International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher
SciFormat Publishing Inc.
ISNI: 0000 0005 1449 8214

2734 17 Avenue SW,
Calgary, Alberta, T3E0A7,
Canada
+15878858911
editorial-office@sciformat.ca

ARTICLE TITLE	QT INTERVAL CHANGES AT HIGH ALTITUDE: A NARRATIVE REVIEW OF CARDIOVASCULAR RISK AND THE ROLE OF WEARABLE TECHNOLOGIES IN REMOTE MONITORING
DOI	https://doi.org/10.31435/ijitss.2(50).2026.5483
RECEIVED	03 April 2026
ACCEPTED	12 June 2026
PUBLISHED	30 June 2026
LICENSE	The article is licensed under a **Creative Commons Attribution 4.0 International License.**

QT INTERVAL CHANGES AT HIGH ALTITUDE: A NARRATIVE REVIEW OF CARDIOVASCULAR RISK AND THE ROLE OF WEARABLE TECHNOLOGIES IN REMOTE MONITORING

Katarzyna Apanasewicz *(Corresponding Author, Email: kasia.apanasewicz@gmail.com)*
J. Strus Multidisciplinary Municipal Hospital in Poznań, Poland
ORCID ID: 0009-0001-0765-5398

Marta Kamrowska
University Clinical Hospital No. 2 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0001-1570-0144

Jakub Świech
University Clinical Hospital No. 2 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0001-1732-4162

Filip Kopacki
University Clinical Hospital No. 2 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0005-7897-8222

Weronika Szczeblewska
Independent Public Provincial Integrated Hospital in Szczecin, Poland
ORCID ID: 0009-0007-3956-622X

Daniel Jaskot
Independent Public Provincial Integrated Hospital in Szczecin, Poland
ORCID ID: 0009-0004-8678-9838

Jakub Marzec
University Clinical Hospital No. 1 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0007-8336-7260

Natalia Kita
University Clinical Hospital No. 2 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0001-2277-6198

Natalia Sztenc
Pomeranian Medical University, Szczecin, Poland
ORCID ID: 0009-0006-4307-7958

Patrycja Broniszewska
University Clinical Hospital No. 2 of Pomeranian Medical University in Szczecin, Poland
ORCID ID: 0009-0000-6577-307X

ABSTRACT

High-altitude exposure induces a range of cardiovascular and electrophysiological adaptations driven primarily by hypobaric hypoxia, autonomic imbalance, and changes in pulmonary hemodynamics. Among these adaptations, alterations in ventricular repolarization, including prolongation of the QT interval and corrected QT (QTc), have attracted increasing attention because of their potential association with arrhythmic risk in both healthy individuals and vulnerable populations. Previous studies have described electrocardiographic changes at altitude, and more recent evidence indicates that QTc may increase during acute or short-term high-altitude exposure and in selected clinical groups, such as patients with obstructive sleep apnea or high-altitude pulmonary hypertension.

This narrative review synthesizes current evidence on QT interval changes at high altitude, assesses their potential clinical significance, and evaluates the emerging role of wearable technologies in remote cardiac monitoring under extreme environmental conditions. A structured literature search was conducted using major databases, including PubMed/MEDLINE, Scopus, and Web of Science.

The available evidence suggests that high altitude may contribute to measurable changes in ventricular repolarization, although the magnitude, persistence, and clinical implications of these alterations remain heterogeneous across studies. Wearable and smartwatch-based ECG technologies offer promising opportunities for remote surveillance; however, current evidence indicates that QT assessment with such devices still requires careful validation and expert interpretation.

These findings may be relevant for clinicians, travelers, and healthcare systems seeking safer strategies for cardiovascular risk assessment in remote and high-altitude environments.

KEYWORDS

QT Interval; High Altitude; Ventricular Repolarization; Wearable Technology; Cardiac Risk; Telemedicine

CITATION

Katarzyna Apanasewicz, Marta Kamrowska, Jakub Świech, Filip Kopacki, Weronika Szczeblewska, Daniel Jaskot, Jakub Marzec, Natalia Kita, Natalia Sztenc, Patrycja Broniszewska. (2026) QT Interval Changes at High Altitude: a Narrative Review of Cardiovascular Risk and the Role of Wearable Technologies in Remote Monitoring. *International Journal of Innovative Technologies in Social Science*. 2(50). doi: 10.31435/ijitss.2(50).2026.5483

