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## National Institute on Aging-Alzheimer's Association guidelines for the neuropathologic assessment of Alzheimer's disease: a practical approach

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### Abstract

We present a practical guide for the implementation of recently revised National Institute on Aging-Alzheimer's Association guidelines for the neuropathologic assessment of Alzheimer's

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disease (AD). Major revisions from previous consensus criteria are: (i) recognition that AD neuropathologic changes may occur in the apparent absence of cognitive impairment, (ii) an “ABC” score for AD neuropathologic change that incorporates histopathologic assessments of amyloid  $\beta$  deposits (A), staging of neurofibrillary tangles (B), and scoring of neuritic plaques (C), and (iii) more detailed approaches for assessing commonly co-morbid conditions such as Lewy body disease, vascular brain injury, hippocampal sclerosis, and TAR DNA binding protein (TDP)-43 immunoreactive inclusions. Recommendations also are made for the minimum sampling of brain, preferred staining methods with acceptable alternatives, reporting of results, and clinico-pathologic correlations.

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## INTRODUCTION

A consensus panel from the United States and Europe was convened recently to update and revise the 1997 [30] consensus guidelines for the neuropathologic evaluation of Alzheimer’s disease (AD). Here we summarize these consensus guidelines [29] and provide direction for their application.

## CLINICO-PATHOLOGIC CORRELATION

“Alzheimer’s disease” refers to a constellation of cognitive and behavioral changes that are typical for patients who have substantial amounts of its hallmark lesions [6,39]. Similar neuropathologic changes, albeit usually at lower levels, also occur in individuals who did not show cognitive or behavioral impairments during life [54]. We recommend that neuropathologists adopt the term “AD neuropathologic change” and report on the presence and extent of lesions observed at autopsy regardless of the individual’s cognitive state, or even if cognitive state is not known.

AD neuropathologic change should be assessed in all cases of dementia. There are many other neurodegenerative disorders that can cause dementia in addition to those discussed here, and any may be co-morbid with AD neuropathologic change, especially in the elderly. We recommend that all lesions be documented for type and extent of co-morbidity in brains of individuals with AD neuropathologic change.

Multiple diseases in cerebrum can conspire to worsen cognitive symptoms; however, it often is difficult to judge the extent to which each disease observed at autopsy may have contributed to a given patient’s cognitive state. It is essential that the extent of AD neuropathologic change, as well as neuropathologic findings for any other disease(s) that may have contributed to cognitive impairment or dementia, be correlated with clinical, neuropsychological, neuro-imaging, and other laboratory data as part of the neuropathology report.

## WORK-UP OF CASES

Autopsy should follow best practices and local regulations. Gross inspection of brain should include assessment of regional atrophy and blood vessels for cerebrovascular disease (CVD). We recommend a minimum sampling of brain regions in Table 1. All gross lesions also should be sampled. Each of the following sections indicates preferred and acceptable alternative methods for detection of neuropathologic changes. While we do not propose specific protocols, our recommendations are compatible with conclusions by others who have optimized reproducibility of some neuropathologic assessments across multiple sites [2-5,41]. We anticipate further efforts for increased harmonization and molecular specification. Finally, although organized for brain autopsy, these neuropathologic

assessments can be applied to specimens from surgery; however, regional evaluation will be limited in biopsy specimens.

## AD NEUROPATHOLOGIC CHANGE

Senile plaques, which are extracellular deposits of the  $\beta$ -amyloid ( $A\beta$ ) peptides, and neurofibrillary degeneration, which is best exemplified by neurofibrillary tangles (NFTs), are considered essential neuropathologic features of AD. Accumulation of  $A\beta$  plaques and NFTs follows distinct regional progressions across brain regions as AD advances. We recommend continued use of the staging scheme for neurofibrillary degeneration as described originally by Braak and Braak [14,15], reduced to four stages (Table 2) that improves inter-rater reliability [42]. We recommend a modified version of Thal phases of  $A\beta$  plaque accumulation [57], adapted to a four-point scale (Table 2). A subset of senile plaques called neuritic plaques appear closely associated with neuronal injury and are characterized by the occurrence of dystrophic neurites that frequently have phospho-tau immunoreactivity [19,36,37,55]. We recommend continued use of the Consortium to Establish a Registry for AD (CERAD) protocol for neuritic plaque scoring [41] (Table 2).

