叶胶质瘤手术入路，经额峡部入路切除岛叶，切除的内侧界面即为壳核外侧面，切除方向接近前后方向[8]。尽管该入路具有诸多优势，但与经典手术入路相似，对壳核外侧面的把控仍主要依靠术者经验。切除过度则误入壳核，导致豆纹动脉或锥体束损伤，引发偏瘫、失语、锥体外系症状甚至昏迷等严重神经功能障碍[2,7,9-14]；未能准确到达壳核外侧面界限，则导致肿瘤残留。传统手术主要依靠术者主观判断壳核“肉豆蔻”样外观，常导致切除不充分或误入壳核的情况[15]。因此，探寻一种简便、可重复的判断方法，帮助术者明确肿瘤底面与壳核外侧面界限，成为亟待解决的问题。临床实践中观察到岛叶胶质瘤MRI表现为，肿瘤内侧较少侵入壳核，而是肿瘤压迫壳核致外侧变平直，使岛叶胶质瘤底面与壳核外侧面之间形成清晰锐利的界限，称为“泾渭分明征”（图1），类似常见的水文景观。针对基底节区出血的研究显示，岛叶底面与壳核外侧面之间存在松散的潜在间隙，类似“安全气囊”，血肿易沿此间隙分布，形成明确的结构隔离。外囊血肿是这一现象的典型表现，血肿沿壳核外侧面分布，隔离岛叶与壳核，形成长柱形血肿带（图2a），待血肿吸收后，岛叶和壳核结构完整且分隔清晰，“安全气囊”得以打开（图2b）。最新研究显示，外囊可耐受约40 ml血肿量而不引发明显的神经功能障碍，证实岛叶底面与壳核外侧面之间存在松散的潜在间隙[16]。此外，以帕金森综合征为主要表现的多系统萎缩（MSA-P）的“壳核裂隙征”也提示壳核与外囊之间存在松散的潜在间隙，壳核萎缩后，壳核外侧组织并未随之塌陷，而是形成间隙[17]。炎症或颅脑创伤致岛叶水肿患者亦观察到这一现象。基于此，本研究提出一种水分离技术，通过生理盐水分离岛叶胶质瘤底面与壳核外侧面之间界限，提高手术效率和安全性，并有效缩短岛叶胶质瘤手术学习曲线。

对象与方法

一、研究对象

1. 纳入与排除标准 （1）经术前MRI诊断为岛叶胶质瘤，且未侵入壳核。（2）首次手术，均经额峡部入路切除肿瘤，手术目标肿瘤全切除，且术后经病理证实为低级别胶质瘤（WHO 2级）。（3）排除复发性胶质瘤、高级别胶质瘤、“泾渭分明征”不明显的胶质瘤及弥散而无法满意切除的胶质瘤。（4）本研究经解放军总医院伦理委员会审批（审批号：S2024-098-01，S2021-610-01）。（5）所有患者及其家属均对手术方案和手术风险知情并签署知情同意书。

2. 一般资料 选择2020年1月至2024年12月在解放军总医院第一医学中心神经外科住院治疗的岛叶胶质瘤患者共17例，男性10例，女性7例；年龄31～64岁，平均44岁；肿瘤位于左侧岛叶8例，右侧岛叶9例；肿瘤体积28.89～75.40 ml，平均为46.15 ml；术前运动功能和语言功能均未见异常。

二、研究方法

1. 药品与设备 生理盐水（规格：500 ml，山东齐都药业有限公司），手术室输液加压袋[规格：500ml，MX4705/4701型，史密斯医疗器械（北京）有限公司]、一次性使用输液器（0.8×19 TWLB，威海洁瑞医用制品有限公司）、直径为0.90 mm的金属针头（贝普医疗科技股份有限公司），以及流量传感器[FD-XS1E，基恩士（中国）有限公司]。按照图3示意图连接设备，组成完整的低压水流系统。

