Novel Wearable Devices in Cardiovascular Fields for Monitoring Arrhythmia

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Agenda

- Introduction
- Rationale of ECG monitoring
- Wearable device for arrhythmia detection
Introduction
Development of wearable health devices
Market information

**Top 5 Wearable Device Comparison**

### Market Share
- **2014**
  - Fitbit: 34.2%
  - Xiaomi: 24.6%
  - Garmin: 10%
  - Samsung: 6.1%
  - Jawbone: 5.3%
  - Others: 5.5%

- **2015**
  - Fitbit: 44.7%
  - Xiaomi: 25.4%
  - Garmin: 10%
  - Samsung: 6.1%
  - Jawbone: 5.3%
  - Others: 5.4%

### Device Comparison

<table>
<thead>
<tr>
<th></th>
<th>Fitbit</th>
<th>Xiaomi</th>
<th>Garmin</th>
<th>Samsung</th>
<th>Jawbone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity</strong></td>
<td>걸음수</td>
<td>걸음수</td>
<td>걸음수</td>
<td>운동방법에 따른 관리</td>
<td>걸음수</td>
</tr>
<tr>
<td></td>
<td>이동거리</td>
<td>이동거리</td>
<td>이동거리</td>
<td>운동량 관리</td>
<td>이동거리</td>
</tr>
<tr>
<td></td>
<td>칼로리</td>
<td>칼로리</td>
<td>칼로리</td>
<td></td>
<td>칼로리</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>수면패턴</td>
<td>수면패턴</td>
<td>수면패턴</td>
<td></td>
<td>수면패턴</td>
</tr>
<tr>
<td><strong>Heart Rate &amp; Sleep</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
<td>다양한 트래커</td>
<td>-</td>
<td>목표 달성에 따른 성과 표시 기능 (배치 최적)</td>
<td>사용자 운동능력에 따른 운동시간 추천</td>
<td>일, 주, 개월 단위 사용자 패턴 분석 기능</td>
</tr>
</tbody>
</table>

*Source: IDC*
Mobile health: physical activity tracking

Before Pokémon Go
Mean 5678 (SD 2833)
Median 5718 (IQR 3675-7279)

After Pokémon Go
Mean 7654 (SD 3616)
Median 7232 (IQR 5041-9744)
Development perspectives

- Physiological Monitoring
- Clinical Diagnosis
- Data Compression
- Energy Harvesting
- Flexible Electronics
- Motion Artifact Elimination
- Features Extraction
**Epidemiology: Word wide**

**Physiological Monitoring**
- ECG
- Photoplethysmogram
- SPO2
- SPCO
- Temperature
- more ...

**Features Extraction**
- Heart rates
- Respiratory rates
- Pulmonary Functions
  - FVC
  - FEV₁
  - PEF
- HRV
  - Autonomous Nervous System
  - Sympathetic Activation
  - Parasympathetic Activation
  - Stress Indication
- more ...

**Clinical Diagnosis & Feedback/Applications**
- Cardiac disease
  - AF, AFL, AT, CHF, PAC, VFL, VF, PVC, Infarction (Heart attack)
- Pulmonary disease
  - Asthma, COPD
- Others
  - Sleep apnea, ANS disabled,
  - Cardiac Rehabilitation, and more

ALL DISEASES Targeted

- Mental disorder
- Diabetes
- Cancer

**Motion Artifact**

**Data Compression**

**Energy Harvesting/Flexible Electronics**

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A considerable proportion of SCAF

- Duration of device-detected subclinical atrial fibrillation and occurrence of stroke in ASSERT

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European Heart Journal (2017) 38, 1339–1344

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SCAF related with CVA
Mass screening of AF

Mass screening for AF in a 75- to 76-year-old population (n=7173): new AF Dx - 218 patients

Circulation. 2015;131:2176-2184
**AF screening cost effectiveness**

- screening of 1000 individuals: 263 fewer patient-years with undetected AF. 8 fewer strokes, 11 more life-years, and 12 more quality-adjusted life years

<table>
<thead>
<tr>
<th></th>
<th>Lifetime costs</th>
<th>Strokes</th>
<th>Life years</th>
<th>QALY</th>
<th>Cost per gained life year</th>
<th>Cost per gained QALY</th>
</tr>
</thead>
<tbody>
<tr>
<td>No screening</td>
<td>€3 885 879</td>
<td>92</td>
<td>9835</td>
<td>6646</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screening</td>
<td>€3 935 891</td>
<td>85</td>
<td>9847</td>
<td>6657</td>
<td>€4365</td>
<td>€4313</td>
</tr>
</tbody>
</table>