### Method

Preferred method for  $\beta$ -amyloid ( $A\beta$ ) plaques is immunohistochemistry for  $A\beta$ , and for neurofibrillary tangles (NFTs) is immunohistochemistry for tau or phospho-tau [14]. Other acceptable methods are Thioflavin S or sensitive silver histochemical stains [15]. It is important to stress that neuritic plaques need to be distinguished from  $A\beta$  deposits by special stains. Preferred methods for detection of neuritic processes in senile plaques are Thioflavin S or modified Bielschowsky stain [41]; immunohistochemical stains for neuritic processes, such as amyloid precursor protein, ubiquitin, neurofilament or phospho-tau, will identify specific, and partially overlapping, subtypes of dystrophic neurites that may differ in disease relevance [21].

### Classification

AD neuropathologic change should be ranked along three parameters,  $A\beta$  plaque score (Figure 1) [57], Braak NFT stage (Figure 2; silver-based histochemistry [15] or phospho-tau immunohistochemistry [14]), and CERAD neuritic plaque score (Figure 3) [41] to obtain an “ABC score” (Table 2). Although cerebral amyloid angiopathy (CAA) is not considered in the “ABC” score, it is very commonly observed in cases with parenchymal  $A\beta$  plaques and should be evaluated and reported systematically as well as appreciated for its potential pathophysiological significance [56,61].

### Reporting

For all cases, regardless of clinical history, reporting should follow the format of these examples: “Alzheimer Disease Neuropathologic Changes: A1, B0, C0” or “Alzheimer Disease Neuropathologic Changes: A3, B3, C3”. Using the system shown in Table 3, the ABC scores are transformed into one of four levels of AD neuropathologic change: Not, Low, Intermediate or High.

**Clinico-pathologic correlations** for individuals *without cognitive impairment* should indicate that it is possible for AD neuropathologic change to predate onset of symptoms by years [54]. For individuals *with cognitive impairment* at the time tissue was obtained, “Intermediate” or “High” level (Table 3 black background) of AD neuropathologic change should be considered adequate explanation of cognitive impairment or dementia, and should be reported with a final diagnosis of Alzheimer’s disease. “Low” level of AD neuropathologic change is not considered adequate explanation for cognitive impairment or

dementia. In all cases with cognitive impairment, regardless of the extent of AD neuropathologic change, it is essential to determine the presence or absence, as well as extent, of other disease(s) that might have contributed to the clinical deficits. For cases *with incomplete clinical history*, higher levels of AD neuropathologic change typically are correlated with greater likelihood of cognitive impairment [29].

## LEWY BODY DISEASE

Lewy body disease (LBD), including Parkinson's disease and dementia with Lewy bodies (DLB), shares abnormal accumulation of  $\alpha$ -synuclein within inclusions called LBs, as well as  $\alpha$ -synuclein-immunoreactive neurites (so called "Lewy neurites") and diffuse cytoplasmic immunoreactivity. LBs are frequent in the setting of moderate-to-severe levels of AD neuropathologic change [27,59], including some early-onset familial AD cases [32,33]. Given our focus on cognitive impairment and dementia rather than movement disorders [16], we recommend a modification of previous consensus guidelines [38] to classify LBD in five stages.

### Method

LBs may be detected in neurons of medulla, pons and midbrain with hematoxylin and eosin (H&E)-stained sections; however, greater sensitivity can be achieved with immunohistochemistry for  $\alpha$ -synuclein and this approach is strongly preferred [3,4,13]. Abnormal neuropil and neuronal cytoplasmic  $\alpha$ -synuclein immunoreactivity are usually present with LBs but will not be apparent by H&E; in some instances, these changes occur in the absence of LBs.

**Classification** of all types of LBD should fall into a one of five categories following a modification of existing criteria (Figure 4) [16,38]: none, brainstem-predominant, limbic (transitional), neocortical (diffuse), or amygdala-predominant (Table 4). Although not part of this classification scheme, it is important to realize that LBD also occurs frequently in the olfactory bulb in older adults and should be sampled when possible [20].

