Hippocampal volumes predict risk of dementia with Lewy bodies in mild cognitive impairment

ABSTRACT

Objective: To predict the risk of probable dementia with Lewy bodies (DLB) competing with Alzheimer disease (AD) dementia by hippocampal volume (HV) in patients with mild cognitive impairment (MCI) with impairments in amnestic or nonamnestic cognitive domains.

Methods: Patients with MCI (n = 160) from the Mayo Clinic Alzheimer’s Disease Research Center, who participated in an MRI study at baseline from 2005 to 2014, were followed with approximately annual clinical evaluations. HVs were analyzed from 3T MRIs using FreeSurfer (5.3). Hippocampal atrophy was determined from the most normal 10th percentile of the measurement distributions in a separate cohort of clinically diagnosed patients with AD dementia. The subdistribution hazard ratios for progression to probable DLB and AD dementia were estimated by taking into account the competing risks.

Results: During a median (range) follow-up of 2.0 (0.7–8.1) years, 20 (13%) patients with MCI progressed to probable DLB, and 61 (38%) progressed to AD dementia. The estimated subdistribution hazard ratio (95% confidence interval) for normal HV relative to hippocampal atrophy for progression to AD dementia was 0.56 (0.34–0.91; p = 0.02) after taking into account the competing risks. The estimated hazard ratio for normal HV relative to hippocampal atrophy for progression to probable DLB was 4.22 (1.42–12.6; p = 0.01) after adjusting for age and after including the MCI subtype in the model.

Conclusions: Preserved hippocampal volumes are associated with increased risk of probable DLB competing with AD dementia in patients with MCI. Preservation of HV may support prodromal DLB over AD, particularly in patients with MCI with nonamnestic features.

GLOSSARY

AD = Alzheimer disease; DLB = dementia with Lewy bodies; DSM-IV = Diagnostic and Statistical Manual of Mental Disorders, 4th edition; HVA = hippocampal volume adjusted for total intracranial volume; MCI = mild cognitive impairment; NIA = National Institute on Aging; RBD = REM sleep behavior disorder.

Identifying patients with mild cognitive impairment (MCI) who are at risk for dementia with Lewy bodies (DLB) is critical for early interventions. Amnestic subtype of MCI has been established on clinical grounds in order to identify individuals who are at risk for Alzheimer disease (AD) dementia.1,2 Patients with MCI who have impairments in nonamnestic cognitive domains may be at an increased risk of DLB.3,4 We have previously demonstrated that the competing risk of progression to probable DLB vs AD is higher in patients with nonamnestic MCI compared to amnestic MCI.5

Hippocampal volumes on antemortem MRI are preserved in patients with DLB who have little or no additional AD pathology at autopsy.6–8 Hippocampal volumes are lower in patients with DLB with increasing Braak neurofibrillary tangle stage regardless of the severity of Lewy

From the Departments of Radiology (K.K., C.R.J.), Health Sciences Research (T.L., S.A.P., W.K.K.), and Neurology (B.F.B., D.S.K., R.C.P.), Mayo Clinic, Rochester, MN; Department of Psychology and Psychiatry (T.J.F.), Mayo Clinic Jacksonville; and Department of Psychology (G.E.S.), University of Florida, Gainesville.

Go to Neurology.org for full disclosures. Funding information and disclosures deemed relevant by the authors, if any, are provided at the end of the article. The Article Processing Charge was paid by the authors.

This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0 (CC BY-NC-ND), which permits downloading and sharing the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.
body disease pathology. Furthermore, while hippocampal phospho-tau burden is associated with hippocampal atrophy, α-synuclein burden does not appear to influence the global hippocampal volume in patients with Lewy body pathology. Therefore preserved hippocampal volumes may predict progression to DLB vs AD in MCI.

Our objectives were two-fold: (1) To determine whether the risk of probable DLB accounting for progression to AD dementia is associated with hippocampal volume in patients with MCI, broadly defined with impairments in amnestic or nonamnestic cognitive domains; and (2) To determine whether MCI subtype and hippocampal volume would independently contribute to predicting the risk of probable DLB vs AD in MCI.

