ORIGINAL ARTICLE

Validation of transcutaneous bilirubin nomogram for identifying neonatal hyperbilirubinemia in healthy Chinese term and late-preterm infants: a multicenter study

Zhangbin Yu\textsuperscript{a}, Shuping Han\textsuperscript{a}, Jinxia Wu\textsuperscript{b}, Mingxia Li\textsuperscript{c}, Huaiyan Wang\textsuperscript{d}, Jimei Wang\textsuperscript{e}, Jiebo Liu\textsuperscript{f}, Xinnian Pan\textsuperscript{g}, Jie Yang\textsuperscript{h}, Chao Chen\textsuperscript{i,*}

\textsuperscript{a} Department of Pediatrics, Nanjing Maternity and Child Health Care Hospital of Nanjing Medical University, Nanjing, China
\textsuperscript{b} Department of Neonatology, Inner Mongolia Maternal and Child Health Care Hospital, Huhehot, China
\textsuperscript{c} Department of Neonatology, The First Affiliated Hospital of Xinjiang Medical University, Urumqi, China
\textsuperscript{d} Department of Neonatology, Changzhou Maternal and Child Health Care Hospital, Changzhou, China
\textsuperscript{e} Department of Neonatology, Gynecology and Obstetrics Hospital, Fudan University, Shanghai, China
\textsuperscript{f} Department of Pediatrics, The Fifth People’s Hospital of Shenzhen, Shenzhen, China
\textsuperscript{g} Department of Neonatology, Guangxi Maternal and Child Health Care Hospital, Nanning, China
\textsuperscript{h} Department of Neonatology, Guangdong Maternal and Children’s Hospital, Guangzhou Medical College, Guangzhou, China
\textsuperscript{i} Department of Neonatology, Children’s Hospital of Fudan University, Shanghai, China

Received 18 July 2013; accepted 20 August 2013
Available online 5 February 2014

KEYWORDS
Hyperbilirubinemia; Jaundice; Neonatal; Bilirubin; Newborn

Abstract
Objective: to prospectively validate a previously constructed transcutaneous bilirubin (TcB) nomogram for identifying severe hyperbilirubinemia in healthy Chinese term and late-preterm infants.

Methods: this was a multicenter study that included 9,174 healthy term and late-preterm infants in eight hospitals of China. TcB measurements were performed using a JM-103 bilirubinometer. TcB values were plotted on a previously developed TcB nomogram, to identify the predictive ability for subsequent significant hyperbilirubinemia.

Results: in the present study, 972 neonates (10.6%) developed significant hyperbilirubinemia. The 40\textsuperscript{th} percentile of the nomogram could identify all neonates who were at risk of significant hyperbilirubinemia, but with a low positive predictive value (PPV) (18.9%). Of the 453 neonates above the 95\textsuperscript{th} percentile, 275 subsequently developed significant hyperbilirubinemia, with a high PPV (60.7%), but with low sensitivity (28.3%). The 75\textsuperscript{th} percentile was highly specific (81.9%) and moderately sensitive (79.8%). The area under the curve (AUC) for the TcB nomogram was 0.875.

\textsuperscript{*} Corresponding author.
E-mail: chen6010@163.com (C. Chen).

0021-7557 © 2014 Sociedade Brasileira de Pediatria. Published by Elsevier Editora Ltda. Este é um artigo Open Access sob a licença de CC BY-NC-ND
http://dx.doi.org/10.1016/j.jped.2013.08.013
Introduction

Hyperbilirubinemia causes severe damage in term and late-preterm infants; the American Academy of Pediatrics (AAP) has formulated methods of surveillance, prediction, and therapy. In China, bilirubin encephalopathy continues to occur, and 348 cases were reported from 28 hospitals from January to December of 2009. Therefore, the identification of neonates at risk of developing significant hyperbilirubinemia and prevention of bilirubin encephalopathy remain a high priority among public health institutions.

The total serum bilirubin (TSB) level after birth was plotted on an hour-specific nomogram by Bhutani et al., and is a valuable method for assessing the risk of subsequent severe hyperbilirubinemia. The AAP has recommended the measurement of TSB in a predischarge newborn population for identification of severe hyperbilirubinemia, based on the Bhutani’s nomogram. However, measurements of TSB levels remain an invasive, stressful, and time-consuming procedure. Transcutaneous bilirubin (TcB) is less time-consuming, and can be used to screen for the need for blood sampling for serum bilirubin level, and thus reduce the measurements of TSB. The values of TcB after birth have also been plotted on an hour-specific TcB nomogram to predict severe hyperbilirubinemia in term and late-preterm infants. These hour-specific TcB nomograms assessed pre-test predictive ability using retrospective data from the same developed TcB nomogram. Theoretically, a predictive nomogram should be developed in one sample and validated in another, and some studies prospectively assessed the post-test predictivity of TcB nomograms in different samples. The after-effect evaluation of the constructed TcB nomogram is very important to explore the possibility for future clinical application.