### Reporting

For all cases, regardless of clinical history, reporting should follow the format of these examples: "Lewy body disease, limbic" or "Lewy body disease, amygdala-predominant".

**Clinico-pathologic correlation** for individuals *without cognitive impairment* should indicate that, although much less common than AD neuropathologic change, LBD has been observed in individuals without apparent cognitive or motor deficit [1,49]; this may represent pre-clinical LBD [12,22,31]. For individuals *with cognitive impairment*, we recommend that "Neocortical LBD" be considered adequate explanation of cognitive impairment or dementia (Table 4 shaded gray); however, this does not preclude contribution from other diseases. "Brainstem-predominant LBD" in the setting of cognitive impairment should prompt consideration of other diseases. "Amygdala-predominant LBD" typically occurs in the context of advanced AD neuropathologic change [59]. For cases *with incomplete clinical history*, we note that "Neocortical LBD" is correlated with greater likelihood of cognitive impairment [1,11-13,22,31-33,38,46,49,52].

## CEREBROVASCULAR DISEASE and VASCULAR BRAIN INJURY

CVD and vascular brain injury (VBI) [50] commonly are encountered in the brains with AD neuropathologic change [25]. We recommend reporting all macroscopic VBI and enumerating microvascular lesions or MVLs (microscopic infarcts/hemorrhages) in standard

screening sections [26,51,53,60]. Diffuse white matter injury is a form of VBI but it is more difficult to judge objectively and is not specific to VBI.

### Method

VBI, including MVLs (Figure 5), may occur in any region of brain but only those MVLs in the standardized sections (Table 1 shaded green) should be enumerated when correlating with cognitive impairment or dementia.

### Classification

All infarcts and hemorrhages should be documented including location, size, and age.

### Reporting

Reporting should follow the format of these examples: “Cerebrovascular disease: Atherosclerosis, moderate, non-occlusive, affecting basilar artery, left internal carotid artery and middle cerebral artery; Arteriolosclerosis, severe, widespread involvement of hemispheric white matter” or “Vascular brain injury: Infarct in the territory of the left middle cerebral artery, remote, measuring 3 × 3 × 2 cm; Lacunar infarct, right anterior caudate, remote, measuring 0.5 × 0.3 × 0.2 cm; Microvascular lesions: 2 remote lesions detected on standard sections (right middle frontal gyrus and right inferior parietal lobule)”

**Clinico-pathologic correlations** for grossly visible infarcts or hemorrhages should follow classic neuropathologic approaches. Although there are some differences in approach, guidelines have emerged for clinico-pathologic correlation of MVLs: one MVL identified in standard sections of brain (Table 1 regions shaded green) is of unclear relationship to cognitive function, while multiple MVLs in these regions are associated with increased likelihood of cognitive impairment or dementia [24,52,62].

## HIPPOCAMPAL SCLEROSIS and TAR DNA BINDING PROTEIN (TDP)-43 INCLUSIONS

Hippocampal sclerosis (HS) is defined by pyramidal cell loss and gliosis in CA1 and subiculum of the hippocampal formation that is out of proportion to AD neuropathologic change in the same structures [7]. HS can be observed in the context of AD neuropathologic change, frontotemporal lobar degeneration (FTLD), and VBI, likely reflecting a heterogeneous etiology. We recommend that HS be reported as present or absent.

TDP-43 immunoreactive inclusions are observed in the majority of cases of HS (Figure 6) [8,28,40,64], about one-half of cases with FTLD and ubiquitin inclusions with or without motor neuron disease, most sporadic cases of amyotrophic lateral sclerosis, and commonly in cases with AD neuropathologic change [8,9] or with LBD [43], as well as other neurodegenerative diseases [48]. With the exception of individuals with mutations in *TARDBP*, *GRN*, *VCP* or *c9ORF72* [10,18], it is not clear whether TDP-43 proteinopathy in these other neurodegenerative diseases is a primary, secondary, or coincidental event [63].