METHODS Participants. Consecutive patients with MCI (n = 160) from the Mayo Clinic Alzheimer’s Disease Research Center participated in an MRI study during October 2005 to January 2014 and were followed approximately annually with clinical evaluations and neuropsychological testing. To be included, the patients had to have a diagnosis of MCI with at least one clinical follow-up evaluation by the end of January 2015. Diagnosis was determined by a consensus committee including the neurologist, neuropsychologist, and the nurse who evaluated each participant. Patients with known neurologic diseases such as epilepsy, brain tumors, or substance abuse that may impact cognitive function were excluded.

The operational definition of MCI was based on clinical judgment through a history from the patient and for the majority of patients from an informant. Published criteria were used for the diagnostic cognitive complaint, cognitive function not normal for age, decline in cognition, essentially normal functional activities, no dementia. In addition, patients with MCI were classified into 1 of 4 MCI subtypes: (1) amnestic MCI single-domain, if the impairment was only in the memory domain; (2) amnestic MCI multiple-domain, if the impairment was in the memory domain and one or more nonmemory domains such as language, attention/executive function, and visuospatial processing; (3) nonamnestic MCI single-domain, if the impairment was in one nonmemory domain and memory was relatively preserved; and (4) nonamnestic MCI multiple-domain, if the impairment was in more than one nonmemory domain with relative preservation of memory. We grouped patients with single and multiple-domain nonamnestic MCI because of the small number of patients with nonamnestic MCI multiple-domain (n = 9).

Diagnosis of dementia was based on DSM-IV criteria, diagnosis of probable AD dementia was based on National Institute on Aging (NIA)-Reagan criteria, although all also fulfilled the NIA-Alzheimer’s Association clinical criteria, and diagnosis of probable DLB was based on the 3rd Consortium Criteria. Hippocampal preservation on MRI is not a core or supportive feature of these criteria, and therefore does not contribute to the diagnosis of probable DLB. The clinical characteristics of DLB were assessed in the following manner: presence of parkinsonism was assessed through the Unified Parkinson’s Disease Rating Scale part III; visual hallucinations were characterized by being fully formed, not restricted to a single episode, and not related to another medical issue, treatment, or advanced dementia; fluctuations were considered to be present if patients scored 3 to 4 on the Mayo Fluctuations Questionnaire; and probable REM sleep behavior disorder (RBD) was diagnosed through The Mayo Sleep Questionnaire validated in a polysomnography-confirmed sample from the community, which revealed a sensitivity of 100% and specificity of 95% using published criteria for the diagnosis of RBD as the gold standard.

MRI All participants underwent MRI examinations at 3T. A 3D high-resolution magnetization-prepared rapid gradient echo acquisition was performed for hippocampal volume measurements. Hippocampal volume was measured with FreeSurfer software (version 5.3) and adjusted for the total intracranial volume (HVa) by calculating the residual from a linear regression of hippocampal volume vs the total intracranial volume. Hippocampal atrophy was determined from the upper 10th percentile of the HVa measurement distributions in patients with clinically diagnosed AD dementia in a previous study from an independent cohort. In a secondary analysis, we derived the HVa cutoff for hippocampal atrophy using the upper 10th percentile of the HVa measurement from the AD converters in our sample.