I. Introduction

High-altitude environments, typically defined as elevations above 2,500 meters above sea level, are characterized by reduced atmospheric pressure and consequent hypobaric hypoxia. These conditions trigger a cascade of physiological adaptations involving the cardiovascular, respiratory, and autonomic nervous systems (Bärtsch & Gibbs, 2007; West, 2012). Acute exposure to high altitude has been shown to increase heart rate, alter autonomic balance, and affect pulmonary hemodynamics, often resulting in measurable changes in electrocardiographic (ECG) parameters (Windsor et al., 2010). Among these, alterations in ventricular repolarization, particularly changes in the QT interval and corrected QT (QTc), have gained increasing attention due to their potential association with arrhythmic risk.

The QT interval reflects the total duration of ventricular depolarization and repolarization and is widely recognized as an important marker of electrical stability of the myocardium. Prolongation of the QT interval has been associated with an increased risk of malignant ventricular arrhythmias and sudden cardiac death in various clinical settings (Goldenberg et al., 2006; Schwartz et al., 2012). However, the interpretation of QT changes in the context of environmental stressors, such as high-altitude exposure, remains complex. Early studies reported electrocardiographic changes in mountaineers and individuals exposed to hypoxic conditions, including variations in heart rate, T-wave morphology, and QT duration (Karliner et al., 1985). More recent investigations suggest that QTc prolongation may occur during acute high-altitude exposure and may be more pronounced during nocturnal periods or in the early phases of acclimatization (Horii et al., 1987; Gudelunas et al., 2025).

Importantly, the magnitude and clinical relevance of QT interval changes at high altitude appear to vary depending on individual susceptibility, duration of exposure, and underlying health status. While healthy

individuals may exhibit transient and clinically insignificant alterations, vulnerable populations—including patients with sleep-disordered breathing, pulmonary hypertension, or pre-existing cardiovascular disease—may demonstrate more pronounced disturbances in ventricular repolarization (Latshang et al., 2016; Aeschbacher et al., 2021). These findings raise important questions regarding risk stratification and the need for monitoring in specific subgroups of individuals traveling to or residing at high altitude.

In parallel with advances in high-altitude physiology, recent years have witnessed rapid development in digital health technologies, particularly wearable and mobile electrocardiographic monitoring devices. Smartwatches and portable ECG systems are increasingly capable of detecting cardiac rhythm disturbances and, in some cases, estimating QT intervals outside of traditional clinical settings (Steinhubl et al., 2015; Perez et al., 2019). These innovations have created new opportunities for remote cardiovascular monitoring in environments where access to conventional diagnostic infrastructure is limited, such as mountainous or remote regions. However, the accuracy and reliability of QT measurements obtained from wearable devices remain an area of ongoing investigation, with current evidence suggesting variable agreement with standard 12-lead ECG (Mannhart et al., 2022; Hoek et al., 2023).

Despite growing interest in both high-altitude cardiology and digital health, there remains a lack of comprehensive synthesis integrating these two domains. Specifically, the relationship between altitude-induced changes in ventricular repolarization and the potential role of wearable technologies in detecting and monitoring these changes has not been comprehensively reviewed. Addressing this gap is particularly relevant in the context of increasing global participation in high-altitude tourism, trekking, and adventure travel, often involving individuals with varying levels of medical fitness.

Therefore, the aim of this review is threefold: (1) to summarize current evidence regarding QT interval and QTc changes during high-altitude exposure, (2) to evaluate their potential clinical and arrhythmic significance across different populations, and (3) to assess the emerging role of wearable technologies in remote cardiac monitoring under high-altitude conditions. By integrating insights from cardiovascular physiology, clinical research, and digital health innovation, this review seeks to provide a comprehensive and interdisciplinary perspective aligned with contemporary challenges at the intersection of technology, health, and society.

II. Methodology

This study was conducted as a narrative review aimed at synthesizing current evidence on the effects of high-altitude exposure on ventricular repolarization, with particular focus on changes in the QT interval and corrected QT (QTc), as well as the emerging role of wearable technologies in remote cardiac monitoring under extreme environmental conditions.

A structured literature search was performed in major electronic databases, including PubMed/MEDLINE, Scopus, and Web of Science. The search strategy included combinations of relevant keywords and Medical Subject Headings (MeSH), such as “QT interval,” “QTc,” “ventricular repolarization,” “high altitude,” “hypoxia,” “electrocardiography,” “arrhythmia,” and “wearable technology.” Boolean operators (“AND,” “OR”) were used to refine the search and ensure comprehensive coverage of the topic.

