Hyperbilirubinemia causes jaundice, a yellowing of the skin and sclera\(^{1}\) that affects about 60% of term and 80% of preterm newborns.\(^{2}\) Around 2% of affected babies are at risk for severe neonatal hyperbilirubinemia (serum bilirubin level > 19.9 mg/dL [340 µmol/L]),\(^{3}\) a risk factor for kernicterus. Kernicterus is a preventable cause of death and long-term disability. In North American and European countries, the incidence of kernicterus varies from 0.44 to 2.7 cases per 100 000 live births.\(^{4,9}\) The economic burden of kernicterus on the Canadian health care system is estimated at $1.3 million (2008).\(^{10}\) However, insurance claim settlements have been as high as $8 million.\(^{11}\) In 2016, failure to identify hyperbilirubinemia ranked as the 13th-riskiest practice in acute care.\(^{11}\) Leading North American authorities recommend universal bilirubin screening with transcutaneous bilirubinometry (TcB) or measurement of total serum bilirubin (TSB) before hospital discharge.\(^{3,12}\) Although TSB is the current clinical standard, the required blood draw is painful.\(^{13,14}\) Transcutaneous bilirubinometry is a safe, noninvasive screening method that is available at...
point of care.15–18 Newer devices have been shown to be effective regardless of skin colour19–21 but are not approved for use with phototherapy22 and may provide less reliable results at extreme values.17,18,23,24 Transcutaneous bilirubinometry hour-specific nomograms, adjusted for increased sensitivity and created among local populations, are increasingly being developed and used.18,23,26

Economic impact studies have shown the cost-effectiveness of universal screening with TSB or TcB compared to clinical follow-up and testing driven by visual assessment.10,27–29 In 2 studies, the investigators compared the cost of TSB-based versus TcB-based universal screening, with mixed results. When TSB was shown to be more cost-effective, expensive disposable tips were required for TcB, and staff time saved was not assessed.10,31 Our literature review revealed no comprehensive economic analysis comparing costs of screening using TSB and TcB that did not require disposable tips. The aim of the current study was to compare the costs associated with 2 jaundice screening methods, universal TSB screening (TSB program) and TSB referred by universal TcB screening (TcB–TSB program), used by a regional screening program for newborn jaundice. Costs were assessed in hospital as well as in urban and rural community settings.

Methods

Our tertiary care centre, with about 5600 births per year, serves the local population of 300 000, 83% of whom are of European ancestry.32 In addition, 30% of patients are referred from outside the local community and surrounding area. Universal screening for newborn jaundice is coordinated with newborn metabolic screening at 24–48 hours of age.3,33 A community follow-up program staffed by registered nurses follows newborns within 24–48 hours of discharge and subsequently for up to 14 days, as clinically indicated. Permanent full- and part-time staff are required to have the International Board Certified Lactation Consultant credential. When blood is drawn at a home visit, it is driven to the laboratory by the nurse. To expedite care and ensure sample integrity, trips to the laboratory are not batched. Metabolic screening in Saskatchewan is advised between 24 and 48 hours of age. Our unit policy is to do it after 24 hours. In 2015, newborns of 35 or more weeks’ gestation received universal TSB screening coordinated with the newborn metabolic screen after 24 hours of age,33 timing of clinical follow-up was based on Canadian guidelines,3 and repeat TSB testing was done based on clinical assessment including visual inspection. In 2016, point-of-care screening with 5 JM-103 and 9 JM-105 (Dräger) TcB meters was integrated into the hospital and community screening protocols. All newborns of 35 or more weeks’ gestation received universal TSB screening before the newborn metabolic screen. In addition, TcB screening was integrated into daily care and was performed daily in hospital, within 4 hours before hospital discharge and at each community follow-up visit. Transcutaneous bilirubinometry readings higher than the 95th lower predictive interval computed with the use of local data were confirmed with measurement of TSB.13,22

We performed a cost-minimization analysis because both TcB and TSB are approved screening methods for newborn jaundice. We compared readmission rates for newborns with a most responsible diagnosis of neonatal jaundice within 12 weeks of birth, premature birth rates, average length of stay, number of community follow-up visits, and the number of TSB and TcB measurements across 2 time periods: before implementation of universal screening with TcB (June 1 to Nov. 30, 2015, time period 1) and after implementation of universal screening with TcB (June 1 to Nov. 30, 2016, time period 2).

