AMBULATORY Heart rhythm MONITORS

What is Currently Available? When Does It Impact Care?

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DISCLOSURES

Research grant from Medtronic External Research Program

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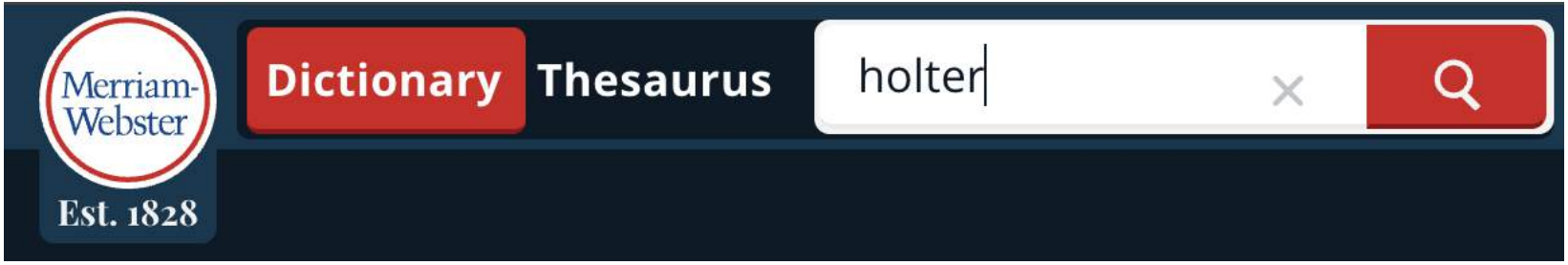

Holter monitor noun

Not a verb!

Hol·ter monitor ˈhōl-tər-

: a portable device that makes a continuous record of electrical activity of the heart and that can be worn by an ambulatory patient during the course of daily activities in order to detect fleeting episodes of abnormal heart rhythms

Holter monitoring noun

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2017 ISHNE-HRS expert consensus statement on ambulatory ECG and external cardiac monitoring/telemetry

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Heart Rhythm 2017;14:e55–e96

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AVAILABLE ANALYSIS

Primary / Established

- Arrhythmia analysis
- Evaluate symptoms – correlation with intermittent cardiac arrhythmias
  - syncope, dizziness, chest pain, palpitations, shortness of breath
- Heart / Rhythm rate trends
- Burden of dysrhythmia
- Response to therapy

Also available...

- Heart rate variability
- ST analysis
- QT dynamicity
- Heart rate turbulence
- Holter derived respiration
- QRS late potentials
- P-wave averaging
- T-wave variability
- Activity level

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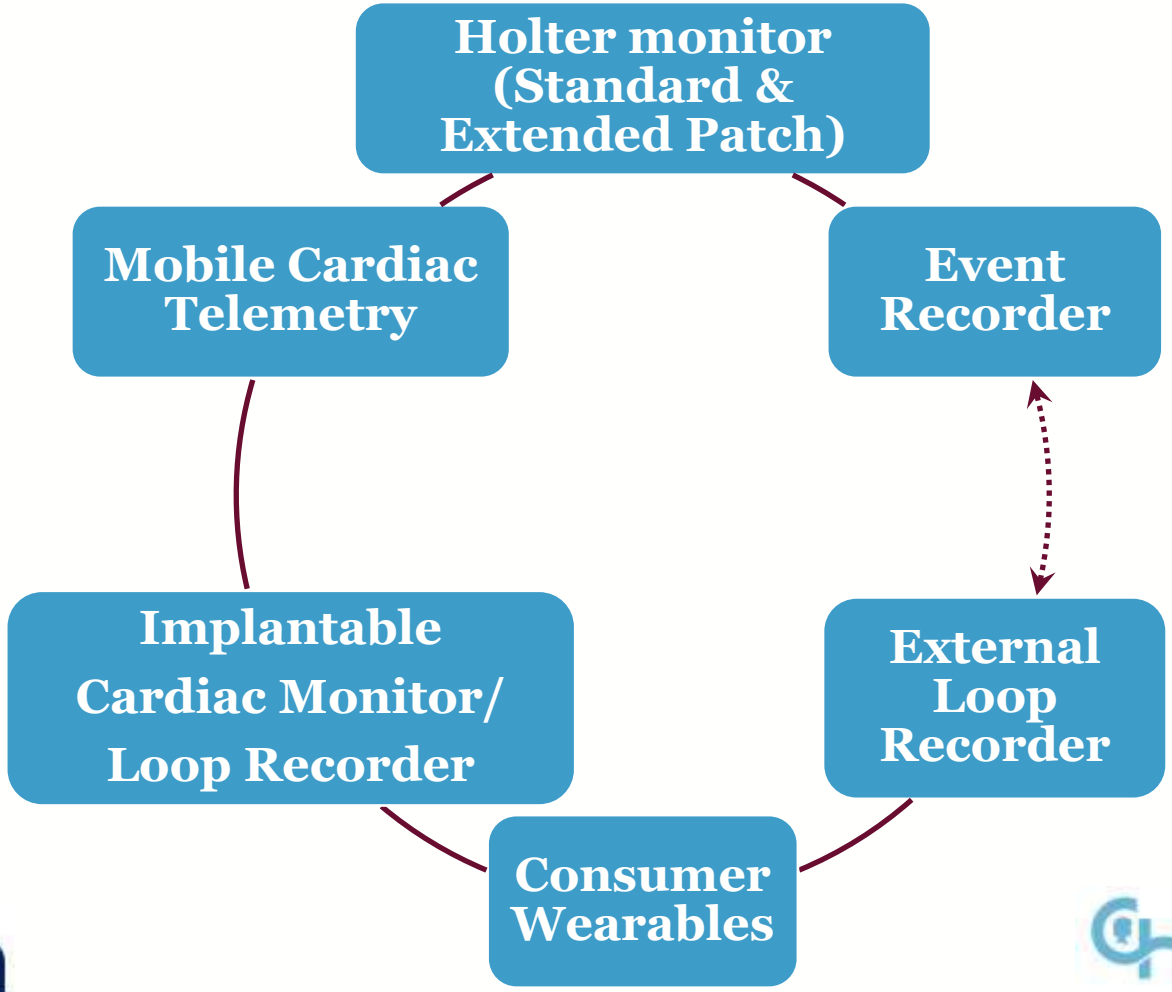
PURPOSE

