Clinicopathological study of patients with C9ORF72-associated frontotemporal dementia presenting with delusions

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Abstract:
© The Author(s) 2014. Background: Several clinical studies point to a high prevalence of psychotic symptoms in frontotemporal dementia associated with C9ORF72 mutations,
but clinicopathological studies addressing the association between C9ORF72 mutations and delusions are lacking. Method: Seventeen patients with pathologically proven frontotemporal lobar degeneration (FTLD) associated with C9ORF72 mutations were identified from Neurodegenerative Disease Brain Bank. Of the 17 cases with C9ORF72 mutation, 4 exhibited well-defined delusions. The clinical history, neurological examination, neuropsychological testing, neuroimaging analysis, and postmortem assessment of the patients with delusions were evaluated and compared with the other cases. Result: The content of the delusions was mixed including persecution, infidelity, and grandiosity. All cases showed parkinsonism; voxel-based morphometry analysis showed greater precuneus atrophy in patients with delusions than those without delusions. All 4 had unclassifiable FTLD with TAR DNA-binding protein inclusions, with characteristics of both type A and type B. Three cases had additional t pathology and another had a-synuclein pathology. Conclusion: C9ORF72 carriers with well-defined delusions likely associated with additional pathologies and parietal atrophy in neuroimaging. Patients presenting with middle-aged onset of delusions should be screened for C9ORF72 mutations, especially if family history and parkinsonism are present.

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Clinico-pathological study of patients with \textit{C9orf72} associated frontotemporal dementia presenting with delusions

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Abstract

Background: Several clinical studies point to a high prevalence of psychotic symptoms in frontotemporal dementia (FTD) associated with \textit{C9ORF72} mutations, but clinico-pathological studies addressing the association between \textit{C9ORF72} mutations and delusions are lacking.

Method: Seventeen pathologically proven frontotemporal lobar degeneration subjects associated with \textit{C9ORF72} mutations were identified from Neurodegenerative Disease Brain Bank. Four of 17 \textit{C9ORF72} mutation cases exhibited well-defined delusions. The clinical history, neurological examination, neuropsychological testing, neuroimaging analysis, and postmortem assessment of the patients with delusions were evaluated and compared with the other cases.

Result: The content of the delusions was mixed including persecution, infidelity, and grandiosity. All cases showed Parkinsonism, voxel-based morphometry analysis showed greater precuneus atrophy in patients with delusions than those without delusions. All four had unclassifiable FTLD-TDP, with characteristics of both type A and type B. Three cases had additional tau pathology and another had α-synuclein pathology.

Conclusion: \textit{C9ORF72} carriers with well-defined delusions likely associated with additional pathologies and parietal atrophy in neuroimaging. Patients presenting with middle age onset of delusions should be screened for \textit{C9ORF72} mutations, especially if family history and Parkinsonism are present.
Keywords:

C9ORF72; neurodegeneration; frontotemporal dementia; delusion; neuropathology; neuroimaging

Running Head:

Delusions in C9ORF72 associated FTD
1 **Background**

Frontotemporal dementia (FTD) is the second most common cause of early onset dementia and is characterized by changes in personality, behavior or language \(^1,2\). FTD is associated with neurodegeneration of the frontal and temporal lobes and occurs in both sporadic and genetic forms. A hexanucleotide repeat expansion in chromosome 9 open reading frame 72 (\(C9ORF72\)) was recently reported as the most frequent genetic cause of behavioral variant FTD (bvFTD), FTD with motor neuron disease (FTD-MND) and amyotrophic lateral sclerosis (ALS) \(^3,4\). Several clinical studies on \(C9ORF72\) patients highlight a high prevalence of psychotic features (delusions and hallucinations) associated with this mutation \(^5,8\).