Statistical analysis. We summarized baseline characteristics of the patients using median (interquartile range) for continuous variables and count (percent) for categorical variables. Because there are 2 competing outcomes of interest, AD dementia and probable DLB, standard survival methods would not be appropriate and would likely give biased results. We used a proportional subdistribution hazards regression survival model considering competing risks, implemented in the R package cmprsk. We estimated the cumulative incidence of either clinically probable DLB or AD dementia in 2 groups: those with and without hippocampal atrophy. Because age is a significant driver of progression to dementia, age was used as the time scale for tighter control of age effects. We summarized the results of the competing risk models using ρ values and subdistribution hazard ratios from product-limit methods to estimate the probability of a particular dementia outcome at a moment in time, given that the particular dementia has not occurred thus far. We plotted the cumulative probabilities of AD or probable DLB in the groups with and without hippocampal atrophy, using an age range covering the youngest (48.8) to oldest (90.5) ages with an event. A similar approach using a multivariate model was used to determine the contributions of hippocampal volume plus MCI subtype (MCI with nonamnestic impairments vs amnestic MCI single-domain) and contributions of hippocampal volume plus presence of clinical features (RBD, parkinsonism, visual hallucinations, and fluctuations) in predicting competing risks of probable DLB and AD dementia.
RESULTS Characteristics of the study cohort at baseline are listed in table 1. After a median (range) follow-up of 2.03 (0.69–8.10) years, patients with MCI progressed to AD dementia (n = 61; 38%), probable DLB (n = 20; 13%), or other dementias (n = 14; 9%) such as frontotemporal dementia (n = 4), multiple system atrophy (n = 1), progressive nonfluent aphasia (n = 3), semantic dementia (n = 2), logopenic progressive aphasia (n = 1), posterior cortical atrophy (n = 1), or corticobasal syndrome (n = 2), or died (n = 3; 2%). Because AD dementia and probable DLB were the 2 competing outcomes of interest, patients with MCI who died or progressed to other dementia were censored at the time of progression to dementia or death. The AD dementia progressor group had a higher frequency of women (p = 0.005) and APOE ε4 carriers than the probable DLB progressor group (p = 0.004). The AD dementia progressor group had lower median Dementia Rating Scale score at baseline compared to the probable DLB progressor group (p = 0.02), but the Mini-Mental State Examination scores were similar (p = 0.53).

Whereas a majority of the patients with MCI were diagnosed with amnestic MCI single-domain (n = 89; 56%), amnestic MCI multiple-domain (n = 34; 21%) and nonamnestic MCI (n = 37; 23%) were less frequent at baseline. Half of the patients with MCI who progressed to probable DLB were diagnosed with nonamnestic MCI (n = 10; 50%); on the contrary, a majority of patients with MCI who progressed to AD dementia were diagnosed with amnestic MCI single-domain (n = 42; 69%) at baseline. Clinical features of DLB were present in a majority of patients with MCI who progressed to probable DLB (n = 19; 95%) and some had 2 or more (n = 16; 80%) or 3 or more (n = 9; 45%) of these clinical features present at baseline. On the contrary, a few of the patients with MCI who progressed to AD dementia had 1 (n = 7; 11%) and none had 2 of the clinical features of DLB present at baseline. HVa were smaller in the AD dementia progressor group compared to the DLB progressor group at baseline (p < 0.001) (figure 1). Whereas a majority of the patients with MCI who progressed to probable DLB had normal

<table>
<thead>
<tr>
<th>Table 1 Baseline characteristics of patients with mild cognitive impairment (MCI) who progressed to dementia with Lewy bodies (DLB) or Alzheimer disease (AD) dementia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Women</td>
</tr>
<tr>
<td>ε4 Carriers</td>
</tr>
<tr>
<td>Age, y</td>
</tr>
<tr>
<td>Education, y</td>
</tr>
<tr>
<td>MMSE</td>
</tr>
<tr>
<td>DRS</td>
</tr>
<tr>
<td>UPDRS</td>
</tr>
<tr>
<td>HVa</td>
</tr>
<tr>
<td>Abnormal HVa</td>
</tr>
<tr>
<td>Follow-up time</td>
</tr>
<tr>
<td>Time from first visit to MRI</td>
</tr>
<tr>
<td>Visual hallucinations</td>
</tr>
<tr>
<td>Fluctuations</td>
</tr>
<tr>
<td>Parkinsonism</td>
</tr>
<tr>
<td>RBD</td>
</tr>
<tr>
<td>MCI subtype</td>
</tr>
<tr>
<td>aMCI single-domain</td>
</tr>
<tr>
<td>aMCI multi-domain</td>
</tr>
<tr>
<td>naMCI</td>
</tr>
</tbody>
</table>

Abbreviations: aMCI – amnestic mild cognitive impairment; DRS – Dementia Rating Scale; HVa – hippocampal volume adjusted for total intracranial volume; MMSE – Mini-Mental State Examination; naMCI – nonamnestic mild cognitive impairment; RBD – REM sleep behavior disorder; UPDRS – Unified Parkinson's Disease Rating Scale part III.

