Cerebrospinal fluid biomarkers for Alzheimer's disease: their role in Clinical Chemistry

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ABSTRACT

In view of current (AChE inhibitors) and future (e.g. anti-Aβ aggregators), development and evaluation of cerebrospinal fluid (CSF) biomarkers for Alzheimer's disease (AD) has become a rapidly growing research field. Diagnostic biomarkers for AD would be especially valuable as aids in the diagnosis early in the course of the disease, when correct diagnosis is difficult, and when therapeutic compounds have the greatest potential of being effective. This paper reviews CSF biomarkers for AD, with emphasis on their role in the clinical diagnosis, and methodological aspects of importance for developing such analyses. Today, two biochemical markers, CSF-tau and CSF-Aβ 42, perform satisfactory enough to have a role in the clinical work-up of patients dementia, if used together with the cumulative information from clinical information and brain-imaging techniques. These markers are especially useful to discriminate early or incipient AD from age-associated memory impairment, depression, and some secondary dementias.

RIASSUNTO

Marcatori di malattia di Alzheimer nel liquido cerebrospinale: ruolo in chimica clinica

In relazioni alle presenti (inibitori della AchE) e future (per esempio anti-aggreganti della Ab) possibilità di approccio terapeutico, lo sviluppo e la valutazione di marcatori diagnostici di malattia di Alzheimer (AD) nel liquido cerebrospinale è un settore di ricerca in rapido sviluppo. Disporre di marcatori affidabili sarebbe di particolare utilità negli stadi precoci della malattia, quando una diagnosi corretta è difficile e quando i farmaci terapeutici avrebbero le maggiori possibilità di successo. Questo lavoro passa in rassegna i marcatori di AD del liquido cerebrospinale, con particolare attenzione al loro ruolo nella diagnosi, ed ai relativi aspetti di metodologia analitica. Oggi, due di tali marcatori, CSF-tau e CSF Aβ 42, forniscono informazioni che possono avere un ruolo nel trattamento clinico della demenza, se utilizzati insieme ai dati clinici ed alla diagnostica per immagini dell'encefalo. I medesimi marcatori sono particolarmente utili per discriminare tra AD iniziale e disturbi della memoria, depressione ed alcune forme secondarie di demenza associate all'invecchiamento.

INTRODUCTION

Alzheimer's disease (AD) is the major cause of dementia in the elderly. Although rare genetic (autosomal dominant) forms of AD exist, most patients have no obvious family history and are classified as having sporadic AD. The neuropathology of AD shows neuronal and synaptic degeneration, and an increased number of senile plaques (SP) and neurofibrillary tangles (NFT) compared to non-demented individuals of comparable age. Synaptic degeneration in AD is found in widespread cortical areas (Masliah et al, 1991). SP are composed of a central core of aggregated β -amyloid (Aβ) (Masters et al, 1985), a breakdown product derived from the amyloid precursor protein (APP) (Kang et al, 1987). NFT are insoluble intracellular thread-like structures made up of a hyperphosphorylated form of the microtubule-associated protein tau, called phospho-tau (Goedert et al, 1993).

Today, several acetylcholine esterase inhibitors are available for symptomatic treatment of AD. Drugs that also may have beneficial effects on the disease process, e.g. compounds affecting the deposition of Aβ, are under development. These possibilities for therapeutic intervention have heightened awareness of the importance of early and accurate diagnosis of AD.

However, current clinical criteria for the diagnosis of AD are relatively vague, and are largely based on the exclusion of other dementing illnesses (McKhann et al, 1984). A relatively high accuracy rate with regard to the clinical diagnosis of AD (80-90%) has been reported (Tierney et al. 1988;

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Jellinger 1996; Galasko et al. 1994). However, these reports emanate from expert research academic centers and are often based on patients in the later stages of the disease who were followed for several years before the confirming autopsy. The diagnostic accuracy rate is probably considerably lower in general hospitals, and especially in the earlier stages of the disease when the symptoms are often silent or indistinct and clinical diagnosis is more difficult. This is unfortunate, as pharmaceutical therapy is probably most effective early in the course of disease, before neurodegeneration is too severe and widespread. Thus, there is a great need for biochemical diagnostic markers (biomarkers) that could aid in the diagnosis of AD early in the course of the disease.