Delusional symptoms are frequently linked to schizophrenic psychoses but are also observed in neurodegenerative diseases \(^9\). It has been suggested that the dysfunction of dopaminergic neurons projecting to the striatum contributes to delusion formation in patients with schizophrenia \(^10\), however other hypotheses also have been proposed for the neurobiological basis of delusions with schizophrenia. Delusions also have been linked to frontal cortex dysfunction causing deficits in cognitive control or executive functions. This may result in premature probabilistic reasoning bias and/or lack of top-down control leading to release of other brain areas and manifesting as delusions \(^11,12\).

Although patients with FTD show severe frontal, temporal and basal ganglia dysfunction, delusions have been considered a relatively rare feature of FTD \(^13\)-\(^15\), and the presence of delusions in FTD has ranged from 2.3% to 12.7% in clinical cohorts \(^15,16\). However, delusions appear to be more common in patients with \(C9ORF72\) mutations: 50% in 32 cases \(^5\) and 42% in 14 cases \(^6\). The
anatomical underpinnings of delusions in FTD remain unclear, and \textit{C9ORF72} cases may contribute to an understanding of the neurobiological basis of delusions.

Here, we report the clinical, neuropsychological, neuroimaging, and neuropathological findings of patients with FTD and delusions who, at autopsy, showed frontotemporal lobar degeneration with TAR DNA-binding protein inclusions (FTLD-TDP) associated with the \textit{C9ORF72} mutation, who had delusions along the clinical course of their disease.

\textbf{Method}

All 17 patients belonging the University of California, San Francisco (UCSF) Neurodegenerative Disease Brain Bank, with a neuropathological diagnosis of FTLD-TDP due to \textit{C9ORF72} expansion were included. Diagnosis of \textit{C9ORF72} expansion was made by genetic testing and confirmed by the finding of p62 positive /TDP-43 negative intraneuronal inclusions in cerebellum and hippocampus \textsuperscript{17}. All subjects and their informants signed an institutional review board-approved research consent form to participate in the study.

Patients were seen at the Memory and Aging Center at the UCSF between 2004 and 2010 and had undergone at least one neurological evaluation, including extensive neuropsychological assessment and neuroimaging. Medical history including psychiatric history is confirmed independently by neurologist and research nurse through caregiver interviews using structured questionnaires.

Out of the 17 patients identified as \textit{C9ORF72} expansion positive, four of them presented with well-defined delusions during the disease evolution. Delusion was defined according to the Diagnostic and Statistical Manual of Mental
Disorders, Fourth Edition (DSM-IV) as “a false belief based upon an incorrect inference about external reality that is firmly sustained despite what almost everyone else believes and despite what constitutes incontrovertible and obvious proof or evidence to the contrary, the belief is not one ordinarily accepted by other members of the person's culture or subculture” 18. Clinical data collected included the time of onset of delusions in relation to other symptoms, previous psychiatric history, the presence of associated hallucinations, and the phenomenological content of the delusions. Subjects’ demographic characteristics are summarized in Table 1.

Neuropsychological data

The patients underwent a detailed neuropsychological battery during their visits. General intellectual function was assessed using the UCSF screening battery described elsewhere 19.

Genotyping

The presence of expanded GGGGCC hexanucleotide repeats in C9orf72 was detected using the repeat-primed PCR reaction as described elsewhere 3. PCR products were run on an ABI3730 DNA Analyzer and analyzed using the Peak Scanner Software.

Neuroimaging

Each patient was scanned with a structural Magnetic Resonance Imaging (MRI) on a 1.5T or 3T scanner within one year of the first UCSF visit. Structural T1-weighted images were preprocessed for voxel-based morphometry
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(VBM) using Diffeomorphic Anatomical Registration Through Exponentiated Lie (DARTEL) running in Statistical Parametric Mapping (SPM) 8 with Matlab. Group comparison of VBM gray matter images were conducted between 4 pathologically proven FTLD-TDP subjects with \textit{C9orf72} mutation who had delusions and remaining 13 subjects who did not.