2. 手术方法 患者仰卧位，气管插管全身麻醉，取患侧额颞部切口。（1）肿瘤显露：经额峡部入路，

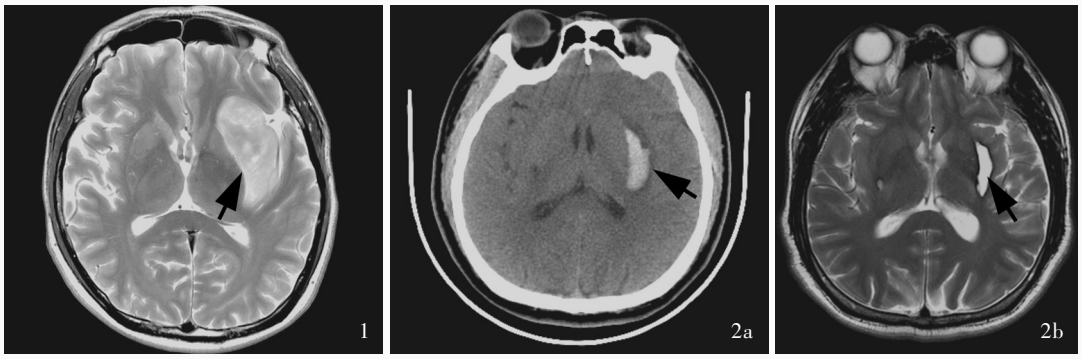


图1 横断面T_2WI显示，左侧岛叶肿胀伴异常高信号影，胶质瘤底面与壳核外侧面之间信号对比明显，界限锐利清晰，形成鲜明对比（箭头所示） **图2** 外囊出血患者头部影像学检查所见 2a 横断面CT显示，左侧外囊高密度血肿影，边界清晰，位于壳核与岛叶之间（箭头所示） 2b 横断面T_2WI显示，左侧外囊血肿吸收后遗留血肿形成的间隙，分隔壳核与岛叶（箭头所示）

Figure 1 Axial T_2WI showed swelling of the left insula with abnormal hyperintensity, and a significant signal contrast between the base of the glioma and the lateral surface of the putamen. The boundary was sharp and clear, presenting a striking contrast (arrow indicates). **Figure 2** Head imaging findings in the patient with external capsule hemorrhage Axial CT showed the hematoma in the left external capsule and had a clear boundary and was located between the putamen and the insula (arrow indicates, Panel 2a). Axial T_2WI showed after the absorption of the hematoma in the left external capsule, a gap formed, separating the putamen from the insula (arrow indicates, Panel 2b).

先沿肿瘤前缘进入侧脑室，沿尾状核头前部向外切除侧脑室至前岛点之间肿瘤；再经峡部进入岛叶，若岛叶肿瘤体积较大，可切除岛叶内部分肿瘤减压。(2)水分离：于壳核外侧Sanai-Berger分区Ⅰ区进行水分离操作，再依次分离Ⅳ区、Ⅲ区和Ⅱ区（图4），以低压生理盐水沿壳核外侧面方向平行冲洗（压力为150～300 mm Hg，1 mm Hg = 0.133 kPa），较易分离肿瘤底面与壳核外侧面，水分离过程中以输液管加装的流量传感器实时监测生理盐水流量。术中根据分离效果动态调整压力并选取适宜流量。分离过程中取瘤镊轻轻牵拉肿瘤，维持一定张力，提高分离效率（图5）。为确保分离的安全性，应确保分离范围限定于岛环状沟内。对位于后岛点附近的肿瘤，因该处无壳核结构，应停止水分离操作，并经术中电生理监测保护锥体束。吸引器同步抽吸流向术区低处的生理盐水，确保术区干净清晰。