### Method and Classification

HS should be evaluated by hematoxylin and eosin (H&E)-stained sections together with neurofibrillary tangle (NFT) stains. HS can be focal, thus its absence in the recommended screening section does not rule out the possibility of HS elsewhere in the hippocampal formation. If HS is present, further evaluation is indicated, including TDP-43 immunohistochemistry. If work up is negative for TDP-43 but there is other evidence to suggest FTLD, consider immunohistochemistry for phospho-tau, ubiquitin, or “fused in

sarcoma” (FUS). In the absence of HS, screening for TDP-43 inclusions as part of evaluating AD neuropathologic change is of unclear value.

## Reporting

HS should be reported as present or absent with a description of immunohistochemistry results.

**Clinico-pathological correlations** need to recognize that HS can occur in several different diseases and has varying clinical implications in different settings. Relatively isolated HS may occur in very old individuals, and in this context it is associated with TDP-43-immunoreactive inclusions and with cognitive impairment [45,47].

## FRONTOTEMPORAL LOBAR DEGENERATION and PRION DISEASE

Both of these classes of neurodegenerative diseases are complex and beyond the scope of this summary. Nevertheless, each must be distinguished from AD neuropathologic change. We refer the reader to recent consensus guidelines for the neuropathologic evaluation of FTL and its subtypes [17,34,35], and issues important in the distinction of AD neuropathologic change from those of some forms of FTL [58]. Finally, not only can the neuropathologic changes of prion disease be co-morbid with AD, but some forms of prion disease can overlap with AD and need to be distinguished with special stains [23].

## SUMMARY

The new consensus criteria recognize the continuum of AD neuropathologic change that underlies the progression of this disease from preclinical to dementia stage. The new consensus criteria also amplify methods for evaluating A $\beta$  plaques, better define intermediate levels of AD pathologic change, and emphasize a structured approach to commonly co-morbid diseases.

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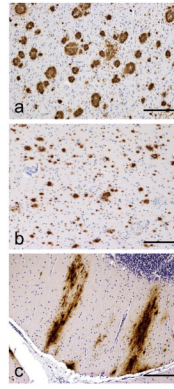


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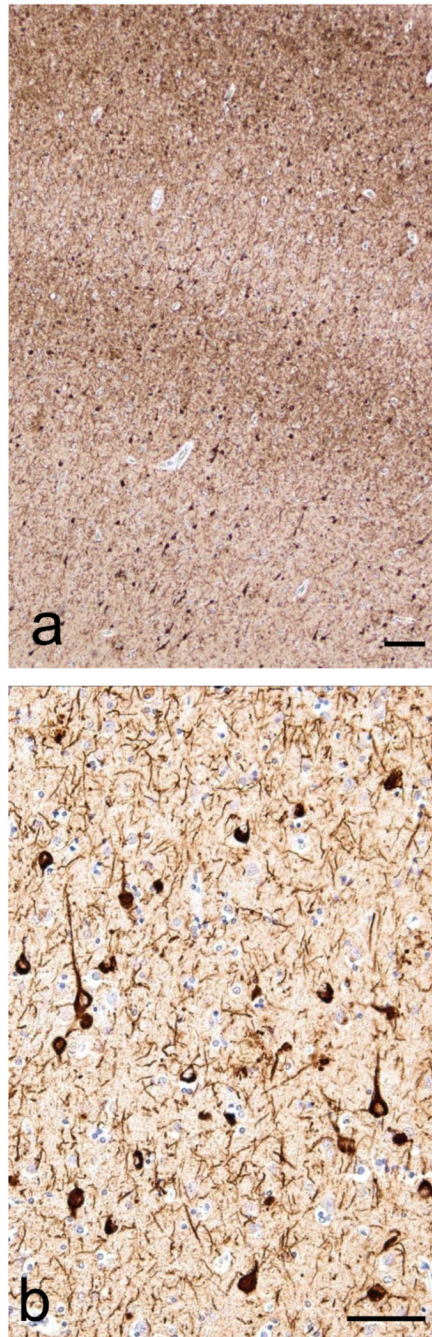


