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1 **Neurological Diseases of Unknown Etiology: Brain-Biopsy Diagnostic Yields and Safety**

2 **Running title:** Brain Biopsy For Diseases of Unknown Etiology

3

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8 **HIGHLIGHTS**

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- 10 • In patients undergoing brain biopsy for neurological diseases of unknown etiology, we found high rates
11 of specific histological (71.3%) and final diagnoses (83.1%), leading to therapeutic management
12 change(s) for 75% of cases.
- 13 • Immunodepression was independently associated with specific histological diagnosis.
- 14 • Brain biopsy–related mortality occurred in 1.1% and permanent neurological morbidity in 0.6% of the
15 patients.
- 16 • For highly selected patients with neurological diseases of unknown etiology, brain biopsy has a high
17 diagnostic yield and low frequency of severe complications.

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1 ABSTRACT

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3 **Background:** For nonneoplastic neurological diseases, no recommendation exists regarding the place or
4 appropriate timing of brain biopsy. The aim of this study was to evaluate the diagnostic yield and safety of brain
5 biopsies from patients with neurological diseases of unknown etiology.

6 **Methods:** We performed a retrospective cohort study from January 1, 2008 to December 31, 2018. We analyzed
7 1847 brain-biopsied patients, including 178 biopsies indicated for neurological diseases of unknown etiology.
8 Specific histological and final diagnosis rates, positive diagnosis-associated factors, complication rate and
9 complication-associated factors were assessed.

10 **Results:** Specific histological diagnosis and final diagnosis rates were 71.3% and 83.1%, respectively, leading to
11 therapeutic management change(s) for 75.3% of patients. Brain- biopsy–related mortality and permanent
12 neurological morbidity occurred in 1.1% and 0.6% of the patients, respectively. The multivariable logistic-
13 regression model retained (odds ratio [95% CI] only immunodepression (2.2 [1.1-4.7]; $P=.04$) as being
14 independently associated with specific histological diagnosis, while supratentorial biopsy-targeted lesions (4.1
15 [1.1-15.2]; $P=.04$) were independently associated with a final diagnosis. Biopsies obtained from comatose
16 patients were less contributive to the diagnosis (0.2 [0.05-0.7]; $P=.01$). Prebiopsy platelet count <100 G/L (28.5
17 [1.8-447]; $P=.02$), hydrocephalus (6.3 [1.2-15.3]; $P=.02$) and targeted lesions <1 cm (4.3 [1.2-15.3]; $P=.03$) were
18 independently associated with brain biopsy-related complications.

19 **Conclusion:** For highly selected patients with neurological diseases of unknown etiology, brain biopsy has a
20 high diagnostic yield and low frequency of severe complications. We advocate that this procedure be considered
21 early in the diagnosis algorithm of these patients.

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23 **Keywords:** brain lesion; cryptogenic neurological disease; diagnostic workup; neuropathology; neurosurgery.

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1 **DECLARATIONS**

2 **Disclosure of Conflicts of Interest:** None

3 **Author's contribution:** All authors had access to the data and a role in writing the manuscript.

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1 INTRODUCTION

2 The contribution of brain biopsy is well-established for patients with suspected neoplastic lesions, for which
3 its diagnostic yield approaches 95% [1,2]. For nonneoplastic neurological diseases, no recommendation exists
4 regarding the place or appropriate timing of brain biopsy. Limited data support using brain biopsy to determine a
5 diagnosis in human immunodeficiency virus (HIV)-positive patients with neurological symptoms [3,4], cerebral
6 angiitis [5], Creutzfeldt–Jakob disease [6] or dementia [7]. For patients with neurological diseases of unknown
7 etiology, brain biopsy is usually the investigational modality of last resort after exhaustive workups with less
8 invasive tests, including imaging, cerebrospinal fluid analysis and electroencephalography, have failed to make a
9 diagnosis. Because brain biopsy is an invasive procedure carrying a risk of severe complications, many
10 physicians favor empirical treatments over taking the risk associated with biopsy to establish a diagnosis.

11 Considering the lack of evidence to guide the decision to biopsy for this challenging subgroup of patients, we
12 conducted a retrospective monocenter study to investigate brain-biopsy diagnostic yield and safety in adults with
13 neurological diseases of unknown etiology.

14

15

16 METHODS

17 Patients

18 We retrospectively reviewed the medical records and histology reports of all adults brain-biopsied at our
19 tertiary medical center, between January 1, 2008 and December 31, 2018. Patients meeting the following
20 conditions were included: 1) neurological disease of unknown etiology or atypical cerebral evolution of systemic
21 and/or neurological underlying diseases; 2) negative comprehensive less-invasive diagnostic work-up including
22 physical examination, laboratory tests, morphological examinations and extra-neurological histological findings;
23 3) indication for brain biopsy validated by a multidisciplinary team including neurologists, neurosurgeons,
24 neurooncologists, neuroradiologists, neuropathologists, internists and nuclear medicine specialists; and 4)
25 complete 6 months follow-up post biopsy or death before 6 months.