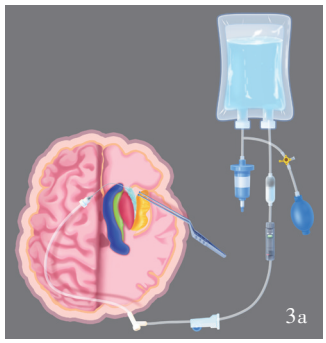
3.评估指标 (1)肿瘤切除率：术后24 h内复查MRI（T_2WI或T_2-FLAIR）评估肿瘤切除程度，计算公式为，肿瘤切除率（%）=（术前肿瘤体积－术后肿瘤体积）/术前肿瘤体积×100%，>95%为近全切除。(2)水分离效果：术后24 h内复查MRI，以壳核外侧面平整程度及岛叶肿瘤残留程度评估水分离效果。(3)神经功能：术后3个月采用西部失语症检查量表（WAB）[18]评估语言功能，包括自发言语（20分）、理解（200分）、复述（100分）、命名（100分）、阅读与书写（150分）、运用与结构（60分）共6个亚项，其中自发言语、理解、复述、命名4个亚项评分归一化处理至10分，加权运算获得失语商（AQ），为100分，AQ < 93.80分判定为失语 。同时测定肌力评估运动功能。(4)功能状态：术后3个月采用Karnofsky功能状态评分（KPS）[19]评估功能状态和日常生活自理能力，>80～100分为日常生活基本自理、>70～80分为日常生活部分自理、>50～70分为日常生活需他人帮助、≤50分为日常生活严重不能自理，评分越高、生活独立性越强。

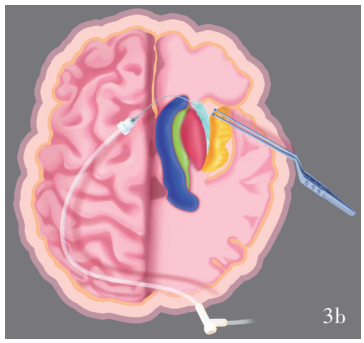
结 果

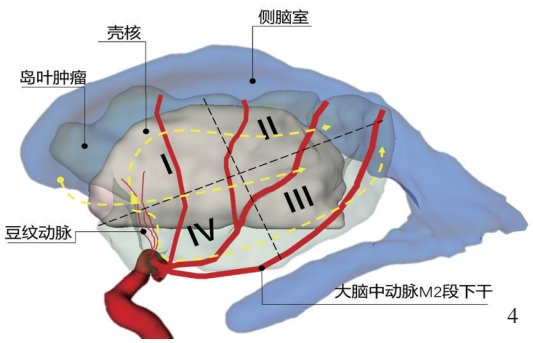
本组患者术中水分离Sanai-Berger分区Ⅰ区者2例，Ⅰ区＋Ⅳ区者6例，Ⅰ区＋Ⅳ区＋Ⅲ区＋Ⅱ区者9例，均较易分离肿瘤底面与壳核外侧面，术中未损伤裸露于壳核外表面的豆纹动脉，分离过程顺利；术后24 h内经MRI证实精准分离肿瘤与壳核外侧面，肿瘤近全切除，壳核外侧面锐利规整，分离效果良好。无水分离相关并发症。术后病理学显示肿瘤与壳核界限清晰，对比鲜明。术后3个月随访，均AQ > 93.80分，言语功能正常；手术相关侧别肌力>4^+级；KPS评分90～100分，中位值90（90，100）分。

典型病例

患者 女性，54岁。因癫痫发作17个月，于







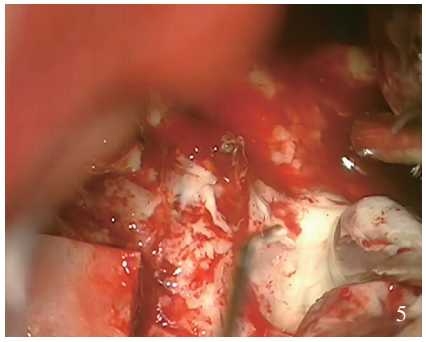


图3　水分离连通装置及水分离肿瘤与壳核外侧面示意图(红色为壳核,黄色为肿瘤)　3a　水分离连通装置示意图　3b　水分离肿瘤与壳核外侧面示意图,取瘤镊轻拉肿瘤以提高分离效率　**图4**　依次水分离Sanai-Berger分区Ⅰ区、Ⅳ区、Ⅲ区和Ⅱ区侧面观　**图5**　水分离过程中以低压生理盐水分离肿瘤底面与壳核外侧面,取瘤镊轻拉肿瘤以提高分离效率