Values represent median (interquartile range) or n (%).

aPatients with MCI who remained stable or were censored at the time of death or progression to dementia syndromes other than DLB or AD dementia.

b p Values are from a Kruskal-Wallis test or Wilcoxon rank sum test for the continuous variables or a χ² test of differences in proportions for the categorical variables among the clinical groups.
HV a (n = 17; 85%), a majority of patients with MCI who progressed to AD dementia had hippocampal atrophy (n = 37; 61%) using the previously published cutoff. 17

Proportional hazards models for the HV a predicting competing risks of AD dementia vs probable DLB showed that patients with MCI with preserved HV a had a higher risk of progression to probable DLB (competing with AD dementia) relative to those with hippocampal atrophy with estimated subdistribution hazard ratio of 5.8 (1.86–18.0; p = 0.002). On the contrary, patients with MCI with preserved HV a had a lower risk of progression to AD dementia (competing with probable DLB) relative to those with hippocampal atrophy with estimated subdistribution hazard ratio of 0.56 (0.34–0.91; p = 0.02). Curves showing the probability of competing risk of progression to AD dementia and probable DLB are displayed in figure 2. We constructed multivariate models to determine whether hippocampal volumes provide information on probable DLB and AD risk when adjusting for MCI subtype. We investigated patients with MCI who had impairments in nonamnestic cognitive domains (i.e., nonamnestic MCI and amnestic MCI multiple-domain) compared to amnestic MCI single-domain, and normal HV a compared to atrophic HV a as predictors of probable DLB and AD dementia risk. In model 1, multidomain-amnestic MCI (p = 0.002), and nonamnestic MCI (p = 0.0003) compared to single-domain amnestic MCI and normal HV a compared to atrophic HV a (p = 0.02) increased the risk of progressing to probable DLB, accounting for competing AD dementia. In model 2, we combined the multidomain-amnestic MCI and nonamnestic MCI groups into one group of patients with MCI having impairments in nonamnestic cognitive domains. MCI with impairments in nonamnestic cognitive domains (p = 0.0003) compared to single-domain amnestic MCI and normal HV a compared to atrophic HV a (p = 0.01) increased the risk of progressing to probable DLB accounting for competing AD dementia. The individual subdistribution hazard ratios for the 2 models are listed in table 2. In a secondary analysis, we used the HV a cutoff (upper 10th percentile) for hippocampal preservation or atrophy derived from the AD progressor MCIs in our cohort and the results did not change (table e-1 at Neurology.org).

Presence of core and suggestive clinical features of DLB as predictors was tested in a separate multivariate model to determine whether hippocampal volumes provide information on probable DLB and AD risk when adjusting for presence of these clinical features of DLB in patients with MCI. MCI with a clinical feature of DLB (RBD, parkinsonism, visual hallucinations, and fluctuations) compared to MCI without any one of these features (p < 0.001) and normal HV a compared to atrophic HV a (p = 0.048) increased the risk of progressing to probable DLB accounting for competing AD dementia (table e-2).

DISCUSSION In patients with MCI, preservation of hippocampal volumes was associated with a higher risk of progression to probable DLB, competing with the risk of progression to AD dementia. Competing risk analysis assumes that a patient with MCI who progresses to dementia will progress to either probable DLB or AD. Therefore the subdistribution hazard ratios for a dementia outcome are estimated by using the other dementia outcome as a competing risk. Patients with MCI with preserved hippocampal volumes had a hazard risk of progression to probable DLB 5.8 times that of those with hippocampal atrophy, when accounting for competing risk of progression to AD dementia. Furthermore, preserved hippocampal volumes predicted the hazard risk of progression to probable DLB along with the diagnosis of MCI with impairments in nonamnestic cognitive domains with or without memory impairment.