- Rhythm identification correlating with events or symptoms
- Heart rate trends, variability (time domain, frequency domain)
- Burden of asymptomatic dysrhythmias (ectopy burden), incessant arrhythmias
- Identification of inconsistent patterns (ventricular preexcitation)
- Evaluation of unexplained palpitations, syncope, or assessing cryptogenic stroke for occult atrial fibrillation
- ST segment deviations correlating with symptoms

WHAT IS AVAILABLE?

Navigating the terms...Picking the right one...



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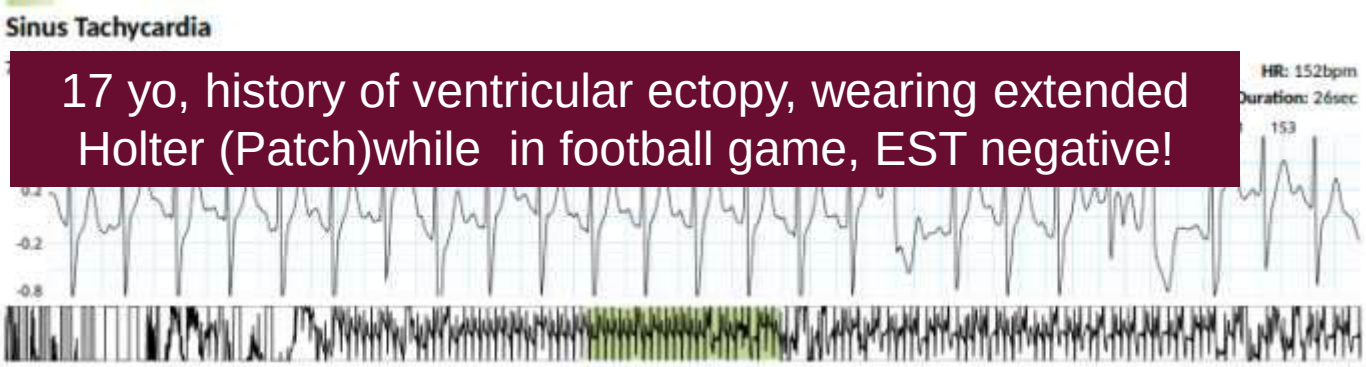
STANDARD HOLTER MONITOR

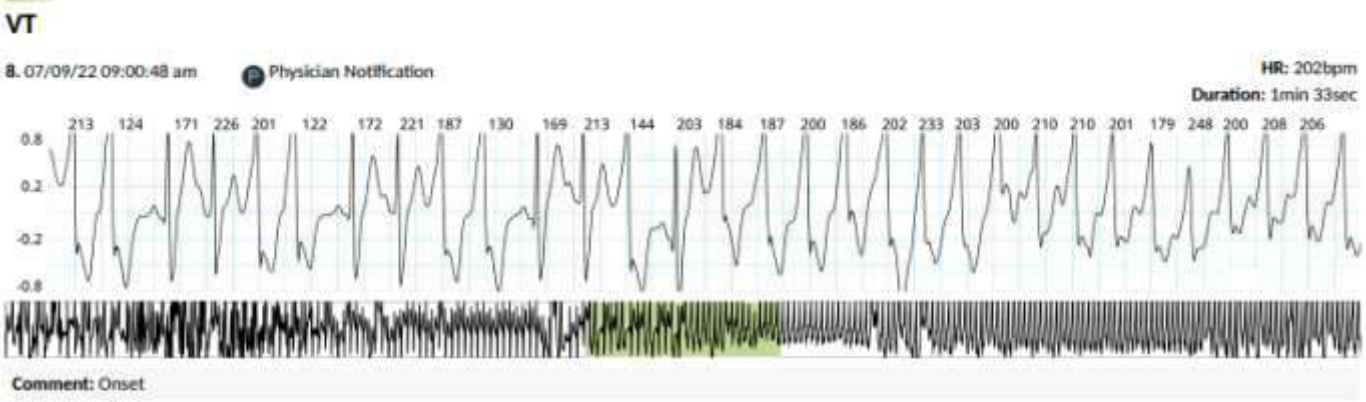
Duration & Leads	Indication	Advantages	Limitations
24–48 (up to 72) hours continuous recording; 2–3 leads (up to 12-lead in some) ***Diagnostic yield:*** *Palpitations: 10-15%* *Syncope: 1-5%*	Frequent daily symptoms (palpitations, arrhythmia); heart rate trends; baseline arrhythmia burden (PVCs, rate control); inconsistent patterns (ventricular preexcitation)	– Continuous data, multi-lead detail – Captures transient arrhythmias during normal activities – Widely available, easy to analyze with standard software 	– Short window: low yield if events infrequent – Patient discomfort (wires, electrodes) – No real-time alerts; offline analysis only 