Figure 3　Schematic diagram of the working dissection and water separation of the tumor from lateral surface of putamen (red indicates the putamen, yellow indicates the tumor). Schematic diagram of the working dissection (Panel 3a). Schematic diagram of water separation of the tumor from lateral surface of putamen, the tumor removal forceps gently pull the tumor to improve separation efficiency (Panel 3b). **Figure 4**　Lateral view of water separation sequence of Sanai-Berger zones Ⅰ, Ⅳ, Ⅲ and Ⅱ. **Figure 5**　During water separation, low-pressure water flow separated the tumor from the putamen, and the tumor was gently pulled by the forceps to improve the separation efficiency.

2024年1月4日入院。患者入院前17个月无明显诱因突发癫痫发作,服用抗癫痫发作药物(具体剂量不详)对症治疗,1年后再次发作。入院后体格检查未见明显神经系统阳性体征。头部MRI显示左侧额颞岛叶异常信号影,考虑岛叶胶质瘤(图6)。临床诊断为左侧岛叶胶质瘤,于2024年1月11日行经额峡部入路胶质瘤切除术。患者仰卧位,做左侧额颞部切口,先经额叶皮质造瘘进入侧脑室,沿尾状核头和壳核前外侧进入峡部,部分瘤内减压后采用水分离技术分离肿瘤底面与壳核外侧面,水流压力200 mm Hg,术中未损伤豆纹动脉,手术全切除肿瘤。术后病理诊断为少突胶质细胞瘤,*IDH*突变和1p/19q共缺失型,WHO 2级,可见肿瘤与壳核界限清晰,对比鲜明(图7),患者共住院22 d,出院时右侧肢体肌力和言语功能均正常。术后3个月随访时,复查MRI显示肿瘤全切除(图6b)。

讨　论

外囊出血的血肿形态规则,呈腊肠状,前后方向上有效分隔壳核与岛叶底面,随着血肿的吸收,壳核与岛叶之间常遗留间隙,发挥类似"安全气囊"的作用,减少血肿对邻近脑组织的破坏,为良好神经功能预后提供保障。临床实践中,破入脑室额角的血肿多发生于尾状核头前部额峡部内侧,恰好位于此间隙的前缘。此外,以帕金森综合征为主要表现的多系统萎缩的影像学特征"壳核裂隙征"也为壳核与外囊结构之间的松散关系提供了证据。岛叶胶质瘤手术中,壳核外侧面与肿瘤底面之间如同成语"泾渭分明"所形容的那样,界限清晰、分明。根据"壳核裂隙征"、"泾渭分明征"、"安全气囊"这一系列现象,我们提出通过水分离技术模拟这一现象的理论。

基于我们课题组在处理高血压基底节区出血的丰富经验[20],进一步提出经额峡部入路切除岛叶胶质瘤的新方法[8]。与经典的经侧方岛叶皮质入路相比,经额峡部入路的前后方向切除岛叶胶质瘤具有显著优势,但壳核外侧面分离仍是充满挑战的环节。尽管经验丰富的术者能够完成这一操作,但若未充分控制,可能导致浅表豆纹动脉损伤。由于壳核相对肿瘤较软,术者进入壳核后才能确认到达,而一旦进入壳核,出血可能性增加,同时导致豆纹动脉损伤风险增加,进而影响手术安全性[15]。

既往对累及壳核的胶质瘤标本进行病理学分析发现,壳核外侧面与岛叶底面之间泾渭分明(图7),提示岛叶胶质瘤手术中借鉴外囊出血的经验,通过水分离技术分离壳核外侧面是一种可行的操作方法。我们提出,通过水流力量可以模拟"上帝之手"将壳核外侧面与肿瘤之间界面分开,进而提