Hippocampal atrophy is associated with a higher risk of progression to AD dementia in patients with MCI. 19 Based on these observations, hippocampal atrophy is included in the research criteria to support the diagnosis of MCI due to AD. 2 However, the...
underlying etiologies of MCI, broadly defined with impairments in amnestic or nonamnestic cognitive domains, are heterogeneous. Both vascular and Lewy body disease may contribute to the cognitive difficulties in patients with MCI. Furthermore, hippocampal volumes may be relatively preserved in patients with MCI, particularly in those with nonamnestic MCI.

In the current study, preserved hippocampal volumes predicted progression to DBL accounting for the competing risk for progression to AD dementia, even after considering nonamnestic MCI compared to amnestic MCI single-domain diagnosis. Impairment in nonamnestic cognitive domains, particularly in the attention and visual-spatial processing domains, increases the risk for probable DBL in MCI. While nonamnestic MCI is characterized by relative preservation of hippocampal volumes, hippocampal atrophy may be present in some patients with nonamnestic MCI. Furthermore, hippocampal atrophy is common in patients with multiple-domain amnestic MCI, and these patients are at risk for both probable DBL and AD dementia. Thus, the distinction of patients with MCI who will progress to DBL vs AD dementia may not be clear only by the MCI subtype. Data from the current study suggest that hippocampal volumes predict progression to probable DBL along with the MCI subtype.

Relative preservation of medial temporal lobe structures is a supportive feature in the 3rd report of the DLB Consortium Criteria, categorized as a feature that is commonly present in DBL. However, as a supportive feature, preservation of hippocampal volume does not contribute to the diagnosis of probable DBL, which is made based on presence of 2 or more core and suggestive features. In particular, hippocampal atrophy suggests additional AD-related neurofibrillary tangle pathology in probable DBL cases and may differentiate patients with mixed AD and Lewy body disease pathology from those with DBL. Preservation of hippocampal volumes is also observed in patients with hippocampal sparing AD, therefore is not specific to DBL. We censored individuals who progressed to dementia syndromes other than AD dementia or probable DBL at the time of progression to dementia and several of these patients as well as those who received a clinical diagnosis of probable DBL or AD dementia may have had atypical AD pathology. Preservation of hippocampal volume in cases of atypical AD dementia may decrease the specificity of preserved hippocampal volumes in predicting progression to probable DBL in MCI. Furthermore, absence of hippocampal atrophy might have rather low positive predictive value in cognitively normal individuals; therefore the application would be limited to patients with MCI.

There are limitations to our study that need to be addressed. First, the study cohort was from an Alzheimer Disease Research Center–based dementia clinic sample, which was relatively small and is prone to ascertainment biases. Epidemiologic studies that examine the transition from MCI to probable DBL and the role of biomarkers in predicting this transition are needed. Furthermore, the outcomes of interest were clinical diagnosis of probable DBL or AD dementia. The clinical criteria for the diagnosis of DBL are criticized for having low sensitivity. Moreover, patients who fulfill the clinical criteria for probable DBL may have additional AD pathology and Lewy body disease pathology may be present in