In 2010, the authors developed an hour-specific TcB nomogram based on TcB levels for the first 168 h after birth in 6,035 healthy term and late-preterm infants. Subsequently, they have conducted a multicenter study to verify the predictive value of the constructed TcB nomogram to identify severe hyperbilirubinemia in healthy term and late-preterm infants.

Methods

Setting

Eight hospitals, including two general hospitals and six maternity hospitals, participated in the study. They were selected because they are the main tertiary centers in...
their areas and because they agreed to participate in this study. The Ethics Committee of the Nanjing Maternity and Child Healthcare Hospital of the Nanjing Medical University approved the study and it was adopted by each participating center. The Nanjing Maternity and Child Healthcare Hospital of the Nanjing Medical University performed the statistical analysis of the collaborative data. The Children’s Hospital of Fudan University did not participate in this survey, but served as a coordinating center and supervised the study.

Selection of participants

This multicenter prospective study was conducted between August 1, 2010, and December 31, 2011. Neonates with gestational age (GA) ≥ 35 weeks and birth weight ≥ 2,000 g were included, and all sick neonates who were admitted to the intensive care unit and those who required phototherapy before discharge were excluded. The decision to use phototherapy was made by the attending physicians according to AAP guidelines. No prophylactic intervention for hyperbilirubinemia was used.

Measurements of TcB and TSB

TcB measurements were performed with a transcutaneous jaundice meter model JM-103 (Minolta - Osaka, Japan). A single device was used for all measurements in each participating unit. All measurements were performed by trained physicians according to the instructions of the manufacturer and using the standard technique. The physicians obtained TcB measurements, which were performed at two sites (the forehead and mid-sternum), and the mean of both measurements was calculated. According to previous studies, the JM-103 is less accurate at TcB levels > 222 μmol/L, which were confirmed with a TSB measurement. The blood samples (50 μL) were drawn by heel stick, and special care was taken to avoid exposure of the collected samples to light. TSB assessment was performed in the clinical chemistry laboratory of each participating unit. Skilled physicians performed the TSB measurements using a UNISTAT reflectance bilirubinometer (Reichert-Jung - Buffalo, NY, USA), according to the manufacturer’s instructions. Significant hyperbilirubinemia was defined as TSB above the 95th percentile for age (high-risk zone), according to the hour-specific percentile nomogram presented by the AAP guidelines.

Follow-up of studied neonates

In each participating unit, the physicians obtained TcB measurements between 7:30 a.m. and 8:00 p.m., and then at time intervals of 12 ± 2 h. At least six measurements were obtained for each infant. A follow-up evaluation within 24 h to 96 h after discharge was offered to all neonates, depending on TcB levels before discharge, which were described in the authors’ previous study. All perinatal and postpartum data of neonates were recorded in a single database for each unit during the study period. Each participating unit adopted the same clinical protocol study, method for sample collection, patient recruitment, and measurements of TcB and TSB. The coordinating center trained the investigators and supervised the implementation, so that the data from each unit could be pooled.

Statistical analysis

Data collected in the eight participating units were pooled by the Nanjing Maternity and Child Healthcare Hospital of the Nanjing Medical University, which conducted the statistical analysis. These data were entered into a custom-designed spreadsheet (Microsoft Excel 2003, Microsoft Corporation - Redmond, WA, USA) and checked for completeness, consistency, and accuracy by two researchers (Qing Sun and Xiaoyue Dong). After checking and verifying these data, the TcB values were plotted on the previously constructed TcB nomogram, separately by two researchers (Qing Sun and Xiaofan Sun). The sensitivity, specificity, positive predictive values (PPV), negative predictive values (NPV), and positive likelihood ratio (PLR) were calculated for the 40th, 75th, and 95th percentile of the TcB nomogram. Receiver operating characteristic (ROC) curve analysis was performed with the Statistical Package for Social Sciences (SPSS), version 16.0 (SPSS Inc. - Chicago, IL, USA), which was used to assess the predictive ability of the TcB nomogram.