Neuropathology

All patients were subjected to an extensive dementia-oriented postmortem assessment at UCSF or at the University of Pennsylvania, following a standard protocol described previously \textsuperscript{20,21}. The brains were procured within 18 hours post-mortem. The majority of the brains was cut into 8–10 mm-thick coronal slabs and alternately fixed, in 10% neutral buffered formalin for 72h, or rapidly frozen; the remaining were hemi-sectioned sagittally with one hemisphere fixed in 10% neutral buffered formalin and the other rapidly frozen. Tissue blocks covering dementia-related regions of interest were dissected from the fixed slabs and basic and immunohistochemical stains were applied following standard diagnostic procedures developed for patients with dementia \textsuperscript{21}. All immunohistochemical runs included positive control sections to exclude technical factors as a cause of absent immunoreactivity. FTLD-TDP subtyping followed the current “harmonized” nomenclature \textsuperscript{22}. All cases were also screened for p62 positive /TDP-43 negative intraneuronal inclusions, pathognomonic markers of \textit{C9orf72} expansion in amygdala \textsuperscript{10,23}, a brain area involved in different kind of delusions. Finally, the presences of additional overlapping neurodegenerative disorders were compared between the two groups.
Results

Case presentation

Case 1

Mr. A, a right-handed man, presented first symptoms at the age of 56. Previously psychiatrically healthy, he became fixated on specific topics, developed paranoia about his neighbors and became frightened by them when they performed yard work. As the disease progressed he also became suspicious of close friends. At the age of 58, he vocalized that he felt his life was threatened and that his wife had been replaced by a demon. He did not have any self-awareness that these thoughts were irrational and false. He was seen by a psychiatrist and a neurologist at the age of 60, after he made obscene gestures to a woman and propositioned his neighbor's wife. He was started with Quetiapine first at 25 mg, increasing to a maximum of 150 mg. It reduced his fears, especially about his wife; however, he progressively became more fearful of others around him.

At the age of 61, he became quieter, mellower, and progressively slower. Fluoxetine started at that time reduced his inappropriate behaviors in public. He habitually strolled around the house and exhibited motor restlessness. He developed increased interest in chocolate. His personal grooming declined. At the age of 62 years, he went out alone and returned after 8 hours sunburned and dehydrated; he reported that he had been looking for his friend who was actually living in another state.

Mr. A was evaluated at the UCSF Memory and Aging Center at the age of 62. He demonstrated utilization behavior and perseverations and was impulsive and easily distracted. On neurological exam, he had mild cogwheeling in the
arms, mild to moderate hypomimia, and mild bradykinesia. Cognitive testing revealed deficits in all domains except for copying tasks and language. His working memory and executive function were most severely impaired (see Table 1). Past medical history was unremarkable for psychiatric symptoms. His family history was negative for dementia. His medications included Fluoxetine (30 mg) and Quetiapine (150 mg). MRI revealed bilateral frontal atrophy. He died suddenly by choking at the age of 64, eight years after the onset of his symptoms.

Neuropathological exam demonstrated brain atrophy (weight: 1170 grams), with most severe degenerative changes involving the dorsal and opercular frontal cortices, as well as the dorsal striatum. Microscopic examination revealed hippocampal sclerosis. Immunohistochemical analysis showed unequivocal evidence of FTLD-TDP, featuring TDP-43 immunoreactive inclusions in many cortical regions examined, especially the dorsal and opercular frontal regions. TDP-43 pathology were consistent with FTLD-TDP, with features of type A and type B. Argyrophilic grain disease, a 4-repeat tauopathy was noted in limbic areas and orbital frontal cortex.

Case 2

Mr. B, a left-handed man started to believe that his wife was cheating on him around the age of 40. This delusion spontaneously remitted after several years, however, it reemerged at age of 62. The couple underwent marriage counseling, but the delusion did not remit again. Concomitantly, he developed difficulty in completing his usual tasks, such as fixing light sockets or cars. Subsequently, he had difficulty in understanding directions and conversation.
Other language problems included poor repetition, and reduction in speech. He became apathetic, but showed increase in appetite. He had no awareness of his cognitive deficits.

