Total tau and Phosphorylated tau 181 Levels in the Cerebrospinal Fluid of Patients With Frontotemporal Dementia Due to P301L and G272V tau Mutations

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Background: Frontotemporal dementia (FTD) is a pathologically heterogeneous group of presenile neurodegenerative disorders, with or without the deposition of hyperphosphorylated tau protein in affected brain regions. Mutations in the tau gene have been found in the familial form of FTD, linked to chromosome 17q21-22, showing a spectrum of tauopathy.

Objective: To evaluate levels of total tau, phosphorylated tau 181 (Ptau-181), and amyloid-β1-42 in the cerebrospinal fluid (CSF) of patients with FTD, with special emphasis on FTD due to tau mutations.

Design: Case-control study.

Setting: Outpatient neurology clinics at 2 university medical centers, in Rotterdam and Amsterdam (the Netherlands).

Patients: Twenty-six patients with FTD (9 with tau mutations P301L and 2 G272V), 18 patients with Alzheimer disease (AD), and 13 nondemented controls.

Methods: Total tau, Ptau-181, and amyloid-β1-42 levels in CSF, obtained by lumbar puncture, were determined by sandwich enzyme-linked immunosorbent assay. Patients were diagnosed after clinical examination, neuro-psychologic evaluation, and neuroimaging. Differences between patient groups were statistically evaluated using nonparametric tests.

Results: Although CSF levels of total tau were mildly increased in FTD patients compared with nondemented controls (P = .05), median CSF total tau levels were low in the subgroup with tau mutations compared with AD patients. Furthermore, CSF levels of Ptau-181 and amyloid-β1-42 were not different in FTD patients, including the patients with tau mutations, compared with nondemented controls.

Conclusions: The tauopathy in P301L and G272V does not appear to be associated with an evident increase in CSF levels of Ptau-181 in FTD patients with these tau mutations, in contrast with findings in patients with AD.

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The clinical diagnosis in the remaining 17 FTD patients with a positive family history: 7 with the P301L mutation and 2 with the G272V mutation were identified in 9 FTD patients with a negative family history was established according to the international clinical criteria, supported by findings on neuroimaging (frontotemporal atrophy or hypoperfusion on single-photon emission computed tomography) and neuropsychologic evaluation. Three of the 26 patients fulfilled the criteria for semantic dementia, and none for primary progressive aphasia.

In addition to these patients, we recruited 18 patients with probable AD (7 women, 11 men; mean ± SD age, 66.0 ± 7.5 years) according to the criteria of the National Institute of Neurological Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association, and 13 nondemented controls (8 women, 5 men; mean age, 57.3 ± 12.6 years). Nondemented controls were subjects who visited the outpatient clinic for thunderclap headache without subarachnoidal hemorrhage, neuritis vestibularis, or nonprogressive subjective memory complaints, but without cognitive impairment on extensive psychometric evaluation or imaging abnormalities. All patients underwent a thorough clinical investigation, including detailed medical and family history, neurologic examination, psychometric evaluations, and neuroimaging, consisting of computed tomography, magnetic resonance imaging, and/or single-photon emission computed tomography scanning with technetium Tc 99m-hexamethyl propyleneamine oxime. Patients receiving a diagnostic lumbar puncture and CSF examination were asked to consent to the collection of an additional 4 mL of fluid for research purposes. The study protocol was approved by the medical ethics committees of Erasmus Medical Center and the VU University Medical Center.

### CSF ANALYSIS

Cerebrospinal fluid samples were obtained by lumbar puncture and stored in polypropylene tubes at −80°C until biochemical analysis, including total protein concentration. The t-tau concentration in the CSF was determined by sandwich enzyme-linked immunosorbent assay using the monoclonal antibody (Mab) AT120 as the capturing antibody, and 2 Mabs (HT7 and BT2) as detection antibodies, recognizing different epitopes (INNOTEST hTAU-Ag; Innogenetics, Ghent, Belgium). The level of Ptau-181 in the CSF was determined by sandwich enzyme-linked immunosorbent assay (INNOTEST PHOSPHO-TAU, using Mab HT7 as the capturing antibody and biotinylated Mab AT270 as the detection antibody, which is specific for a phospho-thr181 epitope. The level of Aβ1-42 in the CSF was determined by sandwich enzyme-linked immunosorbent assay, using Mab 21F12 specific for the C-terminus of Aβ1-42 as the capturing agent, and a biotinylated Mab anti-Aβ1-42 N-terminal antibody (3D6) for detection (INNOTEST β-amyloid1-42).