The cerebrospinal fluid (CSF) is in direct contact with the extracellular space of the brain, and its constituents reflect many biochemical changes in the brain. Since AD pathology is restricted to the brain, CSF is an obvious source of biomarkers for AD. During the last years, CSF biomarkers for AD have also gained increased attention. In this paper, we review the two CSF biomarkers that have been most extensively studied by different research centers and have proved to have the highest clinical diagnostic potential, i.e. CSF-tau and CSF-Aβ 42. We also focus on neurochemical factors of importance for making these biomarkers useful in clinical chemistry.

Besides their diagnostic potential, CSF biomarkers may also be useful to monitor the biochemical effect of therapeutic compounds. In AD, a drug that slows or arrests neurodegeneration might lower the level of a marker of active neuronal damage, such as CSF-tau. Similarly, a drug that acts by decreasing the deposition of Aβ might increase the level of CSF Aβ 42 in repeated samples.

CURRENT CSF biomarkers for AD

CSF - (total) tau protein

Tau is a microtubule-associated protein located in the neuronal axons, while it is not present in dendrites (Goedert, 1993). There are six different isoforms, and numerous phosphorylation sites, of tau in the human brain (Goedert 1993).

An increase in CSF-(total)tau in AD has been recorded in numerous studies (for review see e.g. Andreasen et al. 1998; Galasko 1998). The ability of CSF-tau to discriminate between AD and normal aging has been relatively good, above 80%, in most studies. High CSF-tau levels are, however, also found in a proportion of cases with other dementia disorders. This applies particularly to vascular dementia, in which high CSF-tau levels have been found in a relatively high proportion of cases in some studies (Blennow et al. 1995; Andreasen et al. 1998), while only in occasional cases in other studies (Tato et al. 1995; Mori et al. 1995; Arai et al. 1998; Mecocci et al. 1998; Nishimura et al. 1998; Hulstaert et al. 1999). It has been suggested that vascular dementia patients with high CSF-tau levels may constitute a subgroup with concomitant AD pathology (Andreasen et al. 1998), which implies that CSF-tau might be of use in identifying vascular dementia cases where AD is a contributory factor to the dementia.

In contrast, in patients with other types of dementia (e.g. alcoholic dementia), chronic neurological disorders (e.g. Parkinson's disease, progressive supranuclear palsy) and psychiatric disorders (e.g. depression), elevated CSF-tau levels are found only in occasional cases (Blennow et al. 1995; Molina et al. 1997; Ellis et al. 1998; Mitani et al. 1998; Morikawa et al. 1999; Urakami et al. 1999).

The major clinical usefulness of CSF-tau seems to be in the discrimination of AD from normal aging. It might also be of use in some other differential diagnoses (e.g. depression, alcoholic dementia and Parkinson's disease), which sometimes may be difficult to differentiate form AD on clinical grounds. The fact that an increase in CSF-tau can be found in acute destructive conditions, such as stroke (Arai et al, 1995), does not really reduce the clinical usefulness of CSF-tau, since these disorders are not differential diagnoses from AD.

Most likely, the level of CSF-tau reflects the degree of neuronal/axonal degeneration, regardless of cause. Longitudinal data on CSF tau shows that levels remain stably elevated over 12-24 months of follow-up (Andreasen et al, 1999a). This would enable CSF-tau levels to be used as an outcome measure to assess treatment aimed at neuroprotection.

CSF-Aβ 42

The β-amyloid protein (Aβ or β /A4 protein) is a cleavage-product from the amyloid precursor protein (APP), encoded by a single gene on chromosome 21 (Kang et al, 1987). APP is a transmembrane protein with a single transmembrane domain, a long N-terminal segment and a shorter cytoplasmic C-terminus. The Aβ part of APP encompasses the first 28 extracellular and the following 12-14 transmembrane amino acids. Non-amyloidogenic secretory forms of APP is normally generated by cleavage within the Aβ region by an unidentified enzyme termed α-secretase, while Aβ is produced by an alternative metabolic pathway, in which two proteases, termed β - and γ -secretase cleave APP on each side of the Aβ sequence.