Mr. B was evaluated at the UCSF at the age of 65 years. On neurological examination, language was abnormal with evidence of paraphasic errors and some difficulty with reading. He exhibited Parkinsonism with masked faces and reduced blink frequency, however, there was no increased tone at rest, no tremor, and he walked without difficulty. Verbal and visual memories were moderately impaired, but visuospatial abilities remained normal. Neuropsychological tests confirmed the language deficits and showed moderate executive dysfunction (for details see Table 1). Past medical history was unremarkable. His medications were Donepezil and Fexofenadine (60mg). Family history was unknown because he was adopted. Structural imaging showed generalized atrophy, with frontal predominance.

The Parkinsonism, executive loss and memory dysfunction all progressed, followed by the appearance of progressive apathy. At age 68, he had difficulty swallowing, increased tone in all extremities, upper limb fasciculations, and a prominent jaw jerk. He died from pneumonia at the age of 70, seven years after the onset of symptoms.

Fresh brain weight was 1066 grams. Neuropathology showed atrophy with most severe degenerative changes in the frontal lobes, in particular, the anterior orbital and inferior frontal gyri and the anterior cingulate cortex. Immunohistochemical analysis showed FTLD-TDP with features of type A and type B, consistent with unclassifiable FTLD-TDP. Co-occurring 4-repeat tau pathology was seen and characterized by deposition of neurofibrillary tangles.
and astrocytic inclusions mostly in limbic areas, inferior temporal gyrus and in
precentral gyrus. This tauopathy did not fit into existing criteria for a specific
entity and was classified as an atypical tauopathy.

Case 3

Mr. C, a right-handed man, presented with problems in his management
skills and an increased number of business-related judgment errors at age 46.
Three years later, he had uncharacteristic loss of empathy for his wife who was
hospitalized at that time. At the age of 51, he closed his business and found a
job for a local manager of a discount store, but he soon started to have trouble at
work. He had the grandiose delusion that “they were saving a large store for
him.” He became socially withdrawn and spent more time watching television.
He was fired at the age of 53 years due to his inability to keep the store in good
condition, but his delusion continued.

Also around that time, he became emotionally and physically more distant
from his wife, refused to do jobs around the house, showed increasing apathy.
He exhibited other strange behaviors such as sneaking into the home and
peeking around the corner at his wife. He maintained the grandiose delusion
that someone was saving highly paid jobs for him. He became more rigid and
inflexible about his schedule at home, showing anxiety if meals were not served
on time. He became irritable and developed environmental dependence playing
with items placed in front of him and mimicking other people’s actions. Also, he
developed compulsive symptoms such as repetitive checking of the temperature.
Later on, he inappropriately greeted strangers and developed a preference for
sweets.
Mr. C was evaluated at UCSF at the age of 54 years. On neurological examination, he had a fine resting and action tremor in the left hand. Tone was increased in the arm with evidence of paratonia on the left greater than right. Gait changes were notable for a decreased arm swing on the left. He had no awareness of his deficits or delusion. He performed poorly on neuropsychological assessment of frontal and executive function with relatively intact language and visuospatial function (for details see Table 1). Past medical history was significant for hypercholesterolemia, borderline hypertension and a loss of hearing after a motor accident. Family history was significant for a strong history of autosomal dominant dementia with Parkinsonism in many relatives. His mother died at age 60 with similar symptoms of dementia and Parkinsonism, but she did not have an autopsy. The patient’s MRI showed mild frontal lobe and striatal atrophy.

He died by pneumonia at the age of 59, thirteen years after the onset of his symptoms. Neuropathological examination showed general atrophy and marked ventricular dilatation. The fresh brain weighed 1050 grams. TDP-43 immunopositive neuropil threads were found in multiple regions of the central nervous system and features were consistent with unclassifiable FTLD-TDP. In addition, he showed argyrophilic grain disease restricted to limbic area.

