Bile bilirubin pigment analysis in disorders of bilirubin metabolism in early infancy

W S Lee, P J McKiernan, S V Beath, M A Preece, D Baty, D A Kelly, B Burchell, D J Clarke

Abstract

Background—Early and accurate diagnosis of Crigler–Najjar syndrome, which causes prolonged unconjugated hyperbilirubinaemia in infancy, is important, as orthotopic liver transplantation is the definitive treatment.

Aim—To determine whether bilirubin pigment analysis of bile in infants with prolonged unconjugated hyperbilirubinaemia provides useful diagnostic information in the first 3 months of life.

Methods—Retrospective review of patients with prolonged unconjugated hyperbilirubinaemia referred to the liver unit, Birmingham Children’s Hospital, for the diagnosis of Crigler–Najjar syndrome. Bile bilirubin pigment composition was determined by high performance liquid chromatography. Initial diagnoses were made based on the result of bile pigment composition analysis. Final diagnoses were made after reviewing the clinical course, response to phenobarbitone, repeat bile bilirubin pigment composition analysis, and genetic studies.

Results—Between 1992 and 1999, nine infants aged less than 3 months of age with prolonged hyperbilirubinaemia underwent bile bilirubin pigment analyses. Based on these, two children were diagnosed with Crigler–Najjar syndrome (CNS) type 1, six with CNS type 2, and one with Gilbert’s syndrome. Five children whose initial diagnosis was CNS type 2 had resolution of jaundice and normalisation of serum bilirubin after discontinuing phenobarbitone, and these cases were thought to be normal or to have Gilbert’s syndrome. One of the initial cases of CNS type 1 responded to phenobarbitone with an 80% reduction in serum bilirubin consistent with CNS type 2. In all, the diagnoses of six cases needed to be reviewed.

Conclusions—Early bile pigment analysis, performed during the first 3 months of life, often shows high levels of unconjugated bilirubin or bilirubin monoconjugates, leading to the incorrect diagnosis of both type 1 and type 2 Crigler–Najjar syndrome.

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Keywords: bile; bilirubin pigment analysis; Crigler–Najjar syndrome; Gilbert’s syndrome

Unconjugated hyperbilirubinaemia is an important problem in the neonatal period. Common causes include physiological jaundice, breast milk jaundice, overproduction (that is, polycythaemia), systemic disease (congenital hypothyroidism, sepsis), and inherited disorders of bilirubin metabolism. These latter include Crigler–Najjar syndrome (CNS) types 1 and 2—caused by a deficiency of hepatic uridine diphosphate glucuronyl transferase (UGT) and characterised by high serum levels of unconjugated bilirubin that appear in the first few days after birth—and Gilbert’s syndrome.

Accurate diagnosis of Crigler–Najjar syndrome is important because of the implications for prognosis and treatment. Treatment of CNS type 1 consists of the aggressive use of measures to remove bilirubin (either phototherapy or exchange transfusion), while liver transplantation is the definitive treatment. The major differentiating characteristic between the two types of Crigler–Najjar syndrome is the response to drugs that induce activity of cytochrome P450 enzymes. Phenobarbitone (phenobarbital) causes a significant decline in the serum bilirubin of patients with type 2 disease, with increased hepatic clearance of radiolabelled bilirubin and increased biliary levels of bilirubin diglucuronides. However, differentiating Crigler–Najjar syndrome type 1 from type 2 solely on the basis of response to phenobarbitalone can sometimes be misleading. Differentiation using bile bilirubin pigment analysis has been recommended.

In CNS type 1, duodenal bile is practically devoid of bilirubin conjugates. In CNS type 2, bilirubin monoglucuronides are present and some diglucuronides may be detectable during treatment with phenobarbitone.

In Gilbert’s syndrome, bilirubin diglucuronides are the predominant pigment.

