Cerebrospinal Fluid Glucose and Lactate: Age-Specific Reference Values and Implications for Clinical Practice

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Abstract

Cerebrospinal fluid (CSF) analysis is an important tool in the diagnostic work-up of many neurological disorders, but reference ranges for CSF glucose, CSF/plasma glucose ratio and CSF lactate based on studies with large numbers of CSF samples are not available. Our aim was to define age-specific reference values. In 1993 The Nijmegen Observational CSF Study was started. Results of all CSF samples that were analyzed between 1993 and 2008 at our laboratory were systematically collected and stored in our computerized database. After exclusion of CSF samples with an unknown or elevated erythrocyte count, an elevated leucocyte count, elevated concentrations of bilirubin, free hemoglobin, or total protein 9,036 CSF samples were further studied for CSF glucose (n = 8,871), CSF/plasma glucose ratio (n = 4,516) and CSF lactate values (n = 7,614). CSF glucose, CSF/plasma glucose ratio and CSF lactate were age- but not sex dependent. Age-specific reference ranges were defined as 5–95th percentile ranges. CSF glucose 5th percentile values ranged from 1.8 to 2.9 mmol/L and 95th percentile values from 3.8 to 5.6 mmol/L. CSF/plasma glucose ratio 5th percentile values ranged from 0.41 to 0.53 and 95th percentile values from 0.82 to 1.19. CSF lactate 5th percentile values ranged from 0.88 to 1.41 mmol/L and 95th percentile values from 2.00 to 2.71 mmol/L. Reference ranges for all three parameters were widest in neonates and narrowest in toddlers, with lower and upper limits increasing with age. These reference values allow a reliable interpretation of CSF results in everyday clinical practice. Furthermore, hypoglycemia was associated with an increased CSF/plasma glucose ratio, whereas hyperglycemia did not affect the CSF/plasma glucose ratio.

Introduction

Cerebrospinal fluid (CSF) analysis is an important tool in the diagnostic work-up of neurological disorders like infection or inflammation of the central nervous system, intracranial hemorrhage and inherited metabolic disorders. It is therefore remarkable that little consensus exists amongst different laboratories about the reference ranges for CSF glucose and lactate [1]. CSF glucose is decreased in, amongst others, patients with bacterial meningitis and leptomeningeal carcinomatosis, usually in combination with other abnormal CSF parameters, such as an elevated leucocyte count, total protein or lactate concentration [2–4]. Low CSF glucose, often in combination with low CSF lactate, can also be found in patients with GLUT1 deficiency syndrome, a treatable genetic metabolic disorder that is caused by impaired glucose transport into brain [5]. CSF lactate can be elevated in several disorders, such as subarachnoidal hemorrhage, bacterial meningitis [3], cerebral hypoxia [6], status epilepticus [7], and inborn errors of metabolism [8]. Age-specific reference values are needed for an accurate interpretation of the results of CSF analysis and differential diagnosis. The main objective of this study was to define age-dependent reference values for CSF glucose, CSF/plasma glucose ratio and CSF lactate for everyday clinical practice. Furthermore, we aimed to determine the correlations between CSF glucose or CSF/plasma glucose ratio and plasma glucose in order to gain a better understanding of the dynamics of glucose transport of glucose into brain under physiological as well as pathological (i.e. hypo- and hyperglycemic) conditions.

Methods

Literature study

We performed an extensive literature search using PubMed for studies on the subject of reference values for CSF glucose, CSF/plasma glucose ratio and CSF lactate by using MeSH terms (cerebrospinal fluid, analysis, glucose, CSF/plasma glucose ratio, lactate, reference value). Furthermore, we studied the relevant references mentioned in the articles.

