Demonstration of Components of Antigen 85 Complex in Cerebrospinal Fluid of Tuberculous Meningitis Patients

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Tuberculous meningitis (TBM) is the most common form of chronic infection of the central nervous system. Despite the magnitude of the problem, the general diagnostic outlook is discouraging. Specifically, there is no generally accepted early confirmative diagnosis protocol available for TBM. Various *Mycobacterium tuberculosis* antigens are now recognized as potential markers for diagnosis of TBM. However, their presence remains questionable, and many of these antigens are reported in the blood but not in the cerebrospinal fluid (CSF). This study identifies a specific protein marker in CSF which will be useful in early diagnosis of TBM. We have demonstrated the presence of a 30-kDa protein band in CSF of 100% (n = 5) of confirmed and 90% (n = 138) of suspected TBM patients out of 153 TBM patients. The 30-kDa band was excised from the gel, destained extensively, and digested with trypsin. The resulting peptides were analyzed by liquid chromatography-tandem mass spectrometry (LC-MS/MS). Partially purified proteins from CSF samples of TBM were analyzed by two-dimensional polyacrylamide gel electrophoresis and Western blotting. Immunoblotting and enzyme-linked immunosorbent assay (ELISA) were performed to confirm the presence of proteins in the 30-kDa protein band. The antigen 85 (Ag 85) complex was detected in CSF of TBM patients by indirect ELISA using antibodies against Ag 85 complex. The results of this study showed the 30-kDa protein band contained MTB proteins Rv3804c (Ag 85A) and Rv1886c (Ag 85B), both members of the Ag 85 complex. This was also confirmed by using immunotechniques such as indirect ELISA and the dot immunobinding assay. Detection of Ag 85 complex was observed in CSF of 89% (71 out of 80) of suspected TBM patients that were 30-kDa protein positive. The observed 30-kDa protein in the CSF is comprised of the MTB Ag 85 complex. This protein was earlier reported to be present in the blood of patients with extra-central nervous system tuberculosis. Therefore, this finding suggests that this protein can be used as a molecular marker for any type of tuberculous infection. It also provides a more sensitive immunoassay option for the early and confirmatory diagnosis of TBM.

Tuberculosis is the leading cause of death among communicable diseases, killing nearly 2 million people each year (2, 13). Among tuberculosis infections, tuberculous meningitis (TBM) leads to multiple central nervous system (CNS) complications and remains a major health problem in underdeveloped and developing countries (1, 9, 16). Even in developed countries where a decade ago it was rare, it has reappeared following human immunodeficiency virus infection (6, 14, 29). Early and rapid confirmatory diagnosis is still difficult due to the clinical picture of TBM and similarities of TBM cerebrospinal fluid (CSF) to that of partially treated pyogenic meningitis, which results in frequent diagnostic confusion (4, 21, 28, 33). Early and reliable diagnosis of TBM still poses a great challenge. In most of the cases, diagnosis relies on clinical observations, imaging of the infected area, and detection of *Mycobacterium tuberculosis* in CSF by acid-fast bacillus (AFB) staining and culturing. A number of immunological and molecular methods have been reported, but these cannot be employed in standard pathology laboratories and are often not useful for early confirmative diagnosis of TBM (3, 7, 11, 15, 22, 23, 25, 26, 31, 35).

To overcome the deficiencies in TBM diagnosis, we set forth to identify specific protein markers unique to CSF samples collected from suspected patients with TBM. By analyzing the total sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) protein profile of such CSF, we observed a 30-kDa protein band specific to these patients (18). Further, all 30-kDa protein-positive CSF samples tested with polyvalent antibodies against culture filtrate proteins (CFP) of *M. tuberculosis* strain H₃₇Rv by the single radial immunodiffusion (SRID) method indicated that the CSF of TBM patients possesses *M. tuberculosis* antigens (17).