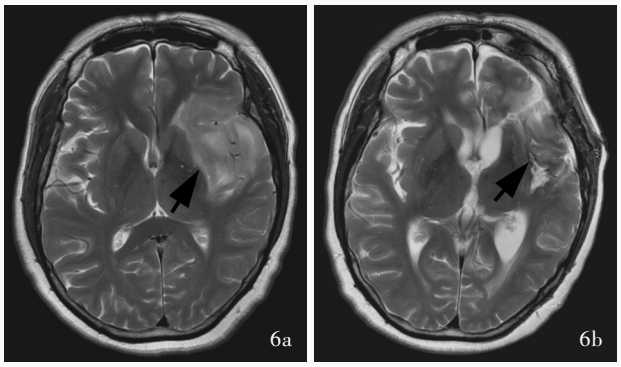


图6　手术前后头部MRI检查所见　6a　横断面T_2WI显示，左侧岛叶异常高信号影，未累及壳核，壳核外侧面与肿瘤界限清晰、对比鲜明（箭头所示）　6b　术后3个月横断面T_2WI显示，肿瘤全切除，原病灶区域可见不规则软化灶，壳核外侧面锐利清晰（箭头所示）

Figure 6　Head MRI findings before and after surgery　Axial T_2WI showed a left insular glioma without involvement of the putamen, with a clear and contrasting between the lateral surface of the putamen and the glioma (arrow indicates, Panel 6a). Axial T_2WI at 3 months postoperatively showed a total resection of the glioma, with a sharp and well defined lateral surface of the putamen (arrow indicates, Panel 6b).