The search included articles published up to January 2026 and was limited to studies available in English. Both original research articles and review papers were considered. Preference was given to peer-reviewed publications, studies with clearly described methodologies, and those addressing electrophysiological changes at high altitude or the application of wearable and digital cardiac monitoring technologies.

Studies were selected based on their relevance to the objectives of the review. Inclusion criteria focused on investigations addressing QT interval dynamics, arrhythmic risk, cardiovascular responses to hypoxic conditions, and the accuracy and clinical utility of wearable ECG devices. Articles lacking sufficient methodological clarity or not directly related to the scope of the review were excluded.

Although this review was conducted as a narrative synthesis, elements of a structured approach were applied, including predefined search terms, database selection, and inclusion criteria. However, no formal PRISMA protocol or flow diagram was implemented. Study selection and interpretation were based on scientific relevance, methodological quality, and contribution to the topic.

III. Results

1. Physiological Effects of High Altitude on the Cardiovascular System

High-altitude environments are characterized by reduced barometric pressure and decreased partial pressure of oxygen, leading to hypobaric hypoxia. These conditions trigger a complex cascade of physiological adaptations involving the cardiovascular, respiratory, and autonomic nervous systems. Acute exposure to altitude results in immediate increases in heart rate, cardiac output, and sympathetic nervous system activity, aimed at maintaining adequate tissue oxygenation despite reduced oxygen availability.

One of the most consistent cardiovascular responses to high altitude is the activation of the sympathetic nervous system, accompanied by elevated circulating catecholamine levels. This response contributes to increased heart rate and myocardial contractility, but also influences cardiac electrophysiology. It has been suggested that heightened sympathetic tone may alter ventricular repolarization dynamics and contribute to variability in electrocardiographic parameters, including the QT interval (Woods et al., 2011).

In addition to autonomic changes, high-altitude exposure is associated with significant alterations in pulmonary hemodynamics. Hypoxic pulmonary vasoconstriction leads to increased pulmonary artery pressure and may result in right ventricular strain, particularly at higher altitudes or during prolonged exposure. These changes can be reflected in electrocardiographic findings, including right axis deviation and alterations in T-wave morphology (Windsor et al., 2010).

Early observational studies provided important insights into electrocardiographic adaptations to high altitude. Karliner et al. (1985), during the American Medical Research Expedition to Everest, reported notable ECG changes among climbers, including increased heart rate, arrhythmic activity, and repolarization abnormalities. Similarly, Saurenmann et al. (1984) demonstrated that beta-adrenergic stimulation plays a significant role in altitude-induced ECG changes, further supporting the involvement of sympathetic mechanisms in cardiac electrophysiology under hypoxic conditions.

Respiratory adaptations also contribute to cardiovascular changes at altitude. Hyperventilation, a hallmark of acclimatization, leads to respiratory alkalosis, which may influence ion channel activity and myocardial excitability. Alterations in potassium and calcium homeostasis have been proposed as mechanisms affecting ventricular repolarization, potentially contributing to changes in QT interval duration.

Another important factor is the alteration of autonomic balance over the course of altitude exposure. While sympathetic activation predominates during initial exposure and physical activity, increased parasympathetic influence during rest and sleep may result in dynamic fluctuations in heart rate and repolarization parameters. Periodic breathing, commonly observed at altitude, may further exacerbate these variations, particularly during nocturnal periods.

Despite these well-documented physiological adaptations, the overall impact of high altitude on cardiac electrophysiology remains complex and heterogeneous. Windsor et al. (2010) emphasized that although electrocardiographic changes are frequently observed, including increased ectopic activity and repolarization abnormalities, clinically significant arrhythmias are relatively uncommon in healthy individuals. Nevertheless, the presence of measurable changes in ventricular repolarization highlights the importance of understanding the underlying physiological mechanisms, particularly in the context of increasing exposure of diverse populations to high-altitude environments.

In summary, high-altitude exposure induces a multifactorial set of cardiovascular adaptations involving autonomic activation, pulmonary vascular changes, and metabolic alterations. These processes collectively influence cardiac electrophysiology and provide the physiological foundation for observed changes in ventricular repolarization, including QT interval variability.