The timing of the duodenal aspirate is important. Subsequent management and prognosis depend on an accurate diagnosis, and clinicians are often under pressure to make an early diagnosis. We have reviewed the eventual outcome of children who had bile bilirubin pigment analysis undertaken in early infancy, in order to determine whether early pigment analysis provides useful diagnostic information.

Methods

We reviewed retrospectively those infants with severe neonatal unconjugated hyperbilirubinaemia who were referred to the liver unit, Birmingham Children’s Hospital, between
1992 and 1999. Common causes of prolonged unconjugated hyperbilirubinemia were excluded by the referring clinicians. Basic demographic data, family history, onset of jaundice, peak serum bilirubin, and clinical response to phenobarbitone treatment were obtained from the case notes. Abdominal ultrasound and liver biopsies were performed when clinically indicated. The final diagnosis was made on the basis of a combination of results of bile bilirubin pigment analysis, genetic studies, clinical course, and response to phenobarbitone.

COLLECTION OF BILE AND BIOCHEMICAL ANALYSES

Phototherapy was suspended at least 24 hours before the collection of bile pigment. Bile was collected during upper gastrointestinal endoscopy. The secretion of bile into the duodenum was facilitated by intravenous injection of 1–2 units/kg of cholecystokinin, and 2–5 ml of bile were extracted from the duodenum. The bile aspirates obtained were immediately shielded from light, frozen with liquid nitrogen, and stored at −80°C. The bilirubin pigment composition of the bile was determined by high performance liquid chromatography (HPLC) analysis of native tetraptrolyles of unconjugated bilirubin and bilirubin glucuronides at the department of molecular and cellular pathology, Ninewells Hospital, Dundee, Scotland, and the Division of Biological Sciences, University of Huddersfield, England, as previously described. The reference ranges of bile bilirubin pigments for normal subjects were: unconjugated 0–2%, monoglucuronides 7–16%, diglucuronides 79–91%. Analysis showed that exposure of bile samples to the light source used during the endoscopy procedure had no significant effect on the measured composition of bilirubin pigments (Clarke DJ, Burchell B, unpublished data). Initial diagnosis of Crigler–Najjar syndrome type 1 or type 2 or Gilbert’s syndrome was made according to the bile bilirubin pigment composition. The three Asians infants were born to consanguineous parents.

GENETIC STUDIES

Genetic studies for Crigler–Najjar syndrome and Gilbert’s syndrome were performed as previously described. Whole blood was obtained and DNA extracted. A homozygosity for a (TA)7TAA (TA7/T7A) has been associated with Gilbert’s syndrome. Crigler–Najjar syndrome types 1 and 2 were diagnosed when there was homozygosity or double heterozygosity for known mutations.

RESULTS

During the period of 1992 to 1999, nine infants aged less than 3 months with severe unconjugated hyperbilirubinemia were referred to the hepatology unit, Birmingham Children’s Hospital, for further diagnosis. There were five boys and four girls. Eight were delivered at term, while case No 6 was delivered at 36 weeks. Six were white (Europid) and three were born to consanguineous Asian parents originating from the Indian subcontinent. There was no family history of severe neonatal jaundice.

All infants had onset of severe jaundice within first week of life (median 3 days). The peak serum bilirubin ranged from 300 to 650 µmol/l (median 396 µmol/l). All required phototherapy, while case No 8 had double exchange transfusions. Four cases (cases 2, 6, 7, and 9) were started on phenobarbitone at 5 mg/kg body weight by their referring clinicians. Five cases were breast fed (cases 3, 4, 5, 7, and 8). Case 5 had an atrioventricular septal defect. Three cases (cases 1, 2, and 3) had liver biopsy as part of the diagnostic workup. All were reported as normal histologically.