Data sources

We obtained cross-sectional data for the 2 study periods. For both periods, we used organizational health data sets to obtain the number of live births, discharges and premature births, length of stay and total number of TSB specimens collected. Data for time and mileage analyses were collected throughout time period 2.

Time and mileage analyses

We identified 2 separate times for measuring TSB: 1) TSB measurement coordinated with the newborn metabolic screen and 2) TSB measurement only. The time for obtaining a sample for TSB measurement with the newborn metabolic screen included only the nurse’s time to draw the sample and graph/interpret the result. In contrast, the time for TSB measurement included only the nurse’s time to prepare for the blood draw, warm the newborn’s heel, collect/send the sample to the laboratory and graph/interpret the result. The time to carry out TcB included the nurse’s time to take the measurement and graph/interpret the result. Nurses in hospital and community settings collected these data. During time period 2, nurses in the community also collected data regarding their home visit mileage, mileage to travel to the laboratory from the home visit, and walking time to transport the sample from the car to the laboratory. We estimated travel time assuming urban travel speeds of 50 km/hour and rural travel speeds of 100 km/hour. The average excess mileage that resulted from transporting samples drawn in urban and rural community settings to the laboratory is the difference between the average mileage to travel from home visit to laboratory to home visit, and the average home visit mileage in each community setting (Figure 1).

Cost estimation

Costs of blood draws for TSB measurement included nurses’ driving times, walking times and mileage related to sample transportation, the time to perform the screens and laboratory charges. Since TcB is done at point of care, costs for the TcB included only the nurses’ times to perform the screens. Capital costs and calibration for TcB equipment and the chemistry analyzer were not assessed. In our setting, public health and hospital nurses are paid at differing rates, and we took this into consideration. Wages included hourly rates and benefits for 2016, and all costs were in 2016 Canadian dollars.
We analyzed the data using SAS 9.4 (SAS Institute) and Microsoft Excel 2013. We computed means and 95% confidence intervals (CIs) for time and mileage. If a sample size was less than 30, we assessed normality using the Shapiro–Wilk test (all relevant p values > 0.05). We performed t tests for time and mileage analyses to identify significant differences between samples. We used Z-tests for the difference in 2 proportions to identify statistical differences between group characteristics and outcomes, including proportion of premature infants and readmission rates. All tests were 2-tailed, with \( p < 0.05 \) defining statistical significance.

**Ethics approval**

The University of Saskatchewan Biomedical Research Ethics Board reviewed this study and determined that it was program evaluation/quality improvement and thus exempt from the requirement for board approval to proceed. Organizational approval was received.

**Results**

The live birth rate during time periods 1 and 2 was 2779 and 2763, respectively. The corresponding numbers of postpartum unit discharges were 2466 and 2493. There was no significant difference in the number of preterm births between the 2 periods (281 and 275, respectively) \( (p = 0.8) \). Observed visits in the community follow-up program were similar across the 2 time periods, with 3399 in time period 1 and 3331 in time period 2. Observed lengths of hospital stay did not increase after the introduction of TcB, with an average length of stay of 1.74 days in time period 1 and 1.70 days in time period 2.

No significant difference in the number of newborns readmitted for jaundice within 2 weeks of discharge was found, with 54 readmissions per 2466 newborns (2.2%) in time period 1 and 58 readmissions per 2493 newborns (2.3%) in time period 2 \( (p = 0.8) \). Likewise, no significant differences were found in readmission rate by gestational age (Table 1). These results support the homogeneity of time periods 1 and 2. Consequently, we assumed that the time and mileage data gathered in time period 2 would be indicative of the corresponding data for time period 1.