### METHODS

#### SUBJECTS

Twenty-six patients with FTD (12 women, 14 men; mean ± SD age, 54.7 ± 7.0 years) were recruited for CSF analysis from the outpatient clinics of the departments of neurology at the Erasmus Medical Center (Rotterdam, the Netherlands) and the VU University Medical Center (Amsterdam, the Netherlands) between January 1997 and December 2001 (Table 1). Tau mutations were identified in 9 FTD patients with a positive family history: 7 with the P301L mutation and 2 with the G272V mutation. The clinical diagnosis in the remaining 17 FTD patients with a negative family history was established according to the international clinical criteria, supported by findings on neuroimaging (frontotemporal atrophy or hypoperfusion on single-photon emission computed tomography) and neuropsychologic evaluation. Three of the 26 patients fulfilled the criteria for semantic dementia, and none for primary progressive aphasia.

In addition to these patients, we recruited 18 patients with probable AD (7 women, 11 men; mean ± SD age, 66.0 ± 7.5 years) according to the criteria of the National Institute of Neurological Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association, and 13 nondemented controls (8 women, 5 men; mean age, 57.3 ± 12.6 years). Nondemented controls were subjects who visited the outpatient clinic for thunderclap headache without subarachnoidal hemorrhage, neuritis vestibularis, or nonprogressive subjective memory complaints, but without cognitive impairment on extensive psychometric evaluation or imaging abnormalities. All patients underwent a thorough clinical investigation, including detailed medical and family history, neurologic examination, psychometric evaluations, and neuroimaging, consisting of computed tomography, magnetic resonance imaging, and/or single-photon emission computed tomography scanning with technetium Tc 99m-hexamethyl propyleneamine oxime. Patients receiving a diagnostic lumbar puncture and CSF examination were asked to consent to the collection of an additional 4 mL of fluid for research purposes. The study protocol was approved by the medical ethics committees of Erasmus Medical Center and the VU University Medical Center.

### RESULTS

The age of patients with FTD at examination was similar to that of nondemented controls (P = .4). The AD patients were significantly older (P < .001) (Table 1). The mean ± SD age of the 9 FTD patients with tau mutations (52.3 ± 7.0 years) did not differ significantly from that of the remaining FTD patients (56.0 ± 6.9 years; P = .2). The mean duration of disease on lumbar puncture in both FTD and AD patients was 3.0 years. Cerebrospinal fluid levels of t-tau, Ptau-181, and Aβ1-42 were similar in men and women. Total protein levels in CSF appeared to be highest in patients with AD (median, 0.51 g/L in patients with AD; 0.36 g/L in FTD patients with tau mutations; 0.37 g/L in patients with sporadic FTD; and 0.34 g/L in nondemented controls), although this difference did not reach statistical significance (P = .1). Levels of t-tau in the CSF of FTD patients were slightly higher than in the nondemented controls (P = .05), whereas this difference was not significant in either of the 2 subgroups individually (Figure 1). Total tau levels in CSF were increased in patients with AD (median, 3.0 ± 2.1 pg/mL in patients with AD; 2.1 ± 1.4 pg/mL in FTD patients with tau mutations) compared with nondemented controls. Cerebrospinal fluid levels of Ptau-181 in the entire FTD group, as well as in the 2 subgroups separately, did not differ from those in controls, while CSF levels of Ptau-181 in AD patients were significantly lower (P < .001) compared with those in the FTD group.