CSF samples

In September 1993 The Nijmegen Observational CSF was started. Results of all CSF samples that were analyzed at the laboratory of our tertiary referral hospital, the Radboud University Nijmegen Medical Centre in Nijmegen, The Netherlands (www. neurochemistry.nl) were systematically collected and stored in our computerized database. This study was approved by the local Medical Ethical Committee, METC Arnhem – Nijmegen. Since laboratory data had routinely been stored in the hospital database...
and were anonymously processed for the purpose of this study, the METC waived the need for patient informed consent. CSF samples that were analyzed between September 1993 and December 2008 (n = 23,618) were included. To define reference values for glucose and lactate in CSF obtained by lumbar puncture we have excluded (1) all CSF samples from patients from the neuroradiological ward or intensive care units (where CSF is often obtained from ventriculat shunts); and CSF samples with (2) an erythrocyte count ≥200/μL or unknown erythrocyte count; (3) a bilirubin concentration ≥0.5 μmol/L and/or a free hemoglobin concentration ≥0.25 mmol/L; (4) an elevated leucocyte count; or (5) an elevated total protein concentration (Fig. 1). We have used strict exclusion criteria for leucocyte count and total protein concentration based on age-specific reference values as given in figure 1 [9–12]. In a previous study we identified all patients with GLUT1DS in our CSF database (n = 3) [13]. These patients were excluded from the present study. We finally included 9,036 CSF samples for further analyses. Patient population consisted of 49.7% males and 50.3% females. The population was predominantly Caucasian.

CSF glucose was determined in 8,871 CSF samples, CSF/plasma glucose ratio in 4,518 samples and CSF lactate concentrations in 7,614 CSF samples. To determine whether multiple lumbar punctures from the same patient influenced our results, we have in second instance also studied the CSF glucose (n = 7,245) and CSF lactate (n = 6,856) concentrations if only the first CSF sample of each patient was included. In second instance, the 5–95th percentile ranges were determined after exclusion of (1) CSF samples from patients with hypoglycaemia (defined as plasma glucose <3.0 mmol/L), hyperglycaemia (defined as plasma glucose >7.8 mmol/L) or unknown plasma glucose level at the moment of lumbar puncture (Fig. 1); (2) CSF samples with a clearly elevated CSF lactate (arbitrarily defined as >3000 μmol/L).

**CSF analysis**

Lumbar punctures were performed in everyday clinical practice, thus on any time of the day, using standard procedures, and preferably after a ‘fasting’ period of at least 4–6 hours. CSF was collected in polypropylene tubes and was immediately transported after withdrawal to the adjacent laboratory. The CSF samples were analyzed within two hours after sample collection. After cell count, CSF was centrifuged at 860 g at room-temperature and glucose, lactate, total protein and blood pigments concentrations were analyzed the same day.

CSF glucose was measured by the hexokinase method [14]. CSF glucose was measured linearly until 10.9 mM with a limit of detection (LOD) of 0.056 mM, a cients of variation (CV) of <1.6% and a recovery of 97–100%.

The CSF lactate concentration was determined by the enzymatic conversion of NAD into NADH, measured at 340 nm, in the presence of lactate dehydrogenase. CSF lactate was measured linear until 13.32 mM with a LOD of 0.020 mM, cients of variation (CV) <1.2% and a recovery of 98–100%.

Total protein concentration in CSF was determined with the Lowry reaction and absorbance is measured at 720 nm. Lactate, glucose and total protein were analyzed with an automated analyzer (Mira Plus; ABX, Eindhoven, The Netherlands). The laboratory participates in external quality control programs of Instand (Düsseldorf, Germany) for the quality control of the glucose, lactate and total protein analyses. Results are available upon request. CSF erythrocytes and leucocytes count were determined manually in a Fuchs-Rosenthal counting chamber. Assay methods were completely validated if the method was altered during the inclusion period (e.g. change in detection device) and were evaluated according to the QC-system (ISO 15189).

**Plasma glucose analysis**

The allowed time frame for parallel sampling of plasma and CSF was 30 minutes. Glucose was measured in plasma by the hexokinase method [14]. Venous blood was sampled in NaF-EDTA tubes and transported on room temperature.

**Statistical analysis**

Statistical analyses were performed using SPSS version 20.0 (SPSS INC, Chicago, IL, USA). Patients were divided into age groups which are commonly used in daily clinical practice (as used by MeSH, Puhmed) (Table 1). We included all 9,036 CSF samples of which 8,871 samples were studied for CSF glucose, 4,516 samples for CSF/plasma glucose ratio and 7,614 samples for CSF lactate values. Reference values for CSF glucose, CSF/plasma glucose ratio and CSF lactate were based on the 5–95th data-observed percentile ranges. 95% Confidence Intervals were based on Bootstrap Percentiles (based on 1000 bootstrap samples).