BILIE BILIRUBIN PIGMENT ANALYSIS

The bile bilirubin pigment analyses were performed between ages of 10 and 58 days (median 25 days) (table 1). Based on the results of analyses (first analysis in case 3), there were two infants with CNS type 1, six with CNS type 2, and one with Gilbert’s syndrome. Case No 3 had two analyses. The second analysis was carried out seven months after the first, while the patient was treated with phenobarbitone and when the serum bilirubin

Table 1  Demographic data, peak serum bilirubin, and results of bile bilirubin pigment analysis in nine children with prolonged and severe unconjugated hyperbilirubinemia

<table>
<thead>
<tr>
<th>Case No</th>
<th>Sex</th>
<th>Ethnicity*</th>
<th>Onset of jaundice (days)</th>
<th>Peak SB (µmol/l)</th>
<th>Conjugated SB (µmol/l)</th>
<th>UC bilirubin (µmol/l)</th>
<th>Age of bile analysis (days)</th>
<th>PB</th>
<th>UC (%) (0–2)†</th>
<th>MC (%) (7–16†)</th>
<th>DC (%) (29–91†)</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>European 1</td>
<td>431</td>
<td>0</td>
<td>431</td>
<td>19</td>
<td>1</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>CNS 1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>European 4</td>
<td>396</td>
<td>2</td>
<td>394</td>
<td>38</td>
<td>+ 1</td>
<td>19</td>
<td>81</td>
<td>0</td>
<td>CNS 2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>Asian 3</td>
<td>650</td>
<td>10</td>
<td>640</td>
<td>25</td>
<td>8</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>CNS 1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>European 2</td>
<td>300</td>
<td>0</td>
<td>300</td>
<td>25</td>
<td>8</td>
<td>2</td>
<td>34</td>
<td>64</td>
<td>Gilbert</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>Asian 1</td>
<td>456</td>
<td>20</td>
<td>436</td>
<td>18</td>
<td>-</td>
<td>36</td>
<td>57</td>
<td>7</td>
<td>CNS 2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>European 6</td>
<td>390</td>
<td>10</td>
<td>380</td>
<td>33</td>
<td>+ 4</td>
<td>64</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>European 2</td>
<td>320</td>
<td>58</td>
<td></td>
<td>58</td>
<td>2</td>
<td>25</td>
<td>46</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>European 5</td>
<td>&gt;500</td>
<td>0</td>
<td>&gt;500</td>
<td>10</td>
<td>-</td>
<td>20</td>
<td>53</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>Asian 4</td>
<td>389</td>
<td>19</td>
<td>380</td>
<td>41</td>
<td>+ 4</td>
<td>43</td>
<td>26</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>European 5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>-</td>
<td>1</td>
<td>18</td>
<td>82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>European 2–3 y</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>4</td>
<td>18</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>European 5</td>
<td>403</td>
<td>20</td>
<td>383</td>
<td>13</td>
<td>+ 14</td>
<td>80</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>European 16 y</td>
<td>63</td>
<td>21</td>
<td>52</td>
<td>16</td>
<td>-</td>
<td>12</td>
<td>70</td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The three Asians infants were born to consanguineous parents.
†Reference range for normal individuals (Clarke DJ, Burchell B, unpublished data).
‡Diagnoses based on analysis of bile bilirubin pigments.
CNS 1, Crigler–Najjar type 1; CNS 2: Crigler–Najjar type 2; DC, bilirubin diglucuronides; m, months; MC, bilirubin monoglucuronides; PB, phenobarbitone treatment during bile bilirubin analysis (+, on phenobarbitone, –, not on phenobarbitone); SB, serum bilirubin; UC, unconjugated; y, years.
had fallen to 80 µmol/l. There was a marked reduction in the unconjugated bilirubin with a substantial increase in the monoglucuronides. For comparison, the results of bile bilirubin pigment analysis of four patients older than 3 months, who were referred to the liver unit for investigations of the underlying cause of jaundice, are also shown in table 1. Cases 10 and 11 were investigated for intermittent jaundice, with a clinical diagnosis of Gilbert’s syndrome. Case 12 was diagnosed clinically as CNS type 2, with persistent jaundice. The serum bilirubin was 150 µmol/l, mainly unconjugated while on phenobarbitone. Case 13 was first noticed to be jaundiced at the age of 16, after an episode of acute gastroenteritis. The serum bilirubin was 150 µmol/l, mainly unconjugated while on phenobarbitone. In addition, both case 8 and case 9 had negative genetic studies for the Crigler–Najjar syndrome mutation and Gilbert’s syndrome (TA6/TA6, which is not associated with Gilbert’s syndrome). They have all had normal serum bilirubin since discontinuation of phenobarbitone. Following treatment with phenobarbitone. The diagnosis was thought to be physiological jaundice or Gilbert’s syndrome. In contrast, in all the four cases who had bile bilirubin pigment analysis done after 3 months of age, the diagnosis that was made on the basis of the results of bile bilirubin pigment analysis concurred with the clinical diagnosis.