26 Patients were not considered for brain biopsy until a comprehensive less-invasive diagnostic work-up was
27 fully performed and came back negative.

28 Patients who underwent brain biopsy for histological confirmation of an obvious primary or secondary
29 cerebral neoplasm, or brain abscess were not included. Patients with incomplete data were excluded. For the 4
30 patients with repeat biopsies, only the first was included in the analysis.

1 **Study Variables and Outcomes**

2 Main outcome variables were: 1) obtaining a specific histological diagnosis, 2) making a final diagnosis, 3)
3 brain-biopsy–related complications. Other variables included demographic characteristics, medical history,
4 clinical manifestations, laboratory findings before brain biopsy, full less-invasive diagnostic work-up conducted
5 for every patient and 6-month survival postbiopsy.

6 Histological results of brain biopsies were categorized into 3 groups: specific lesion, nonspecific lesion,
7 normal brain. Obtaining a specific histological diagnosis was defined as brain-biopsy findings of a specific
8 lesion sufficient by itself to make a diagnosis and to modify therapeutic management. The final diagnosis was
9 reached by combining the brain-biopsy findings integrated with the patient’s medical history and the results of
10 the less-invasive diagnostic work-up. Brain biopsies containing specific lesion(s) were classified as contributory
11 to the final diagnosis. Brain biopsies with nonspecific lesion(s) could nonetheless be classified as contributing to
12 a final diagnosis. A multidisciplinary discussion among neurosurgeons, pathologists, neuroradiologists,
13 neurologists and internists determined whether a brain biopsy with nonspecific lesion(s) contributed to a final
14 diagnosis. During those discussions, participants systematically and comprehensively reviewed each patient’s
15 medical history, neurological and extra-neurological findings, less-invasive diagnostic work-up, brain-biopsy
16 microbiology and histology results. The treating physician’s main hypothetical diagnosis and treatment at the
17 time of biopsy and changes made thereafter were noted. Two senior neuroradiologists analyzed all the imaging
18 studies, including available 3.0 Tesla magnetic resonance imaging (MRI) (T1-weighted and T2-weighted, fluid-
19 attenuated inversion-recovery [FLAIR], T1-weighted with gadolinium injection, gradient-echo T2*-weighted,
20 and diffusion-weighted) sequences and multiparametric imaging data. Two senior neuropathologists examined
21 all histological slides. During the multidisciplinary discussion, participants had to agree unanimously that the
22 brain biopsy contributed to making the final diagnosis.

23 Brain-biopsy–related complications were defined as occurring during the month following the procedure. In
24 the light of current literature on complications of diagnostic intracerebral procedures, we used a previously
25 published graded severity scale with composite items including a prevailing surgical component [8,9]: grade 1:
26 complication visible only on postoperative computed-tomography (CT) scan or transient event that did not
27 require treatment; grade 2: transient complication that resolved completely but required treatment; grade 3:
28 persistent neurological deficit >12 months postbiopsy; grade 4: biopsy-related death.

29

30

1 **Surgical Procedures and Postoperative Management**

2 A stereotactic biopsy technique was used for deep-seated lesions. The biopsies were taken under local
3 anesthesia with all the patients placed in a Leksell-G stereotactic frame; 3-dimensional, spoiled, gradient-
4 recalled, gadolinium-enhanced MRI and FLAIR sequences were obtained on a 1.5 Tesla MR scanner (Signa,
5 General Electric, Boston, MA) after intravenous injection of gadolinium contrast material. An enhanced CT scan
6 was rarely obtained instead of the MRI for technical reasons. Once these images were acquired, the trajectory
7 and depth were planned according to the lesion to be targeted. Stereotactic coordinates were calculated with
8 Framelink (Medtronic, Minneapolis, MN) software. The biopsy path was carefully chosen so as to avoid
9 damaging critical superficial and deep veins and arteries. This route was simultaneously controlled millimeter-
10 by-millimeter in the 3 spatial planes (3D view), and in the perpendicular and parallel oblique views of the needle
11 trajectory. The entry site was shaved, and biopsy was obtained under standard aseptic surgical conditions
12 without antibiotic prophylaxis. Patients were placed in a semi-recumbent position and the stereotactic arc was
13 used to determine the incision site. After making a stab incision, a 3-mm twist-drill hole was made at the
14 previously calculated coordinates. An intracerebral biopsy needle was then introduced through the drill hole and
15 advanced towards the target and 6–10 tissue samples, $\sim 1 \times 10$ mm, at different depths surrounding and within
16 the targeted lesion.