**Results**

**Literature study**

Reference ranges for CSF glucose, CSF/plasma glucose ratio and CSF lactate based on studies including large numbers of CSF samples were not available. Most studies had been performed in newborn or young infants and were based on a small number of patients (i.e. <350 patients) and only a few had been performed in patients without an explicit neurological disorder. We have summarized the results of our literature study in Table 2. In all studies CSF glucose was measured by the hexokinase method and CSF lactate was determined enzymatically.

**CSF glucose concentrations**

CSF glucose concentrations were measured in 8,871 out of 9,036 (96%) CSF samples. CSF glucose ranged from 1.0 to 11.9 mmol/L (mean 3.42 mmol/L; SD 0.769). CSF glucose concentrations were age-dependent with remarkably low 5th percentile values until the age of 6 months (1.7–2.0 mmol/L) (Fig. 2A and Table S1). After the age of 6 months the CSF glucose 5th percentile values gradually increased over the entire age range studied (from 2.4 to 2.9 mmol/L). CSF glucose 95th percentile values were highest in neonates (5.6 mmol/L) and lowest in patients aged 3–6 months (3.9 mmol/L) and 3–4 years (3.8 mmol/L). Above the age of 4 years a gradual increase in the CSF glucose 95th percentile was seen (from 4.0 to 6.1 mmol/L). After exclusion of CSF samples from patients with an abnormal or unknown plasma glucose level at the moment of lumbar puncture, the CSF glucose 3rd percentile value did not show a change of >10% of the original value. CSF glucose 95th percentile values, however, did change more than 10% in patients aged 4-5 weeks, 1–12 months and ≥60 years after the application of these exclusion criteria. Numbers were unaffected in the other age groups.

**CSF/plasma glucose ratio**

Plasma glucose was measured in 4,516 out of 9,036 (50%) paired samples and ranged from 0.80 to 40.4 mmol/L (mean 5.5 mmol/L; SD 1.98). An elevated plasma glucose (>7.8 mmol/L) was found in 338 samples (7.5%). Plasma glucose was elevated in 13.5% of the samples from patients older than 50 years of age, compared to 3.7% in samples from patients younger than 50 years
Figure 1. Flow chart of inclusion of CSF samples. N – number of CSF samples.
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Reference Values for CSF Glucose and Lactate

Table 1. Age-specific reference values for CSF glucose, CSF/plasma glucose ratio and CSF lactate.

<table>
<thead>
<tr>
<th>Age</th>
<th>CSF glucose mmol/L</th>
<th>CSF/plasma glucose</th>
<th>CSF lactate mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>0–4 weeks</td>
<td>1.9–5.6</td>
<td>0.42–1.10 (1.38)*</td>
</tr>
<tr>
<td>Infant</td>
<td>4–8 weeks</td>
<td>1.7–5.6 (5.1)*</td>
<td>0.36–1.20</td>
</tr>
<tr>
<td></td>
<td>2–6 months</td>
<td>1.9–4.9 (3.9)*</td>
<td>0.39–1.10</td>
</tr>
<tr>
<td></td>
<td>6–12 months</td>
<td>2.4–4.9 (4.3)*</td>
<td>0.44–1.05</td>
</tr>
<tr>
<td>Toddler</td>
<td>1–3 years</td>
<td>2.4–4.2</td>
<td>0.44–0.84</td>
</tr>
<tr>
<td>Preschool</td>
<td>child</td>
<td>3–4 years</td>
<td>2.4–3.8</td>
</tr>
<tr>
<td>School child</td>
<td>4–10 years</td>
<td>2.5–4.0</td>
<td>0.45–0.84</td>
</tr>
<tr>
<td>(Pre)adolescent</td>
<td>10–18 years</td>
<td>2.6–4.3</td>
<td>0.47–0.83</td>
</tr>
<tr>
<td>Young adult</td>
<td>18–30 years</td>
<td>2.7–4.4</td>
<td>0.46–0.90</td>
</tr>
<tr>
<td>Adult</td>
<td>30–50 years</td>
<td>2.8–4.4</td>
<td>0.46–0.88</td>
</tr>
<tr>
<td>Middle aged</td>
<td>50–60 years</td>
<td>2.8–4.2 (4.8)*</td>
<td>(0.43) 0.48–0.87*</td>
</tr>
<tr>
<td>Aged</td>
<td>60–80 years</td>
<td>2.9–4.4 (5.6)*</td>
<td>(0.42) 0.46–0.84*</td>
</tr>
<tr>
<td>≥80 years</td>
<td>2.9–4.5 (6.1)*</td>
<td>(0.35) 0.42–0.81*</td>
<td>1.4–2.7</td>
</tr>
</tbody>
</table>