### Table 1. Clinical Data and Cerebrospinal Fluid Analyses per Diagnostic Category

<table>
<thead>
<tr>
<th>Diagnostic Category</th>
<th>No. of Patients</th>
<th>Sex, F/M</th>
<th>Age, Mean ± SD, y</th>
<th>Duration, Mean ± SD, y</th>
<th>t-tau, Median (25th-75th Percentile), pg/mL</th>
<th>Ptau-181, Median (25th-75th Percentile), pg/mL</th>
<th>Aβ1-42, Median (25th-75th Percentile), pg/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTD</td>
<td>26</td>
<td>12/14</td>
<td>54.7 ± 7.0</td>
<td>3.0 ± 1.8</td>
<td>299 (179-499)</td>
<td>33 (25-43)</td>
<td>683 (458-771)</td>
</tr>
<tr>
<td>Tau mutation</td>
<td>9</td>
<td>4/5</td>
<td>52.3 ± 6.9</td>
<td>2.1 ± 1.4</td>
<td>330 (184-338)</td>
<td>31 (28-42)</td>
<td>528 (409-708)</td>
</tr>
<tr>
<td>Sporadic</td>
<td>17</td>
<td>9/8</td>
<td>56.0 ± 6.9</td>
<td>3.5 ± 1.8</td>
<td>298 (178-706)</td>
<td>34 (22-71)</td>
<td>756 (441-831)</td>
</tr>
<tr>
<td>AD</td>
<td>18</td>
<td>7/11</td>
<td>66.0 ± 7.5</td>
<td>3.0 ± 2.1</td>
<td>478 (360-698)</td>
<td>80 (54-101)</td>
<td>280 (222-312)</td>
</tr>
<tr>
<td>Nondemented</td>
<td>13</td>
<td>8/5</td>
<td>57.3 ± 12.6</td>
<td>NA</td>
<td>171 (117-310)</td>
<td>51 (21-42)</td>
<td>547 (421-625)</td>
</tr>
</tbody>
</table>

Abbreviations: Aβ1-42, β-amylloid1-42 protein; AD, Alzheimer disease; FTD, frontotemporal dementia; NA, not applicable; Ptau-181, tau phosphorylated at Thr181; t-tau, total tau.
were significantly higher than in nondemented controls (P<.001). Neither the ratio of CSF Ptau-181 to CSF total protein nor the ratio of CSF Ptau-181 to CSF t-tau was statistically different in any of the groups. Patients with FTD, including those with tau mutations, had similar levels of CSF Aβ1-42 compared with nondemented controls, in contrast with AD patients, who had lower levels of CSF Aβ1-42 compared with nondemented controls (P<.001). There was no significant correlation between CSF t-tau, CSF Ptau-181, or CSF Aβ1-42, and age at lumbar puncture or duration of disease in any of the patient groups. The correlation between CSF t-tau and CSF Ptau-181 was high in all groups. There was no correlation between the duration of the symptoms in patients with tau mutations and levels of CSF t-tau or CSF Ptau-181 (Table 2).

**COMMENT**

To our knowledge, this study is the first to address CSF levels of tau in FTD patients with tau mutations. The levels of t-tau in CSF were slightly higher in FTD patients than in nondemented controls, although this elevation could not be confirmed in the subgroup of patients with P301L or G272V tau mutations. The levels of Ptau-181 in CSF were not increased in FTD patients, neither in those with FTD with tau mutations nor in those with sporadic FTD. At the same time, we confirmed previous findings of increased CSF t-tau and Ptau-181 levels, and lowered CSF Aβ1-42 in AD patients.

One of the drawbacks of this study is that pathologic confirmation was lacking in patients with sporadic FTD and AD. Despite this, the clinical diagnosis was firmly established using international clinical criteria and supported by neuroimaging and neuropsychologic examination findings. These clinical criteria have been shown to be highly specific for FTD. A second drawback of this study is the small sample size, which made it difficult to detect small differences among groups. However, although the group of FTD patients with tau mutations may be too small to detect statistically significant changes, the striking homogeneity in CSF Ptau-181 levels suggests that similar results would be achieved with larger patient numbers.

The observation of mildly increased levels of CSF t-tau in the entire FTD group is similar to findings in previous studies of FTD. Increased CSF t-tau has also been found in a variety of other neurologic disorders, including AD, corticobasal degeneration, Creutzfeldt-Jakob disease, and acute stroke. Therefore, these elevated levels probably reflect nonspecific neuronal and axonal degeneration and are not merely a consequence of neurofibrillary tauopathy. The finding of increased levels of CSF Ptau-181 in patients with AD and corticobasal degeneration suggests that CSF tau levels may be more useful in differentiating these conditions from other disorders without tauopathy. Several studies of CSF levels of Ptau-181, using antibodies directed against several different phosphorylated epitopes (threonine-181, serine-199, and threonine-231), have all shown an increase in CSF levels of Ptau-181 in AD patients.