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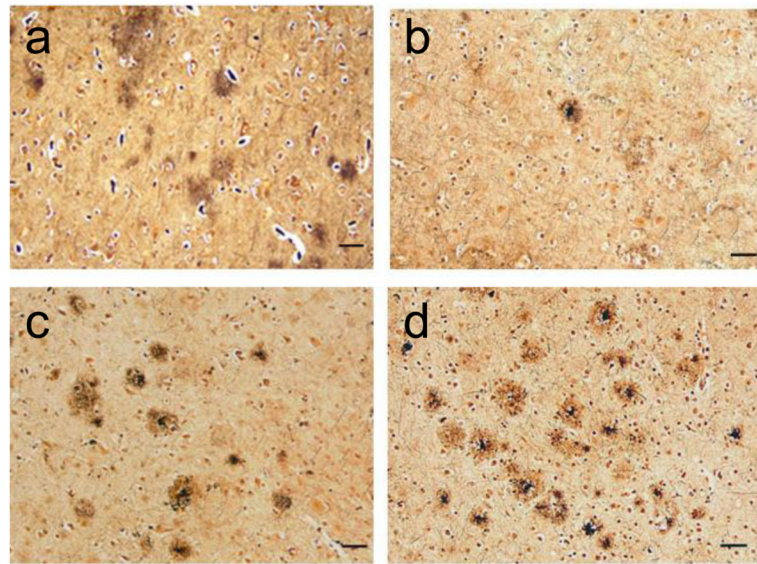
**Figure 1. “ABC” Score for Alzheimer’s Disease Neuropathologic Change**

Immunohistochemical detection of A $\beta$  plaques in (a) neocortex with as an example of “A1”, (b) neostriatum as an example of “A2”, and (c) molecular layer of cerebellum as an example of “A3”. Scale bars are 500 microns. Anti-A $\beta$  was antibody 6F/3D (Novocastra, Newcastle, United Kingdom).



**Figure 2. “ABC” Score for Alzheimer’s Disease Neuropathologic Change**

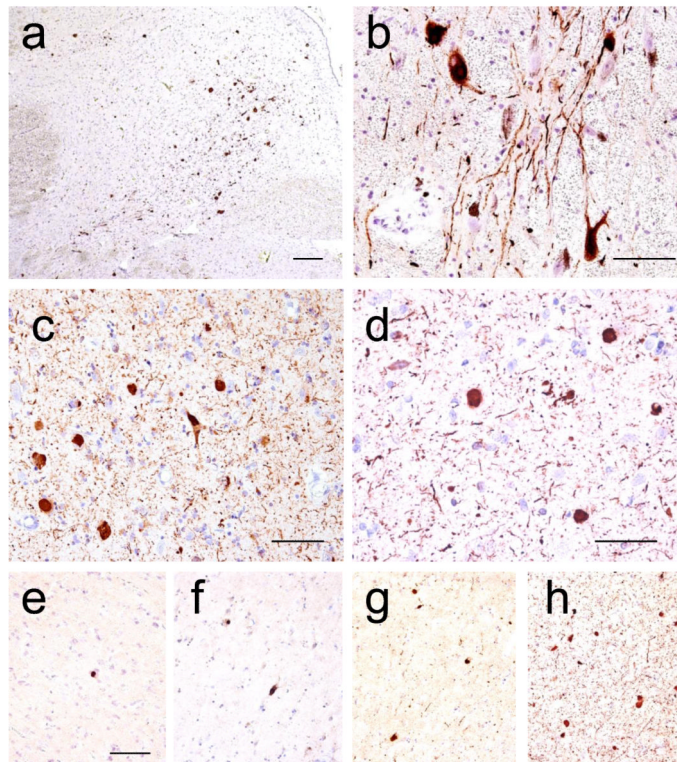
Immunohistochemical detection of neurofibrillary degeneration using phospho-tau antibody in the occipital cortex (Brodmann areas 17 and 18) as an example of “B3”. Scale bars equal (a) 150 microns and (b) 100 microns. PHF-1 antibody was generously provided by Dr. Peter Davies.



