Camera-based PPG on a Phone: A Clinically Defensible Early-Warning Triage Model

How a single finger-on-camera scan can support early escalation for potential cardiac and cerebrovascular deterioration (without claiming diagnosis).

Important: Camera PPG is a triage signal, not a diagnostic test for myocardial infarction (MI) or stroke. The goal is to detect *physiologic instability* that often precedes collapse and to trigger timely clinical contact.

1. The core physiological truth

Acute events like MI, malignant arrhythmia, shock physiology, and some stroke/TIA presentations share a common pattern: the body transitions from a compensated state to a stressed, unstable state. Before collapse, the autonomic and hemodynamic control loops shift.

A phone camera PPG does not 'see' the coronary artery or the brain. It can, however, measure the downstream consequences of instability at the peripheral microvascular pulse: timing, regularity, and waveform morphology.

2. What typically shifts before collapse (and what PPG can observe)

Physiology shift (what changes)	PPG-observable proxy (finger camera PPG)	Why it matters for early deterioration triage
Sympathetic surge + stress tachycardia	Heart rate (HR), beat-to-beat intervals	Sustained tachycardia is a generic but high-signal marker of physiologic stress (pain, ischemia, hypovolemia, infection).
Loss of vagal tone / autonomic instability	HRV time-domain (RMSSD, SDNN), frequency surrogates (LF/HF proxies), non-linear metrics (Poincare SD1/SD2)	Acute HRV drop relative to a person's baseline is consistent with rising physiologic strain; useful as an early warning even when symptoms are vague.
Peripheral vasoconstriction / low perfusion	PPG amplitude and perfusion index (normalized pulse amplitude), pulse area	When perfusion falls, the optical pulse can shrink and become noisy; a drop with good signal quality can indicate hemodynamic compromise or shock physiology.
Changes in arterial tone / wave reflection	Systolic upstroke slope, rise time, reflection index surrogate, dicrotic notch timing	Waveform morphology shifts with vascular tone and stiffness; abrupt change plus symptoms may support escalation rather than reassurance.
Respiratory distress / hyperventilation	Respiratory rate from amplitude/interval modulation (RSA), respiration-induced intensity variation	Respiratory stress often co-travels with cardiac events; adds context to tachycardia and low HRV.
Arrhythmia / irregular rhythm	Irregularity indices, ectopic burden estimate, AF-like variability pattern; rhythm strip of PPG pulses	Some collapses are triggered by arrhythmia. A robust irregular rhythm flag is action-guiding for urgent evaluation.
BP/afterload shifts (indirect)	Pulse width, systolic time-to-peak, diastolic decay constant proxies	Camera PPG cannot measure BP directly, but shape changes can support a 'hemodynamic stress' classification when combined with baseline and symptoms.

3. The 'one-scan' promise: how to avoid asking users to scan repeatedly

A single scan can be meaningful only if the system has context. The practical approach is:

- **Minimal baseline banking:** ask users to do a short scan once daily for 7-14 days during normal health (30-60 seconds). This builds a personal reference without burden.

- **Symptom-triggered scan:** when a user feels 'not right' (chest discomfort, breathlessness, unusual fatigue, dizziness, palpitations, one-sided weakness), they do one guided scan.

- **Instant comparison:** the algorithm compares today's features to the person's baseline distribution and to population safety rails, then returns a triage recommendation with confidence.

- **Edge case handling:** if signal quality is poor or the result is borderline, the app asks for one repeat after 3-5 minutes of rest (not many repeats).

4. Technical pipeline (camera PPG) - what is computed

Input: 30-60 seconds of fingertip video with flash. Output: feature vector + confidence + triage class.

4.1 Acquisition and quality control

- Guide finger pressure and stillness with on-screen feedback (motion bar, exposure stability).

- Reject segments with saturation, low light, or motion artifacts using signal quality indices (SQI).

- Ensure minimum usable duration (e.g., 25-40 seconds clean).

4.2 Signal extraction

- Compute a raw PPG-like waveform by averaging pixel intensity in the red channel (or combined channels) over time.

- Band-pass filter (typical 0.5-8 Hz) to isolate pulse; remove baseline drift.

- Detect pulse peaks/foot points; derive inter-beat intervals (IBI).

4.3 Feature computation (examples)

- **Rate and rhythm:** HR, IBI series, irregularity indices, ectopic-like patterns, AF-like variability flags.