17 For cortical and/or meningeal lesions, biopsies were obtained via open craniotomy or a burr hole. We
18 considered a gold standard diagnostic open biopsy to be 1 cm³ of leptomeninges and cortex including grey and
19 white matter. For MRI-negative patients, the biopsy was preferentially taken from the right middle frontal lobe
20 gyrus, unless history, examination or imaging asymmetry suggested another location would provide a higher
21 diagnostic yield.

22 The tissue samples collected were divided into several parts for neuropathological, bacteriological,
23 parasitological and virological investigations. When the available tissue was deemed sufficient, smears were
24 routinely prepared for urgent intraoperative neuropathological examination [10]. When the histological diagnosis
25 could not be made based on tissue from one target, another target was selected. When the differential diagnosis
26 included infection, tissue was set aside for microbiology studies. The management of samples in the pathology
27 lab relied on the following process: (i) systematic freezing of one fragment to allow further molecular
28 investigations looking for infectious agents or for mutations of neoplasms or for an abnormal clonality of
29 lymphoid cells, (ii) short fixation before overnight paraffin embedding to allow urgent preliminary results in less
30 than 30 hours, (iii) a first-line panel of techniques adapted to the clinical context and to the examination of the

1 smear, (iv) preparation of unstained sections to spare the sample from iterative sessions of microtome cutting
2 and to allow fast execution of a second-line panel. The first line panel included -in the absence of neoplasm on
3 the smear- : (i) Gram, Grocott methenamine silver, Periodic Acid-Schiff/PAS, and Ziehl-Neelsen stains to detect
4 infectious pathogens, (ii) Ki67, CD3, CD20, Iba1 immunolabelings to evaluate inflammation, potential
5 lymphoproliferation and microglial activation, (iii) if immunocompromised patient, toxoplasma and virus JC
6 immunolabelings. The second-line panel was adapted to the histological aspect of the standard staining and to
7 results of the first-line panel: for example Epstein-Barr Virus hybridization in case of large lymphoid B cells, or
8 luxol blue and double immunolabeling of myelin basic protein & neurofilament in case of potential
9 demyelinating lesion.

10 Patients were monitored for at least 6 h in the recovery unit. Prior to transfer to the neurosurgery department,
11 a postoperative CT scan was obtained to rule out immediate complications.

12

13 **Statistical Analyses**

14 Results expressed as number (%) were compared with χ^2 tests; continuous variables expressed as mean \pm SD
15 or median [interquartile range, IQR] were compared with Student's *t*-test or Wilcoxon's rank test. Patients'
16 demographic, clinical and biological characteristics were tested in univariable analyses for association with
17 obtaining a specific histological diagnosis, final diagnosis or the occurrence of any complication.

18 Thereafter, multiple logistic-regression analyses using backward, stepwise variable elimination were run
19 (with the variable exit threshold set at $P > 0.10$). Factors achieving $P \leq 0.10$ in our univariable analyses and
20 parameters previously reported to be strongly associated with diagnosis or complication(s) were entered into the
21 multivariable model. All potential explanatory variables included in the multivariable analyses were subjected to
22 collinearity analysis with a correlation matrix. Variables associated with one another were not included in the
23 model. Model goodness-of-fit was assessed with the determination coefficient (R^2). $P < .05$ defined statistical
24 significance. Analyses were computed with IBM SPSS Statistics v22.0 software (IBM Corp, Armonk, NY).

25

26 **Standard Protocol Approvals, Registrations and Patient Consents**

27 The database is registered with the *Commission Nationale de l'Informatique et des Libertés*. In accordance
28 with the ethical standards of our hospital's institutional review board, the Committee for the Protection of
29 Human Subjects, and French law, written informed consent was not needed for demographic, physiological and
30 hospital-outcome data analyses because this observational study did not modify existing diagnostic or

1 therapeutic strategies; however, patients were informed of their inclusion in the study. The manuscript was
2 prepared in accordance with the STrengthening the Reporting of OBServational studies in Epidemiology
3 (STROBE) statement.

4

5 **Data Availability Statement**

6 Anonymized data will be shared on request from any qualified investigator.

7

8 **RESULTS**

9 **Study Population**

10 During the study period, 1847 patients underwent a brain biopsy; the 178 biopsied to investigate a
11 neurological disease of unknown etiology were included in the study (**Figure 1**). The yearly number of brain
12 biopsies and their indications for the 1847 patients are reported in **Supplemental Table 1**. The main reason for
13 those latter biopsies was the histological confirmation of an obvious primary or secondary cerebral neoplasm (n
14 = 1504, 90.4%).