**Discussion**

The diagnosis of Crigler–Najjar syndrome types 1 and 2 and Gilbert’s syndrome can usually be made from a combination of response to phenobarbitone, bile bilirubin pigment analysis, and genetic studies. In vitro measurement of UGT activity in liver biopsy tissue to differentiate CNS type 1 from CNS type 2 is complex and not routinely available. Phenobarbitone treatment reduces serum bilirubin by 26% or more in CNS type 2, while no reduction occurs in type 1. However, there are some exceptions to this observation, and in addition, the reduction in serum bilirubin may not be apparent within a few months after starting treatment. Sinaasappel et al performed bile bilirubin pigment analysis in nine patients with Crigler–Najjar syndrome (four type 1 and five type 2), aged between 1 and 18 years, and concluded that the two types could be differentiated on

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**Table 2 Initial diagnosis, response to phenobarbitone, genetic studies, and final diagnosis**

<table>
<thead>
<tr>
<th>Case</th>
<th>Initial diagnosis</th>
<th>Response to PB</th>
<th>Genetic studies</th>
<th>Follow up and outcome</th>
<th>Final diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CNS 1</td>
<td>None</td>
<td>Phototherapy 10 h/day, awaiting liver transplant</td>
<td></td>
<td>CNS 1</td>
</tr>
<tr>
<td>2</td>
<td>CNS 2</td>
<td>Good</td>
<td>On PB; SB 78-139 µmol/l</td>
<td></td>
<td>CNS 2</td>
</tr>
<tr>
<td>3</td>
<td>CNS 1</td>
<td>Good</td>
<td>Phototherapy discontinued at 1 year; SB 90-110 µmol/l while on PB</td>
<td></td>
<td>CNS 2</td>
</tr>
<tr>
<td>4</td>
<td>Gilbert</td>
<td>Good</td>
<td>PB for 1 week; SB 33 µmol/l while not on PB</td>
<td></td>
<td>Gilbert</td>
</tr>
<tr>
<td>5</td>
<td>CNS 2</td>
<td>Good</td>
<td>Not on PB; SB 9 µmol/l</td>
<td></td>
<td>Gilbert/normal?</td>
</tr>
<tr>
<td>6</td>
<td>CNS 2</td>
<td>Good</td>
<td>SB normalised after stopping PB</td>
<td></td>
<td>Gilbert/normal?</td>
</tr>
<tr>
<td>7</td>
<td>CNS 2</td>
<td>Good</td>
<td>PB x 14; SB 17 µmol/l 3 months after discontinuing PB</td>
<td></td>
<td>Gilbert/normal?</td>
</tr>
<tr>
<td>8</td>
<td>CNS 2</td>
<td>Good</td>
<td>&quot;TA6/TA6 after discontinuing PB&quot;</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>9</td>
<td>CNS 2</td>
<td>Good</td>
<td>Clinically not jaundiced, not on PB</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>10</td>
<td>CNS 2</td>
<td>Good</td>
<td>Not on PB</td>
<td></td>
<td>Gilbert</td>
</tr>
<tr>
<td>11</td>
<td>CNS 2</td>
<td>Good</td>
<td>Not on PB</td>
<td></td>
<td>Gilbert</td>
</tr>
<tr>
<td>12</td>
<td>CNS 2</td>
<td>Good</td>
<td>On PB, SB 150 µmol/l</td>
<td></td>
<td>CNS 2</td>
</tr>
<tr>
<td>13</td>
<td>Gilbert</td>
<td></td>
<td>Not on PB</td>
<td></td>
<td>Gilbert</td>
</tr>
</tbody>
</table>