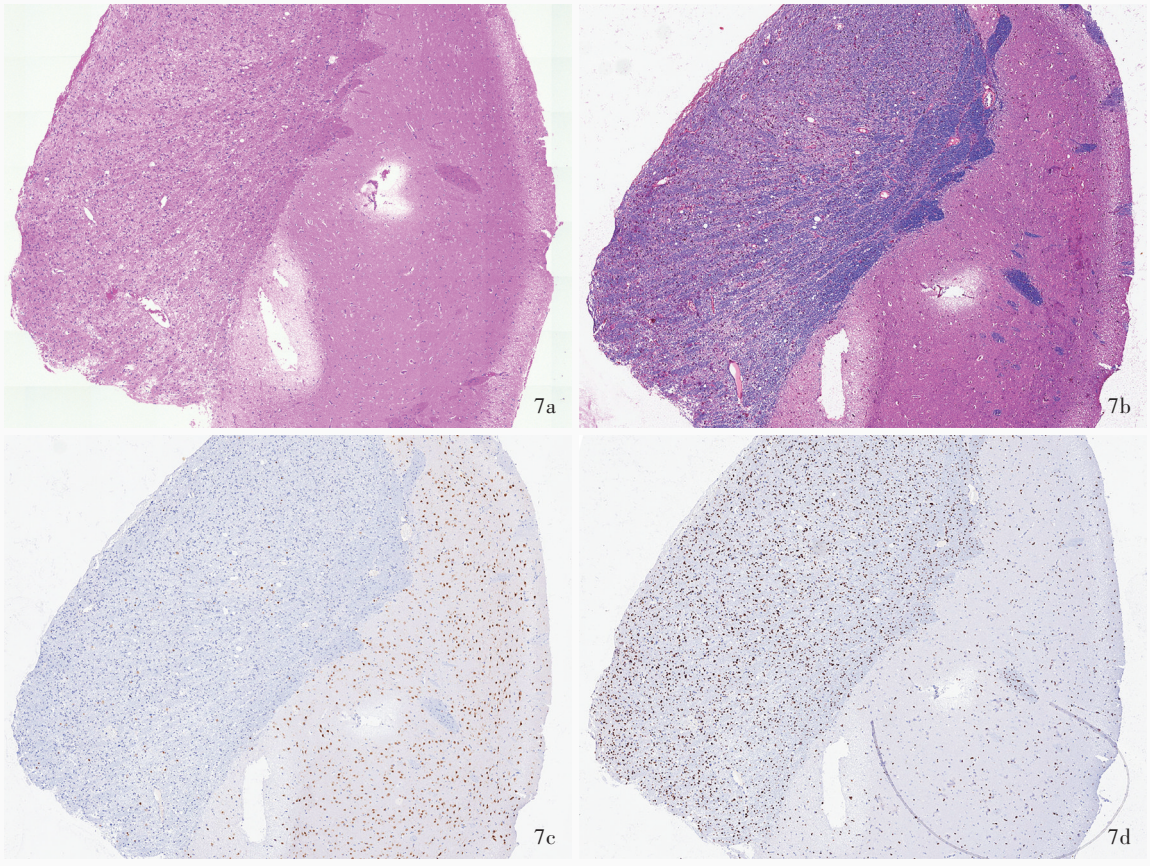


图7　光学显微镜观察所见　低倍放大　7a　肿瘤与壳核界限清晰，对比鲜明（左侧为肿瘤，右侧为壳核）　HE染色　7b　肿瘤组织内髓鞘呈亮蓝色，壳核内未见髓鞘染色　LFB染色　7c　神经元胞体位于壳核内，岛叶肿瘤内未见染色，壳核与肿瘤界限锐利清晰　NeuN染色　7d　神经胶质主要位于肿瘤内，与壳核对比鲜明　Olig染色

Figure 7　Light microscopy findings　Low power magnified　Tumor and putamen were well defined and contrasting (tumor was on the left, putamen was on the right; Panel 7a).　HE staining　Inside the tumour, myelin sheath was bright blue, no myelin staining was seen in the putamen (Panel 7b).　LFB staining　Neuron were located in the putamen, no staining was seen in the insula tumor, the boundary between the putamen and the tumor was sharp and clear (Panel 7c).　NeuN staining　Neuroglia were mainly located in the tumor, contrasting sharply with the putamen (Panel 7d).　Olig staining

高手术精准性和安全性。水分离技术最早由匈牙利神经外科医师Toth于1987年提出，尽管最初未得到广泛认可，但近年逐渐成为一种有效的外科技术。既往主要用于外侧裂分离、脑膜瘤、颅内动脉瘤和颅内动静脉畸形手术，尤其用于蛛网膜界面的分离[21]，亦有Nakagawa等[22]采用喷射压力切割脑组织或肝组织的文献报道。本研究无需采用喷射压力切割，而是采用低压水流和常规手术室耗材，易获得，便于日常神经外科手术。然而，水分离技术也存在一定的并发症风险，错层现象的发生（即应分离的界面未能打开）可能导致脑组织破坏，与水流压力过高或水流方向不当有关。为避免这一

问题，水流方向应平行于分离界面，且在分离过程中需瘤内减压与水分离交替进行，避免错层现象的发生。为防止出现类似基底节区出血破坏功能和结构的情况，避免将水流直接注入间隙，而是通过冲洗的方式进行分离。

我们课题组在前期的预探索中发现对于壳核受累的岛叶胶质瘤，水分离效果较差，而在壳核未受累的低级别胶质瘤中水分离效果较好。因此，本方法特别适用于壳核未受累的低级别岛叶胶质瘤，幸运的是，低级别胶质瘤在岛叶胶质瘤中比例较高。后续我们将继续优化水分离技术参数，并开展前瞻性随机对照试验，进一步验证其在不同类型岛叶胶质瘤中的应用疗效，并探讨如何更好地定制水分离装置。

综上所述，水分离壳核外侧面与岛叶底面是一种有效分离方法，可以提高手术安全性。分离过程中，利用水流力量精准分离壳核外侧面与肿瘤底面界限，高效、安全切除肿瘤。与传统手术方法相比，水分离技术不仅减少术中可能出现的并发症，而且可以更好地实现最大程度的安全切除，保留重要脑功能区，有助于改善患者预后。

利益冲突 无

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