15 The general characteristics of the 178 retained patients and their brain biopsies are presented in **Table 1**. The
16 male-to-female ratio was 1.9 and the mean age on biopsy day was 47.1 ± 15.4 years. Their medical histories
17 worth noting included immunocompromised status (42.7%), autoimmune diseases (14.6%), HIV (14.0%),
18 hematological malignancies (10.1%), organ transplantations (7.3%) and solid-organ tumors (6.2%). One-third
19 had been taking or were prescribed corticosteroids before the biopsy. Clinical manifestations included
20 neurological deficit (74.9%), extra-neurological symptoms (32.2%), altered consciousness (30.3%), seizures
21 (28.1%), fever (15.5%) and coma (11.4%). Elevated cerebrospinal fluid proteins and meningitis, respectively,
22 were reported in 53.8% and 30.3% of patients with lumbar puncture. Most patients had multifocal (58.8%),
23 bilateral (54.2%) or gadolinium-enhanced (57.4%) lesions. The biopsy-targeted lesion was predominantly
24 supratentorial (93.2%), with largest diameter >1 cm (71.0%) and gadolinium-enhanced (58%). The most
25 frequent biopsy technique was stereotaxic (69.5%), with MRI-guidance for 74.8%.

26

27 **Diagnoses and Main Outcomes**

28 Brain biopsies contained a specific lesion, nonspecific lesion or normal brain, respectively, for 127 (71.3%),
29 46 (25.8%) and 5 (2.8%) patients. Nonspecific lesions contributed to a final diagnosis for 21/46 (45.7%)
30 patients. A final diagnosis could be made for 148 (83.1%) patients (**Figure 1**), most frequently: autoimmune or

1 inflammatory diseases (21.9%), infections (20.2%), hematological malignancies (19.6%), demyelinating disease
2 (6.7%), metastasis (3.9%) and glioma (3.4%) (**Table 2**). Four patients had multiple diagnoses. Another biopsy
3 was obtained from 4 (2.2%) patients and it contributed to the diagnosis for 4 of them. Brain-biopsy findings led
4 to therapeutic management change(s) for 75.3% of the patients. The mean \pm SD follow-up postbiopsy was 23.7 \pm
5 28.8 months and 1-year survival was 75.8%.

6

7 **Diagnostic Yield-Associated Factors**

8 Comparisons between patients with specific and nonspecific histological lesion are reported in **Table 1**.
9 Patients with specific lesions suffered significantly more frequently from immunocompromised status, fever,
10 meningitis and elevated C-reactive protein levels. The logistic-regression model for multivariable analyses
11 retained only immunocompromised status as being a significantly independent predictor of a specific
12 histological lesion (**Table 3**). Comparisons between patients whose biopsies contributed or not to the final
13 diagnosis are presented in **Supplemental Table 2**.

14 Univariable analyses (**Supplemental Table 3**) identified patients given a final diagnosis as having only more
15 frequent supratentorial biopsy-targeted lesions (95.2% vs. 83.3%; $P = .02$). The logistic-regression model for
16 multivariable analyses retained (odds ratio [95% confidence interval]) supratentorial biopsy-targeted lesion (4.1
17 [1.1 to 15.2]; $P = .04$) as independent predictors of a final diagnosis, while biopsies obtained from comatose
18 patients were less contributive to the diagnosis (0.2 [0.05 to 0.7]; $P = .01$).

19

20 **Complications and Factors Associated with Them**

21 During the month following the biopsy, 22 (12.3%) patients developed grade-1, -2, -3 or
22 -4 complications (**Supplemental Table 4**). Fifteen (68.2%) of those complications were grade-1 asymptomatic
23 and diagnosed only on systematic postbiopsy imaging. Seventeen complications were postbiopsy hemorrhages,
24 none of which required surgical hematoma evacuation. Two biopsies were fatal: 1 in the context of acute
25 myeloid leukemia and persistent profound thrombopenia, and the other of multiple myeloma on mechanical
26 ventilation and hemodialyzed.

27 Univariable analyses of complication-associated factors are reported in **Supplemental Table 5**.

28 The multivariable logistic-regression model (**Table 4**) retained prebiopsy platelet count <100 G/L,
29 hydrocephalus and targeted lesions <1 cm as being independently associated with developing a brain biopsy-
30 related complication, while a prebiopsy history of seizures or neurological deficit was significantly associated

1 with less postbiopsy complication.

2

3 **DISCUSSION**

4 For patients with neurological disease of unknown etiology, the place of brain biopsy remains controversial,
5 because it is an invasive option that should only be considered when the global benefit surpasses the risk of
6 inducing harm.

