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Spinal cord astroblastoma with \textit{EWSR1-BEND2} fusion classified as \textit{HGNET-MNI} by methylation classification: A case report

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Abstract

The most recurrent fusion of central nervous system high-grade neuroepithelial tumor with MN1 alteration (HGNET-MN1) is MN1 rearrangement. Here, we report the case of a 36-year-old man with spinal cord astroblastoma showing Ewing Sarcoma breakpoint region 1/EWS RNA-binding protein 1 (EWSR1)-BEN domain-containing 2 (BEND2) fusion. The patient presented with back pain, gait disturbance and dysesthesia in the lower extremities and trunk. Magnetic resonance imaging showed an intramedullary tumor at the T3–5 level, displaying homogeneous gadolinium enhancement. Partial tumor removal was performed with laminectomy. Histological examinations demonstrated solid growth of epithelioid tumor cells showing high cellularity, a pseudopapillary structure, intervening hyalinized fibrous stroma, and some mitoses. Astroblastoma was diagnosed, classified as HGNET-MN1 by the German Cancer Research Center methylation classifier. MN1 alteration was not detected by fluorescence in situ hybridization (FISH), but EWSR1-BEND2 fusion was detected by FISH and RNA sequencing. Previously, a child with EWSR1-BEND2 fusion-positive spinal astroblastoma classified as HGNET-MN1 was reported. In conjunction with that, the present case provides evidence that EWSR1-BEND2 fusion is identified in the entity of HGNET-MN1. Taken together, the BEND2

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alteration rather than *MN1* may determine the biology of a subset of the central nervous system HGNET-*MN1* subclass.

**Keywords**

astroblastoma, CNS high-grade neuroepithelial tumor with *MN1* alteration (HGNET-*MN1*), Ewing Sarcoma breakpoint region 1/EWS RNA-binding protein 1 (*EWSR1*), BEN domain-containing 2 (*BEND2*), *EWSR1*-BEND2 fusion

**Introduction**

Astroblastomas are rare neuroepithelial tumors of unknown origin [8, 18], arising mostly in the cerebrum and rarely in the spinal cord. These tumors most often occur in the first to fourth decades of life, and show a female predominance [8, 18]. Although their status as a pathological entity has not been fully determined, the genetic architecture of these tumors has gradually been elucidated.

In 2016, genome-wide DNA methylation analyses of primitive neuroectodermal tumors of the central nervous system (CNS-PNETs) identified four new molecular entities, and one new entity termed CNS high-grade neuroepithelial tumor with MN1 alteration (HGNET-*MN1*) was overrepresented by astroblastoma [13]. Similarly, around half of
pathologically diagnosed astroblastomas were classified as CNS HGNET-\textit{MN1} [7]. This group has been characterized by \textit{MN1} (22q12.3) rearrangement, in which BEN domain-containing 2 (\textit{BEND2}; Xp22.13) and CXXC-type zinc-finger protein 5 (\textit{CXXC5}; 5q31.2) are the main fusion partners of the \textit{MN1} gene [13]. In 2020, our research group reported the case of a 3-month-old boy with spinal astroblastoma, classified as CNS HGNET-\textit{MN1} by the German Cancer Research Center (DKFZ) methylation classification [3, 17] but lacking \textit{MN1} rearrangement. The tumor instead showed gene fusion between \textit{Ewing sarcoma breakpoint region 1/EWS RNA-binding protein 1 (EWSR1)} and \textit{BEND2} [17]. Herein, we report the case of another patient with primary spinal astroblastoma showing \textit{EWSR1}-\textit{BEND2} fusion.

\textbf{Clinical summary}

A 36-year-old man presenting with back pain, gait disturbance and dysesthesia in the lower extremities and trunk was referred to our institution. Neurological examination demonstrated bilateral dysesthesia below the T10 level and thermal hypoalgesia below the S2 level on the right, accompanied by motor weakness of the lower limbs that required a walking aid. Magnetic resonance imaging (MRI) showed a welldemarcated intramedullary tumor spreading exophytically at the T3–5 level, displaying
hypointensity on T1-weighted imaging, hyperintensity on T2-weighted imaging, and homogeneous gadolinium enhancement (Fig. 1a-c). No lesion was observed in either the cerebrum or cerebellum. In addition, $^{18}$F-fluorodeoxyglucose-positron emission tomography showed no apparent accumulation in the tumor (data not shown). The patient underwent partial tumor removal via T3–5 laminectomy. The tumor formed a solid extra-axial mass, which looked grayish (Fig. 1d). The exophytic portion was well-demarcated and able to be safely peeled off the spinal cord. The intramedullary portion displayed no clear boundary.