Case 4

Mr. D, a right-handed man, started to exhibit social withdrawal and executive dysfunction in his late 30s. He became reluctant to join in conversations, completed tasks more slowly and had difficulty concentrating and multi-tasking. In his 40s, he became careless and failed to finish tasks at
work. By his late 40s, he became even slower, and less talkative. At the age of 54, he developed auditory hallucinations and delusions, believing that various “friends” were talking to him and to each other through TV. Also, he thought that people were watching him through the bathroom mirrors. He believed he was a “sex god” and that various neighbors dated him. He also believed that an imposter replaced his physician. He occasionally accused his wife of infidelity. He exhibited less emotion but inappropriately laughed at serious TV shows. At the age of 56, his speech output declined and his response time became delayed, he walked more slowly. He accompanied his family to work but did little work by himself. Table manners deteriorated and he ate enormous quantities of food voraciously in a messy fashion, including eating food off the floor. He also became apathetic.

Mr. D was evaluated at the UCSF Memory and Aging Center at the age of 57. His affect was flat, his speech was effortful, and he was perseverative, stimulus-bound and demonstrated poor insight. His neurological examination showed jerky ocular pursuit, increased arm tone with cogwheeling in the left greater than right, slowed finger taps, fasciculations throughout the arms and legs, a fine postural tremor of the outstretched hands, and a slow stooped gait. His exam was also notable for delayed response times, marked utilization behavior, and inability to perform tasks. Neuropsychological testing showed moderate impairments in episodic memory encoding and consolidation, impaired language comprehension, verbal agility, and repetition, marked executive impairment, and impaired abstract reasoning, with relatively spared visuospatial skills (see Table 1).

His past medical history includes hypertension, ankylosing spondylitis, and
prostate resection. Regarding family history, his mother was diagnosed with Parkinson’s disease dementia and had a brain autopsy showing neuronal loss in the substantia nigra without Lewy bodies. His medications included Donepezil (10mg), Quetiapine (800mg), divalproex sodium (500mg), and Trazodone (300mg). His MRI showed moderate bilateral lateral parietal atrophy as well as bifrontal atrophy, vermian atrophy, and bilateral caudate atrophy.

He died at 58 years of age. The fresh brain weighed 1340 grams. Neuropathological exam showed atrophy with most severe degenerative changes involving the prefrontal and perirolandic cortices, substantia nigra and lower motor neurons of the brainstem and spinal cord. Immunohistochemical analysis showed an unclassifiable FTLD-TDP with frequent granular or compact neuronal cytoplasmic inclusions, in superficial and deep layers of affected cortices, subcortical and brainstem and spinal cord structures. Although primary motor cortex showed TDP-43 pathology, no corticospinal tract demyelination was observed, making motor neuron disease a more appropriate pathological characterization than ALS. In addition, Lewy body pathology was observed in the dorsal motor nucleus of the vagus, corresponding a very early Parkinson’s disease Braak stage I.  

All the 17 cases fulfilled the most recent bvFTD clinical consensus criteria. Among the remaining 13 cases lacking well-defined delusions, one case showed confabulation that disappeared within 2 years from its appearance. The other cases did not show any other psychotic symptoms. Seven cases had motor neuron symptoms to variable extend, and one case had family history of ALS. Two cases have Parkinsonism. Mean age at disease onset is 60.4 years old.
mean age at death is 68.2 years old. Neuropathologically, in addition to TDP-43 pathology, three non-delusional cases had additional non-AD tau pathology.

**Neuroimaging Results**

VBM analysis showed greater atrophy in left parietal precuneus area at the level of uncorrected p<0.005 in the four cases with delusions compared with other 13 cases without delusions (Figure 1). In the small volume correction analysis for left parietal precuneus area, the atrophy was also significant at a Family Wise Error (FWE)-corrected p level of <0.05.

