Diagnosis at the Point of Care with a Smartphone Dongle

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Learning objectives

• Explain benefits of using microfluidic technologies in point-of-care (POC) devices.
• Describe utility of smartphones in expanding access to point-of-care diagnostics.
• Identify opportunities and advantages of early testing with target users.
Worldwide disease burden

Vast differences in resources

High resource setting

Low resource setting
Microfluidics miniaturizes assays

Fast reaction time, low sample volume, low reagent consumption
Triplex: antenatal care panel
- HIV (gp41, gp36, O-IDR)
- Syphilis treponemal (r17)
- Syphilis non-trep (cardiolipin)
Quantitative optical detection

Negative sample

Positive sample

LED
Test zone
Pinhole
Photodiode
Quantitative optical detection

\[ y = 0.006x + 0.024 \]

\[ R^2 = 0.989 \]
Boom in consumer electronics

Smartphones are powerful tools enabled by advancements in semiconductor technology.

- Processor
- GPS
- Camera
- Gyroscope
Coupling microfluidics with smartphones

- Smartphones
  - Fast **computing** power
  - Interactive interface for **training/education**
  - **Communication** to centralized databases

The combination of **microfluidics** and **smartphone** technology has the potential to bring previously inaccessible diagnostic technology to the point of care.
Smartphone dongle

**Power-free vacuum**
- Low-power
- Reduced price

**Audio jack power/data**
- Portable power source
- Universal interface

**Low-cost optics**
- Objective readout
- Reduced price

**User-friendly app**
- Low training burden

**Microfluidic test**
- 15 min assay time
- Auto-reagent handling
- Multiplexing
Automated reagent handling
Power-free fluid flow

1. one-way valve
   - cassette inlet
   - cassette outlet

2. vacuum chamber
   - cassette inlet
   - cassette outlet
3D printed dongle case

- Vacuum chamber
- Slot for microfluidic chip
- LEDs and photodiodes

7cm x 5cm x 5cm, 130 gm
Audiojack powering and data transmission

Audio-based powering

19 kHz audio signal is sent by the phone and converted to DC power.

Data transmission via FSK

Photodiode readings are sent as binary through the audiojack via Frequency Shift Keying.

1 0 1 0 1
Extremely-low power consumption

Average 1.6mW 0.22mW per test
In-app directions

Enter Patient ID

001

PHASE I

3) Insert cassette into the dongle.

4) Press bulb fully to initiate vacuum.
Clear objective results

Phase 2 is done.

View Results

Results

<table>
<thead>
<tr>
<th>Patient ID</th>
<th>001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time</td>
<td>12.26 PM</td>
</tr>
<tr>
<td>HIV</td>
<td>Positive</td>
</tr>
<tr>
<td>Syph Trep</td>
<td>Negative</td>
</tr>
<tr>
<td>Syph Non-Trep</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Finish
Using the device
Testing in the field

• Healthcare workers used our devices in 3 clinics around Kigali, Rwanda.
• This testing represents first trial with:
  – Target end-users
  – Fingerprick whole blood
Treponemal and Non-treponemal markers
Lyophilized gold secondary antibodies

Lyophilizing antibodies provided increased stability and portability.
Prepared microfluidic tests at Columbia

The robotic arm helped to create large consistent batches (100 microfluidic cassettes).
### Study participants: patients

<table>
<thead>
<tr>
<th>Patients</th>
<th>(n = 96)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average age</strong></td>
<td>31 (21-62)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>40</td>
</tr>
<tr>
<td>Female (preg)</td>
<td>56 (23)</td>
</tr>
<tr>
<td><strong>Clinic</strong></td>
<td></td>
</tr>
<tr>
<td>VCT (Voluntary counseling and testing)</td>
<td>52</td>
</tr>
<tr>
<td>PMTCTCT (Prevention of mother to child transmission)</td>
<td>38</td>
</tr>
<tr>
<td>GC (General consultation)</td>
<td>6</td>
</tr>
</tbody>
</table>
Study participants: healthcare workers

<table>
<thead>
<tr>
<th>Healthcare workers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td></td>
</tr>
<tr>
<td>Laboratory technicians</td>
<td>5</td>
</tr>
<tr>
<td>Experience with RDT</td>
<td>5</td>
</tr>
<tr>
<td>Experience with fingerprick</td>
<td>5</td>
</tr>
<tr>
<td>Nursing education</td>
<td>3</td>
</tr>
</tbody>
</table>

Received 30 minute training
- Visual demonstration and individual practice
Fingerprick testing: HIV

Reference test: HIV ELISA
Sensitivity: 100% (59-100)  Specificity: 87% (78-99)
Fingerprick testing: Treponemal syphilis

Reference test: TPHA
Sensitivity: 92% (64-100) Specificity: 92% (83-97)
Fingerprick testing: Non-treponemal syphilis

Reference test: RPR

Sensitivity: 100% (48-100)  Specificity: 79% (69-87)
Venipuncture testing: showed similar results

<table>
<thead>
<tr>
<th></th>
<th>HIV</th>
<th>Syphilis (TP)</th>
<th>Syphilis (non-TP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference test</td>
<td>HIV ELISA</td>
<td>TPHA</td>
<td>RPR</td>
</tr>
<tr>
<td>Sensitivity (95% CI)</td>
<td>100% (59-100)</td>
<td>77% (46-95)</td>
<td>80% (28-99)</td>
</tr>
<tr>
<td>Specificity (95% CI)</td>
<td>91% (83-96)</td>
<td>89% (80-95)</td>
<td>82% (73-90)</td>
</tr>
</tbody>
</table>
Patient feedback

Overall dongle preference

Preferred fingerstick over venipuncture
- Yes: 91
- No: 2
- Not Sure: 2

Preferred tests with short turnaround time
- Yes: 94
- No: 11

Would recommend dongle to others
- Yes: 93
- No: 21
- Not Sure: 1
## Patient feedback

### Dongle recommended based on:

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity</td>
<td>27</td>
</tr>
<tr>
<td>Less pain or less blood taken</td>
<td>29</td>
</tr>
<tr>
<td>Multiplexing capability</td>
<td>41</td>
</tr>
<tr>
<td>Fast turn-around time</td>
<td>53</td>
</tr>
</tbody>
</table>

### Fingerprick preference based on:

<table>
<thead>
<tr>
<th>Preference</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less blood</td>
<td>38</td>
</tr>
<tr>
<td>Fear of needles</td>
<td>39</td>
</tr>
<tr>
<td>Problems with venipuncture</td>
<td>50</td>
</tr>
<tr>
<td>Faster</td>
<td>55</td>
</tr>
<tr>
<td>Less painful</td>
<td>89</td>
</tr>
</tbody>
</table>

Number of responses
• Felt it was simple to operate
• Valued multiplexing capability, objective read-out, fast turn-around
• Suggested use in low patient-volume settings (mobile clinics)
• Suggested use as back-up test in power outages
Conclusions

• Healthcare workers could operate the assay after a short **30 minute training**.
• The device showed **comparable results** to other diagnostic tests run in the field.
• Testing in the intended setting gave us **valuable feedback** from the user.
• **Smartphones** and **low-power engineering** enabled truly POC diagnostic testing.
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