Postoperatively, the residual tumor showed rapid growth with necrotic change. Based on the previous report showing that radiotherapy with concomitant chemotherapy was effective, the patient underwent focal irradiation with 54 Gy in 30 fractions along with bevacizumab (10 mg/kg) and temozolomide (75 mg/m$^2$). In the late phase of the adjuvant treatment, the tumor reduced in size and perifocal edema was also diminished (Fig. 1e-h). The patient recovered from back pain and started to walk without assistance. However, massive dissemination of the tumor was identified 12 months after chemoradiotherapy (Fig. 1i).

Pathological findings
Histopathological examination of the tumor tissue showed solid growth of epithelioid tumor cells. A vague perivascular arrangement of tumor cells (Fig. 2a), those in a pseudopapillary pattern (Fig. 2b), and intervening hyalinized fibrous stroma (Fig. 2c) were occasionally observed, but astroblastic pseudorosettes were not discernible. The tumor cells possessed round-to-oval nuclei and relatively abundant eosinophilic cytoplasm with 4 mitoses per 10 high-power fields (Fig. 2d). No necrosis, true rosettes, or calcification was seen. Immunohistochemical analyses showed that tumor cells were strongly and diffusely positive for epithelial membrane antigen (EMA) (Fig. 2e) and focally positive for glial fibrillary acidic protein (GFAP) (Fig. 2f), with nuclear positivity for Olig2 (Fig. 2g) and Ki-67 labeling index 20% (Fig. 2h). Tumor cells were also positive for S-100, but negative for p53, progesterone receptor, and cytokeratin AE1/AE3 (data not shown). A histological diagnosis of astroblastoma was established.

The tumor was classified as HGNET-MNI according to the DKFZ methylation classifier[3], with a calibrated score of 0.98. We then analyzed MNI and BEND2 rearrangements by fluorescence in situ hybridization (FISH). No MNI rearrangement was detected (Fig. 3a). Due to the previous case of a child showing EWSR1-BEND2 fusion in astroblastoma, we performed FISH analysis using EWSR1 and BEND2 probes. EWSR1 rearrangement as well as colocalization of EWSR1 and BEND2 probes was detected (Fig.
3b, c). Consistent with RNA sequencing and following FISH analysis suggesting EWSR1-BEND2 fusion, direct sequencing of the cDNA indicated that the breakpoints fell within exon 7 in EWSR1 and exon 2 in BEND2, resulting in an in-frame fusion (Fig. 3d).

Discussion

Astroblastoma is a rare and diagnostically challenging glial tumor, accounting for 0.48–2.8% of all gliomas [1]. Astroblastoma occurs mainly in children and young adults. Most astroblastomas occur in the cerebral hemispheres, with the frontal lobe as the most common primary site [12]. Although brainstem and spinal cord origins have been reported on rare occasions [12, 16, 17], most such cases have been reported recently, probably due to advances in the genetic classification of CNS tumors. The majority of histologically diagnosed astroblastomas have been classified as CNS HGNET-MNI, with the remaining classified as pleomorphic xanthoastrocytoma, glioma or ependymoma [14, 15]. Pediatric cerebral astroblastomas that were classified as CNS HGNET-MNI were reported to show better prognosis, although the significance of the genetic signature in spinal HGNET-MNI remains undetermined [14].