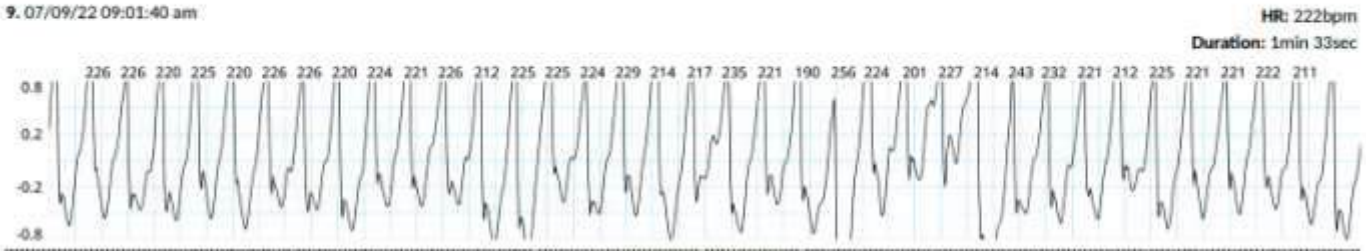
EXTENDED HOLTER MONITOR

Duration & Leads	Indication	Advantages	Limitations
7–14 days continuous; 1–2 leads via adhesive patch ***Diagnostic yield:*** *Palpitations: 50-70%* *Syncope: 5-10%* 	Intermediate-frequency symptoms or when >48h monitoring desired with better comfort: palpitations happening every few days, med compliance checks	– No wires, lightweight: improved comfort → higher patient compliance – Long recording period improves arrhythmia detection – Water-resistant; patients can exercise and shower	– Single-lead ECG with closely spaced electrodes → limited ability to interpret complex arrhythmias or P-wave detail – One-time use: if it falls off or patient removes, recording is interrupted – Data not analyzed until after completion

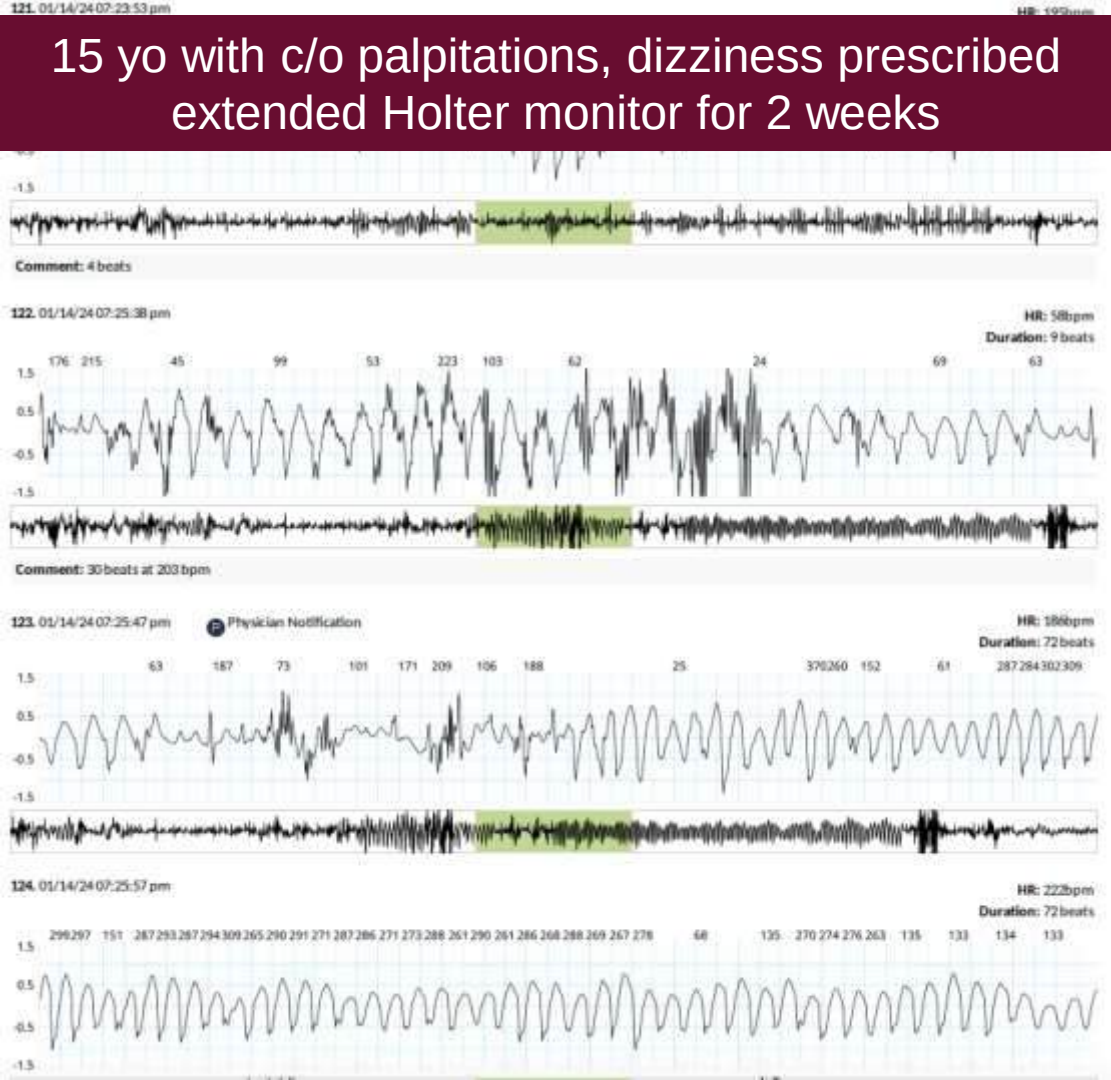
17 yo, history of ventricular ectopy, wearing extended Holter (Patch)while in football game, EST negative!