2. QT Interval: Clinical Significance and Measurement

The QT interval represents the total duration of ventricular depolarization and repolarization and is a fundamental parameter in electrocardiographic assessment of cardiac electrical stability. It is measured from the onset of the QRS complex to the end of the T wave and is influenced by multiple physiological and pathological factors, including heart rate, autonomic tone, electrolyte balance, and pharmacological agents (Goldenberg et al., 2006).

Because the QT interval varies with heart rate, corrected QT (QTc) values are commonly used in clinical practice to allow for more accurate comparisons. Several correction formulas have been proposed, including Bazett's, Fridericia's, and Framingham methods, each with its own limitations. Bazett's formula, although widely used, is known to overcorrect at high heart rates and undercorrect at low heart rates, which may be

particularly relevant in conditions such as high-altitude exposure, where heart rate variability is common (Vandenberk et al., 2016).

Prolongation of the QT interval is clinically significant, as it has been associated with an increased risk of malignant ventricular arrhythmias, including torsades de pointes, and sudden cardiac death. Both congenital and acquired forms of long QT syndrome have been extensively studied, with multiple genetic and environmental factors contributing to impaired ventricular repolarization (Schwartz et al., 2012; Roden, 2004). In addition, numerous medications—including antiarrhythmic drugs, certain antibiotics, and psychotropic agents—are known to prolong the QT interval, further increasing arrhythmic risk under specific conditions (Goldenberg et al., 2006).

Accurate measurement of the QT interval presents several methodological challenges. One of the primary difficulties lies in the identification of the end of the T wave, particularly in cases of low amplitude, bifid, or merged T and U waves. Variability in lead selection, signal quality, and observer interpretation may further contribute to inconsistencies in QT measurement across studies and clinical settings (Goldenberg et al., 2006).

Accurate assessment of ventricular repolarization extends beyond simple QT interval measurement and includes analysis of T-wave morphology and repolarization dynamics, which may provide additional insights into arrhythmic risk (Couderc, 2010). Advanced electrocardiographic parameters, such as QT dispersion, Tpeak–Tend interval, and beat-to-beat variability, have been proposed as complementary markers of repolarization heterogeneity and electrical instability.

Furthermore, the increasing use of digital and wearable ECG technologies introduces additional considerations regarding QT measurement accuracy. While these devices offer promising opportunities for remote monitoring, their reliance on single-lead recordings and susceptibility to signal artifacts may limit their precision compared to standard 12-lead ECG systems (Mannhart et al., 2022; Hoek et al., 2023).

In summary, the QT interval remains a key parameter in the assessment of ventricular repolarization and arrhythmic risk. However, its interpretation requires careful consideration of methodological limitations, physiological variability, and measurement conditions. Advances in both conventional and digital electrocardiography continue to refine our understanding of QT dynamics and their clinical implications.

3. QT Interval Changes in Healthy Individuals at High Altitude

The majority of available evidence indicates that exposure to high-altitude environments is associated with measurable alterations in ventricular repolarization, particularly reflected in changes in the QT interval and corrected QT (QTc). These changes are most commonly observed during acute or short-term exposure to hypobaric hypoxia and may vary depending on altitude level, duration of exposure, and individual physiological responses.

Early investigations into electrocardiographic adaptations at altitude provided initial evidence that hypoxic conditions can influence cardiac electrophysiology. In a seminal study, Horii et al. (1987) performed continuous electrocardiographic monitoring in mountaineers and demonstrated a significant prolongation of nocturnal QTc intervals despite a concomitant shortening of RR intervals. This finding suggested that repolarization changes may occur independently of heart rate and may be influenced by alterations in autonomic regulation during hypoxic exposure.

A recent study by Gudelunas et al. (2025) reported that four days of exposure to high altitude resulted in a statistically significant increase in QTc duration in healthy adult participants, with mean prolongation exceeding 20 ms compared to baseline measurements at sea level. Notably, these electrophysiological changes occurred in the absence of overt clinical symptoms, suggesting that subclinical repolarization abnormalities may develop even in otherwise healthy individuals.

Similarly, Liu et al. (2024), in a sub-analysis of the SCARF study, demonstrated that acute high-altitude exposure was associated with prolongation of QTc and Tpeak–Tend (Tp–e) intervals, both of which are considered markers of ventricular repolarization heterogeneity and arrhythmic susceptibility. Importantly, these changes were found to be at least partially reversible following descent and reoxygenation, supporting a direct relationship between hypoxic stress and repolarization dynamics.