**Neuropathological analyses**

p62 positive/TDP-43 negative characteristic inclusions in the amygdala were seen in most of the 17 cases and no notable difference was found between the two groups. Among the 13 patients without delusions, three showed overlapping argyrophilic grain disease restricted to limbic areas and one showed an atypical tauopathy.

**Discussion**

We report the clinical, neuropsychological, neuroimaging, and neuropathological findings in four FTLD-TDP cases with delusions associated with *C9orf72* mutations. *C9orf72* mutation cases account for 12% of familial and 3% of sporadic FTD cases. Pathologically, *C9orf72* mutations are associated with FTLD-TDP, type B, as well as type A, or a unclassifiable type that features both type A and type B characteristics. Additionally, depositions of ubiquitin or p62-positive/TDP-negative characteristic inclusions...
are found in cerebellum, hippocampus and thalamus. These inclusions contain dipeptide-repeat proteins translated in an ATG-independent fashion from the hexanucleotide repeats and are pathognomonic of \textit{C9ORF72} expansion. On structural imaging, in addition to atrophy in frontal, insular, and anterior temporal areas commonly affected in bvFTD, patients with \textit{C9ORF72} mutations show atrophy in parietal, occipital, cerebellar, and thalamus.\textsuperscript{6,8,26}

Psychotic features (particularly delusions) are seen in up to 50% of \textit{C9ORF72} mutation carriers\textsuperscript{5,6}, a much larger frequency than in other FTLD types\textsuperscript{15}. Therefore, the distinctive anatomical and neurochemical features of \textit{C9ORF72} may reveal insights into the neurobiological basis of psychosis\textsuperscript{5,8,27}.

Before the discovery of \textit{C9ORF72} mutation, delusions were thought to be a relatively rare symptom in FTD patients. Some of these reports show patients with young-onset FTD who were diagnosed with psychotic disorders before the dementia-onset\textsuperscript{28,29}. Paranoid delusions were the most frequent symptoms in these series. Other case reports showed complex delusions\textsuperscript{30}, grandiose delusions\textsuperscript{31}, and Cotard delusions\textsuperscript{32}. Snowden et al. reported that most of the delusions with their \textit{C9ORF72} mutation cases were somatic delusions such as alterations in temperature perception, preoccupation with bowel movements, and leg pain\textsuperscript{5}, which was different from our series showing various delusions.

Compared to FTD, delusions are a relatively common symptom in Alzheimer’s disease (AD) and Dementia with Lewy bodies (DLB). A review article reported a median prevalence of 36\% (9.3–63\%) for delusions in AD, most involving delusion of theft, which can be included in the persecutory delusion category\textsuperscript{10,33}. Studies focusing on the underlying biological background of delusions in AD have suggested that persecutory delusions occur early in the
disease course and are associated with neurochemical and neuropathological changes in frontostriatal and temporal-limbic circuits. On the other hand, delusional misidentification in AD is associated with greater global cognitive deficits and advanced limbic pathology. In patients with DLB, hallucinations are the most frequent psychotic symptoms, with a prevalence from 63 to 78%, followed by misidentifications (56%) and paranoid delusions (25 to 28%). Paranoid or persecutory delusions in DLB subjects were hypothesized to be associated with dysfunction in the frontal cortex in addition to occipital cortex dysfunction.

Several studies on schizophrenia suggest that development of delusion is associated with a dysfunction of dopamine regulation in the ventral striatum, which leads to aberrant assignment of salience to stimuli. Also, dysfunction in brain areas associated with executive behavioral control such as the prefrontal cortex (PFC) may lead to alterations in affective state, disinhibition, and ways of thinking that might increase the risk of delusion formation. PFC was found to be implicated in prediction-error processing, and reality monitoring tasks, structural volume loss in the PFC correlates with symptoms of delusion. Thalamic dysfunction may also result in reduced ability to adjust sensory responsiveness to ongoing behaviors in patients with schizophrenia. Psychosis in schizophrenia is associated with source-monitoring deficits whereby self-initiated behaviors become attributed to outside sources, and one of the functions of the thalamus is to adjust sensory responsiveness in accordance with the behavioral contextual cues. Lower numbers of cerebellar Purkinje neurons also seen in association with psychosis in patients with schizophrenia and bipolar disorder. The decreased synthesis
and release of reelin from cerebellar granule cells could be associated with the pathophysiology that regulates GABAergic neuron dysfunction in the cerebellum of these patients.