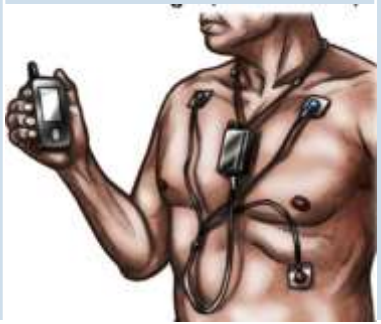
15 yo with c/o palpitations, dizziness prescribed extended Holter monitor for 2 weeks



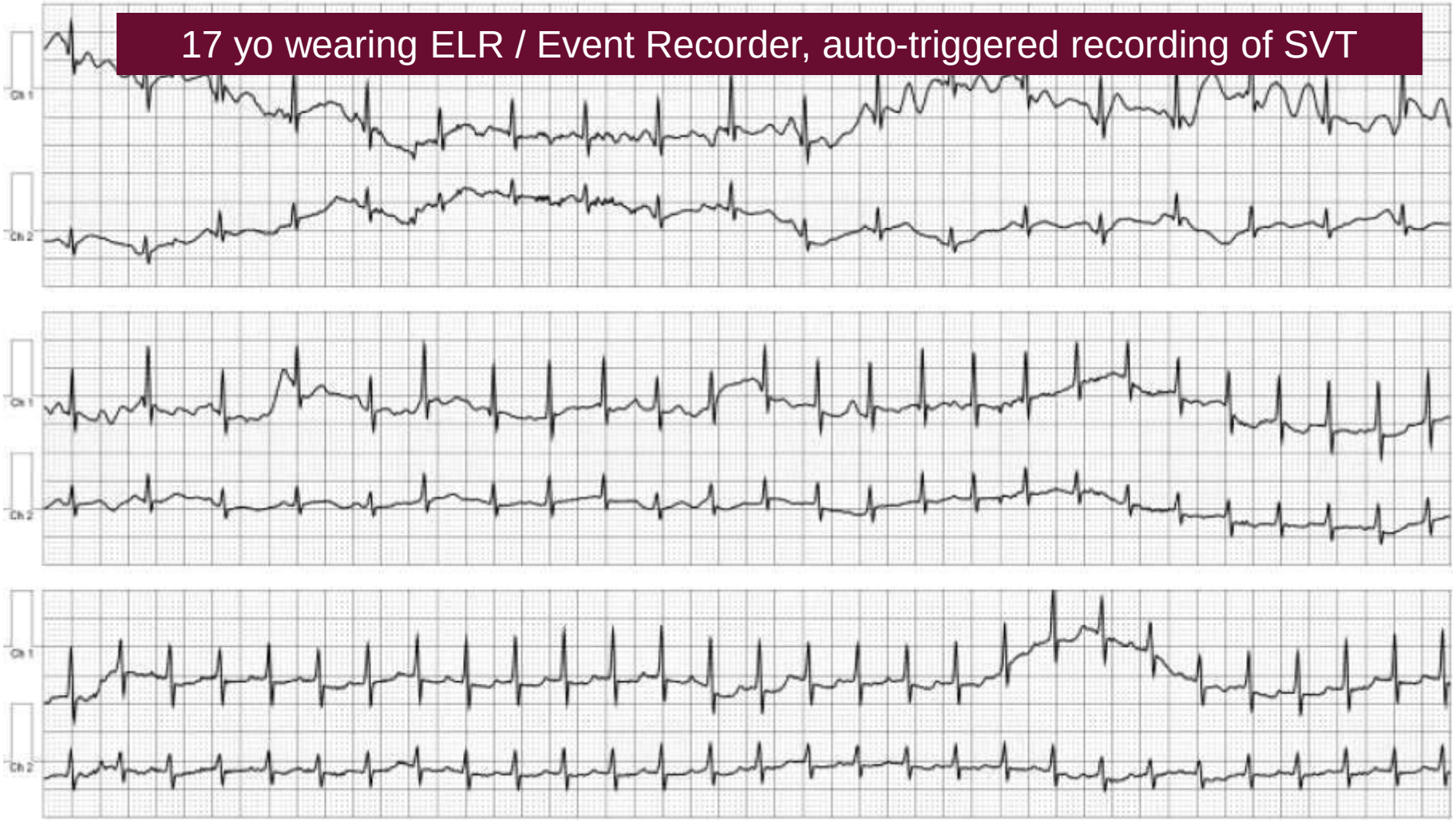
EVENT RECORDER

Duration & Leads	Indication	Advantages	Limitations
On-demand single lead (no continuous recording); records ~30–60 sec Up to 30 days **Manual activation by patient** ***Diagnostic yield:*** *Palpitations: 50-60%* *Syncope: Not applicable*	Infrequent symptoms (weekly or less) that are brief and recognizable by patient 	– Very portable; no need to wear continuously – Simple to use; patient triggers when symptoms occur, capturing the event – Immediate alarm generation	– No baseline recording: misses asymptomatic or sudden events (e.g., syncope without warning) –Recording starts after activation – User dependent: requires patient to recognize and activate during event

EXTERNAL LOOP RECORDER

Duration & Leads	Indication	Advantages	Limitations
On-demand single lead (no continuous recording); records ~30–60 sec; Up to 30 days **Automatic or manual activation by patient** ***Diagnostic yield:*** ***<u>3-7 days</u>*** *Palpitations: 50-70%* *Syncope: 5-10%* ***<u>1-4 weeks</u>*** *Palpitations: 70-85%* *Syncope: 15-25%*	Worn continuously for 2–4 weeks (sometimes up to 30 days) 	– Extended monitoring increases diagnostic yield (captures sporadic events) – Loop memory records pre-event data, capturing arrhythmia onset – Auto-detection of arrhythmias triggers recording without patient action – Immediate alarm generation	– Must wear sensor 24/7 for weeks: compliance challenges (especially in kids) – No real-time physician notification –Electrodes can cause skin irritation over long term

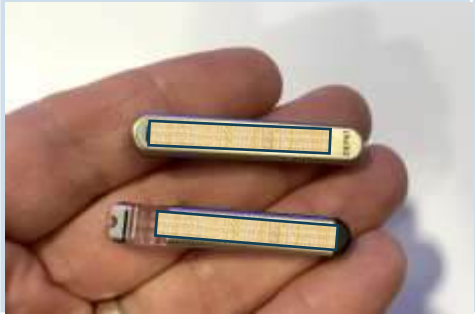
17 yo wearing ELR / Event Recorder, auto-triggered recording of SVT