Despite these consistent trends, the magnitude and reproducibility of QT interval changes across studies remain variable. Differences in altitude exposure—ranging from moderate elevations (approximately 2,500–3,500 m) to extreme altitudes exceeding 5,000 m—as well as variability in acclimatization status and physical exertion, likely contribute to heterogeneity in findings. Furthermore, methodological differences, including the

use of different QT correction formulas and ECG acquisition techniques, complicate direct comparisons between studies (Vandenberk et al., 2016).

An important and recurrent observation across several studies is the greater degree of QTc prolongation during nocturnal periods. This phenomenon may be explained by alterations in autonomic balance, including increased parasympathetic activity during sleep, combined with periodic breathing patterns and intermittent hypoxia commonly observed at altitude. These findings highlight the importance of continuous or ambulatory monitoring when assessing repolarization dynamics in high-altitude environments.

From a clinical perspective, current evidence suggests that QT interval prolongation in healthy individuals exposed to high altitude is generally modest and transient. Reviews of high-altitude cardiology indicate that, in the absence of underlying cardiovascular disease, such electrophysiological changes rarely result in clinically significant arrhythmias (Windsor et al., 2010; Woods et al., 2011). Nevertheless, the presence of measurable changes in ventricular repolarization underscores the importance of understanding potential cumulative effects of hypoxia, physical exertion, dehydration, and environmental stressors.

Overall, the available literature supports the conclusion that high-altitude exposure can influence QT interval dynamics in healthy individuals, particularly during acute exposure and early acclimatization phases. However, the clinical significance of these changes remains uncertain, and further research is required to determine whether QT prolongation represents a benign adaptive response or a potential marker of increased arrhythmic risk under specific environmental and physiological conditions.

4. QT Interval Changes in Vulnerable and Clinical Populations

The effects of high-altitude exposure on QT interval dynamics appear to be more pronounced and clinically relevant in vulnerable populations compared to healthy individuals. Patients with pre-existing cardiopulmonary conditions, impaired oxygenation, or autonomic dysfunction may exhibit greater disturbances in ventricular repolarization under hypoxic stress.

One of the most extensively studied groups in this context includes patients with obstructive sleep apnea (OSA). Exposure to moderate altitude has been shown to exacerbate nocturnal hypoxemia and increase QTc duration in these individuals, likely due to intermittent hypoxia and enhanced sympathetic activation (Latshang et al., 2016). These findings are consistent with broader evidence indicating that sleep-disordered breathing is associated with increased QT variability and arrhythmic risk, particularly under conditions of oxygen desaturation (Somers et al., 1993).

Patients with high-altitude pulmonary hypertension (HAPH) represent another high-risk group. Studies conducted in high-altitude populations have demonstrated prolonged QT intervals and increased QT dispersion in individuals with HAPH, suggesting increased heterogeneity of ventricular repolarization (Aeschbacher et al., 2021). Importantly, oxygen supplementation has been shown to partially reverse these changes, further supporting the role of hypoxia as a key modulator of repolarization dynamics (Furian et al., 2021).

Chronic hypoxic exposure may also lead to structural and electrophysiological remodeling of the myocardium. Experimental and clinical studies suggest that sustained hypoxia can alter ion channel expression and myocardial conduction properties, thereby increasing susceptibility to arrhythmias (Bärtsch & Gibbs, 2007; West, 2012). These adaptations may be particularly relevant in long-term high-altitude residents or individuals with underlying cardiopulmonary disease.

Additional evidence suggests that specific physiological states may further influence QT dynamics at altitude. For example, pregnant women residing at moderate altitude have been reported to exhibit prolonged QT intervals, potentially reflecting the combined effects of hypoxia and increased cardiovascular demand (Batmaz et al., 2016). Similarly, individuals with cardiovascular comorbidities may demonstrate greater electrophysiological instability when exposed to hypoxic stress, even in the absence of overt symptoms.

Pharmacological factors also play a critical role in this context. Many commonly used medications—including certain antibiotics, antipsychotics, and antiarrhythmic drugs—are known to prolong the QT interval. Under high-altitude conditions, where dehydration, electrolyte imbalance, and hypoxia are prevalent, the proarrhythmic effects of these medications may be amplified (Roden, 2004; Goldenberg et al., 2006). This highlights the importance of careful medication review prior to high-altitude exposure.