Reference values are based on the 5th to 95th percentile values. The subgroups from the original data (see Tables S1,S2,S3) were clustered into age groups which are commonly used in daily clinical practice (as used by MeSH, Pubmed).

*Reference range after exclusion of CSF samples of patients with an unknown or abnormal plasma glucose (<3.0 mmol/L or >7.8 mmol/L) at the moment of lumbar puncture (only represented if >10% different from to the original value). Numbers between brackets represent values without correction for plasma glucose.

†Reference range after exclusion of CSF samples with CSF lactate >3000 μmol/L (only represented if >10% different from the original value). Number between brackets represents upper limit without exclusion of CSF samples with CSF lactate >3000 μmol/L.

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of age. A lowered plasma glucose (defined as <3.0 mmol/L) was found in 24 samples (0.5%) of patients aged 0–78 years (mean 19.4 years; SD 22.9).

The CSF/plasma glucose ratio is described in Fig. 2B and Table S2. CSF/plasma glucose ratio ranged from 0.17 to 2.03 (mean 0.65; SD 0.14). Low CSF/plasma glucose ratio 5th percentile values were seen below the age of 6 months (0.36–0.42) and in children aged 3–4 years (0.43) compared to neighboring age groups. Above the age of 4 years the CSF/plasma glucose 5th percentile values decreased gradually from 0.44 to 0.46 until the age of 40 years, with a continuous decrease afterwards to 0.35. CSF/plasma glucose ratio 95th percentile values were high in patients below the age of 12 months (1.03–1.38).

After exclusion of CSF samples from patients with abnormal (defined as >7.8 mmol/L or <3.0 mmol/L) or unknown plasma glucose level, CSF/plasma glucose ratio 95th percentile values were >10% lower compared to the original value in patients below the age of 4 weeks, whereas >10% higher 5th percentile values were found in patients older than 50 years of age. Numbers were unaffectate for the non-Caucasians.

CSF lactate concentrations

CSF lactate concentrations were measured in 7,614 out of 9,036 (84%) CSF samples. CSF lactate ranged from 0.16 to 12.5 mmol/L (mean 1.7; SD 0.48). CSF lactate showed a clear age-dependent pattern (Fig. 2C and Table S3). CSF lactate 5th percentile concentrations were, like CSF glucose, remarkably low in (young) children (0.86–1.14 mmol/L) and increased with age. CSF lactate 95th percentile values were particularly high in neonates (3.4 mmol/L) and low in children aged 6 months to 10 years (2.0–2.1 mmol/L). After the age of 18 years a gradual increase of the 95th percentile value was seen from 2.2 to 2.7 mmol/L. Exclusion of CSF samples with a CSF lactate value of >3000 μmol/L did not lead to a change of >10% of the original value of the 5th of 95th percentile value, except in patients under the age of 4 weeks and in patients aged 3–6 months.

Age-specific reference values

If multiple CSF samples from the same patient were excluded and only the first CSF sample of each patient was included, the 5th and 95th percentile ranges for CSF glucose (n = 7,245), CSF/plasma glucose ratio (n = 3,862) and CSF lactate (n = 6,856) values did not change >10% compared to the original value. Age-specific reference values were therefore based on the 5th and 95th percentile ranges of all CSF samples (8,871 CSF samples for CSF glucose; 4,516 samples for CSF/plasma glucose ratio and 7,614 samples for CSF lactate) (Table 1). Reference ranges for CSF glucose, CSF/plasma glucose ratio and CSF lactate did not differ between males and females.