**Figure 3. “ABC” Score for Alzheimer’s Disease Neuropathologic Change**

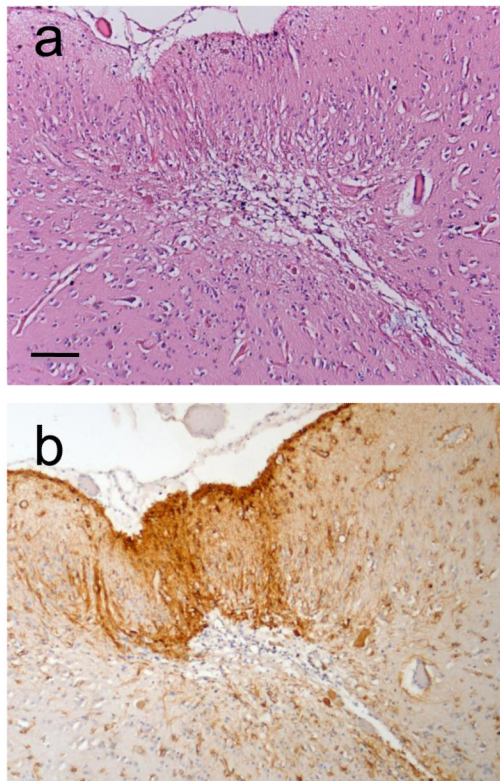
Bielschowsky stain of neocortex shows (a) diffuse plaques but not neuritic plaques as an example of “C0”, and increasing density of neuritic plaques as examples of (b) “C1” (1 to 5 neuritic plaques per 1 mm<sup>2</sup>), (c) “C2” (> 6 but < 20 neuritic plaques per 1 mm<sup>2</sup>), and (d) “C3” (> 20 neuritic plaques per 1 mm<sup>2</sup>). Scale bars equal 100 microns.





**Figure 4. Lewy Body Disease Classification**

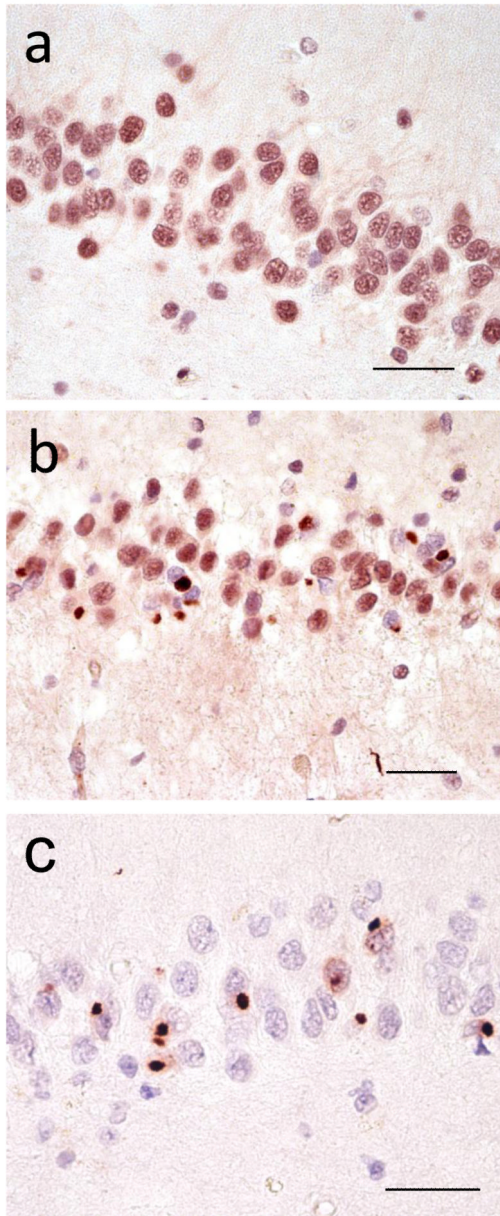
Immunohistochemical detection of  $\alpha$ -synuclein in (a, scale bar 250 microns) dorsal motor nucleus of the vagus nerve and (b, scale bar 125 microns) substantia nigra neurons as examples of “Brainstem-predominant LBD”, (c, scale bar 50 microns) amygdala as an example of “Amygdala-predominant LBD”, (d, scale bar = 200 microns) anterior cingulate gyrus as an example of “Limbic (Transitional) LBD”, and (e - h, scale bar = 100 microns) superior temporal gyrus as an example of “Neocortical (diffuse) LBD” with varying levels of LBD severity: mild (e), moderate (f), severe (g), and very severe (h) [38]. Anti-alpha-synuclein was antibody KM51 (Novocastra, Newcastle, United Kingdom).