**Screening measurements**

In time period 1, there were 3844 blood draws for TSB measurement. In time period 2, there were 1099 blood draws for TSB and 6523 TcB screens (total of 2758.6 per 1000 live
births). Thus, although we observed a reduction of 71.4% in TSB blood draws, we observed an increase in the number of screens per 1000 live births (from 1383.2 to 2758.6). There were reductions of 75.3% and 49.3% in TSB blood draws in hospital and in the community, respectively (Table 2).

**Time and mileage analyses**

Table 3 summarizes the average times and mileage associated with the community follow-up program. Travel time estimates were found to be 5.5 and 12.0 minutes, respectively. The excess average mileage values for urban and rural TSB sample transportation were 4.58 km (95% CI 3.23–5.94) and 20.04 km (95% CI 8.37–31.72), respectively. The average nurse’s time (regardless of location) for a lone blood draw for TSB measurement was significantly longer than for performing TcB ($p < 0.001$).

**Cost estimation**

Cost estimates varied by method and location (Table 4). Most of the location variability was due to travel time, with nurse driving and walking times accounting for 52.3% of the total urban cost and 53.2% of the total rural cost.

Over the 6-month period, the estimated total savings with the TcB–TSB hospital and community programs were $19 760 and $6417, respectively (Table 5), yet the total number of screens completed increased by 153% and 481%, respectively. In hospital, the greatest savings were a reduction in cost due to a reduction in laboratory expenses (74.7% of the cost reduction), followed by a decrease in nurses’ time to screen (23.3%) (data not shown). In the community program, the largest savings were related to a reduction in travel time (75.3%), followed by a reduction in laboratory expenses (16.2%) and a decrease in mileage (8.5%). In the community, the cost of the nurses’ time to screen increased by 44.7% with the TcB–TSB program owing to policy that increased access to noninvasive screening at point of care.

**Interpretation**

In the current study, the estimated cost per TcB screen in hospital and community (urban and rural) settings was $3.54 and $3.76, respectively, whereas the cost per TSB screen was $15.82 in hospital, and $50.21 and $65.03 in urban and rural community settings, respectively. We observed an overall

| Location | Time period 1, no. of samples | Time period 2, no. of samples | % reduction |
|----------|-----------------------------|-------------------------------|-------------|
| Hospital | Observed 3264                | Standardized* 1174.5          | 805         |
| Community| 580                         | 208.7                        | 294         |
| Total    | 3844                        | 1383.2                       | 1099        |

*Per 1000 live births.

| Variable | No. of cases | Mean (95% CI) | Median | Range            |
|----------|--------------|---------------|--------|-----------------|
| **Nurses’ time, min** | | | | |
| Walk community sample from car to hospital laboratory | 18 | 15.06 (11.76–18.35) | 15.00 | 4.00–26.00 |
| Draw blood sample | 18 | 12.52 (10.44–14.59) | 12.00 | 6.33–20.00 |
| Perform transcutaneous bilirubinometry | 56 | 2.94 (2.55–3.33) | 2.33 | 0.33–7.00 |
| **Mileage, km** | | | | |
| Home visits | | | | |
| Urban | 524 | 8.36 (7.91–8.81) | 7.00 | 1.00–25.00 |
| Rural | 110 | 33.95 (31.51–36.39) | 31.00 | 9.00–75.00 |
| Travel to laboratory | | | | |
| Urban | 127 | 6.47 (5.83–7.12) | 6.00 | 1.00–18.00 |
| Rural | 14 | 27.00 (20.70–33.30) | 27.00 | 3.00–53.00 |

Note: CI = confidence interval.
decrease of 71.4% in blood draws for TSB measurement with the introduction of TcB (75.3% in hospital and 49.3% in the community) despite improved access to screening of 153% in hospital and 481% in the community with TcB–TSB. The estimated total savings for the TcB–TSB hospital and community programs were $19,760 and $6,417, respectively, despite the improved access to screening. Assuming a 3-year lifespan for a TcB meter, the annual cost per meter would be about $3,600. Extrapolating the cost savings to 1 year ($52,400), in our setting, a cost-neutral program would have 14 meters in circulation, equivalent to 1 meter per 390 births per year. In addition, patients received intangible benefits such as availability of point-of-care results and reduced exposure to painful heel pokes.