7 Previous series, mostly published in the 1990s and 2000s, included 14 to 64 patients brain biopsied for
8 cryptogenic neurological disease [5,11–20]. Their reported diagnostic yields were relatively low, 29–68%
9 [11,14,15,18,20–23], leading some authors to argue that it was too low and that the procedure was not
10 contributory to patient management [12–15,24], while others emphasized brain-biopsy usefulness [5,16–20].
11 Since then, the numerous breakthroughs made in neurosurgery, pathology, immunology and microbiology have
12 increased the diagnostic yield and improved the safety of the procedure. Our frequency of diagnoses made
13 directly with brain biopsies during the last decade was higher for our series (71.3%) and was even better (83.1%)
14 when nonspecific lesions were interpreted in light of the patient’s medical history. Moreover, since 2016,
15 metagenomic next-generation sequencing (NGS) of brain tissue has enabled diagnoses that cannot be made using
16 routine microbiological testing [25]. These recently reported new techniques [26] pave the way to further
17 improve in the diagnostic yield of these invasive procedures. Further studies will be needed to evaluate the need
18 for brain biopsy and its diagnostic yield is the setting of new neuronal antibodies and NGS techniques. Lastly,
19 although 16.9% of the biopsies were non-contributory for a final diagnosis, they indeed excluded neoplastic or
20 infectious diseases, thereby enabling specific therapy (e.g., immunosuppressants ...) to be started, if needed.

21 We highlighted several new characteristics associated with obtaining a diagnosis. First,
22 immunocompromised status was the sole factor associated with specific histological lesions. This subgroup’s
23 frequency and diversity of neurological diseases (opportunistic infections, inflammatory diseases and neoplasia)
24 [4,27–29] render brain biopsies highly informative. Moreover, dual pathologies were found in 4/76 (5.2%)
25 immunocompromised patients. Second, infratentorial biopsy-targeted lesions were less frequently associated
26 with making a final diagnosis. Deep cerebellum and brain-stem lesions, which prevent efficiently obtaining
27 biopsies, are indeed technically more complex [30,31]. Third, contrary to preconceived ideas, small or
28 noncontrast-enhanced lesions were not associated with a low diagnosis rate. Last, biopsies taken from comatose
29 patients were less likely to contribute to the final diagnosis. In these patients, the urgent need for diagnosis might

1 lead to retain wider indication of brain biopsy. Although, our results suggest that the benefit/risk ratio should be
2 careful weighed for these patients.

3 Comparing the diagnostic yields in a context of diseases of unknown etiology, brain biopsy appears to be
4 highly beneficial compared to those of other solid-organ biopsies. The diagnostic yields were all lower than
5 herein: 40–59% for transbronchial lung biopsies for suspected sarcoidosis, with a complication rate of 12%
6 [32,33]; slightly better at ~65% for percutaneous biopsies of benign lung nodules [34]; worse with only 18%
7 definite diagnoses for endomyocardial biopsies, which impacted therapeutic management for 29% of the
8 patients [35]; 30–50% for accessory salivary-gland biopsies for Löfgren’s syndrome and other forms of
9 sarcoidosis [36,37]; and 81% for punch skin biopsies from patients with suspected cutaneous sarcoidosis [38].

10 Pertinently, brain biopsy is an invasive procedure as its complications may be fatal. However, large series of
11 brain biopsies obtained for brain tumor investigations showed that permanent neurological morbidity and
12 mortality frequencies were low, ranging from 0 to 5.6% [39,40] and 0 to 4% [41,42], respectively. Herein, we
13 also reported a low rate of severe (grade 3–4, 1.7%) complications in the setting of neurological diseases of
14 unknown etiology. Likewise the frequencies of silent hemorrhagic complications in our series (7.9%) agreed
15 with those previously reported (7–26%) [43,44].

16 Intriguingly, the main factor associated with complications in our study was low platelet counts on the days
17 preceding biopsy, despite all patients having had >100 G/L platelets the day of biopsy. This finding underscores
18 that, for thrombocytopenic patients, perioperative platelet transfusions do not prevent the risk of late biopsy-site
19 bleeding. Based on those findings, we think that a platelet count >100 G/L should be maintained for at least 7
20 days postbiopsy [45,46]; however, we observed very late (21 days) hemorrhagic complications in patients with
21 sustained profound thrombocytopenia. For thrombocytopenic, brain-biopsy candidates, the procedure’s
22 benefit/risk ratio must be thoroughly evaluated, especially when sustained thrombocytopenia is foreseeable.