![Graph showing the number of patients with detected AF over years after screening.](image)

Europace (2015) 17, 1023–1029

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Wearable device for arrhythmia detection
# 2017 ISHNE-HRS expert consensus statement

## Table 1 Characteristics of ambulatory cardiac monitoring devices

<table>
<thead>
<tr>
<th>Duration of recording</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of recorder</td>
<td>External event recorder</td>
<td>Standard Holter recorder</td>
<td>Patch/Vest/Belt recorder</td>
<td>Patch/Vest/Belt recorder</td>
<td>Implantable loop recorder</td>
</tr>
<tr>
<td></td>
<td>Smartphone-based recorder</td>
<td>Mobile cardiac telemetry</td>
<td>Event loop recorder</td>
<td>Mobile cardiac telemetry</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modality of recording</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event recording</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous recording</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autotigger recording</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of recording leads</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lead (2 electrodes)</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 leads (3 electrodes)</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 leads (5–7 electrodes)</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 leads (10 electrodes)</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of recording system</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive wired electrodes</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patch/Vest/Belt wireless system</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Built-in electrodes</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Available analyses</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrhythmia analysis</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST analysis</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>HRV—Heart rate variability</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>QT dynamicity</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>HRT—Heart rate turbulence</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>HDR—Holter-derived respiration</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>QRS late potentials</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>P-wave averaging</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>T-wave variability</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Activity level</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Heart Rhythm, Vol 14, No 7, July 2017

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<table>
<thead>
<tr>
<th>Duration of recording</th>
<th>Type of recorder</th>
<th>Palpitations (%)</th>
<th>Syncope (%)</th>
<th>Cryptogenic stroke (%) (Silent AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;60 s</td>
<td>Event recorder</td>
<td>50-60</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>24-48 hr</td>
<td>Standard Holter</td>
<td>10-15</td>
<td>1-5</td>
<td>1-5</td>
</tr>
<tr>
<td>3-7 days</td>
<td>Patch/Vest/Belt Recorder/MCT/ELR</td>
<td>50-70</td>
<td>5-10</td>
<td>5-10 (?)</td>
</tr>
<tr>
<td>1-4 weeks</td>
<td>ELR/Patch/Vest/Belt Recorder/MCT</td>
<td>70-85</td>
<td>15-25</td>
<td>10-15 (?)</td>
</tr>
<tr>
<td>≤36 months</td>
<td>ILR</td>
<td>80-90</td>
<td>30-50</td>
<td>15-20 (?)</td>
</tr>
</tbody>
</table>
2017 ISHNE-HRS expert consensus statement

A First generation external ambulatory ECG monitoring

a Holter monitoring
Patient wears monitor (Typically 24–48 h)
Patient keeps diary of symptoms and times when they occur
Patient returns monitor to technician to be scanned after recording period
Technician gives physician final report

b Event monitoring
Patient carries monitor (Typically 30 days)
Patient places monitor on chest to record during symptom
Patient transmits data over telephone to monitoring station
Monitoring station sends data to physician

C Loop monitoring
Patient wears monitor (Typically 30 days)
Patient activates monitor during symptom (some devices auto-trigger if arrhythmia is detected and alert patient)
Patient transmits data over telephone to monitoring station
Monitoring station sends data to physician

Heart Rhythm, Vol 14, No 7, July 2017
2017 ISHNE-HRS expert consensus statement

B Second generation external ambulatory ECG monitoring

a Holter monitoring
Patient wears monitor patch (up to 7-14 days)
Patch monitor records all ECG data during period
Patient mails back monitor after recording period to central receiving station
Technician reviews data and sends report to physician

b Ambulatory telemetry monitoring - (Non-real time)
Patient wears monitor (up to 30 days)
Monitor sends all ECG data to a handheld device
The handheld device transmits ECG data to a central monitoring station
Physicians are notified by technician if significant arrhythmia is detected

(c Ambulatory telemetry monitoring - (Real time)
Patient wears monitor (up to 30 days)
Monitor sends all ECG data continuously to central monitoring station
Physicians are notified by technician if significant arrhythmia is detected
Physicians can also log onto secure web server at any time to view real time ECG data
# Ambulatory monitoring devices: smartphone based recorder