These early investigations led us to hypothesize that molecular identification of the TBM-specific 30-kDa CSF protein would allow for development of specific reagents and protocols for the rapid and accurate diagnosis of TBM. In this report, the application of two-dimensional polyacrylamide gel electrophoresis (2D-PAGE) and liquid chromatography tandem mass spectrometry (LC-MS/MS) identified two mycobacterial proteins of the antigen 85 (Ag 85) complex (Rv3804c and Rv1886c) and one host-derived protein (immunoglobulin 1g) kappa light
fused for 10 min at 250 rpm at 4°C. The supernatant was removed and stored at −20°C in 1-mL aliquots.

**One- and two-dimensional polyacrylamide gel electrophoresis.** Partially purified proteins from six TBM CSF samples were precipitated with ammonium sulfate (40%), and the precipitate was washed with saturated ammonium sulfate. The pellets were hydrated with water and dialyzed against 10 mM ammonium bicarbonate. The protein concentration of each sample was measured by biocinchonic acid assay (Pierce Chemical Co.). An aliquot (10 μg) of each sample was resolved by SDS-PAGE using a 15% Tris-glycine gel, transferred to nitrocellulose, and probed with the monoclonal antibody against the Ag85 complex (CS-90). Color development was achieved using anti-mouse antibody conjugated to alkaline phosphatase followed by development with 4-bromo, 3-chloro, 2-indolyl, 1-phosphate and nitroblue tetrazolium.

**Two samples containing sufficient protein were additionally analyzed by 2D-PAGE.** Samples were applied to isoelectric focusing strips with linear pH 4 to 7 gradients and focusing conducted using a ZOOM IPGRunner (Invitrogen, Carlsbad, CA). Strips were resolved by SDS-PAGE using 4 to 12% Bis-Tris gels (Invitrogen) followed by either staining with Coomassie or transfer to nitrocellulose. Proteins of the Ag85 complex were identified by Western blot analysis.

**Liquid chromatography-tandem mass spectrometry.** To partially purify the 30-kDa protein, the CSF was resolved by SDS-PAGE and the 30-kDa protein was electropheluted as reported earlier (20). This partially purified material was again resolved by SDS-PAGE, the gel was stained with Coomassie blue, and the 30-kDa band was excised from the gel. The protein was destained, digested in the gel with trypsin, and the peptides were extracted by standard methods (10). Recovered peptides were hydrated with 5% acetonitrile in 0.1% glacial acetic acid and applied to a 0.2-μm C18 reversed-phase capillary high-performance liquid chromatography column (Michrom Bio Resources, Auburn, CA). The peptides were eluted with an increasing gradient of acetonitrile at a flow rate of 5 μL per min using an Eldex MicroPro capillary solvent delivery system (Napa, CA). The effluent was introduced directly into a Thermo-Finnigan LCQ electrospray ion trap mass spectrometer (San Jose, CA) where data-dependent MS/MS was employed. Specifically, the parent ion yielding the greatest relative abundance from the full MS scan was selected for MS/MS fragmentation and information obtained was used to construct a dynamic exclusion list for 1 min. Ion fragmentation was achieved using 40% normalized collision energy. MS/MS data were interrogated against the *M. tuberculosis* database (12) and nonredundant database housed at the National Center for Bioinformatics using the BioWorks 3.1 software suite (ThermoFinnigan) and SEQUEST (8).

**M. tuberculosis antigens.** Ag85 complex and its three components, Ag85A, Ag85B, and Ag85C from *M. tuberculosis* strain H37Rv, were obtained from mid-log-phase cultures as previously described (5). Briefly, sterile culture filtrate proteins were precipitated with 40% saturated ammonium sulfate. Proteins were equilibrated into phosphate buffer (pH 6.8) and loaded onto a phenyl Sepharose column. Columns were eluted via a pH gradient (pH 6.8 to 8.0) followed by an increasing concentration of ethylene glycol. Ag85 complex and individual components A, B, and C were cleaned up using either a second phenyl Sepharose chromatographic column or a G-7 Sephadex column (Amersham, Pharmacia, Piscataway, NJ). Antibodies. The monoclonal antibody to the purified Ag85 complex (CS-90) and polyclonal sera to Ag85 complex (04.Ag85.11.11.32.p) and culture filtrate proteins of *M. tuberculosis* strain H37Rv (C193) were obtained from Colorado State University through the TB Research Materials and Vaccine Testing Contract (NO1-AI-75320).