There are two major C-terminal variants of Aβ, a shorter form ending at Val-40 (Aβ 40), and a longer form ending at Ala-42 (Aβ 42). Aβ 42 aggregates more rapidly than Ab 40 and is also the predominating form of amyloid in diffuse plaques and in SP (for review see Dickson et al. 1997).

Aβ is generated as a soluble peptide during normal cellular metabolism, and is secreted into the extracellular space and biological fluids, including CSF (Haass et al. 1992). A marked decrease in CSF-Aβ 42 is found in a high percentage of patients with AD (Motter et al. 1995; Galasko et al. 1998; Andreasen et al. 1999b; Hulstaert et al. 1999). The sensitivity is above 80-90%, resulting in a relatively good ability for CSF-Aβ 42 to distinguish AD from normal aging and depression. However, the specificity for CSF-Aβ 42 for the diagnosis of AD compared to other

dementias has been less extensively studied than for CSF-tau, and needs to be further evaluated.

Measurement of Aβ in CSF may reflect cerebral amyloid deposition. Hypothetically, in AD Aβ secreted from neurons, and possibly other cells in the brain, binds to existing aggregates of Ab in extracellular SP, with lower levels remaining to circulate in the CSF (Andreasen et al, 1999b). Longitudinal data show that CSF-Aβ 42 levels remain relatively stable over 12-24 months of follow-up (Andreasen et al, 1999b). This implies that CSF could be used to monitor the effects of anti-amyloid drugs in AD.

Combination of CSF-tau and CSF-Aβ 42

The strategy of combining CSF-tau and CSF-Aβ 42 as biomarkers for AD is appealing, since the concentrations of these substances are believed to reflect two of the central pathogenic processes in the disorder, and the combination might thus result in increased sensitivity and specificity. Indeed, some large studies have shown that both sensitivity and specificity increase for the combination compared with CSF-tau or CSF-Aβ 42 alone (Galasko et al, 1998; Kanai et al, 1998; Hulstaert et al. 1999, Andreasen et al, 2000).

Also when used as routine analyses in clinical chemistry, and the sensitivity and specificity figures are determined on all consecutive patients admitted for investigation of cognitive disturbances during one year in a community-based setting, the sensitivity to identify AD is above 90% (Andreasen et al, 2000).

Further, the combination of CSF-tau and CSF-Aβ 42 also has a high sensitivity to predict progression to AD in patients with mild cognitive impairment (Andreasen et al, 1999c). This finding shows that these CSF markers show abnormal values very early in the disease process, already before the clinical dementia.

CSF-tau and CSF-Aβ 42 in clinical chemistry

As for all other test in clinical chemistry, methodological factors have to be evaluated when developing CSF biomarkers. CSF sampling, handling and storage can influence levels of many analytes. It has to be evaluated whether a molecule passes from serum to CSF across the blood-brain barrier, which occurs for many proteins that have higher levels in serum than in CSF (Tibblin et al, 1977). If so, the CSF levels will reflect the periphery more than the CNS. Neither CSF-tau nor CSF-Aβ 42 are affected by this problem (Blennow et al, 1995; Vanderstichele et al, 1998). Further, CSF-tau or Aβ 42 do not show concentration gradients in lumbar CSF (Vanderstichele et al, 1998), which, if present, complicates the interpretation of lumbar CSF levels, since these will vary with the volume and portion of CSF analyzed (Blennow et al, 1993).

However, the hydrophobic Aβ peptide may absorb to some types of test tubes commonly used for lumbar puncture or for centrifugation in the laboratory (Andreasen et al, 1999b). The level of Aβ 42 decreases to about 65% in polystyrene or in glass tubes, as compared with polypropylene tubes (Andreasen et al, 1999b). Therefore, polypropylene tubes must be used both for CSF sampling and for centrifugation and storage.