The first case of primary spinal astroblastoma was reported only recently, by
Yamada et al. in 2018 [16]. This may stem from reporting bias: astroblastoma is not usually recognized as a differential diagnosis for spinal cord tumor, and some cases might be misclassified as ependymoma or astrocytoma. Thanks to advances in genetic analyses such as methylation classifier [3], a final diagnosis has become easier to reach with more confidence. Although histologically diagnosed astroblastoma and HGNET-MN1 may not be identical, molecular classification of HGNET-MN1 by methylation analysis was compatible with the diagnosis of astroblastoma in the present case. Three cases of spinal astroblastoma have been reported to date, including our own. These three cases are summarized in Table 1 [16, 17]. The tumor was located in the upper cervical spine in one pediatric case and in the upper thoracic spine for the other two tumors in young adults. All three tumors showed an invasive growth pattern despite a well-defined border on MRI examination, and were all treated by partial resection followed by chemoradiotherapy. This treatment showed efficacy in both young adult cases, although the pediatric case proved resistant to the treatment and showed dismal prognosis. The first case was suggested to show a chromosomal structural abnormality involving the MN1 gene by FISH. Interestingly, EWSR1-BEND2 fusion without MN1 rearrangement was detected in two cases, with methylation patterns compatible with CNS HGNET-MN1 according to the DKFZ classifier. Whether this type of fusion is specific to spinal astroblastoma...
warrants further investigation. Spinal astroblastoma is an extremely rare tumor, but ependymoma- or anaplastic ependymoma-like tumors or other spinal glial tumors in the spinal region with some unusual findings may be reclassified into astroblastoma if tested by genetic analysis. Thus, previous cases of spinal tumor need to be reviewed, and astroblastoma should be considered among the differential diagnoses for spinal tumors, especially in cases involving children and young adults.

**HGNET-MNI** demonstrates variable morphological and immune-phenotypical features. The characteristic features are astroblastic pseudorosettes and stromal sclerosis [14]. In the present case, only the *hyalinized fibrous stroma* was identified, while astroblastic pseudorosettes were not well observed [6]. Immunoreactivities for GFAP, S-100 protein, Olig2, and EMA were variably demonstrated in HGNET-MNI [5, 14].

Only four cases with *EWSR1-BEND2* fusion have been previously reported: one pancreatic neuroendocrine tumor [11], one spinal ependymoma [9], one spinal astroblastoma [17] and the present case. Three of four *EWSR1-BEND2* fusion tumors were localized in the spinal cord. Fusion between *EWSR1* (22q12.2) and partners, i.e., erythroblastosis virus-transforming sequence (avian ETS) transcription factor family, causes various mesenchymal tumors, including Ewing's sarcoma [10]. The N-terminal
transcriptional activating domain of *EWSR1* contributes to tumorigenesis. *BEND2* protein is characterized by two BEN domains that bind DNA and are involved in transcription and chromatin regulation [4]. Both domains derived from *EWSR1* and *BEND2* are necessary for tumorigenesis [17]. In addition, in both cases of fusion with *MN1* [2] and *EWSR1* [17], RNA sequencing revealed increased expression of *BEND2* downstream from the breakpoints [13]. This indicates that the fusion of *BEND2* enhances transcription of *BEND2*, which might be associated with oncogenesis. As suggested by a previous report, the presence of *EWSR1-BEND2* fusion tumors could indicate that *BEND2* rather than *MN1* may define the biology of a subset of CNS HGNET [17]. Accumulation of case series as well as functional analyses of fusion genes are needed to clarify the pathophysiology of *EWSR1-BEND2*-positive astroblastoma and CNS HGNET-MN1.

**List of abbreviations**

HGNET-MN1: CNS high-grade neuroepithelial tumor with MN1 alteration; EWSR1: Ewing Sarcoma breakpoint region 1/EWS RNA-binding protein 1; BEND2: BEN domain-containing 2; DKFZ: the German Cancer Research Center; FISH: fluorescence *in situ* hybridization; CNS-PNETs: primitive neuroectodermal tumors of the central nervous system.
Declarations

Ethics Statement and Consent for publication

This report was carried out in accordance with the principles of the Declaration of Helsinki, and approval was obtained from the institutional review boards at Kyoto University Hospital (approval number: R1285, R2088). Informed consent was obtained from the patient for publication.

Availability of data and material

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

T.T. and Y.A. designed the study of the tumor. S.M., T.H., and H.H. performed histological analyses and diagnosis. S.N., Y.N., and K.I. performed genetic analyses and data analyses. Y.M., H.K., Y.M., K.N., and S.M. collected samples. T.T. and Y.A. wrote the manuscript. All authors read and approved the final manuscript.