<table>
<thead>
<tr>
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<td></td>
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<td>Mobile cardiac telemetry</td>
<td>Mobile cardiac telemetry</td>
<td>Mobile cardiac telemetry</td>
<td>Event loop recorder</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modality of recording</th>
<th>Event recording</th>
<th>Continuous recording</th>
<th>Autotrigger recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 min</td>
<td>✔️</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Kardia mobile – Alive core
AF screening by Kardia mobile – Alive core

<table>
<thead>
<tr>
<th>총원</th>
<th>심방세동 발견자</th>
<th>남자</th>
<th>여자</th>
<th>평균연령</th>
</tr>
</thead>
<tbody>
<tr>
<td>956</td>
<td>37</td>
<td>349</td>
<td>607</td>
<td>70.56</td>
</tr>
</tbody>
</table>

![Heartbeat ECG Image]
Wearable watch type ECG

- Two polarities
  - Positive: left wrist
  - Negative: right finger tip

- Dry electrodes (Gel not required)
- Less than 1mV measured
- Higher gain amplification with high common-mode rejection required

- Any device NOT FDA approved
- Currently tested and evaluated at
  1) Namho Kim, Professor, Wonkwang University Hospital, Korea
  2) Yunyoung Nam, Professor, Sooncheonhyang University, Korea
  3) Oscar Maitas, Surgeon, Cookil-John Stroger Hospital, Chicago, USA
Smartwatch Algorithm for Automated Detection of Atrial Fibrillation

**AliveCor (Mountain View, California) Kardia Band**

The smartwatch strap with an electrode sensor that records heart rhythm

Patient places thumb on the sensor to record rhythm

The application utilizes an algorithm to differentiate sinus rhythm (SR) from atrial fibrillation (AF), or would label the recording as unclassified if it does not meet certain criteria

The app informs the patient if AF is detected; the results are transmitted to the patient's physician

<table>
<thead>
<tr>
<th>Method for interpreting the recording</th>
<th>% of patients with interpretable results</th>
<th>Accuracy of AF diagnosis compared to 12 lead electrocardiogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>App algorithm only</td>
<td>66%</td>
<td>93% sensitivity; 84% specificity</td>
</tr>
<tr>
<td>Physician only</td>
<td>87%</td>
<td>99% sensitivity; 83% specificity</td>
</tr>
<tr>
<td>Recordings labeled as “unclassified” by the app algorithm when reviewed</td>
<td>100%</td>
<td>100% sensitivity; 80% specificity</td>
</tr>
</tbody>
</table>
Smartwatch Algorithm for Automated Detection of Atrial Fibrillation

Sensitivity, specificity

**Table 3** Unclassified KB Readings When Read by Electrophysiologist Compared to Electrophysiologist-Interpreted 12-Lead ECG

<table>
<thead>
<tr>
<th>Electrophysiologist-Interpreted 12-Lead ECG</th>
<th>AF/Flutter</th>
<th>SR</th>
<th>Noninterpretable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF/flutter</td>
<td>14</td>
<td>5</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>SR</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Missing/noninterpretable</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>34</td>
<td>0</td>
<td>57</td>
</tr>
</tbody>
</table>

Sensitivity, specificity, and κ coefficient are calculated only for the simultaneous transmission with interpretation (in bold). Sensitivity of 100% (14 of 14; 95% confidence interval: 77% to 100%), specificity of 80% (20 of 25; 95% confidence interval: 64% to 96%), and κ coefficient of 0.74 (95% confidence interval: 0.54 to 0.95) for numbers in bold.

Abbreviations as in Table 2.

**Table 5** KB Automated Reading Compared to Electrophysiologist-Interpreted KB Recordings

<table>
<thead>
<tr>
<th>KB Automatic Reading</th>
<th>Electrophysiologist-Interpreted KB Recordings</th>
<th>AF/Flutter</th>
<th>SR</th>
<th>Missing/Noninterpretable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF/Flutter</td>
<td></td>
<td>71</td>
<td>1</td>
<td>2</td>
<td>74</td>
</tr>
<tr>
<td>SR</td>
<td></td>
<td>5</td>
<td>36</td>
<td>2</td>
<td>43</td>
</tr>
<tr>
<td>Missing/unclassified</td>
<td></td>
<td>20</td>
<td>21</td>
<td>18</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>96</td>
<td>58</td>
<td>22</td>
<td>176</td>
</tr>
</tbody>
</table>

Sensitivity, specificity, and κ coefficient are calculated only for the simultaneous transmission with interpretation (in bold). Sensitivity of 93% (71 of 76; 95% confidence interval: 88% to 99%), specificity of 97% (36 of 37; 95% confidence interval: 92% to 100%), and κ coefficient of 0.88 (95% confidence interval: 0.79-0.97) for numbers in bold.