There are a variety of neurological disorders strongly associated with psychosis. Often, psychosis occurs in association with temporal lobe dysfunction and is seen in patients with temporal lobe epilepsy, herpes simplex encephalitis, and autoimmune encephalitis that target the temporal lobes. Disorders of the basal ganglia and brain stem have a higher than expected prevalence of delusions and psychosis as is seen with Huntington's disease, Fahr's syndrome, and Wilson's disease. These results suggest that variety neurobiological substrates may predispose to delusions.

Why, then, did the four FTD cases with C9ORF72 mutations presented here exhibit delusions? Mahoney et al. hypothesize that dysfunction of thalamic and cerebellar projections could be related to the neuropsychiatric features associated with this C9ORF72 mutations cases, including hallucinations and delusions. This thalamic and cerebellar pathology is relatively unique to C9ORF72 mutation FTD cases. Although this hypothesis remains appealing, it is important to note that the other 13 cases in our series without delusions also showed changes in thalamus and cerebellar structures.

Thus, based on above-mentioned knowledge of delusions in other neurodegenerative disorders and schizophrenia, we hypothesized that in addition to PFC dysfunction that is common in patients with FTD, other regions might have contributed to development of delusions in our series of patients. VBM analysis showed more atrophy in left parietal precuneus area in
delusional patients compared to the non-delusional patients. Although the result is significant even after correction, our sample is small and the time gap latency between delusion onset and MRI acquisition should be taken into consideration. This parietal involvement has also been reported in other C9ORF72 mutation series. Precuneus is involved in discriminating self-relevant information from self-irrelevant information and in retrieving source memories. Therefore, in addition to executive dysfunction, failing to discriminate between self-relevant and self-irrelevant information and to retrieve the information source must make the patients hypersensitive to all information. Although the precuneus is very vulnerable to AD and to associate with delusions in patients with AD, such delusions are typically delusions of theft, rather than bizarre delusions as observed in our C9orf72 mutation series. Thus, we speculate that degree of frontal involvement may contribute to the variety of delusions in our cases.

Downey et al. suggested a distributed anatomical correlate in thalamo-cerebello-cortical circuitry including parietal cortex as a key terminus to explain altered body schema processing in C9orf72 related FTD patients. Our findings corroborate their observations. In fact, their results provide a useful framework for interpreting our findings, in particular the candidate mechanism of self/non-self regulation. However, as they point out, the spectrum of neuropsychiatric phenomena attributable to altered body schema processing is potentially much wider than delusions and hallucinations. Thus, our results have to be interpreted causally. Although precuneus changes may be neuroanatomical basis underlying delusions in C9orf72 related FTD patients, it is not possible to rule out a broader change in network vulnerable to this
Neuropathological information revealed that 3 out of 4 delusional patients presented an overlapping tauopathy (2 AGD and 1 atypical tauopathy). This 75% frequency is significantly higher than frequency of tauopathies in non-delusional cases 23% (3/13) and may indicate an association. Patients with AGD are prone to present persecutory delusions. Thus, the mixture of tau pathology and FTLD-TDP pathology especially in frontal cortex and ventral striatum, may have contributed to the clinical picture of delusions. In case 4, there was an additional Lewy body pathology. Lewy body pathology is associated with visual hallucinations, which were present in this patient, but the link is weakened because Lewy body pathology was restricted to the dorsal motor nucleus of the vagus nerve. None of the previous three subjects showed hallucinations in any modality. This may indicate a difference in pathological background between delusions and hallucinations. However, Snowden et al. reported that among 4 pathological confirmed cases with psychosis, 1 had tau pathology without TDP-43 pathology and the others had TDP-43 pathology without accompanying pathology. Synergistic effects of FTLD-TDP and certain tauopathies in causing delusions deserve investigation in a larger cohort, once it becomes available.