Surprisingly, CSF Ptau-181 levels in the present study were low in FTD patients with tau mutations compared with AD patients. These findings indicate that accumulation of Ptau-181 in the brains of patients with tauopathy does not necessarily lead to an increase in CSF levels of Ptau-181. Additional factors are probably involved in determining why certain disorders with tauopathy, such as AD, are associated with
an increase in CSF levels of Ptau-181, and others are not. A possible explanation for this observation may be that the tau deposits in P301L and G272V are located intracellularly (in the shape of pretangles or Pick-like inclusions, respectively) and might not reach the CSF, while the extracellular ghost tangles found in AD are not seen. 20 It will be interesting to examine the CSF of patients with the R406W tau mutation, as the pathologic neurofibrillary change found in this mutation closely resembles that in AD. 21 Alternatively, the difference in CSF Ptau-181 levels in these 2 conditions may be explained by different clearance mechanisms. The observation that calpain 2 activity co-localized specifically with the neurofibrillary tangles in AD, but not the tau-containing Pick bodies of Pick disease, may reflect a different proteolytic process in these 2 disorders. 22

In the current study, CSF was only available from patients with P301L and G272V missense mutations, both of which reduce the ability of mutant tau protein to interact with microtubules and other molecules. 23 Intronic and some coding region mutations in exon 10 of tau have a primary effect at the messenger RNA level, resulting in a change in ratio of 3 to 4 repeat tau isoforms without affecting the binding properties of the protein. 24 Because of the different mechanisms by which tau mutations lead to neurodegeneration, it is unpredictable whether CSF levels of t-tau or Ptau-181 may be altered in patients with tau mutations that affect the alternative splicing of exon 10. Analysis of the CSF of patients with different types of tau mutations, as well as various other types of tauopathy, may contribute to our understanding of which factors determine the selective increase in levels of different CSF proteins in neurodegenerative disorders in general.

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Author contributions: Study concept and design (Drs Rosso and van Swieten); acquisition of data (Drs Rosso, Pijnenburg, Schoonenboom, Scheltens, and van Swieten, and Ms van Herpen); analysis and interpretation of data (Drs Rosso, Heutink, and van Swieten); drafting of the manuscript (Drs Rosso, Schoonenboom, Heutink, and van Swieten); critical revision of the manuscript for important intellectual content (Ms van Herpen and Drs Pijnenburg, Scheltens, Heutink, and van Swieten); statistical expertise (Dr Rosso); obtained funding (Drs van Swieten and Heutink); administrative, technical, and material support (Ms van Herpen, and Drs Schoonenboom, Scheltens, and Heutink); study supervision (Drs Scheltens, Heutink, and van Swieten).

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Table 2. Characteristics of Patients With Tau Mutations

<table>
<thead>
<tr>
<th>Patient/Sex/Age</th>
<th>Duration, y</th>
<th>CSF t-tau, pg/mL</th>
<th>CSF Ptau-181, pg/mL</th>
<th>CSF-Aβ42, pg/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>P301L Mutation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/F/49</td>
<td>0.5</td>
<td>266</td>
<td>27</td>
<td>528</td>
</tr>
<tr>
<td>2/M/58</td>
<td>2.0</td>
<td>345</td>
<td>44</td>
<td>674</td>
</tr>
<tr>
<td>3/M/52</td>
<td>0.8</td>
<td>569</td>
<td>42</td>
<td>720</td>
</tr>
<tr>
<td>4/F/62</td>
<td>5.0</td>
<td>214</td>
<td>34</td>
<td>475</td>
</tr>
<tr>
<td>5/F/53</td>
<td>1.1</td>
<td>332</td>
<td>31</td>
<td>692</td>
</tr>
<tr>
<td>6/M/83</td>
<td>2.0</td>
<td>155</td>
<td>28</td>
<td>324</td>
</tr>
<tr>
<td>7/F/45</td>
<td>2.3</td>
<td>331</td>
<td>28</td>
<td>478</td>
</tr>
<tr>
<td>G272V Mutation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/M/45</td>
<td>3.2</td>
<td>330</td>
<td>42</td>
<td>748</td>
</tr>
<tr>
<td>9/M/45</td>
<td>2.2</td>
<td>123</td>
<td>20</td>
<td>343</td>
</tr>
</tbody>
</table>

Abbreviations: Aβ42, β-amyloid42 protein; CSF, cerebrospinal fluid; Ptau-181, tau phosphorylated at Thr181; t-tau, total tau.

REFERENCES