Moreover, the concept of reduced repolarization reserve is particularly relevant in vulnerable populations. Individuals with underlying genetic or acquired predispositions may have limited capacity to compensate for external stressors, such as hypoxia or autonomic fluctuations. As a result, even modest QT prolongation may have greater clinical significance in these groups (Schwartz et al., 2012).

In summary, QT interval changes at high altitude are not uniform across populations and are significantly influenced by underlying health status and physiological vulnerability. In high-risk individuals, these changes may reflect clinically relevant disturbances in ventricular repolarization and warrant closer monitoring and individualized risk assessment.

5. Mechanisms of QT Interval Changes at High Altitude

The mechanisms underlying QT interval alterations at high altitude are complex and multifactorial, involving the interplay of hypoxia, autonomic nervous system modulation, respiratory adaptations, and hemodynamic changes. Although the exact contribution of each factor remains incompletely understood, existing evidence suggests that ventricular repolarization is particularly sensitive to hypoxic stress and associated physiological responses.

Hypobaric hypoxia represents the primary trigger for cardiovascular adaptation at high altitude. Reduced oxygen availability leads to activation of the sympathetic nervous system and increased circulating catecholamines, which have been shown to influence cardiac electrophysiology. Enhanced sympathetic tone may affect ion channel activity, particularly those involved in ventricular repolarization, thereby contributing to QT interval variability (Woods et al., 2011; Somers et al., 1993). Experimental and observational studies have also demonstrated that beta-adrenergic stimulation plays a significant role in altitude-induced electrocardiographic changes (Saurenmann et al., 1984).

In parallel, respiratory adaptations to hypoxia—most notably hyperventilation—result in respiratory alkalosis. This shift in acid–base balance can influence myocardial excitability and ion transport mechanisms, including potassium and calcium flux across cardiac cell membranes. Alterations in these ionic currents are known to affect the duration of action potentials and may contribute to prolongation of ventricular repolarization, as reflected in QT interval changes (Roden, 2004).

Autonomic nervous system imbalance is another key factor. Acute exposure to altitude is associated with increased sympathetic activity, while parasympathetic influence becomes more prominent during rest and sleep. This dynamic interplay may lead to fluctuations in QT interval duration, particularly during nocturnal periods. Periodic breathing, a common phenomenon at altitude, may further exacerbate intermittent hypoxia and autonomic instability, thereby increasing variability in repolarization parameters (Latshang et al., 2016).

Hemodynamic changes also contribute to electrophysiological alterations. Hypoxic pulmonary vasoconstriction leads to elevated pulmonary artery pressure and increased right ventricular afterload. This may result in right ventricular strain, which has been associated with changes in repolarization patterns on ECG (Windsor et al., 2010). Chronic exposure to hypoxia, as observed in high-altitude residents, may further lead to structural remodeling of the myocardium, potentially influencing electrical conduction and repolarization heterogeneity (Aeschbacher et al., 2021).

In addition to systemic and cardiac factors, metabolic and environmental stressors may modulate QT interval dynamics. Dehydration, electrolyte imbalances, and increased physical exertion—common in high-altitude settings—can further influence myocardial electrophysiology. For example, hypokalemia is a well-known contributor to QT prolongation and may occur in the context of altitude-related diuresis or inadequate fluid intake (Goldenberg et al., 2006).

Despite these proposed mechanisms, it is important to note that the relationship between hypoxia and QT interval changes is not entirely consistent across studies. Variability in individual susceptibility, acclimatization processes, and methodological differences in QT measurement may contribute to inconsistent findings. Furthermore, the relative contribution of each physiological mechanism may differ depending on altitude level, duration of exposure, and the presence of underlying medical conditions (Bärtsch & Gibbs, 2007).

In summary, QT interval changes at high altitude result from a combination of hypoxia-driven autonomic activation, respiratory and metabolic alterations, and hemodynamic stress. These mechanisms collectively influence ventricular repolarization and may contribute to increased variability in QT interval duration. However, further research is required to clarify the precise pathways involved and to determine their relative clinical significance in different populations.

6. Arrhythmic Risk and Clinical Implications

The relationship between QT interval prolongation and clinically significant arrhythmias at high altitude remains complex and not fully understood. While QT prolongation is a well-established marker of arrhythmic risk in clinical cardiology, its interpretation in the context of high-altitude exposure requires careful consideration of physiological adaptations, environmental stressors, and individual susceptibility.