- **Autonomic stress:** RMSSD, SDNN, pNN50, Poincare SD1/SD2, entropy-like measures (if signal permits).

- **Perfusion and morphology:** normalized pulse amplitude (perfusion index proxy), pulse area, rise time, upstroke slope, dicrotic notch timing proxy, diastolic decay constant proxy.

- **Respiration context:** respiration rate estimate from amplitude and interval modulation.

5. The escalation engine: clinically defensible decision logic

Regulators and clinical mentors will ask: *On what scientific basis did you escalate?* The answer must be transparent, logged, and based on measurable deviations plus symptom context.

5.1 Two-layer decisioning (recommended)

- **Layer A: Safety rails (population thresholds)** - immediate red flags even without baseline: extreme tachycardia/bradycardia, highly irregular rhythm, very low perfusion with good SQI.

- **Layer B: Personalized anomaly score** - compare current features to the user's own baseline; compute z-scores and a combined instability index.

5.2 An example triage output (not diagnosis)

Triage class	Rule-of-thumb logic (illustrative)	User instruction
Green - likely stable	Features within baseline range; no safety-rail flags; high SQI	Self-care guidance; if symptoms persist/worsen, contact clinician.
Amber - needs medical advice soon	Moderate deviation from baseline in >=2 domains (e.g., HRV drop + tachycardia) OR persistent symptoms with mild physiologic shift	Call doctor/teleconsult within hours; avoid sleep-if-uncertain.
Red - urgent evaluation	Strong deviation from baseline OR safety-rail trigger (irregular rhythm flag, marked tachycardia with low HRV, low perfusion with good SQI) especially with high-risk symptoms	Seek urgent care now; offer one-tap call + share report to clinician/family.

5.3 The escalation rationale record (audit trail)

Every escalation should generate a short, machine- and human-readable rationale that can be reviewed by a clinician:

- Signal quality: SQI score, usable duration.

- Deviation evidence: e.g., 'HR +28% vs baseline median', 'RMSSD -55% vs baseline', 'PPG amplitude -40% vs baseline'.

- Pattern evidence: irregular rhythm flag probability and supporting pulse plot.

- Symptom context: user-reported symptom cluster and onset time.

- Action: recommended next step and why (triage class).

6. Mapping to MI, stroke/TIA, and 'collapse' scenarios (what is realistic)

You can responsibly claim detection of **instability**, not disease. For specific events:

- **MI / ischemia:** many patients show autonomic stress (tachycardia, HRV suppression), sometimes arrhythmia, and physiologic strain. PPG can support escalation when symptoms are ambiguous.

- **Stroke/TIA:** PPG cannot measure focal neurological deficit. It can still provide supportive context (new AF-like irregularity, stress physiology) that justifies urgent evaluation when neuro symptoms are present.

- **Impending collapse/shock physiology:** falling peripheral perfusion and rising tachycardia with HRV collapse is directionally consistent with decompensation; PPG can provide an early warning to not 'sleep it off'.

7. How doctors and hospitals use it (workflow)

- **Patient-facing:** one guided scan during symptoms -> immediate triage + shareable report (PDF) + 'call now' option.
- **Doctor-facing dashboard:** timeline of scans, baseline ranges, raw waveform snippets, key features, triage history, and one-click documentation note.
- **Care pathways:** OPD triage, post-discharge monitoring, high-risk cohorts (HTN, diabetes, CKD, prior MI, post-stent, heart failure).
- **Clinical governance:** clinician can override triage; system learns from outcomes (label feedback) under a validated change-control process.

8. Validation strategy (what you compare against in pilots)

- For rhythm: compare irregularity flags vs ECG patch / Holter where available (subset validation).
- For physiologic stress: compare features against vitals in ED/OPD (HR, BP, SpO2), and clinician-assessed acuity scores.
- For outcomes: track ED referrals, admissions, and confirmed diagnoses; evaluate sensitivity for 'needs urgent evaluation' rather than MI diagnosis.
- Report calibration: false alarm rate, time-to-care, and user adherence (one scan at symptom time).

Limitations and guardrails

- Camera PPG is sensitive to motion, finger pressure, skin temperature, and ambient conditions; SQI gating is mandatory.
- Single-site PPG cannot directly estimate blood pressure or perfusion to organs; it infers peripheral pulse behavior.
- Triage categories must be presented as decision support, not diagnosis: include safety language and emergency disclaimers.

This document is a concept note intended to support product, clinical, and regulatory discussions for an early-warning triage workflow.