Relation between plasma glucose, CSF glucose and CSF/plasma glucose ratio

A linear relation between plasma glucose and CSF glucose was found (Figure 3A). Hypoglycemia was associated with an increased CSF/plasma glucose ratio in most patients, whereas hyperglycemia was associated with only a minimal decrease of the CSF/plasma glucose ratio in the majority of the samples (Figure 3B).

Discussion

Our study allowed for the first time to define age-specific reference values for CSF glucose, CSF lactate and CSF/plasma glucose for children and adults based on a large number of CSF samples. Reference ranges did not differ between males and females, which is in line with previous findings [15]. To our best knowledge, no studies are available reporting differences in CSF glucose or lactate based on race. We therefore believe that our data, mainly based on CSF samples from Caucasians, can be generalized to non-Caucasians.
Table 2. Summary of literature search for reference ranges of CSF glucose, CSF/plasma glucose ratio and CSF lactate.

<table>
<thead>
<tr>
<th>Reference</th>
<th>N</th>
<th>Inclusion criteria</th>
<th>Age</th>
<th>CSF glucose concentration (mmol/L)</th>
<th>CSF/plasma glucose</th>
<th>CSF lactate concentration (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knight et al., 1981</td>
<td>314</td>
<td>Healthy children</td>
<td>1 wk–16 yrs</td>
<td>Mean: 3.63; P2.5–97.5: 2.56–5.54</td>
<td>2.72–4.54</td>
<td>Mean: 1.75; P2.5–97.5: 0.98–3.17</td>
</tr>
<tr>
<td>Vamosi et al., 1983</td>
<td>144</td>
<td>Cisternal CSF specimens of fasted adults free from organic brain disease</td>
<td>16–69 yrs</td>
<td>-</td>
<td>-</td>
<td>Mean ± 2SD: 0.68–2.1</td>
</tr>
<tr>
<td>Ahmed et al., 1992</td>
<td>108</td>
<td>Noninfected term neonates</td>
<td>0–30 dys</td>
<td>Mean ± SD: 2.8±0.7</td>
<td>1.65–3.95</td>
<td>Mean: 0.62</td>
</tr>
<tr>
<td>Bonadio et al., 1992</td>
<td>75</td>
<td>Term febrile infants with negative cultures</td>
<td>0–8 wks</td>
<td>Mean ± SD: 2.56±0.56</td>
<td>1.64–3.48</td>
<td>-</td>
</tr>
<tr>
<td>Cameron et al., 1993</td>
<td>100</td>
<td>Children with normal CSF glucose, protein and cell count</td>
<td>Children (not further specified)</td>
<td>Range: 3.3–5.5</td>
<td>-</td>
<td>Range: 0.5–3.2</td>
</tr>
<tr>
<td>Benoist et al., 2003</td>
<td>197</td>
<td>Hospitalized children</td>
<td>0–15 yrs</td>
<td>-</td>
<td>-</td>
<td>Median: 1.5; SD 0.255 Range: 0.6–2.2</td>
</tr>
</tbody>
</table>

N - number of CSF samples included in study; wk(s) – week(s); dys – days; yrs – years; P – percentile.

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Since it seems impossible to obtain CSF from healthy volunteers (especially children) under standardized conditions (e.g., after fasting), we included CSF samples from our computerized database of patients with a medical indication for a lumbar puncture, which reflects the daily clinical practice. Because of the large number of samples it was not feasible to obtain clinical information from the patients. In order to exclude as many as possible CSF samples of patients with overt neurological disorders, we have therefore used strict exclusion criteria based on other CSF parameters (Fig. 1). Furthermore, since the concentrations of CSF glucose and CSF lactate in ventricular CSF differ from lumbar CSF values, we have excluded all ventricular CSF samples.