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This study included analysis based upon data generated by the German Cancer Research Center (DKFZ) methylation classifier.

References


astroblastoma enables reclassification of most cases into more specific molecular entities. Brain Pathol 28: 192-202 Doi 10.1111/bpa.12561


Table 1. Summary of cases of spinal astroblastoma

<table>
<thead>
<tr>
<th>Author</th>
<th>Age</th>
<th>Sex</th>
<th>Location</th>
<th>Ki-67</th>
<th>Genetic analysis</th>
<th>Treatment</th>
<th>Postoperative survival</th>
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<table>
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<th>Case</th>
<th>Age</th>
<th>Sex</th>
<th>Level</th>
<th>Percentage</th>
<th>Rearrangement</th>
<th>Treatment</th>
<th>Follow-up</th>
<th>Status</th>
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<tbody>
<tr>
<td>Yamada et al., 2018</td>
<td>20 years</td>
<td>female</td>
<td>T1</td>
<td>5%</td>
<td>MNI rearrangement</td>
<td>RT+TMZ+BEV</td>
<td>1 year</td>
<td>(alive)</td>
</tr>
<tr>
<td>Yamasaki et al., 2020</td>
<td>3 months</td>
<td>male</td>
<td>medulla-C4</td>
<td>34%</td>
<td>EWSR1-BEND2 fusion</td>
<td>RT+TMZ+ETP / BEV</td>
<td>30 days</td>
<td>(dead)</td>
</tr>
<tr>
<td>Present case</td>
<td>36 years</td>
<td>male</td>
<td>T3-5</td>
<td>20%</td>
<td>EWSR1-BEND2 fusion</td>
<td>RT+TMZ+BEV</td>
<td>2 years</td>
<td>(alive)</td>
</tr>
</tbody>
</table>


**Figure Legends**

**Figure 1.** Sequential MRI at initial diagnosis and after partial tumor resection

a–c: An intra-axial tumor is identified at the T3–5 level. T2-weighted imaging demonstrates peritumoral edema in the spinal cord (a). The tumor shows homogeneous enhancement (b, c). d: Intraoperative view of the tumor. An exophytic tumor is observed at the T4 level, showing grayish coloration. e–f: At 1 month postoperatively, residual tumor at the T4 level shows rapid growth and perifocal edema extending downward to the C5 level (e). Gadolinium-enhanced T1-weighted imaging shows necrotic changes at the center of the tumor (f). g-h: In late phase of radiotherapy concomitant with...
chemotherapy using temozolomide and bevacizumab, perifocal edema resolves (g) in association with a reduction in tumor size (h). Massive dissemination of the tumor was identified 12 months after chemoradiotherapy (i).

Figure 2. Histopathological examination of the resected spinal tumor

a–c: Low magnification (×10) images with hematoxylin and eosin (HE) staining show perivascular arrangement of tumor cells (a) and a pseudopapillary pattern (b). A higher magnification (×40) images show intervening hyalinized fibrous stroma (c), epithelial-like tumor cells with round-to-oval nuclei and eosinophilic cytoplasm and a mitotic figure (white arrow) (d). e–h: Immunohistochemically, tumor cells display strong, diffusely positive staining for EMA (e), focally positive staining for GFAP (f), and positive nuclear staining for Olig2 (g). Ki-67 labeling index is 20% (h).

Figure 3. Genetic analyses of the resected spinal tumor

a–c: FISH analysis. No MN1 rearrangement is identified (a: red, MN1 centromeric probe; green, MN1 telomeric probe). EWSR1 rearrangement is detected as a split signal with break-apart of two probes for EWSR1 (b: arrows; red fluorescence, EWSR1 centromeric probe; green, EWSR1 telomeric probe). EWSR1-BEND2 fusion is suggested by
colocalization of the red *EWSR1* centromeric probe and the green *BEND2* probe (c: red fluorescence, *EWSR1* centromeric probe; green, encompassing the *BEND2* gene). 

Direct sequence of the cDNA at the break point shows fusion between *EWSR1* exon 7 and *

*BEND2* exon 2.
Figure 1.
Figure 2.
Figure 3.