**Figure 5. Microvascular Lesion**

Cerebral cortex stained with (a) hematoxylin and eosin or for (b) immunohistochemical detection of glial fibrillary acidic protein reveals a microvascular lesion (MVL). Scale bar = 500 microns. Anti-GFAP was antibody 6F2 (DAKO, Glostrup, Denmark).





**Figure 6. TDP-43 Inclusions**

Immunohistochemical detection of TDP-43 in the dentate gyrus in a subject (a) without hippocampal sclerosis or (b) another case with hippocampal sclerosis that shows cytoplasmic inclusions in granule neurons that are (c) further highlighted by phospho-TDP-43. Scale bars equal 50 microns. Anti-TDP-43 was antibody 10782-2-AP (ProteinTech, Chicago IL, USA). Anti-phospho-TDP-43 was antibody TIP-PTD-M01 (pS409/410-1 from Cosmo Bio, Tokyo, Japan).

**Table 1**  
**Minimum recommended brain regions to be sampled and evaluated**

Each brain region should receive a hematoxylin and eosin (H&E) stain. In addition, regions are recommended for additional stains to reveal Alzheimer’s disease (AD) neuropathologic change and Lewy body disease (LBD). A tiered approach to assessment of A $\beta$ /amyloid plaques and LBD is recommended to reflect their typically ordered appearance in brain. While NFTs also typically follow an ordered appearance in AD, we recommend wider screening to assist in capturing other tauopathies. H&E-stained sections can be used for evaluating vascular brain injury (VBI) in each region and hippocampal sclerosis (HS) as designated. We recommend that enumeration of microvascular lesions (MVLs) for clinico-pathologic correlations of cognitive impairment and dementia be limited to the six regions shaded green. Other lesions should be sampled as appropriate.

Region	AD Neuropathologic Change			LBD	VBI & HS
	A	B	C		
	Stain for A $\beta$ /amyloid plaques [57]	Stain for NFTs [14,15]	Stain for NPs [41]	Stain for LBs	H&E
Medulla including DMV				1°: IHC or H&E <sup>3</sup>	VBI
Pons including LC				1°: IHC or H&E <sup>3</sup>	VBI
Midbrain including SN	3°: if 2° is +			1°: IHC or H&E <sup>3</sup>	VBI
Cerebellar cortex and dentate n.	3°: if 2° is +				VBI
Thalamus and subthalamic n. <sup>1</sup>					MVL
Basal ganglia at level of AC with basal nucleus of Meynert <sup>1</sup>	2°: if 1° is +	Consider <sup>4</sup>			MVL
Hippocampus and EC <sup>1</sup>	2°: if 1° is + <sup>2</sup>	Yes	Consider <sup>4</sup>	2°: IHC in at least one if 1° +	HS
Cingulate, anterior					VBI
Amygdala				1°: IHC <sup>3</sup>	VBI
Middle frontal gyrus <sup>1</sup>	1° <sup>2</sup>	Yes	Yes	2°: IHC in at least one if 1° +	MVL
Superior & middle temporal gyri <sup>1</sup>	1° <sup>2</sup>	Yes	Yes		MVL
Inferior parietal lobule <sup>1</sup>	1° <sup>2</sup>	Yes	Yes		MVL
Occipital cortex (BA 17 & 18) <sup>1</sup>	Consider <sup>4</sup>	Yes	Consider <sup>4</sup>		MVL
WM at ACA, MCA, and PCA watershed					Consider <sup>4</sup>

Note: Stains for A $\beta$ /amyloid plaques should be considered in other regions not needed for classification, such as in the precuneus or cingulate, as neuroimaging studies indicate that these sites are among the earliest to demonstrate retention of amyloid-binding molecules, a marker of fibrillar A $\beta$  accumulation.

Abbreviations: DMV is dorsal motor nucleus of the vagus, LC is locus ceruleus, SN is substantia nigra, AC is anterior commissure, EC is entorhinal cortex, WM is white matter, NFTs is neurofibrillary tangles, NPs is neuritic plaques, LBs is Lewy bodies, ACA is anterior cerebral artery, MCA is middle cerebral artery, PCA is posterior cerebral artery, BA is Brodmann area.