Our results align with findings by De Luca and colleagues, who estimated that, based on the positive predictive value of TcB with the BiliChek meter (Respirronics), this device could safely avert 58%–79% of blood draws based on TcB thresholds of 10.0 mg/dL (171 µmol/L) and greater than 12.0 mg/dL (205 µmol/L). Other investigators have reported smaller reductions in TSB blood draws; however, they compared universal TcB screening to visual assessment, which led to fewer initial TSB measurements. Overall program cost determination is affected by the threshold for TSB sampling. After implementation of TcB screening with a locally validated nomogram, our TSB rates were 291.3 and 106.4 per 1000 live births in hospital and the community, respectively. Other studies with the JM-103 device and specific unit protocols showed similar calculated rates, ranging from 101.8 to 141.6 per 1000 live births in hospital and the community.

Our estimates of the cost of 1 TSB screen and 1 TcB screen are similar to those in the literature, which range from US$15 to £19.23 (Can$39.31) based on nursing time and laboratory expenses for TSB, and £1.3 (Can$2.66) based on nursing time for TcB. The $26 200 in savings in our study equates to $1060 in savings per 100 patients, similar to the figure of US$1500 per 100 newborns reported by Srinivas and colleagues.

### Limitations

We used 2-week readmission rates for jaundice as a proxy to identify differences in health outcomes between screening methods since the incidence of kernicterus, peak bilirubin level and phototherapy time were not assessed. Furthermore, we were not able to distinguish infants of 35–37 weeks' gestational age from those of 38 weeks or more of gestational age. We estimated travel time from the mileage data, assuming standard rates of speed of 50 km/h in urban areas and...
100 km/h in rural areas. This does not take into consideration traffic congestion or route and likely underestimated travel time and accompanying costs. Historical data provided the total number of TSB measurements completed in hospital and in the community. We assumed that, in time period 1, every infant in hospital had 1 TSB blood draw concurrently with the newborn metabolic screen and that the remainder were follow-up TSB blood draws. We also assumed that, in time period 2, every TSB blood draw was a follow-up, both in hospital and in the community follow-up program. This likely led to an underestimate of cost savings of the TcB–TSB program, as the lone TSB blood draws took on average 5.8 minutes longer to take than the TSB blood draws obtained in conjunction with the metabolic screen, leading to a higher estimated cost for the TcB–TSB program. Owing to the nature of summary health data, we were unable to perform statistical analysis on the change in total TSB blood draws from time period 1 to time period 2, which limits the generalizability of our findings. However, our findings fall within those predicted by De Luca and colleagues, based on the positive predictive value of TcB with a similar TcB meter. We also could not statistically assess the difference in length of stay or number of community follow-up visits between time periods.

Conclusion
Transcutaneous bilirubinometry is noninvasive, reduced the requirement for blood draws by over 70% and improved access to screening. It reduced the nurses’ time to screen and provided immediate results at the point of care. The infants in the 2 study periods had similar lengths of stay and readmission rates. With TcB screening, savings in hospital were related to reductions in nursing time and laboratory costs, whereas savings in the community program were related to reductions in travel time, laboratory costs and mileage. Over the 6-month period, the number of screenings doubled while the number of painful heel pokes decreased and the overall program cost decreased by $26177. Further research is required to determine whether there is an ideal time to screen with TcB and whether screening at regular points of contact informs care, for example, whether additional screening results in earlier treatment of at-risk newborns or lower peak bilirubin levels.

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