23 Notably, small targeted lesions were more frequently associated with complications. Those outcomes can be
24 explained by the limited number of possible trajectories to reach the target lesion. Notably, the topography of
25 lesions was not associated with complications. Finally, preoperative hydrocephalus was associated with a higher
26 rate of postoperative complications, suggesting that brain biopsy could exacerbate radiological findings and
27 clinical symptoms related to hydrocephalus, probably through hemorrhagic and edema-inducing mechanisms.
28 Ultimately, we would like to emphasize that the risk of severe complications of a brain biopsy should always be
29 weighed against the risks borne by the natural evolution of an undiagnosed and untreated severe neurological
30 disease (lymphoma, leukemia, infection, cancer, vasculitis...). In many cases, the latter is frequently more life-

1 threatening than the former, as supported by the 2 biopsy-attributable deaths during the year following biopsy vs.
2 42 because of disease-attributed deaths.

3 In the end, we suggest that several elements should be required to consider a brain biopsy in a patient with
4 neurological disease of unknown etiology : 1) 3.0 Tesla brain MRI with spectroscopy and perfusion sequence, 2)
5 negative comprehensive less-invasive laboratory and morphologic work-up including a total-body CT-scan, 3)
6 negative pathological examination of extra-neurological lesions, if present, 4) brain lesion considered accessible
7 by a trained neurosurgical team, 5) no bleeding disorders and the possibility of maintaining platelets over 100
8 G/L during the first 7 days after the biopsy, 6) validation of the brain biopsy indication during a
9 multidisciplinary discussion. When these criteria are met cumulatively, we advocate that this procedure be
10 considered early in the diagnosis algorithm of these patients.

11 Our study has limitations and strengths. First, it is retrospective, monocentric, observational design, but many
12 patients with rare diseases undergoing a rather uncommon procedure were included. Second, our definition of
13 “neurological disease of unknown etiology” may be controversial; however, all cases were analyzed
14 retrospectively during retrospective multidisciplinary discussions to ascertain the diagnosis. Third, our institution
15 being a tertiary referral center induces a selection bias, but also reflects the real-world picture of neurological
16 diseases of unknown etiology. While some of the final diagnosis in this study can usually be achieved without a
17 brain biopsy (tuberculosis, viral encephalitis, multiple sclerosis, ADEM...), many patients were referred to our
18 institution because of a diagnostic dilemma that had not been solved with the comprehensive less-invasive work-
19 up. Fourth, we could not obtain the median time from symptoms onset to brain biopsy. Indeed, some patients
20 had a long medical history with many clinical symptoms while others had no specific neurological symptoms.
21 Last, brain-biopsy safety and efficacy in our center relies on the experience of our neurosurgeons and
22 neuropathologists, and those results may not be immediately reproducible in every center.

23

24 CONCLUSIONS

25 Our results suggest that, for highly selected patients with neurological diseases of unknown etiology, brain
26 biopsy has a high diagnostic yield and low frequency of severe complications. We advocate that this procedure
27 be considered early in the diagnosis algorithm of patients with neurological diseases of unknown etiology.

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1 **FIGURE LEGENDS**

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3 *Figure 1.* Flow-chart of patient inclusion in this study on brain-biopsy contribution to diagnosis.

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Table 1. Patient and Biopsy Characteristics with Comparison According to Biopsy Specific Lesion Status

Characteristic	All patients <i>n</i> = 178	Specific lesion <i>n</i> = 127	No specific lesion <i>n</i> = 51	<i>P</i>
Males	117 (65.7)	88 (69.3)	29 (56.9)	0.1
Age on biopsy day, years	47.1±15.4	47.4±15.4	46.4±15.5	0.7
Medical history				
Immunocompromised	76 (42.7)	62 (48.8)	14 (27.5)	0.009
Cardiovascular	34 (19.1)	22 (17.3)	12 (23.5)	0.3
Autoimmune diseases	26 (14.6)	21 (16.5)	5 (9.8)	0.2
Human immunodeficiency virus	25 (14.0)	21 (16.5)	4 (7.8)	0.1
Hematological malignancies	18 (10.1)	13 (10.2)	5 (9.8)	0.9
Organ transplantation	13 (7.3)	12 (9.4)	1 (2)	0.08
Solid-organ tumor	11 (6.2)	6 (4.7)	5 (9.8)	0.2
Treatments before biopsy				
Corticosteroids	60/173 (34.7)	42/122 (34.4)	18 (35.3)	0.9
Antiplatelet therapy	21/174 (12.1)	15/123 (12.2)	6 (11.8)	0.9
Anticoagulant	6/174 (3.4)	3/123 (2.4)	3 (5.9)	0.3
Clinical findings before biopsy				
Neurological defect	131/175 (74.9)	92/124 (74.2)	39 (76.5)	0.7
Altered consciousness (GCS 8-14)	53/175 (30.3)	38/124 (30.6)	15 (29.3/4)	0.9
Coma (GCS 3-7)	27/174 (15.5)	12/124 (9.7)	8 (15.7)	0.3
Seizure	20/175 (11.4)	38 (29.9)	12 (23.5)	0.4
Extra-neurological symptoms	56/174 (32.2)	43/123 (35)	13 (25.5)	0.2
Fever	50 (28.1)	24/123 (19.5)	3 (5.9)	0.02
Laboratory findings before biopsy				
Meningitis	44/145 (30.3)	35/99 (35.4)	9/46 (19.6)	0.05
Elevated CSF proteins	78/145 (53.8)	57/99 (57.6)	21/46 (45.7)	0.2
White blood cell count, <3 G/L	6/163 (3.6)	4/119 (3.4)	2/50 (4)	0.9