The reference range for CSF glucose is generally set at 2.5–4.4 mmol/L, but ranges with a lower limit of 2.0 mmol/L or an upper limit of 6.5 mmol/L are used as well [1,16]. We found an age-dependent pattern for CSF glucose with 5th percentile values ranging from 1.7 to 2.9 mmol/L and 95th percentile values from 4.5 to 5.6 mmol/L. Age-dependency of CSF glucose had been described before in children [17]. CSF glucose 5th percentile values were remarkably low until the age of 6 months (1.7–2.0 mmol/L), which is in line with previous studies [9,18] (Table 2). The 95th percentile value in our study was especially high in neonates (3.6 mmol/L), which is higher than previously
described (3.5–4.0 mmol/L) [18]. Low CSF glucose 5th percentile values and high 95th percentile values in neonates in our study might be related to the high frequency of hypoglycemia and hyperglycemia in neonates, especially in preterm infants and neonates with a low birth weight [19,20]. After exclusion of CSF samples from patients with abnormal or unknown plasma glucose the 95th percentile values in infants aged 4 to 8 weeks and 3 to 12 months increased more than 10% compared to the original value. This was due to a skewed distribution most likely caused by the low number of CSF samples in these subgroups after exclusion of samples with abnormal or unknown CSF glucose (Table S2).

CSF glucose 3–95th percentile values were relatively high in patients older than 50 years of age. This was probably related to the increasing frequency of hyperglycemia in patients aged 50 years and older (13.5% compared to 3.7% in patients younger than 50 years of age). In a study comparing the CSF/blood glucose ratio from patients with diabetes mellitus and noninflammatory neurological conditions with patients with bacterial meningitis, the CSF glucose ranged from 2.78 to 25 mmol/L in patients with diabetes, with CSF/blood glucose ratio ranging from 0.20–3.46 [21]. To our best knowledge no studies are available on CSF glucose and lactate values in patients with diabetes without neurological disorders. In order to correct the reference range for CSF glucose and CSF/ plasma glucose ratio for patients with abnormal plasma glucose, we have in second instance excluded all patients with abnormal (defined as >7.8 mmol/L or <3.0 mmol/L) or unknown plasma glucose. Reference ranges for CSF glucose before and after correction for plasma glucose are described in Table 1.

The reference value for CSF/plasma glucose ratio is typically about 0.6 and is generally set at 0.5–0.8 [15]. Our study confirms this reference range, although a slight age-dependent pattern for CSF/plasma glucose ratio was found. Below the age of 12 months the 95th percentile values in infants aged 4 to 8 weeks and 3 to 12 months increased more than 10% compared to the original value. Numbers and CSF/blood glucose values in these subgroups after exclusion of CSF samples with hypoglycemia (blood glucose <3.0 mmol/L), hyperglycemia (blood glucose >7.8 mmol/L), or unknown blood glucose at the moment of lumbar puncture (only shown if >10% different from the original value).

Supporting Information

Table S1 N (total) – total number of CSF samples. N – number of CSF samples with measured CSF glucose concentration. 95% CI – 95% Confidence Interval based on Bootstrap Percentiles (based on 1000 bootstrap samples). Numbers and CSF glucose concentrations between brackets represent the results after exclusion of CSF samples with hypoglycemia (blood glucose <3.0 mmol/L), hyperglycemia (blood glucose >7.8 mmol/L), or unknown blood glucose at the moment of lumbar puncture (only shown if >10% different from the original value).

Table S2 N (total) – total number of CSF samples. N – number of CSF samples with measured CSF glucose concentration. 95% CI – 95% Confidence Interval based on Bootstrap Percentiles (based on 1000 bootstrap samples).* Sample size too small for bootstrapping. Numbers and CSF/blood glucose values between brackets represent the results after exclusion of CSF samples with hypoglycemia (blood glucose <3.0 mmol/L), hyperglycemia (blood glucose >7.8 mmol/L), or unknown blood glucose at the moment of lumbar puncture (only shown if >10% different from the original value).
Table S3  N (total) – total number of CSF samples. N – number of CSF samples with measured CSF glucose concentration. 95% CI – 95% Confidence Interval based on Bootstrap Percentiles (based on 1000 bootstrap samples). Numbers and CSF lactate concentrations between brackets represent the results after exclusion of CSF samples with CSF lactate >3000 μmol/L (only shown if >10% different from the original value).

Author Contributions
Conceived and designed the experiments: WGL MAW RAW MMV. Performed the experiments: MMV. Analyzed the data: WGL. Contributed reagents/materials/analysis tools: MMV. Wrote the paper: WGL. Interpretation of data: WGL MAW RAW MMV. Revising of the article for intellectual content: WGL MAW RAW MMV.

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