**Western blotting.** The CSF of 30-kDa protein-positive CSF patients was subjected to SDS-PAGE and electroblotted to nitrocellulose membrane as per standard protocols (22). The membrane was probed with a 1:1,000 dilution of polyclonal antibodies to Ag85 complex (24) to Ag85 complex for 2 h at room temperature, followed by the secondary antibody, goat anti-rabbit IgG conjugated to horseshad peroxidase (HRP). Antibody reactivity was visualized by detection of HRP activity with tetramethylbenzidine-hydrogen peroxide (TMB/H2O2) as substrate. The Ag85 complex was used as a positive control in the Western blot analysis. A total of 31 CSF samples, including those from 25 TBM patients (clinically suspected = 20, confirmed cases = 5), were randomly selected for the Ag 85 complex detection.

**Demonstration of Ag85 complex components using 30-kDa protein antibodies.** Wells of flat-bottom microtiter plates were coated with 100 μl (10 μg/ml) of Ag85 components (Ag85A, Ag85B, Ag85C) in a separate wells and incubated overnight at 4°C. The wells were then washed with PBS (pH 7.4) and blocked by the addition of 100 μl of 2.5% blocking reagent (BSA) in PBS at 37°C for 1 h. After removal of blocking solution, antibodies generated against 30-kDa protein were added to all the wells (1:5,000) and incubated at 37°C for 60 min. The wells were again washed with the PBS, 100 μl of affinity purified HRP-conjugated anti-rabbit IgG (Bangalore Genei, India) (1:0,000) was added to the
wells, and this mixture was incubated at 37°C for 60 min. The wells were washed extensively with PBS; TMB/H₂O₂ substrate solution (100 μl) was added into the wells and incubated at room temperature for about 20 min for development of the color. The reaction was stopped with addition of 100 μl of 2.5 N H₂SO₄. The absorbance of each well was read at 450 nm (20).

Demonstration of the 30-kDa protein using polyclonal antibody (04.Ag85.1.11.32_rp) to Ag₈₅ complex. The same procedure was used for 30-kDa protein demonstration with the Ag₈₅ complex antibodies as described above, with little modification. Briefly wells of microtiter plates were coated with 100 μl (5 μg/ml) of eluted 30-kDa protein antigen and incubated overnight at 4°C. The antigen was then blocked by addition of 100 μl of 2.5% BSA in PBS and incubated at 37°C for 60 min. After washing with PBS, polyclonal antibody (04.Ag₈₅.1.11.32_rp) to Ag₈₅ complex was added and incubated at 37°C for 60 min. The wells were again washed with the PBS, and 100 μl of affinity purified HRP-conjugated anti-rabbit IgG (Bangalore Genei, India) (1:10,000) was added to the wells and incubated at 37°C for 60 min. The wells were washed extensively with PBS; TMB/H₂O₂ substrate solution (100 μl) was added to the wells and incubated at room temperature for about 20 min for development of the color. The reaction was stopped with addition of 100 μl of 2.5 N H₂SO₄. The absorbance of each well was read at 450 nm (20).

Dot immunobinding assay. A total of 240 CSF samples, including 80 from TBM patients (clinically suspected = 75, confirmed cases = 5), were selected for detection of Ag₈₅ complex. Strips of nitrocellulose were cut and placed on glass slides. Three circles were marked on each strip and numbered 1, 2, and 3, respectively. Two microliters of Ag₈₅ complex (10 mg/ml) (positive control), 2 μl of CSF (10 mg/ml) (negative control), and 2 μl of CSF from TBM patients were deposited into circles 1, 2, and 3, respectively. The nitrocellulose strips were blotted dry and blocked with 2.5% BSA in PBS for 60 min at 37°C. Polyclonal antibody (04.Ag₈₅.1.11.32_rp) to Ag₈₅ was added at a concentration of 1:2,000, and the nitrocellulose strips were processed as described earlier (19).