- <sup>1</sup> Consider taking bilateral sections if both cerebral hemispheres are available
- <sup>2</sup> Screen leptomeningeal and parenchymal vessels for cerebral amyloid angiopathy (CAA)
- <sup>3</sup> Screen for LBs with immunohistochemistry or H&E in brainstem and immunohistochemistry in amygdala. If positive, then expand immunohistochemistry for LBs in brainstem, limbic, and neocortical regions.
- <sup>4</sup> Consider performing noted stains in these regions; however, this is not necessary to perform ABC score.

**Table 2**

**“ABC” Score for AD Neuropathologic Change**

“A”	Thal Phase for A $\beta$ plaques [57]	“B”	Braak and Braak NFT Stage [14,15]	“C”	CERAD neuritic plaque score [41]
0	0	0	None	0	None
1	1 or 2	1	I or II	1	Sparse
2	3	2	III or IV	2	Moderate
3	4 or 5	3	V or VI	3	Frequent

**Table 3**  
**“ABC” Score for Level of AD Neuropathologic Change**

AD neuropathologic change is evaluated with an “ABC” score (Table 2): A $\beta$ /amyloid plaques (A), NFT stage (B), and neuritic plaque score (C). The combination of A, B, and C scores is designated as “Not”, “Low”, “Intermediate” or “High” AD neuropathologic change. “Intermediate” or “High” AD neuropathologic change (black background) is considered sufficient explanation for dementia.

AD Neuropathologic Change		B <sup>1</sup>		
A <sup>2</sup>	C <sup>3</sup>	0 or 1	2	3
0	0	Not <sup>4</sup>	Not <sup>4</sup>	Not <sup>4</sup>
1	0 or 1	Low	Low	Low <sup>5</sup>
	2 or 3 <sup>7</sup>	Low		
2	Any C	Low <sup>6</sup>		
3	0 or 1	Low <sup>6</sup>		
	2 or 3	Low <sup>6</sup>		

<sup>1</sup> NFT stage should be determined by the method of Braak [14,15].

<sup>2</sup> A $\beta$ /amyloid plaque score should be determined by the method of Thal, *et al.* [57].

<sup>3</sup> Neuritic plaque score should be determined by the method of CERAD [41].

<sup>4</sup> Medial temporal lobe NFTs in the absence of significant A $\beta$  or neuritic plaques occurs in older people and may be seen in individuals without cognitive impairment, with mild impairment, or with cognitive impairment from causes other than AD [44]. Consider other diseases when clinically or pathologically indicated.

<sup>5</sup> Widespread NFTs with some A $\beta$ /amyloid plaques but limited neuritic plaques is relatively infrequent and when it occurs, other diseases, particularly tauopathies, should be considered. Such cases may not fit easily into a specific Braak stage, which is intended for categorization of AD-type NFTs.

<sup>6</sup> Higher levels of A $\beta$  or neuritic plaques with low Braak stage should prompt consideration of contribution by co-morbidities like vascular brain injury, Lewy body disease, or hippocampal sclerosis. Also, consider additional sections as well as repeat or additional protocols to demonstrate other non-AD lesions.

<sup>7</sup> High levels of neuritic plaques in setting of low Thal phase is a rare occurrence and should prompt reconsideration of neuritic vs. diffuse plaques, and the possible contribution of other diseases to cognitive impairment or dementia.

**Table 4**  
**Classification of Lewy Body Disease**

Results from the tiered approach to assessment of LBD in Table 1 should be as described here. Neocortical (diffuse) LBD is considered adequate explanation of dementia (shaded gray). It is important to note this classification is focused on the clinical context of cognitive impairment or dementia. LBD also occurs early in olfactory bulb, and even can occur outside of the brain.

<b>None</b>	<b>No LBs or related changes in IHC for <math>\alpha</math>-synuclein</b>
<b>Brainstem-predominant</b>	LBs in medulla, pons, or midbrain
<b>Limbic (Transitional)</b>	LBs in cingulate or entorhinal cortices, usually with brainstem involvement
<b>Neocortical (Diffuse)</b>	LBs in frontal, temporal, or parietal cortices usually with involvement of brainstem and limbic sites, which may include amygdala
<b>Amygdala-predominant</b>	LBs in amygdala with paucity of LBs in the above regions