### Table 2 Multivariable model including hippocampal volume and mild cognitive impairment (MCI) subtype

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Predictors</th>
<th>Subdistribution HR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preserved HVa vs atrophic HVa</td>
<td>4.46 (1.27-15.67)</td>
<td>0.0200</td>
<td></td>
</tr>
<tr>
<td>aMCI-MD vs aMCI-SD</td>
<td>12.84 (2.59-63.65)</td>
<td>0.0018</td>
<td></td>
</tr>
<tr>
<td>naMCI vs aMCI-SD</td>
<td>11.21 (2.96-42.38)</td>
<td>0.0003</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preserved HVa vs atrophic HVa</td>
<td>4.22 (1.42-12.6)</td>
<td>0.0098</td>
<td></td>
</tr>
<tr>
<td>aMCI-MD plus naMCI vs aMCI-SD</td>
<td>11.96 (3.08-46.46)</td>
<td>0.0003</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: aMCI-MD – amnestic mild cognitive impairment–multiple-domain; aMCI-SD – amnestic mild cognitive impairment–single-domain; CI – confidence interval; HR – hazard ratio; HVa – total intracranial volume-adjusted hippocampal volume; naMCI – nonamnestic mild cognitive impairment. Subdistribution hazard ratio is reported for dementia with Lewy bodies progression accounting for competing Alzheimer disease progression.

*MCI with impairments in nonamnestic cognitive domains.
patients with AD dementia. Thus, many of our cases may have mixed AD and Lewy body disease patholo-
gies. Pathologic confirmation of the diagnosis of DBL
and AD is critical. Many of the patients with MCI had
one or more of the core and suggestive features of
probable DBL. We found that hippocampal volumes
may be predictive of DBL vs AD diagnosis in addition
to these clinical features. However, this finding should
be interpreted with caution, because DBL competing
with AD diagnosis was predicted based on the very
features that are used for diagnosing probable DBL,
and addition of the clinical features to the models
introduced multicollinearity due to correlations among
the predictors. An autopsy-confirmed and longitudi-

nally followed cohort of patients with MCI is needed
to determine the sensitivity and specificity of the core
and suggestive clinical features of Lewy body disease
at the stage of MCI. Finally, approximately 49% of
the patients with MCI in our cohort were stable during
follow-up. It is expected that there will be patients
who progress to probable DBL or AD dementia from the
MCI stable group in the future.

In a cohort of consecutive patients with MCI from
a referral clinic, we demonstrated that those with pre-
served hippocampal volumes are at an increased risk for
probable DBL, competing with the risk of progression
to AD dementia, even after considering the MCI sub-
type. Therefore both nonamnestic features and hippo-
campal preservation may be considered for identifying
patients with MCI at risk for probable DBL. Better
response to cholinesterase inhibitors and neuroleptic
sensitivity may need to be addressed in patients with
MCI who are likely to progress to probable DBL.

AUTHOR CONTRIBUTIONS
Dr. Kantarcı: study concept and design, acquisition of data, analysis and interpretation of the data, drafting the manuscript. T. Lesnick: study con-
cept and design, analysis or interpretation of the data, critical revision of the manuscript for important intellectual content. Dr. Ferman: study concept
and design, acquisition of data, critical revision of the manuscript for impor-
tant intellectual content. S.A. Przybelski: study concept and design, analysis or interpretation of the data, critical revision of the manuscript for impor-
tant intellectual content. Dr. Boeve: acquisition of data, critical revision of the manuscript for important intellectual content. Dr. Smith: acquisition of
data, critical revision of the manuscript for important intellectual content. Dr. Kremers: study concept and design, analysis or interpretation of the data, critical revision of the manuscript for important intellectual content. Dr. Kno
man: acquisition of data, critical revision of the manuscript for important intellectual content. Dr. Jack: acquisition of data, analysis and interpretation of the data, critical revision of the manuscript for important intellectual content. Dr. Potter: acquisition of data, critical revision of the manuscript for important intellectual content.

STUDY FUNDING
NIH (R01 AG040042, R01 AG11378, P50 AG16574, U01 AG06786, C06 RR018989), Mangurian Foundation, and the Robert H. and Clarice
Smith and Abigail Van Buren Alzheimers Disease Research Program.

