

# CardioWatch Pro — ECG Analysis Pipeline Validation

On-device analysis of Apple Watch single-lead ECG recordings · zenmindstudio.com

## What the pipeline does

CardioWatch Pro processes 30-second Apple Watch ECG recordings (single lead, ~512 Hz) entirely on the user's iPhone: Butterworth band-pass filtering (0.5–40 Hz) → gradient-based R-peak detection → wavelet (DWT) wave delineation → interval measurement (RR, PR, QRS, QT; QTc via Bazett) → conservative rule-based labeling of signal features such as premature ventricular complexes (PVCs). Measurements are always displayed alongside clinical reference ranges. No data leaves the device.

## Validation datasets

- **MIT-BIH Arrhythmia Database** (PhysioNet) — records 100, 119, 207, 208, 233; thirty 30-second windows resampled from 360 Hz to 512 Hz to match Apple Watch sampling. Ground truth: cardiologist beat annotations.
- **MIT-BIH Normal Sinus Rhythm Database** — 5 records, thirty 30-second windows, for false-positive testing on clean rhythm.
- **76 real Apple Watch recordings** — spanning Apple's own classifications: sinus rhythm (60), high heart rate (8), poor recording (7), inconclusive (1).

## PVC labeling vs. cardiologist annotations

**79.4%**

Recall — share of annotated PVCs the pipeline caught

**94.8%**

Precision — share of PVC labels that matched an annotated PVC

**0.864**

F1 score (301 ground-truth PVC beats)

Beat matching tolerance:  $\pm 195$  ms against MIT-BIH beat-center annotations.

## False-positive behavior on normal rhythm

Recording set	Duration	False PVC labels	Rate
All normal-rhythm windows (MIT-BIH NSR + Apple Watch)	56 min	12	$\approx 1$ per 9 recordings
Apple Watch, classified "sinus rhythm" by Apple	30 min	9	$\approx 1$ per 7 recordings
Apple Watch, "high heart rate" / "poor recording"	7.5 min	0	0

One recording = one 30-second ECG window.

## Limitations

- Single-lead ECG cannot assess ST-segment changes; the pipeline deliberately performs no ST or ischemia analysis.
- Rule-based labeling is tuned to be conservative; recall is lower on records with unusual PVC morphology (MIT-BIH 207/208).
- Low signal-quality recordings are flagged as such rather than labeled; low-confidence results are marked "reference only" in the app.
- Validation is ongoing; this summary reflects the test suite shipped with app version 1.7.

**Important.** CardioWatch Pro is not a medical device and does not provide medical diagnosis. All measurements and labels are for reference only and cannot replace professional medical advice. If you experience chest pain, severe dizziness, or difficulty breathing, call emergency services immediately.

# CardioWatch Pro — 心电分析管线验证

Apple Watch 单导联心电图的本机分析 · zenmindstudio.com

## 分析管线做什么

CardioWatch Pro 在用户 iPhone 上本机处理 30 秒 Apple Watch 心电记录（单导联，约 512 Hz）：Butterworth 带通滤波（0.5–40 Hz）→ 梯度法 R 峰检测 → 小波（DWT）波形定界 → 间期测量（RR、PR、QRS、QT；QTc 采用 Bazett 公式）→ 保守的规则式信号特征标注（如室性早搏 PVC）。所有测量值均与临床参考范围并列展示。数据不离开设备。

## 验证数据集

- **MIT-BIH 心律失常数据库** (PhysioNet) — 记录 100、119、207、208、233；三十个 30 秒窗口，从 360 Hz 重采样至 512 Hz 以匹配 Apple Watch 采样率。金标准：心脏科医生的逐搏标注。
- **MIT-BIH 正常窦性心律数据库** — 5 条记录、三十个 30 秒窗口，用于干净心律下的误报测试。
- **76 条真实 Apple Watch 记录** — 覆盖 Apple 原生分类：窦性心律（60）、高心率（8）、记录结果不佳（7）、不确定（1）。

## PVC 标注 vs 医生标注

**79.4%**

召回率 — 医生标注的 PVC 中被检出的比例

**94.8%**

精确率 — 算法标注中与医生标注吻合的比例

**0.864**

F1 分数（金标准 PVC 共 301 个）

逐搏匹配容差：相对 MIT-BIH 搏动中心标注  $\pm 195$  毫秒。

## 正常心律下的误报表现

记录集	时长	误报 PVC 数	频率
全部正常心律窗口（MIT-BIH NSR + Apple Watch）	56 分钟	12	≈ 每 9 条记录 1 次
Apple Watch, Apple 分类为「窦性心律」	30 分钟	9	≈ 每 7 条记录 1 次
Apple Watch, 「高心率」/「记录结果不佳」	7.5 分钟	0	0

一条记录 = 一个 30 秒心电图窗口。

## 局限性

- 单导联心电图无法评估 ST 段变化；管线特意不做任何 ST 段或缺血相关分析。
- 规则式标注以保守为调校目标；在 PVC 形态特殊的记录（MIT-BIH 207/208）上召回率偏低。
- 信号质量差的记录会被标记为质量不佳而非强行标注；低置信度结果在应用内标记为「仅供参考」。
- 验证持续进行中；本摘要对应应用 1.7 版随附的测试套件。

**重要提示：**CardioWatch Pro 不是医疗器械，不提供医学诊断。所有测量值与标注仅供参考，不能替代专业医疗建议。如出现胸痛、严重眩晕或呼吸困难，请立即拨打急救电话，不要依赖本应用。