MOBILE CARDIAC TELEMETRY

Duration & Leads	Indication	Advantages	Limitations
Worn continuously for up to 30 days; up to 3 lead (patch or chest leads + transmitter) Can stream the data continuously to caregivers ***Diagnostic yield:*** ***<u>3-7 days</u>*** *Palpitations: 50-70%* *Syncope: 5-10%* ***<u>1-4 weeks</u>*** *Palpitations: 70-85%* *Syncope: 15-25%*	High-risk arrhythmias needing immediate detection or diagnostic urgency 	– Real-time monitoring: instant transmission and analysis of events – Auto-trigger algorithms + 24/7 tech review -> rapid physician alert – Combines benefits of continuous data, long duration, with added immediacy – Immediate alarm generation	– Expensive, insurance approval often needed – High false-positive alert risk – requires filtering and can burden clinicians – Battery/charger and phone connectivity required; more complex for patient

IMPLANTABLE CARDIAC MONITOR

Duration & Leads	Indication	Advantages	Limitations
Up to 3 years continuous; 1 lead sensor subcutaneously ***Diagnostic yield:*** *Palpitations: 80-90%* *Syncope: 30-50%* 	Rare, unexplained events where noninvasive monitors failed or impractical: unexplained syncope, cryptogenic stroke, sporadic serious palpitations, atrial fibrillation burden post ablation ventricular ectopy burden	– Longest monitoring period → highest diagnostic yield for intermittent arrhythmia – Hands-off for patient: no external gear; good for compliance – MRI-compatible; remote data transmission available	– Minor surgery needed to implant; small infection/complication risk – Cost, device procedure – Data review is periodic (no instant alert unless using remote monitoring alerts); may capture non-actionable arrhythmias

LINQ II™ LNQ22
Device Serial Number: RLB326022G

Date of Implant:
21-Jul-2022

Reason for Monitoring:
Syncope

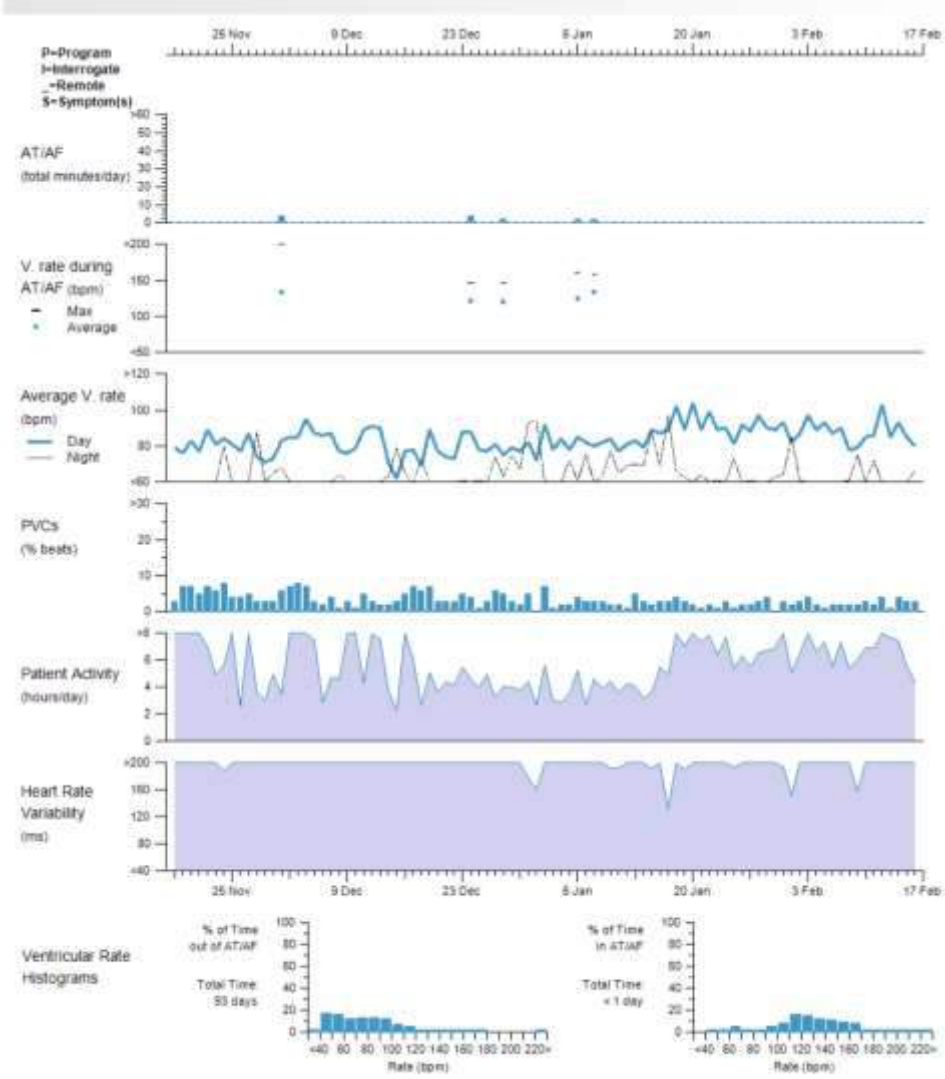
	Current	Lifetime	Parameters
Symptom	0	70	Two 15 min Episodes
Tachy	0	0	>214 bpm,>=16 beats
Pause	0	0	>3 seconds
Brady	0	0	<30 bpm,>=12 beats
AT	0	0	Off
AF	0	0	>=10 min
Time in AT/AF	**0.0%**	---	
PVCs (% beats)	**3.2%**	---	On