Results

Eight hospitals participated in the multicenter study. The number of neonates from each hospital are listed in Table 1; 9,174 neonates (5,385 males and 3,789 females), of whom 945 (10.3%) were late-preterm, were enrolled in the study. Mean GA was 38.6 ± 2.9 weeks and mean birth weight was 2,875 ± 412 g; 5,275 (57.5%) neonates were born by cesarean section. Regarding feeding, 3,165 (34.5%) neonates were exclusively breast-fed, and 3,376 (36.8%) were exclusively bottle-fed. Of the total population studied, 514 (5.6%) neonates were small for gestational age, 661 (7.2%) experienced a weight loss greater than 10%, and 147 (1.6%) were diagnosed as having ABO incompatibility.

<table>
<thead>
<tr>
<th>Collaborative units</th>
<th>Participants, n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanjing Maternity and Child Healthcare Hospital, Nanjing Medical University</td>
<td>1,796</td>
</tr>
<tr>
<td>Inner Mongolia Maternal and Child Healthcare Hospital</td>
<td>1,703</td>
</tr>
<tr>
<td>The First Affiliated Hospital of Xinjiang Medical University</td>
<td>1,394</td>
</tr>
<tr>
<td>Changzhou Maternal and Child Healthcare Hospital</td>
<td>1,271</td>
</tr>
<tr>
<td>Gynecology and Obstetrics Hospital, Fudan University</td>
<td>1,046</td>
</tr>
<tr>
<td>The Fifth People’s Hospital of Shenzhen</td>
<td>927</td>
</tr>
<tr>
<td>Guangxi Maternal and Child Health Hospital</td>
<td>565</td>
</tr>
<tr>
<td>Guangdong Maternal and Children’s Hospital, Guangzhou Medical College</td>
<td>472</td>
</tr>
<tr>
<td>Total</td>
<td>9,174</td>
</tr>
</tbody>
</table>
recently, the neonatal glucose-6-phosphate dehydrogenase (G6PD) deficiency, increased weight loss, and exclusive breastfeeding.

**Table 2** Predictive characteristics of percentile values of predischage TcB for subsequent significant hyperbilirubinemia.

<table>
<thead>
<tr>
<th>Predischarge TcB</th>
<th>Significant hyperbilirubinemia</th>
<th>Predictive characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (9174)</td>
<td>Present (972)</td>
</tr>
<tr>
<td>Above the 95th percentile</td>
<td>453</td>
<td>275</td>
</tr>
<tr>
<td>Below the 95th percentile</td>
<td>8,721</td>
<td>697</td>
</tr>
<tr>
<td>Above the 75th percentile</td>
<td>2,258</td>
<td>776</td>
</tr>
<tr>
<td>Below the 75th percentile</td>
<td>6,916</td>
<td>196</td>
</tr>
<tr>
<td>Above the 40th percentile</td>
<td>5,137</td>
<td>972</td>
</tr>
<tr>
<td>Below the 40th percentile</td>
<td>4,037</td>
<td>0</td>
</tr>
</tbody>
</table>

NPV, negative predictive value; PPV, positive predictive value; TcB, transcutaneous bilirubin.

**Figure 1** ROC curve for predicting significant hyperbilirubinemia using the predischage hour-specific TcB nomogram. ROC, receiver operating characteristic curve; TcB, transcutaneous bilirubin.

Regarding the percentiles, 972/9,174 (10.6%) neonates were above the 95th percentile based on AAP guidelines (significant hyperbilirubinemia). In 453 (4.9%) neonates, predischarge TcB was > 95th percentile (Table 2). Of these, 275 neonates subsequently developed significant hyperbilirubinemia (PPV: 60.7%, sensitivity: 28.3%). In 4,037 (36.8%) neonates, predischarge TcB was < 40th percentile; none of whom developed significant hyperbilirubinemia (NPV: 100.0% and specificity: 49.2%). The 75th percentile curve showed a sensitivity of 79.8% and an NPV of 97.2%; the specificity was 81.9%. The AUC for predischarge TcB percentiles was 0.875 (Figure 1).

The PLR that determines the risk assessment for subse-quent significant hyperbilirubinemia for each risk zone is presented in Table 3. Among 453 neonates with predischarge TcB in the high-risk zone (> 95th percentile), 275 (60.7%) subsequently developed significant hyperbilirubinemia. Conversely, 178 newborns in the 95th percentile did not develop significant hyperbilirubinemia (PLR = 12.9) (Table 3). Of the 1,805 newborns in the upper-intermediate risk zone (76th to 95th percentile), 501 (27.8%) jumped to the high-risk zone (PLR = 4.4). Of the 2,879 neonates in the lower-intermediate risk zone (40th to 75th percentile), 196 (6.8%) climbed to the high-risk zone (PLR = 2.0). Of the 4,037 neonates in the low-risk zone (< 40th percentile), none moved upwards into the high-risk zone (Table 3).