Both CSF-tau and CSF-Aβ 42 are determined using sandwich ELISA techniques, using antibodies directed against different epitopes of the proteins, making the analyses very sensitive and specific. Current ELISA assays for CSF-tau use monoclonal antibodies that detect all isoforms of tau independent of phosphorylation, and thus measure the "total" CSF-tau level (Blennow et al, 1995), while Aβ ELISA assays are specific to Aβ 42, with minimal cross-reactivity against peptides ending at residues 43 or 40 (Motter et al. 1995; Vanderstichele et al. 1998).

The biological variation is low for both CSF-tau (Andreasen et al, 1998) and CSF-Aβ 42 (Andreasen et al, 1999b), i.e. very similar CSF levels are found when longitudinal CSF samples are analyzed from individual patients. Also the analytical variation is low, the coefficient of variance (CV) for internal control samples when CSF-tau and CSF-Aβ 42 are run as a routine clinical neurochemical analyses during one year is approximately 10% (Andreasen et al, 2000).

Finally, it is also of importance to consider clinical confounding factors when evaluating CSF biomarkers for AD. One problematic issue is that studies are most often performed on clinically diagnosed patients, and data on neuropathologically confirmed cases are scarce. Although the positive predictive value for the clinical diagnosis of AD (i.e. the probability that AD is present when the criteria are met) has been relatively high, about 85%, the negative predictive value (i.e. the probability that AD is not present when the diagnostic criteria are not met) has been considerably lower (Tierney et al. 1988; Jellinger 1996; Galasko et al. 1994). This is especially troublesome for some of the non-AD dementias (e.g. vascular dementia and frontotemporal dementia). In fact, neuropathological studies have found that a high proportion (40-80%) of clinically diagnosed patients with vascular dementia have notable concomitant AD pathology (Jellinger 1996; Kosunen et al. 1996). The fact that current clinical diagnostic criteria cannot be considered to be of 'gold standard' quality results in that it is difficult to get high sensitivity and specificity figures for CSF biomarkers. Further, even if they are asymptomatic, age-matched control subjects may harbor presymptomatic AD lesions in their brains (Tomlinson & Henderson 1976; Davies et al. 1988; Price & Morris 1999), which also reduces the specificity figures of CSF biomarkers for AD.

THE CLINICAL use of CSF biomarkers for AD

Much effort has focused on finding a single neurochemical marker for AD. This may be elusive unless the marker is related to a pathogenic step that is unique to AD. For example, neuronal and synaptic degeneration is not only found in AD but also in most chronic degenerative disorders of the brain. Similarly, deposition of Aβ is not

specific to AD, but is also found in normal aging, dementia pugilistica, Lewy body dementia, and after acute brain trauma, while deposition of PHF to in inclusions such as tangles may form in normal aging, dementia pugilistica, myotonic dystrophy, and other forms of tau are found in inclusions in progressive supranuclear palsy and frontotemporal dementia(Davies et al, 1988; Roberts et al, 1994; Mc Kenzie et al, 1996). Thus, since the central neuropathological findings in AD are not specific for AD, it is unlikely that one single biochemical marker will absolutely discriminate between AD and other dementia disorders.

Instead, the combination of several CSF biochemical markers (e.g. CSF-tau, CSF-Aβ 42 and possibly other like phospho-tau and α/β -secretase cleaved APP) could be used in conjunction with other diagnostic methods. The overall accuracy of the clinical diagnosis of AD may increase if the diagnosis is based on cumulative information gained from the clinical examination, brain-imaging techniques (e.g. SPECT and MRT scans), and CSF biochemical markers. As an analogy, the clinical diagnosis of myocardial infarction is based on the combination of clinical symptomatology, electrocardiogram, and biochemical markers (e.g. creatine kinase). Today, the CSF markers tau and Aβ 42, when used as an adjunct to clinical diagnosis, have the potential to help to differentiate AD from some problematic differential diagnoses, especially age-associated memory impairment, depressive pseudo-dementia, Parkinson's disease, progressive supranuclear palsy and alcoholic dementia.

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