Battery

Observ
- No ob

ECG

Current ECG: *17-Feb-2025 00:05:18*



CONSUMER WEARABLES

Duration & Leads	Indication	Advantages	Limitations
Smartwatch ECG/PPG, handheld ECG e.g., Apple Watch, Kardia Mobile, Fitbit On-demand single-lead ECG (smartwatch/handheld) or continuous pulse rhythm via PPG (photoplethysmography)	Screening or supplemental use in health-aware patients; detecting AF in at-risk patients, capturing symptomatic episodes in tech-savvy patients	– Ubiquitous and easy to use – Can record event immediately (e.g., watch ECG during palpitation) – AI algorithms achieve high AF detection accuracy (smartwatch AF detection sensitivity ~98% in studies)	– Not continuously recording full ECG (PPG detects irregularity, but ECG only when patient activates) – Data not automatically shared with providers (reliant on patient) – Limited scope: primarily AF detection; may miss non-AF arrhythmias

WHAT TO DO IN AN UNCOOPERATIVE CHILD?

Alternate locations will work for many of the patch monitors

Samson RA, Beal AE, Hill ME, Fortin RL, Gallagher SP. Use of Single-Patch Electrode Ambulatory Monitoring Devices in Variable Thoracic Locations in Small Children. JACC: Clinical Electrophysiology. 2021

COST OF INAPPROPRIATE USE

...Or Abuse

CHOP...LAST 10 MONTHS

Holter (Standard / Extended): 3948

Event Recorder: 605

Mobile Cardiac Telemetry: 87

Implantable Cardiac Monitor: 20* (1 year)

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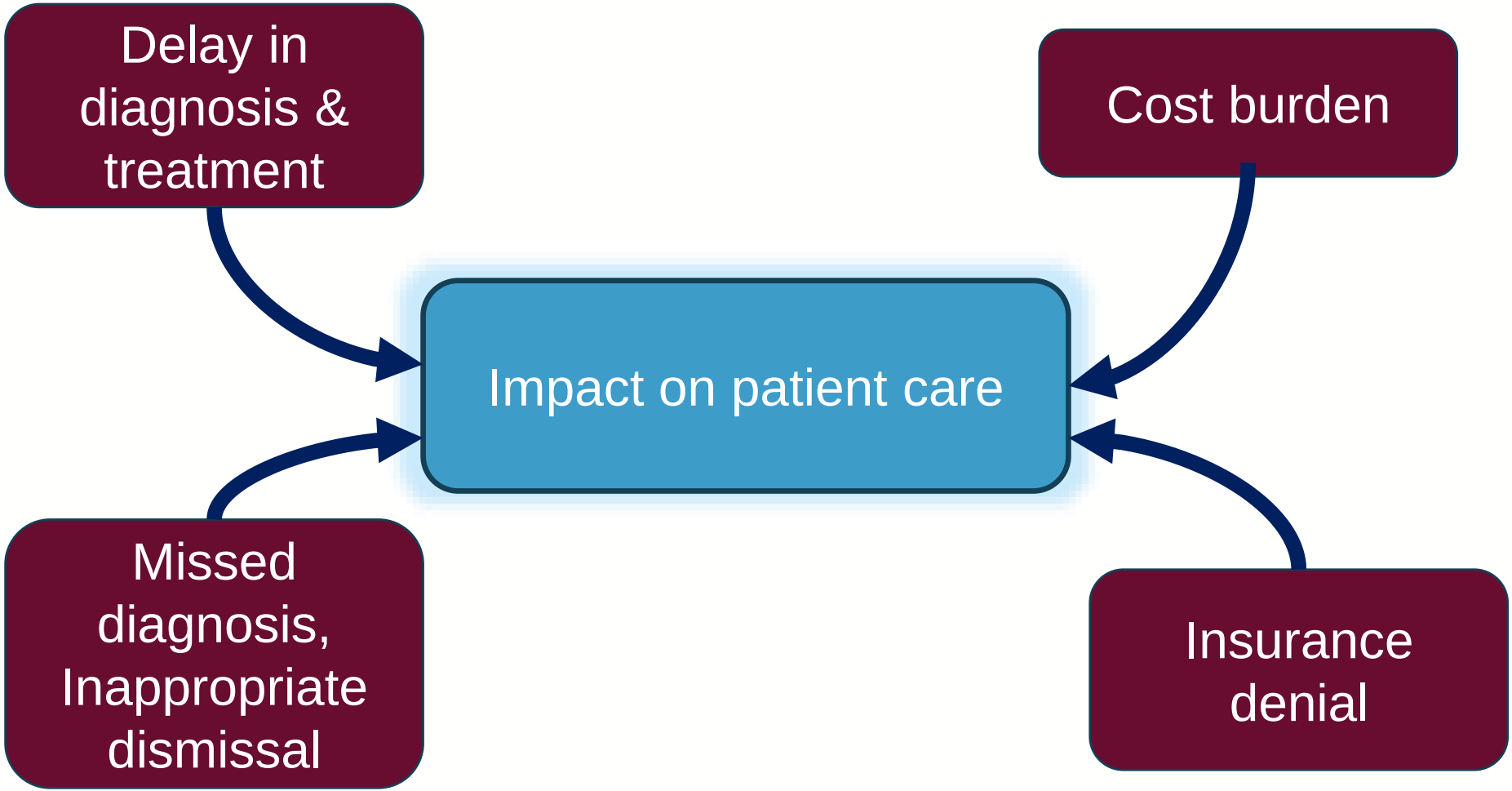
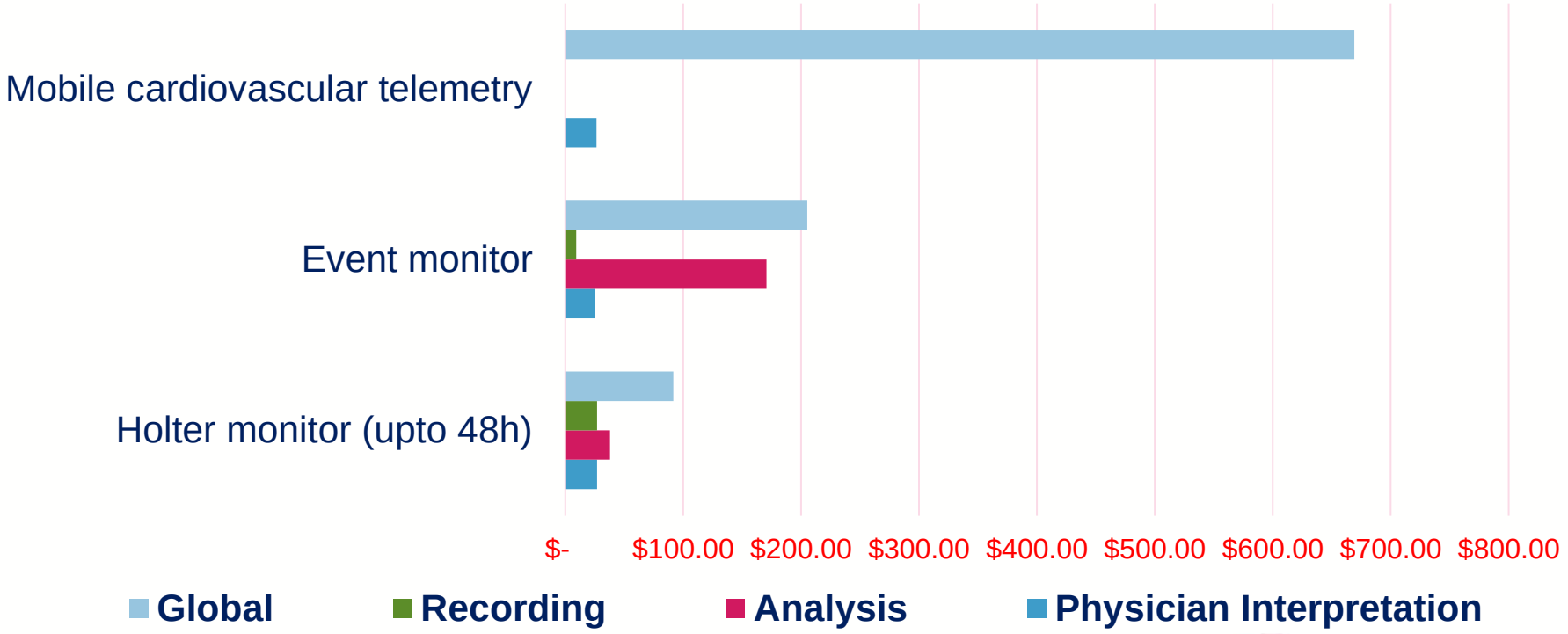