Hypoxia, the defining feature of high-altitude environments, may create a potentially proarrhythmic milieu through multiple mechanisms. These include sympathetic nervous system activation, autonomic imbalance, electrolyte disturbances, and alterations in myocardial oxygen supply. Increased circulating catecholamines and enhanced beta-adrenergic stimulation may affect ion channel activity and contribute to electrical instability of the myocardium (Somers et al., 1993; Woods et al., 2011). In addition, hypoxia-related respiratory alkalosis and fluctuations in potassium and calcium levels may further modulate ventricular repolarization and increase QT variability (Roden, 2004).

Despite these theoretical mechanisms, available evidence suggests that clinically significant arrhythmias—such as sustained ventricular tachycardia or sudden cardiac death—are relatively rare in healthy individuals at high altitude. More commonly observed are benign rhythm disturbances, including premature atrial or ventricular contractions, which are typically transient and of limited clinical significance (Windsor et al., 2010). These findings indicate that QT interval changes in healthy individuals may reflect physiological adaptation rather than a direct marker of imminent arrhythmic events.

However, the situation differs in vulnerable populations. Individuals with pre-existing cardiovascular disease, congenital or acquired long QT syndrome, or impaired oxygenation may exhibit increased susceptibility to arrhythmias under hypoxic conditions. In such individuals, even modest QT prolongation may be clinically relevant due to reduced repolarization reserve and increased vulnerability to triggered activity (Schwartz et al., 2012; Roden, 2004). Similarly, patients with obstructive sleep apnea or pulmonary hypertension may experience more pronounced repolarization disturbances during altitude exposure (Latshang et al., 2016; Aeschbacher et al., 2021).

Risk stratification at high altitude remains an important but insufficiently explored aspect of clinical practice. Current evidence suggests that arrhythmic risk is influenced by a combination of environmental factors and individual characteristics, including baseline cardiovascular status, genetic predisposition, and medication use. In particular, drugs known to prolong the QT interval—such as certain antibiotics, antipsychotics, and antiarrhythmic agents—may have enhanced proarrhythmic effects in the setting of hypoxia, dehydration, and electrolyte imbalance (Goldenberg et al., 2006).

Clinical guidelines emphasize the importance of pre-travel assessment in patients with known cardiovascular disease who are planning high-altitude exposure. Recommendations from expert groups, including the European Society of Cardiology, support individualized risk evaluation, taking into account arrhythmic history, medication profile, and functional capacity (Parati et al., 2018). Such an approach may help identify high-risk individuals and guide preventive strategies, including medication adjustment or closer monitoring.

Another important concept in this context is “repolarization reserve,” which refers to the myocardium’s ability to maintain stable electrical activity despite external stressors. Hypoxia, electrolyte disturbances, and pharmacological factors may reduce this reserve, thereby increasing susceptibility to arrhythmias even in individuals without overt structural heart disease (Roden, 2004). This may partly explain the variability in clinical outcomes observed among individuals exposed to similar high-altitude conditions.

Environmental and behavioral factors also contribute to arrhythmic risk. Physical exertion, dehydration, sleep disturbances, and periodic breathing patterns may exacerbate autonomic fluctuations and promote electrical instability. Nocturnal hypoxia, in particular, has been associated with increased variability in repolarization parameters and may represent a critical period for arrhythmic vulnerability, especially in predisposed individuals (Latshang et al., 2016).

From a clinical perspective, interpretation of QT interval changes at high altitude should always be contextualized. Isolated, mild, and transient QT prolongation in otherwise healthy individuals is unlikely to indicate significant risk. However, in the presence of additional risk factors—such as underlying cardiac disease, medication effects, or significant hypoxemia—QT prolongation may serve as an important warning sign.

In summary, although high-altitude exposure may promote conditions favorable to arrhythmogenesis, serious arrhythmic events remain uncommon in healthy individuals. In contrast, vulnerable populations may exhibit increased susceptibility due to impaired repolarization reserve and additional physiological stressors. These findings highlight the importance of individualized risk assessment, appropriate pre-exposure evaluation, and targeted monitoring strategies in selected populations.

7. Wearable Technologies and Remote Cardiac Monitoring

Recent advances in digital health technologies have significantly expanded the possibilities for cardiovascular monitoring beyond traditional clinical environments. Wearable devices, including smartwatches and portable electrocardiographic (ECG) systems, have emerged as promising tools for real-time, non-invasive assessment of cardiac function. These technologies are particularly relevant in high-altitude settings, where access to medical infrastructure is often limited and early detection of cardiovascular abnormalities may be critical.