Abbreviations as in Table 2.
Smartwatch Algorithm for Automated Detection of Atrial Fibrillation

ECG examples

A

B

Smartwatch Algorithm for Automated Detection of Atrial Fibrillation

ECG examples

A

B

Smartphone-based Event Recorder in ER patients

Multicenter trial: patients with palpitation/presyncope

- Randomised (n = 243)
  - Allocated to Intervention arm (n = 126)
  - Allocated to Control arm (n = 117)
  - Removed after randomisation – did not meet inclusion criteria (n = 1)

Baseline data collection
- n = 125
- n = 117

Follow-up
- Lost to follow-up (n = 1)
- Lost to follow-up (n = 1)

Analysis
- Analysed (n = 124)
- Analysed (n = 116)
Number of participants undiagnosed
Smartphone-based Event Recorder in ER patients

- symptomatic rhythms

<table>
<thead>
<tr>
<th>Symptomatic rhythm*</th>
<th>Intervention n = 124</th>
<th>Control n = 116</th>
<th>Total n = 240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus rhythm (40–100)</td>
<td>48 (55.6%)</td>
<td>5 (9.5%)</td>
<td>53 (33.3%)</td>
</tr>
<tr>
<td>Sinus tachycardia (&gt;100)</td>
<td>12</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Ectopics</td>
<td>8</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>SVT</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Atrial flutter</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Sinus bradycardia (&lt;40)</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Atrial tachycardia</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other rhythm</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Method of diagnosis of symptomatic rhythm*</td>
<td>65 (55.6%)</td>
<td>0 (0%)</td>
<td>65 (33.3%)</td>
</tr>
<tr>
<td>AliveCor</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>24-hour Holter</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>48-hour Holter</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7 + day Holter</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Subsequent ED visit ECG</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>GP visit ECG</td>
<td>11</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>
Remote Heart Rhythm Sampling Using the AliveCor Heart Monitor to Screen for Atrial Fibrillation

REHEARSE-AF Study: Patients ≥65 years of age with a CHADS-VASc score ≥2 free from AF

5846 Potential participants (5726 identified using GP databases, 120 invited following research centre attendance)

1272 Volunteered to participate

Letter of invitation

Telephone call, research centre visit

1004 Enrolled

3305 Did not respond
1269 Declined invitation

268 Excluded for clinical or logistical reasons

3 Excluded due to protocol violations

500 AliveCor (intervention arm)

501 Standard Care (control arm)

Circulation. 2017;136:1784–1794
Remote Heart Rhythm Sampling Using the AliveCor Heart Monitor to Screen for Atrial Fibrillation

- **iECG arm**: twice-weekly recording and transmission of a 30-second single-lead iECG trace to a secure server (Monday and Wednesday recommended, plus additional submissions if symptomatic) over a 12-month period.

![Graphs showing anxiety and confidence levels](image)

Circulation. 2017;136:1784–1794

Wonkwang university school of medicine and hospital
Remote Heart Rhythm Sampling Using the AliveCor Heart Monitor to Screen for Atrial Fibrillation

1001 patients (500 iECG, 501 RC) : 19 new AF Dx
### Table 1: Characteristics of ambulatory cardiac monitoring devices

<table>
<thead>
<tr>
<th>Duration of recording</th>
<th>&lt;1 min</th>
<th>24–48 hr</th>
<th>3–7 days</th>
<th>1–4 weeks</th>
<th>≤36 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of recorder</td>
<td></td>
<td></td>
<td></td>
<td>Patch/Vest/Belt recorder</td>
<td>Implantable loop recorder</td>
</tr>
<tr>
<td></td>
<td>External event recorder</td>
<td>Standard Holter recorder</td>
<td>Patch/Vest/Belt recorder</td>
<td>Patch/Vest/Belt recorder</td>
<td>Patch/Vest/Belt recorder</td>
</tr>
<tr>
<td></td>
<td>Smartphone-based recorder</td>
<td>Mobile cardiac telemetry</td>
<td>Mobile cardiac telemetry</td>
<td>Mobile cardiac telemetry</td>
<td>Mobile cardiac telemetry</td>
</tr>
<tr>
<td>Modality of recording</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event recording</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous recording</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autotrigger recording</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

*Wonkwang university school of medicine and hospital*
iRhythm ZioXT

single-use, water resistant, 14-day, ambulatory ECG monitoring skin adhesive patch that monitors
Home-Based Wearable Continuous ECG Monitoring Patch

JAMA. 2018;320(2):146-155
Cumulative Rate of First Diagnosis of AF

![Graph showing cumulative rates of atrial fibrillation diagnosis over time.]