Indirect ELISA. CSF samples (100 μl of a 1:10 dilution) from TBM patients and non-TBM patients were added to the microtiter wells and blocked with 2.5% BSA in PBS. After washing with PBS, polyclonal antibody (04.Ag₈₅.1.11.32_rp) against Ag₈₅ complex was added and plates were incubated at 37°C for 60 min. The wells were washed, followed by addition of the secondary antibody (goat anti-rabbit IgG-HRP) and incubation for 60 min at 37°C. The antibody reactivity was detected by addition of the TMB/H₂O₂ substrate as described for antibody detection. A total of 240 CSF samples, including 80 from TBM patients, were selected for this study.

Detection of antibodies to Ag₈₅A, Ag₈₅B, and Ag₈₅C in CSF samples of TBM patients. Indirect ELISA as described earlier by Kashyap et al. (20) was employed with minor modification. The flat-bottom microtiter wells were coated with 100 μl (10 μg/ml) of Ag₈₅ components (Ag₈₅A, Ag₈₅B, Ag₈₅C) in separate wells and incubated overnight at 4°C. The wells were then washed with PBS solution, pH 7.4, and then nonspecific sites of coated antigen were blocked by the addition of 100 μl of 0.5% BSA—PBS at 37°C for 60 min. One hundred microliters of CSF from TBM patients was diluted in PBS (1:10), added to the wells, and incubated at 37°C for 60 min. The wells were again washed with the PBS. One hundred microliters of affinity-purified HRP-conjugated anti-human IgG (Bangalore Genei, India) diluted 1:10,000 in PBS was added to the wells and incubated at 37°C for 60 min. After another washing with PBS, 100 μl of TMB/H₂O₂ substrate solution was added to the wells and incubated at room temperature for about 20 min. The reaction was then stopped with 100 μl of 2.5 N H₂SO₄. The absorbance of each well was read at 450 nm (20).

RESULTS

The CSF samples of patients admitted to the Neurology Department of CIIMS hospital were grouped into three different categories on the basis of clinical observations and biochemical and pathological analyses of CSF samples. These CSF samples were then subjected to SDS-PAGE analysis to observe total protein profile and to demonstrate and assign the specificity of the band(s) to TBM.

In our earlier publications using SDS-PAGE, we demonstrated the presence of a 30-kDa protein band in the CSF of 92% (n = 37) of suspected TBM patients out of 40 cases and when the sample set of non-TBM patients (n = 105) was analyzed, it only gave 6% (n = 6) of nonspecificity in terms of presence of the 30-kDa protein (18). In the last 6 years, we have analyzed CSF samples of 153 TBM patients (showing 90% [n = 138] positivity for 30-kDa protein) and 531 non-TBM patients (showing only 2.3% [n = 12] false-positive results for 30-kDa protein antigen) (data not shown). We have also demonstrated the presence of M. tuberculosis antigens in the CSF of 30-kDa protein-positive TBM patients using polyclonal antibodies to CFP. This has been demonstrated using the SRID assay, where 94% (n = 17) of TBM patients out of 18 patients gave positive results (17).

Since these earlier reports strongly suggested the 30-kDa protein as a marker in the diagnosis of TBM, a full characterization of the 30-kDa protein was initiated. The 30-kDa protein band, along with other CSF proteins, was harvested from the CSF as described above, and the protein extract was analyzed by 2D-PAGE (Fig. 1A). Probing of the 2D-PAGE protein profile with the monoclonal antibody for Ag₈₅ (CS-90)
demonstrated reactivity against two protein spots in the size and pI range of the Ag85 proteins (Fig. 1B).