Hemoglobin, <10 g/dL	35/168 (20.8)	28/119 (23.5)	7/49 (14.3)	0.2
Platelet count, G/L	250 [197-317]	244 [192-307]	274 [221-334]	0.04
<150 G/L	24/169 (14.2)	19/120 (15.8)	5/49 (10.2)	0.3
<100 G/L	2/168 (1.2)	5/120 (4.2)	1/49 (2.0)	0.5
C-Reactive protein, >10 mg/L	50/169 (29.6)	41/120 (34.2)	9/49 (18.4)	0.04
MRI findings before biopsy				
Multifocal lesions	104/177 (58.8)	74 (58.3)	30/50 (60)	0.8
Bilateral lesions	96/177 (54.2)	64 (50.4)	32/50 (64)	0.1
Hydrocephalus	16/176 (9.1)	11/126 (8.7)	5/50 (10)	0.8
Gadolinium enhancement	101/176 (57.4)	75/126 (59.5)	26/50 (52)	0.4
Meningeal involvement	27/176 (15.3)	19/126 (15.1)	8/50 (16)	0.9
Largest lesion diameter, mm	18.3 [10.9-28.7]	18.2 [10.6-28.3]	19.6 [11.1-30.2]	0.9
<10 mm	40/172 (23.3)	29/123 (23.6)	11/49 (22.4)	0.9
10-20 mm	53/172 (30.8)	39/123 (31.7)	14/49 (28.6)	0.7
>20 mm	79/172 (45.9)	55/123 (44.7)	24/49 (49)	0.6
Biopsy-targeted lesion characteristics				
Subcortical	72/176 (40.9)	52/126 (41.3)	20/50 (40)	0.9
Deep-brain	64/176 (36.4)	44/126 (34.9)	20/50 (40)	0.5
Cortical	29/176 (16.5)	21/126 (16.7)	8/50 (16)	0.9
Meningeal	9/176 (5.1)	8/126 (6.3)	1/50 (2)	0.2
Supratentorial	164/176 (93.2)	119/126 (94.4)	45/50 (90)	0.3
Size >1 cm	125/176 (71.0)	93/126 (73.8)	32/50 (64)	0.2
Gadolinium-enhanced	102/176 (58)	74/126 (58.7)	28/50 (56)	0.7
Biopsy technique				
Stereotaxic	123/177 (69.5)	88/126 (69.3/8)	35 (68.6)	0.9
MRI-guided	92/123 (74.8)	67/88 (76.1)	25/35 (71.4)	0.6

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- 1 Abbreviations: CSF = cerebrospinal fluid; GCS = Glasgow coma score; MRI = magnetic resonance imaging.
 - 2 Continuous variables, expressed as mean \pm SD or median [interquartile range (IQR)], were compared with
 - 3 Student's *t*-test or Wilcoxon's rank test; categorical variables, expressed as *n* (%), were compared with χ^2 tests.

Table 2. Final Diagnoses for the 178 Patients Brain-Biopsied for Neurological Diseases of Unknown Etiology

Final Diagnosis	Value
Autoimmune or inflammatory diseases	39 (21.9)
Cerebral vasculitis	16
Sarcoidosis	9
Behçet's disease	5
Autoimmune encephalitis	2
Others*	7
Infectious diseases	36 (20.2)
Toxoplasmosis	9
Progressive multifocal leukoencephalopathy	8
Tuberculosis	7
Viral encephalitis	7
Parasitic/fungal diseases	4
Nocardiosis	1
Hematological malignancies	35 (19.6)
Lymphoma	13
EBV-induced lymphoproliferative disease	12
Histiocytosis	6
AL Amyloidosis [£]	2
Graft-vs.-host disease	1
Acute myeloid leukemia	1
Demyelinating disease	12 (6.7)
Multiple sclerosis	6
Acute disseminated encephalomyelitis	6

Metastasis	7 (3.9)
Glioma	6 (3.4)
Others[†]	9 (5.1)
Multiple diagnoses[‡]	4 (2.2)
None	30 (16.9)

Abbreviation: EBV = Epstein–Barr virus; AL, Amyloid Light. Results are expressed as *n* (%) or *n*.