DISCLOSURE
K. Kantarcı serves on the Data Safety Monitoring Board for Takeda Global Research & Development Center, Inc.; data monitoring boards
of Pfizer and Janssen Alzheimer Immunotherapy; and is funded by the NIH (R01 AG040042 [PI], R21 NS066147 [PI], P50 AG41701/Project
2 [PI], P50 AG16574/Project 1 [PI], and R01 AG11378 [Co-I]). T. Lesnick reports no disclosures relevant to the manuscript. T. Ferman
is funded by the NIH (P50-AG16574) and the Mangurian Foundation. S. Przybelski reports no disclosures relevant to the manuscript. B. Boeve
has served as an investigator for clinical trials sponsored by GE Healthcare and FORUM Pharmaceuticals; receives royalties from the publication of a book titled Behavioral Neurology of Dementia (Cambridge Medicine, 2009); serves on the Scientific Advisory Board of the Tau Consortium; has consulted for Isis Pharmaceuticals; and receives research support from the NIH (U01 AG045390, U54 NS092089, P50 AG16574, U01 AG06786, R01 AG019866, R01 AG032306, R01 AG041797) and the Mangurian Foundation. G. Smith is funded by the NIH.
W. Kremers is funded by the NIH. D. Knopman served as Deputy Editor for Neurology®; served on a Data Safety Monitoring Board for Lilly Pharmaceuticals; serves on a Data Safety Monitoring Board for Lundbeck Pharmaceuticals and for the DIAN study; served as a consul-
tant to TauRx Pharmaceuticals ending in November 2012; was an inves-
tigator in clinical trials sponsored by Baxter and Elan Pharmaceuticals in
the past 2 years; is currently an investigator in a clinical trial sponsored by TauRx; and receives research support from the NIH. C. Jack serves as
a consultant for Janssen, Bristol-Meyer-Squibb, General Electric, and
Johnson & Johnson; is involved in clinical trials sponsored by Allo
n and Baxter, Inc.; and receives research support from Pfizer, Inc., the
NIA (AG11378 [PI]), P50-AG16574 [Co-I], and U01-AG029490-01
[Co-I]), and the Alexander Family Alzheimer’s Disease Research Profes-
sorship of the Mayo Foundation. R. Petersen serves on scientific advisory
boards for Elan Pharmaceuticals, Wyeth Pharmaceuticals, and GE Healthcare
and receives research support from the NIH (P50-AG16574 [PI] and
U01-AG06786 [PI], R01-AG11378 [Co-I], and U01-24904 [Co-I]). Go
to Neurology.org for full disclosures.

Received September 28, 2015. Accepted in final form August 24, 2016.

REFERENCES
1. Petersen RC, Smith GE, Waring SC, Ivnik RJ, Tangalos
EG, Kokmen E. Mild cognitive impairment: clinical char-
2. Albert MS, DeKosky ST, Dickson D, et al. The diagnosis
of mild cognitive impairment due to Alzheimer’s disease:
recommendations from the National Institute on Aging-
Alzheimer’s Association workgroups on diagnostic guide-
lines for Alzheimer’s disease. Alzheimers Dement 2011;7:
270–279.
impairment associated with limbic and neocortical Lewy
body disease: a clinicopathological study. Brain 2010;133:
540–556.
4. Yoon JH, Kim M, Moon SY, Yong SW, Hong JM. Olfac-
tory function and neuropsychological profile to differenti-
ate dementia with Lewy bodies from Alzheimer’s disease in
patients with mild cognitive impairment: a 5-year follow-
mild cognitive impairment progresses to dementia with
6. Burton EJ, Mukauvo-Ladinska EB, Perry RH, Jaros E,
Barber R, O’Brien JT. Neuropathological correlates of
volumetric MRI in autopsy-confirmed Lewy body dement-
MRI and neuropathologic classification of dementia with
atrophy rates in autopsy-confirmed dementia with Lewy
Hippocampal volumes predict risk of dementia with Lewy bodies in mild cognitive impairment
Kejal Kantarci, Timothy Lesnick, Tanis J. Ferman, et al.
Neurology published online November 2, 2016
DOI 10.1212/WNL.0000000000003371

This information is current as of November 2, 2016