**Discussion**

TSB measurements are an invasive procedure that involves pain, neonatal stress, and risk of infection. A noninvasive determination of bilirubin concentrations (TcB) is advantageous, and is suitable for universal neonatal screening. The new generation of noninvasive TcB-measuring devices (BiliCheck™ and JM-103) have presented good correlations with TSB measurements (BiliCheck™: 0.8212, JM-103: 0.8686). Recently, some studies developed predictive nomograms based on measurements of TcB or TSB to assess the risk for significant hyperbilirubinemia in healthy term and late-preterm infants. The results showed that the TcB nomogram was equivalent to the TSB nomogram, and both could be used to identify subsequent significant hyperbilirubinemia.

A predictive nomogram should be developed in one sample and validated in another. The present study was a multicenter study to verify the predictive value of the TcB nomogram constructed in 2010. The result showed that the AUC was 0.875, which was lower than the pre-test predictive ability in the previous study (AUC = 0.920). The previously constructed TcB nomogram was developed from a single hospital, which could not represent the demographic characteristics of the Chinese neonatal population. The multicenter study included eight units, which showed different genetic and environmental features. Therefore, a population-based TcB nomogram should be constructed, which should show a better predictive ability.

The rate of TcB increase is affected by smaller gestational age, blood incompatibilities, glucose-6-phosphate dehydrogenase deficiency, increased weight loss, and exclusive breastfeeding. Therefore, risk factors should be assessed when planning appropriate follow-up strategies according to the predischarge TcB. Six centers assessed the predictive value of predischarge TcB, and the AUC was 0.86; however, combined clinical risk factors (earlier GA, bruising, positive direct antiglobulin test, Asian race, exclu-
Table 3 Predictive ability of percentile values of predischarge TcB for subsequent significant hyperbilirubinemia.

<table>
<thead>
<tr>
<th>Risk zone</th>
<th>Percentile</th>
<th>Number (9,174)</th>
<th>Significant hyperbilirubinemia</th>
<th>Predictive ability</th>
<th>Probability of disease</th>
<th>PLR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Present (972)</td>
<td>Absent (8,202)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-risk</td>
<td>&gt; 95&lt;sup&gt;th&lt;/sup&gt;</td>
<td>453</td>
<td>275</td>
<td>178</td>
<td>60.7%</td>
<td>12.9</td>
</tr>
<tr>
<td>Upper-intermediate</td>
<td>76&lt;sup&gt;th&lt;/sup&gt;-95&lt;sup&gt;th&lt;/sup&gt;</td>
<td>1,805</td>
<td>501</td>
<td>1,304</td>
<td>27.8%</td>
<td>4.4</td>
</tr>
<tr>
<td>Lower-intermediate</td>
<td>40&lt;sup&gt;th&lt;/sup&gt;-75&lt;sup&gt;th&lt;/sup&gt;</td>
<td>2,879</td>
<td>196</td>
<td>2,683</td>
<td>6.8%</td>
<td>2.0</td>
</tr>
<tr>
<td>Low-risk</td>
<td>&lt; 40&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4,037</td>
<td>0</td>
<td>4,037</td>
<td>0.0%</td>
<td>0</td>
</tr>
</tbody>
</table>

PLR, positive likelihood ratio; TcB, transcutaneous bilirubin

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors are grateful to the staff of the Affiliation for their support and comments during the preparation of this manuscript. The authors would like to thank the following investigators who participated in the multicenter study: Jin Wang (Department of Neonatology, Children’s Hospital of Fudan University, Shanghai, China), Qing Sun (Department of Pediatrics, Nanjing Maternity and Child Health Care Hospital of Nanjing Medical University, Nanjing, China), Xiaoyue Dong (Department of Pediatrics, Nanjing Maternity and Child Health Care Hospital of Nanjing Medical University, Nanjing, China), Xiaofan Sun (Department of Pediatrics, Nanjing Maternity and Child Health Care Hospital of Nanjing Medical University, Nanjing, China), Hongyun Wang (Department of Neonatology, Inner Mongolia Maternal and Child Health Care Hospital, Hohhot, China), Yanping Zhu (Department of Neonatology, The First Affiliated Hospital of Xinjiang Medical University, Urumqi, China), Ying Wang (Department of Neonatology, Changzhou Maternal and Child Health Care Hospital, Changzhou, China), Xiaolei Zhuang (Department of Neonatology, Gynecology and Obstetrics Hospital, Fudan University, Shanghai, China), Jun Long (Department of Pediatrics, The Fifth People’s Hospital of Shenzhen, Shenzhen, China), and Qiufan Wei (Department of Neonatology, Guangxi Maternal and Child Health Hospital, Nanning, China).

References


