BiliCam: Using Mobile Phones to Monitor Newborn Jaundice

Lilian de Greef, Mayank Goel, Min Joon Seo, Eric C. Larson, James W. Stout MD MPH, James A. Taylor MD, Shwetak N. Patel
What is BiliCam?

A smartphone-based system to assess newborn jaundice.
Overview

100 newborn clinical study
Performs similarly to an FDA approved device

$7000
What is BiliCam?

A smartphone-based system to assess newborn jaundice.
What is BiliCam?

A smartphone-based system to assess newborn jaundice.
Jaundice
yellowish skin from excess bilirubin

84% of all newborns
peaks in 3-5 days
ultimate levels devastating
1 in 14 undergo phototherapy
Screening Method?
Total Serum Bilirubin
TSB

Medical Gold Standard
Transcutaneous Bilirubinometer
TcB

$7000
Non-invasive
Quick results
Correlates 0.75-0.93
Screening tool for TSB
Newborn Bilirubin Levels

![Graph showing newborn bilirubin levels with 25th and 75th percentile ranges.](image-url)
Screening Challenges

In Hospital

At Home

Visual Assessment

- Parents
- Many physicians
- Traveling practitioners

Tend to underestimate
BiliCam

cost
portability
accessibility
Using BiliCam
Using BiliCam
Using BiliCam

Bilirubin level: 7 mg/dL
Study Design

Informed by 6 months of formative work

- interviews
- focus groups
- contextual inquiry
- pilot study (40 newborns)
Study Design

100 newborn participants
• <1 day old when enrolled
• 59% white

2 medical centers

Data collected by medical professionals using iPhone 4S
Data Collected
(for each participant)

Photos: with & without flash

TSB (ground truth)

TcB (control)
Data Collected
(for each participant)

3 - 5 days old

Photos: with & without flash

TSB (ground truth)

TcB (control)
Data Collected (for each participant)

- < 1 day old
  - Photos: with & without flash
- 3 - 5 days old
  - Photos: with & without flash
  - TSB (ground truth)
  - TcB (control)
Data Collected (for each participant)

"Baseline"
< 1 day old
Photos: with & without flash

"Follow-Up"
3 - 5 days old
Photos: with & without flash
TSB (ground truth)
TcB (control)
Data Collection App

Standardize
- white balance
- card position
- phone position

Please place the card on the infant’s belly.

Let’s get a clear video of the sternum, forehead, and card.
Noisy Data
Automatic Quality Control

- Ideal
- Glare
- Overexposed
- Occlusion
- Shadow
- Underexposed
Algorithm Overview

Color Balance → Extract Features → Apply Regressions

Bilirubin Estimate
Color Balance

Different lighting conditions
Algorithm Overview

1. Color Balance
2. Extract Features
3. Apply Regressions
4. Bilirubin Estimate
Bilirubin Absorption Properties
Feature Extraction

with & without flash

RGB

YCbCr

L*a*b*
Feature Extraction

Gradient (of RGB channels)

Skin with & without flash

RGB

YCbCr

L* a* b*
# Feature Extraction

<table>
<thead>
<tr>
<th></th>
<th>RGB</th>
<th>YCbCr</th>
<th>L<em>a</em>b*</th>
<th>Gradient (of RGB channels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>with flash</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>without flash</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

**total: 21 features**
Processing Features

• scaled
  - unit variance
  - zero mean

• PCA
  - 6 component features
  - to reduce redundancy

• use both scaled & PCA
Algorithm Overview

1. Color Balance
2. Extract Features
3. Apply Regressions
4. Bilirubin Estimate
Regression Ensemble

- Least Angle Regressions
- LARS-Lasso
- Elastic Net
- Combine
- Bilirubin Estimate
Regression Ensemble

- Least Angle Regressions
- LARS-Lasso
- Elastic Net
- Support Vector Regressions

Combine

Bilirubin Estimate
Regression Ensemble

- Least Angle Regressions
- LARS-Lasso Elastic Net
- Support Vector Regressions
- k-Nearest Neighbor
- Random Forest Regression

Combine

Bilirubin Estimate
Regression Ensemble

- Least Angle Regressions
- LARS-Lasso Elastic Net
- Support Vector Regressions
- k-Nearest Neighbor
- Random Forest Regression

If regressions agree, take the mean.

Bilirubin Estimate
Regression Ensemble

Leaves-One-Out Cross Validation

**regressions agree**

Yes

No

90th percentile

mean

Bilirubin Estimate

Least Angle Regressions

LARS-Lasso Elastic Net

Support Vector Regressions

k-Nearest Neighbor

Random Forest Regression
Results

![Graph showing TSB Ground Truth (mg/dl) vs. Estimated Bilirubin (mg/dl)]
Results

TSB Ground Truth (mg/dl) vs. Estimated Bilirubin (mg/dl)

The graph shows a linear relationship between TSB Ground Truth and Estimated Bilirubin, indicating no significant deviation from linearity.
Results

BiliCam
0.85 rank order correlation

Flash & no flash images
Baselines made no difference
Results

BiliCam
0.85 rank order correlation

TcB
0.92 rank order correlation

TcBs correlate
0.75 - 0.93
Bhutani Nomogram

Bilirubin (mg/dL)

Age (days)

- High risk
- High intermediate risk
- Low intermediate risk
- Low risk
Interpretation

9 high risk cases based on TSB
Interpretation

BiliCam
2/9 missed high risk (22%)
85% blood draws avoided
Interpretation

**BiliCam**
- 2/9 missed high risk (22%)
- 85% blood draws avoided

**TcB**
- 2/8 missed high risk (25%)
- 88% blood draws avoided
Limitations & Future Work

Narrow demographic

- 100 newborns
- in Seattle
- 59% white
- limited data with dark skin

More studies worldwide
Limitations & Future Work

iPhone 4S only

Investigate other phones
Limitations & Future Work

Good skin segmentation unclear with current card design
Limitations & Future Work

New card design
BiliCam: Using Mobile Phones to Monitor Newborn Jaundice

Lilian de Greef, Mayank Goel, Min Joon Seo, Eric C. Larson, James W. Stout MD MPH, James A. Taylor MD, Shwetak N. Patel

lidegreef@uw.edu
BiliCam
Conclusion

Can be effective in-home screening tool
Estimates bilirubin comparably to TcB
Accessible, portable, low-cost
Kernicterus Statistics

In the US
- Kernicterus: 21 ($8 mill)
- Hazardous jaundice: 1158 ($50,000)
- Extreme jaundice: 2,317 ($20,000)
- Severe jaundice: 35,000 ($8,500)
- Phototherapy: 290,000 ($1,000)
- Visible jaundice: 3.5 million
- Births/year: 4.1 million

Middle- & low-income countries:
- 75,000 cases kernicterus/year
- 114,000 newborn deaths/year
- 65% newborn deaths from kernicterus
Image Segments

Forehead

Sternum

Card Patches
Icterometer