Delay in diagnosis & treatment
Cost burden
Impact on patient care
Missed diagnosis, Inappropriate dismissal
Insurance denial

FEE SCHEDULE*



*2014 Medicare

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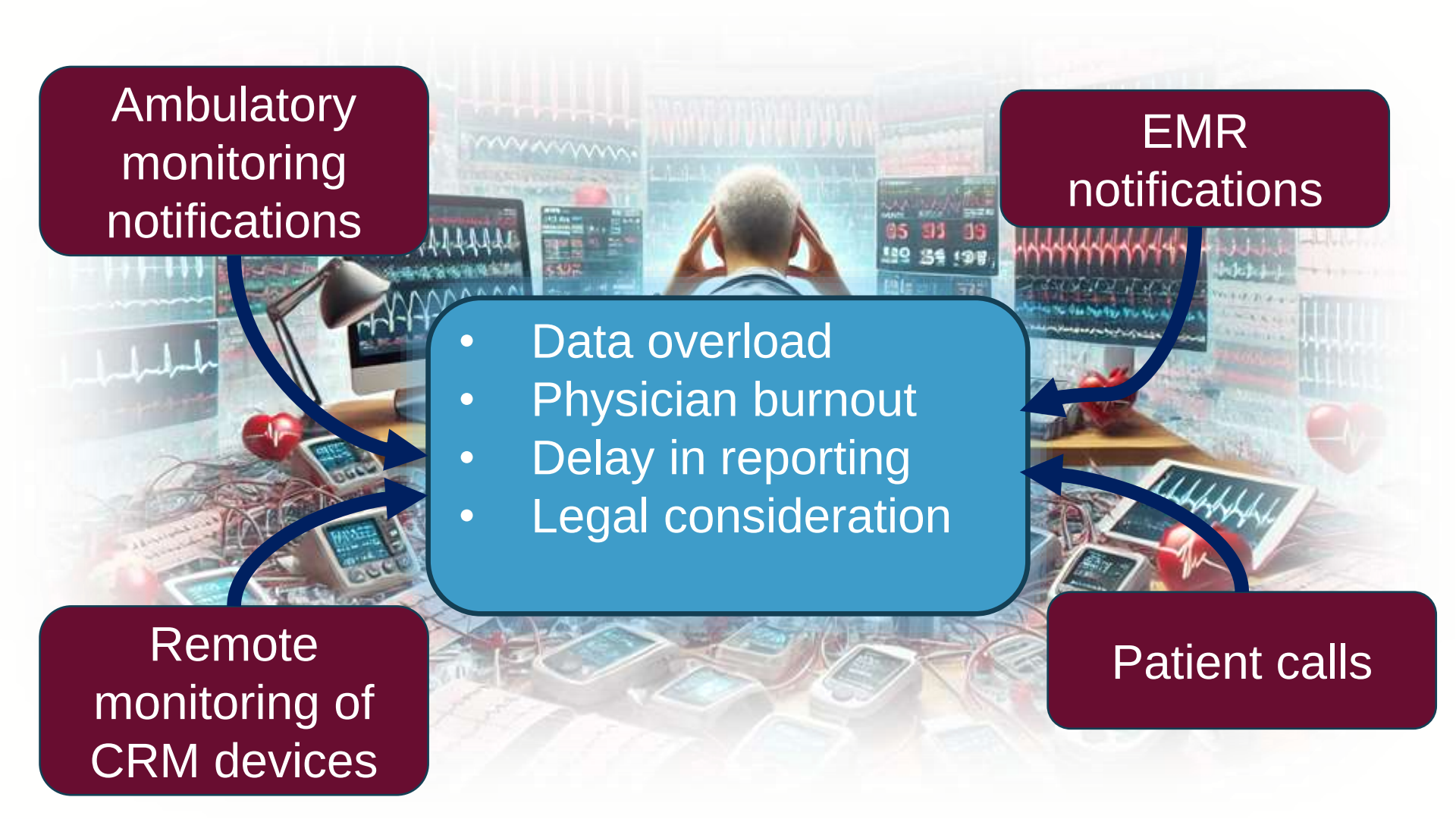
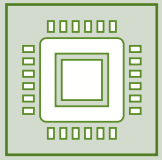