* Immune reconstitution inflammatory syndrome, 2; and 1 each: inflammatory pseudotumor, CD8+ encephalitis, Rasmussen encephalitis, paraneoplastic encephalitis or neuromyelitis optica.

[‡]Two Lambda Light Chain Amyloidosis.

[†]One each: mitochondrial cytopathy, Alzheimer’s disease, mycosis fungoides, radionecrosis, methotrexate toxicity, craniospinal hypotension pachymeningitis, hemiplegic migraine, progressive cerebral ataxia or orthochromic leukodystrophia.

[‡]Progressive multifocal leukoencephalopathy and EBV-induced lymphoproliferative disease *n* = 2, and 1 each: toxoplasmosis and Immune reconstitution inflammatory syndrome or toxoplasmosis and EBV-induced lymphoproliferative disease.

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Table 3. Univariable and Multivariable Logistic-Regression Model Analyses of Factors Associated with Brain Biopsy Containing a Specific Lesion

Variable	Univariable analysis			Multivariable analysis		
	OR	95% CI	P	OR	95% CI	P
Male	1.7	0.8-3.3	0.1			
Medical history						
Immunocompromised	2.5	1.2-5.1	0.01	2.2	1.1-4.7	0.04
Human immunodeficiency virus	2.3	0.7-7.1	0.1			
Clinical findings before biopsy						
Fever	3.8	1.1-13.2	0.03			
C-Reactive protein >10 mg/L	2.3	1.1-5.2	0.04			
MRI findings before biopsy						
Bilateral lesions	0.6	0.3-1.1	0.1			
Biopsy-targeted lesion characteristic						
Size >1 cm	1.6	0.8-3.2	0.2			

1 Abbreviation: OR = odds ratio; MRI = magnetic resonance imaging.

2 The multiple logistic-regression model was run using backward-stepwise variable elimination (with the variable
3 exit threshold set at $P > 0.10$). All potential explanatory variables included in the multivariable analyses were
4 subjected to collinearity analysis with a correlation matrix. Variables associated with one another were not
5 included in the **model**. $P < 0.05$ defined statistical significance.

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Table 4. Univariable and Multivariable Logistic-Regression Model Analyses of Brain-Biopsy Complication-Associated Factors (grade 1–4).

Variable	Univariable Analysis			Multivariable Analysis		
	OR	95% CI	P	OR	95% CI	P
Age, years	1.0	0.9-1.1	0.1			
Clinical findings before biopsy						
Neurological defect	0.4	0.2-1.1	0.07	0.2	0.06-0.9	0.04
Seizure	0.2	0.05-0.9	0.049	0.08	0.1-0.4	0.006
Laboratory findings before biopsy						
Elevated CSF proteins	2.0	0.7-5.2	0.16			
White blood cell count < 3G/L	3.5	0.6-20.6	0.6			
Platelet count <100 G/L	16.0	2.7-93.6	0.002	28.5	1.8-447	0.02
MRI findings before biopsy						
Hydrocephalus	2.6	0.7-8.9	0.1	6.3	1.3-30.4	0.022
Largest lesion diameter, mm						
<10 mm	2.7	0.8-5.9	0.1	4.3	1.2-15.3	0.03
>10 mm	0.4	0.1-1.1	0.1			
>20 mm	0.4	0.1-1.2	0.1			
Targeted-lesion characteristic						
Size > 1 cm	0.4	0.18-1.1	0.08			

Abbreviation: OR = odds ratio; CI = confidence interval.

The multiple logistic-regression model was run using backward-stepwise variable elimination (with the variable exit threshold set at $P > 0.10$). All potential explanatory variables included in the multivariable analyses were subjected to collinearity analysis with a correlation matrix. Variables associated with one another were not included in the **model**. $P < 0.05$ defined statistical significance.

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1 **SUPPLEMENTAL DIGITAL CONTENT**

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3 **Supplemental Table 1.** Yearly numbers and indications of brain biopsies between 2008 and 2018

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5 *Supplemental Table 2.* Patient and biopsy characteristics with comparison according to biopsy contribution to
6 the final diagnosis

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8 *Supplemental Table 3.* Univariable and multivariable logistic-regression model analyses of factors associated
9 with brain biopsy contributing to the final diagnosis

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11 *Supplemental Table 4.* Details of the 22 brain-biopsy complications according their grade

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13 *Supplemental Table 5.* Univariable analysis of factors associated with a brain-biopsy–related complication