Although postmortem examination can potentially identify the underlying basis of neuropsychiatric symptoms, its power is limited by the long lag between the onset of delusions and expiration. It is possible that the advance stage of the disease by the time of passing precludes identification of more subtle differences between patients with specific symptoms. It might explain why we could not
find any distinctive pathological findings in parietal and precuneus in the
delusional group. This also supports the hypothesis that precuneus can be a
component of a network that may show differential vulnerability.

Interestingly, all of our four delusional cases had Parkinsonism, compared
to 2/13 non-delusional cases. However, iatrogenic Parkinsonism cannot be
discarded as two delusional cases (case 1 and case 4) and one non-delusional
subject were treated with atypical antipsychotics. This may indicate higher
sensibility of delusional subjects to dopamine dysfunction, both associated to
delusions and to Parkinsonism. Association between delusions and
Parkinsonism in \textit{C9ORF72} mutation cases suggests an overlapping
vulnerability of certain brain areas to both Lewy body disease and \textit{C9ORF72}
mutation-related pathology, even though both have different abnormal protein
deposition signatures. One clinico-pathological study with 68 patients shows a
greater loss of dopaminergic neurons in the substantia nigra of patients with
\textit{C9ORF72} mutations than those without \textsuperscript{58}. Parkinson disease itself is not
associated with \textit{C9ORF72} mutations \textsuperscript{59}.

Finally, delusions in our series often preceded the behavioral and cognitive
disabilities. This observation may increase the likelihood of misdiagnosis and
delayed appropriate treatment. FTD cases are often diagnosed as having
atypical psychosis such as late-onset schizophrenia or late-life depression with
psychotic features\textsuperscript{60}. Indeed, patients with FTD receive a prior psychiatric
diagnosis significantly more often than patients with AD (FTD, 50.7\% vs. AD,
23.1\%) \textsuperscript{61}. Clinicians need to consider the possibility of this mutation and assess
the family history when a patient presents with middle age onset delusions.

Conclusion

All of our FTD series with the C9ORF72 mutation presenting delusions had some additional pathology and Parkinsonism, which suggests a common anatomy or neurochemistry underlying these delusions. VBM analysis suggests relationship between precuneus and appearance of delusions, although the number of cases is small to draw conclusions. Further work with larger cohorts will be required to investigate the biological correlates of delusions in this genetic FTD group. Their presentations of this mutation carrier are heterogeneous and may be at higher risk of being misdiagnosed with primary psychosis. Clinicians need to consider the possibility of this mutation and assess the family history when a patient presents with middle age onset delusions.

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The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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REFERENCES


http://mc.manuscriptcentral.com/jgpn


Table 1
Clinical, neuropsychological, and brain imaging features of 4 cases

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<th>Right handed Male</th>
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<td>apathy</td>
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<td>loss of personal hygiene</td>
<td>apathy / lack of interest rigid inflexible in schedule</td>
<td>irritable</td>
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<td>FTLD-TDP, unclassifiable atypical tauopathy</td>
<td>FTLD-TDP, unclassifiable argyrophilic grain disease</td>
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</table>

* California Verbal Learning Test, 4 time registration, 30 second recall, and 10 minutes recall of 9 words

**(+) means mild atrophy and (++) means severe atrophy, based on expert neurologist who is blind to patients’ clinical information

FTLD-TDP: frontotemporal lobar degeneration with TAR DNA-binding protein inclusions
Figure 1

T-score map showing regions greater atrophy in 4 C9ORF72 mutation carriers with delusions compared to 13 patients without delusions

(2.50<T<4.50)