Ambulatory monitoring notifications
EMR notifications
Data overload
Physician burnout
Delay in reporting
Legal consideration
Remote monitoring of CRM devices
Patient calls

EMERGING TECHNOLOGIES



AI and Algorithm Advances: Artificial intelligence is being integrated to improve arrhythmia detection accuracy and efficiency; can enhance identification of subtle arrhythmias, predict arrhythmic risk. Machine learning algorithms filter noise and reduce false alarms in ambulatory data.

Wearable Biosensors: Beyond ECG, devices measuring photoplethysmography (PPG) or combining multi-vital signals (heart rate, oxygen, activity) are under study for arrhythmia screening. ***Textile electrodes*** (“smart shirts”) and **implantable micro-monitors** might offer more comfortable or long-term solutions.

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ARTIFICIAL INTELLIGENCE
&
AMBULATORY HEART RHYTHM MONITORING

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Cardiologist-level arrhythmia detection and classification in **ambulatory** electrocardiograms using a deep neural network.

Semi-Supervised Learning for Automatic Atrial Fibrillation Detection in 24-Hour Holter **Monitoring**.

Zhang P, Chen Y, Lin F, Wu S, Yang X, Li Q.

Use of Wearable Technology and Deep Learning to Improve the Diagnosis of Brugada Syndrome.

Liao S, Bokhari M, Chakraborty P, Suszko A, Jones G, Spears D, Gollob M, Zhang Z, Wang B, Chauhan VS.

JACC Clin Electrophysiol. 2022 Aug;8(8):1010-1020. doi: 10.1016/j.jacep.2022.05.003.

Artificial intelligence cloud platform improves arrhythmia detection from insertable **cardiac monitors** to 25 **cardiac rhythm** patterns through multi-label classification.

The Epidemic and Data-Free Zone of Nonsustained Ventricular Tachycardia: An Unintended Consequence of Digital **Monitoring** and a Path Forward.

Pundi K, Marcus GM, Turakhia M.

Circulation. 2023 Sep 5;148(10):805-807. doi: 10.1161/CIRCULATIONAHA.123.066049.

Artificial intelligence for direct-to-physician reporting of **ambulatory** electrocardiography.

Johnson LS, Zadrozniak P, Jasina G, Grotek-Cuprjak A, Andrade JG, Svennberg E,

Dynamic risk stratification of worsening **heart** failure using a deep learning-enabled implanted **ambulatory** single-lead electrocardiogram.

Howard JP, Vasudevan N, Sarkar S, Landman S, Koehler J, Keene D.

Eur Heart J Digit Health. 2024 May 8;5(4):435-443. doi: 10.1093/ehjdh/ztae035. eCollection 2024 Jul.

QTNet: Deep Learning for Estimating QT Intervals Using a Single Lead ECG.

Alam R, Aguirre AD, Stultz CM.

Annu Int Conf IEEE Eng Med Biol Soc. 2023 Jul;2023:1-4. doi: 10.1109/EMBC40787.2023.10341204.

Neiman ZM, Raitt MH, Rohrbach G, Dhruva SS.

J Am Heart Assoc. 2024 Mar 5;13(5):e032890. doi: 10.1161/JAHA.123.032890. Epub

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Large-Scale Assessment of a Smartwatch to Identify Atrial Fibrillation

Among participants who received notification of an irregular pulse, 34% had atrial fibrillation on subsequent ECG patch readings and 84% of notifications were concordant with atrial fibrillation.

Christopher B. Granger, M.D., Manisha Desai, Ph.D., and
Mintu P. Turakhia, M.D., M.A.S., for the Apple Heart Study Investigators*

N Engl J Med 2019

FUTURE PARADIGM

- A blend of medical-grade monitors and consumer tech could provide continuous risk monitoring
- Cloud-based platforms may aggregate data from wearables, with AI triaging alerts to clinicians
- Goals:
  - earlier arrhythmia detection
  - prevention of events like stroke or sudden cardiac arrest
  - improving convenience for patients

CONCLUSIONS

- Ambulatory ECG monitors are indispensable tools for diagnosing intermittent arrhythmias in pediatric and adult patients.
- Each modality has unique strengths: Holter for short-term continuous data, patches and ELRs for extended monitoring, MCT for real-time oversight, and ILRs for long-term diagnostic clarity.
- Optimal selection and utilization of ambulatory monitors, guided by evidence and patient needs, can lead to cost-effective, high-yield monitoring ensuring timely diagnosis, targeted therapy, and improved outcomes in arrhythmia management.
- Emerging innovations (wearable tech, AI) promise to further enhance arrhythmia detection and patient engagement in their care.


Thank you!