No. at risk

<table>
<thead>
<tr>
<th>Condition</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>365</th>
</tr>
</thead>
<tbody>
<tr>
<td>All monitored</td>
<td>1738</td>
<td>1681</td>
<td>1555</td>
<td>1469</td>
<td>1446</td>
</tr>
<tr>
<td>Monitored: diagnosed by patch</td>
<td>1738</td>
<td>1681</td>
<td>1555</td>
<td>1469</td>
<td>1446</td>
</tr>
<tr>
<td>Monitored: diagnosed clinically</td>
<td>1738</td>
<td>1681</td>
<td>1555</td>
<td>1469</td>
<td>1446</td>
</tr>
<tr>
<td>Matched control</td>
<td>3476</td>
<td>3348</td>
<td>3028</td>
<td>2832</td>
<td>2762</td>
</tr>
</tbody>
</table>

JAMA. 2018;320(2):146-155
Home-Based Wearable Continuous ECG Monitoring Patch

Distribution of Individual Percentage of Total Atrial Fibrillation Burden During Monitoring

JAMA. 2018;320(2):146-155
Days of Electrocardiogram Patch Wear Until a First Diagnosis of Atrial Fibrillation (AF)

![Graph showing frequency and cumulative percentage of atrial fibrillation episodes over time for two patches.](image-url)
Shirt type ECG monitoring

OMsignal system: Omgarment – OMshirt and bra
Shirt type ECG monitoring

- Validation with standard holter monitoring
Validation with standard holter monitoring

A. Distribution of heartbeat intervals All Subjects

B. Distribution of heartbeat intervals Men

C. Distribution of heartbeat intervals Women

D. OMsignal and Sorin signals overlay 001-016

D. OMsignal and Sorin signals overlay 001-003
Plethysmography (PPG)

- Simple optical technique for blood volume change detection in vessels
- Transmittance mode: photodetector and light source are on the opposite side each
- Reflectance mode – on the same side
- Beating of the heart causes pulse changes in the $SpO_2$ signal.
- This is the Photoplethysmogram (PPG) signal.

![Photodetector](Image)

![Light source](Image)

Pulse Rate 82 bpm
Watch-type PPG device

- Reflectance mode (LED and photodector on the same side)
- Started from smartphone built-in camera based PPG monitoring from a fingertip** (collaboration with NIH research group in 2011~2012)
- Green LED (550 nm) most acceptable
- Finger tip, ear lobe and forehead is the best site for the pulse measurement
- Weaker signal on a wrist
- Easily corrupted by motion artifacts (even finger movement)

Watch-type PPG device for SPO2

- Two LEDs Red(660nm), IR(940nm) and Photodetector on the same side
- Duty cycle 50% and switching frequency 500Hz
- Generate PWD through MCU
- Amplified gain 100, sample-and-hold followed by LPF 10Hz

Watch-type PPG device for SPO2


PPG based AF detection
AF characteristics

AF: 1) P-wave absence
2) Irregular RR intervals
Calculate TVCF (Time Varying Coherence Funct)
- MIT-BIH AF database subject 8455
- ARMA by Time-Varying Optimal Parameter Search (TVOPS)
- Initial model (5,5)
- 64 point FFT
- segment length 128 beats

- Tested on 23 subjects from MIT-BIH AF database
- Good ability of beat by beat detection

- Given total 479,986 AF beats, 18.7 ± 16.4 beats error
- **Sensitivity: 98.2%, Specificity: 97.7% Accuracy: 97.9%**

PPG based AF detection

courtesy of Lee et al.
PPG based AF detection

A.

B.

C.
Deep neural network

Smartwatch PPG coupled with a deep neural network can passively detect AF

Table 3. Performance Characteristics of Deep Neural Network in Validation Cohorts

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardioversion cohort (sedentary)</td>
<td>98.0</td>
<td>90.2</td>
<td>90.9</td>
<td>97.8</td>
<td>0.97</td>
</tr>
<tr>
<td>Subset of remote cohort (ambulatory)</td>
<td>67.7</td>
<td>67.6</td>
<td>7.9</td>
<td>98.1</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Summary

Cardiovascular Mobile Health

Patient

Health Promotion and Prevention

Disease Detection and Management

Family/Social Network

Medical Team


Wonkwang university school of medicine and hospital
Thank you for attention