A more highly purified 30-kDa protein band of the CSF of TBM patients was recovered by electroelution (Fig. 2). Analysis by LC-MS/MS of peptides derived through a trypsin digestion of the 30-kDa band revealed the presence of Ag85A (Rv3804c) and Ag85B (Rv1886c) (Table 1). A single peptide derived from the human immunoglobulin kappa light chain VLJ region (accession no. BAC01690.1) was also identified.

The polyclonal antibody against Ag85 complex of MTB was tested against 30-kDa protein-positive TBM CSF samples by Western blot analysis (Fig. 3). This finding was also confirmed by dot immunobinding assay and reverse dot immunobinding assay. Further, the reactivity of antiserum generated against the 30-kDa CSF protein was demonstrated by indirect ELISA for the individual components of the Ag85 complex, Ag85A, -B, and -C, purified from M. tuberculosis (Fig. 4, top), while no reactivity was observed with LAM or native GroES antigen (not shown). The bottom panel of Fig. 4 demonstrates the reactivity of eluted 30-kDa protein (isolated from CSF of TBM patients) with polyclonal antibody (04.Ag85.1.11.32.rp) to Ag85 by indirect ELISA. The highest activity was observed in a 1:40 dilution.

The detection of Ag85 complex in the CSF of TBM patients (n = 80) containing the 30-kDa protein versus non-TBM patients (n = 160) was confirmed by dot immunobinding assay and indirect ELISA using anti-Ag85 complex polyclonal sera. Seventy-four (93%) of the TBM patients tested positive for the Ag85 complex versus 4 (2.5%) non-TBM patients. Figure 5 shows the diagnostic tree for Ag85 complex detection generated from STARD (Standards for Reporting of Diagnostic Accuracy [http://www.consort-statement.org/stardstatement.htm]) analysis (Fig. 5). The specific detection of antibodies against Ag85A, Ag85B, or Ag85C in the CSF samples of 10 of these positive TBM patients was determined by indirect ELISA. A high concentration of antibodies against Ag85A was

| Protein | Peptide sequence | Amino acid positiona | Massb | % Totalb |
|---------|-----------------|----------------------|-------|---------|
| Rv1886c | PGLPVEYLOVPSPSMGR | 4–20 | 1,828.1 | 5.29 |
| VQFQSGGNSnopVYLLDGLR | 24–43 | 2,136.4 | 6.18 |
| WETFLTSELPOWLSANR | 97–113 | 2,079.3 | 6.01 |
| FQDAYNAGGHNATPFGSGPNTSWEYWAQLNAMK | 240–275 | 4,013.3 | 11.61 |
| FQDAYNAGGHNATPFGSGPNTSWEYWAQLNAMKDGOLDSSLGAG | 240–285 | 4,899.2 | 14.17 |
| % Coverage | 31.65 |

| Protein | Peptide sequence | Amino acid positiona | Massb | % Totalb |
|---------|-----------------|----------------------|-------|---------|
| Rv3804c | PGLPVEYLOVPSPSMGR | 4–20 | 1,828.1 | 5.03 |
| VQFQSGGNSnopVYLLDGLR | 24–43 | 2,107.4 | 5.92 |
| % Coverage | 10.95 |

a Amino acid position of the peptide in the mature protein.
b Monoisotopic mass calculated for each peptide.
c Percentage the peptide contributes to the total mass of the mature protein.
observed in all the samples (Fig. 6). Non-TBM patients were not specifically reactive toward these individual antigens.

**DISCUSSION**

TBM remains one of the most serious chronic medical conditions resulting from infection with *M. tuberculosis*, if not treated promptly. Clinical observation coupled with CSF analysis of TBM patients can be similar to other infectious sequelae, such as partially treated pyogenic meningitis, fungal meningitis, and viral meningitis (21). Further, diagnostic confirmation of TBM via observation of tubercle bacilli in the CSF by AFB staining is rare and does not exceed 50% even when adequate CSF samples are obtained (32).