*Double heterozygous: G→C mutation at nucleotide 923 of exon 2 of UGT1A1, and T residue deletion at nucleotide 1221 at exon 4.*

*Heterozygous for C→T mutation at nucleotide 625 of exon 1 of UGT1A1.*

*Negative for CNS mutation in addition to homozygous TA6/TA6, which is not associated with Gilbert’s syndrome.*

*Father, paternal grandmother, and uncle have TA7/TA7, which has been associated with Gilbert’s syndrome.*

CNS 1, Crigler–Najjar syndrome type 1; CNS 2, Crigler–Najjar syndrome type 2; PB, phenobarbitone; SB, serum bilirubin.
In a recent study, we observed that while bile aspirate for bilirubin pigment analysis is performed in early infancy, the effect of maturation of UGT needed to be considered. Ciotti et al observed a delayed response to phenobarbitone in a child with CNS type 2, who was initially diagnosed as type 1 because of non-response to phenobarbitone for the first 7 months of life. They attributed such delay to a simple developmental phenomenon, causing slow development of the secondary structural changes necessary for UGT activity. Such a developmental phenomenon could explain the observations made in this study that bile bilirubin pigment analysis performed early in life showed low levels of unconjugated bilirubin and monoglucuronones in the bile because of relatively low activity of the enzyme UGT. With maturation and the introduction of phenobarbitone, the process of glucuronidation increased and the serum bilirubin fell. Rubaltelli et al observed that with phenobarbitone treatment there was an absolute increase in the monoglucuronide concentration but not the diglucuronide concentration in the bile. We observed that in case 3, after phenobarbitone treatment, there was a significant increase in both the mono- and diglucuronides in the bile.

In has been shown convincingly that mutations in the UGT1 gene—the gene locus encoding the enzyme UGT in patients with CNS type 1—are responsible for abolishing the hepatic UGT activity in vitro in COS cells. Mutation analysis for both Crigler–Najjar syndrome and Gilbert's syndrome is now available. This is useful for confirmation of the clinical diagnosis and for genetic counselling, but is complicated and not routinely available. The only CNS type 1 case in this series was shown to be a homozygous of TA6/TA6, which is not associated with Gilbert's syndrome. As a result of this study, we subsequently reviewed the policy of investigating children with prolonged unconjugated hyperbilirubinaemia. The protocol has been revised to avoid performing bile bilirubin pigment analysis too early and thereby overdiagnosing Crigler–Najjar syndrome types 1 and 2. After excluding other more common causes of unconjugated hyperbilirubinaemia, a therapeutic trial of phenobarbitone at a dose of 5 mg/kg body weight should be started while continuing phototherapy if necessary (fig 1). Such patients

**Figure 1.** Proposed schematic investigation of prolonged unconjugated hyperbilirubinaemia. SB, serum bilirubin.
should then be repeatedly reviewed; if by 3 months of age there is persistent elevation of unconjugated serum bilirubin, vigorous treatment with phototherapy and phenobarbitone should be continued. Bile bilirubin pigment analysis should be delayed until after 3 months of age. Although genetic studies may be useful, currently they are complex to perform and not routinely available, but they can be done if there is a particular concern.

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