In an attempt to develop a rapid test for the diagnosis of TBM, we analyzed CSF samples from confirmed and suspected TBM patients along with control CSF samples from patients with non-TBM and noninfectious CNS disorders. The SDS-PAGE protein profile of TBM patient CSF samples demonstrated the presence of the 30-kDa protein band (100% of confirmed and 92% of suspected patients). Analysis of 30-kDa protein-positive CSF samples by SRID analysis with polyclonal antisera generated against Ag85 complex demonstrated reactivity against the 30-kDa protein, indicating that this protein may be comprised of the Ag85 complex from *M. tuberculosis*.

Further, visualization of this protein by SDS-PAGE analysis of CSF in TBM patients treated with anti-TB medication (such as isoniazid, pyrazinamide, rifampin, and ethambutol) is reduced (18). This strengthens our argument that the 30-kDa protein band observed in the CSF of TBM patients not only is an important marker for early diagnosis of TBM but also can be useful in assessing the response to therapy.

**FIG. 4.** (Top) Reactivity of 30-kDa protein antibodies generated using the 30-kDa protein eluted from CSF of TBM patients with components of antigen 85 complex (Ag85A, Ag85B, Ag85C). All the components reacted with 30-kDa antibodies (1:100). (Bottom) Reactivity of eluted 30-kDa protein (isolated from CSF of TBM patients) with polyclonal antibody (04.Ag85.1.11.32.rp) to Ag85 by indirect ELISA. Highest activity was observed in a 1:40 dilution.

**FIG. 5.** Diagnostic classification tree showing Ag85 complex detection in CSF of TBM and non-TBM patients.
was hypothesized that this protein represented an with 94% sensitivity and 99% specificity (22). At the time, it was hypothesized that this protein represented an M. tuberculosis cell wall antigen, though its discrete identity was not confirmed.

In this report, the 30-kDa protein band from the CSF of patients with confirmed and suspected cases of TBM was demonstrated to react with antibodies directed against Ag85 complex. Additionally, antibodies produced against the 30-kDa CSF band reacted with the Ag85 complex, and the individual components of the Ag85 complex, Ag85A, -B, and -C. Thus the 30-kDa band was partially purified from the CSF and the excised band was digested with trypsin and analyzed by LC-MS/MS and 2D-PAGE. These studies cumulatively identified two mycobacterial antigens, Rv1886c and Rv3804c (Ag85B and -A, respectively) in the CSF of TBM patients.

The 30- to 31-kDa Ag85 complex has been the focus of intensive research for several years and comprises three related proteins, Ag85A (31 kDa), Ag85B (30 kDa), and Ag85C (31.5 kDa). Interestingly, these have been found in the blood of non-CNS tuberculous patients (24, 27, 30, 35). More recently, these antigens have been demonstrated in the sputum of pulmonary tuberculosis patients (34). We have also observed these antigens in the serum of patients with sputum AFB-positive pulmonary tuberculosis (our unpublished observations).

After confirming the presence of proteins from the Ag85 complex in the CSF, 80 CSF samples from 30-kDa protein-positive TBM patients and 160 CSF samples from 30-kDa protein-negative non-TBM cases were selected for detection of the Ag85 complex. The Ag85 complex was detected in 93% of the CSF samples of TBM patients. This was also confirmed by the immunoblot analysis.

The literature suggests that this is the first report of demonstration of the Ag85 complex in the CSF of TBM patients. This coincides with other studies demonstrating the presence of the Ag85 complex in the serum of patients with pulmonary and other non-CNS tuberculosis. Ag85 complex expression in the CSF of TBM patients might provide prospective insights in the area of infection by M. tuberculosis.

In conclusion, the 30-kDa protein band noted in the CSF of TBM patients is comprised of mycobacterial products, including components of the Ag85 complex, and can be used to develop an immunodiagnostic assay with increased sensitivity and specificity. Such a test would be rapid, sensitive, and cost-effective and could be easily performed in any standard pathology laboratory.

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