Large-scale studies have demonstrated the feasibility of wearable devices in detecting cardiac rhythm abnormalities in real-world settings. For example, the Apple Heart Study showed that smartwatch-based monitoring can identify arrhythmias such as atrial fibrillation in large populations, highlighting the scalability and clinical potential of these technologies (Perez et al., 2019). Similarly, other investigations have confirmed the ability of wearable ECG systems to provide continuous or intermittent cardiac monitoring and support early detection of clinically relevant changes (Tison et al., 2018; Sana et al., 2020).

Wearable ECG devices are increasingly capable of detecting heart rhythm disturbances and, in some cases, estimating key electrocardiographic parameters, including the QT interval. A systematic review by Hoek et al. (2023) identified a growing body of evidence supporting the feasibility of using smart devices for QT monitoring. These technologies can provide clinically useful approximations of QT and QTc intervals; however, variability in measurement accuracy remains a significant limitation (Mannhart et al., 2022; Saghir et al., 2020).

The integration of artificial intelligence (AI) into wearable ECG analysis represents a further advancement in this field. Machine learning algorithms have been shown to improve the accuracy of QTc estimation and reduce user-dependent variability, with several studies reporting clinically acceptable agreement with standard 12-lead ECG measurements (Maille et al., 2021; Tison et al., 2018). This approach may be particularly valuable in remote or resource-limited environments, including high-altitude settings.

Despite these technological advances, several important limitations must be considered. Most wearable devices rely on single-lead ECG recordings, which may not capture the full complexity of ventricular repolarization observed in multi-lead ECG systems. According to established standards for electrocardiographic monitoring, accurate assessment of cardiac electrophysiology typically requires multi-lead ECG recordings, which remain the clinical reference for comprehensive evaluation (Drew et al., 2010). This limitation is particularly relevant for QT interval assessment, as T-wave morphology and lead selection can significantly influence measurement accuracy (Koshy et al., 2018). In addition, motion artifacts, environmental conditions, and user technique may further compromise signal quality, especially in physically demanding high-altitude environments.

Environmental factors specific to high altitude may further challenge the reliability of wearable monitoring. Cold exposure, reduced peripheral perfusion, and increased physical activity may impair sensor performance and signal acquisition. These factors must be taken into account when interpreting data obtained from wearable devices in such settings (Woods et al., 2011).

Nevertheless, wearable technologies offer unique advantages in the context of high-altitude medicine. Continuous or intermittent monitoring of cardiac parameters may enable early detection of abnormalities, facilitate remote medical decision-making, and improve safety for individuals traveling to remote or extreme environments. This is particularly relevant given the increasing global participation in high-altitude tourism and adventure activities (Bärtsch & Gibbs, 2007).

From a broader perspective, the integration of wearable technologies into healthcare reflects a growing trend toward decentralization of medical monitoring and expansion of telemedicine. Digital health solutions enable real-time data collection, increased accessibility, and more personalized patient management, aligning with modern approaches to preventive and remote care (Steinhubl et al., 2015).

Future developments in wearable cardiac monitoring may include multi-lead portable systems, improved sensor technologies, and enhanced signal processing algorithms. These innovations are expected to increase the accuracy and clinical applicability of wearable ECG devices, particularly in challenging environments such as high altitude.

However, the clinical application of wearable QT monitoring at high altitude requires further validation. Current evidence suggests that while wearable devices can provide useful screening information, they should not replace standard diagnostic methods when clinically significant abnormalities are suspected. Instead, these technologies should be considered complementary tools within a broader framework of risk assessment and medical supervision.

In summary, wearable technologies represent a rapidly evolving and promising approach to cardiovascular monitoring in high-altitude environments. While current limitations related to measurement accuracy and signal quality persist, ongoing technological advancements—including AI-assisted analysis—are likely to enhance their reliability and clinical utility. Future research should focus on validating these tools in real-world high-altitude conditions and defining their role in risk stratification and preventive cardiology.

A summary of key studies on QT interval changes at high altitude is presented in Table 1.

Table 1. Summary of key studies on QT interval dynamics at high altitude

Study	Population	Study Design	Altitude / Exposure	Key Findings	Clinical Implications	Limitations
Horii et al., 1987	Mountaineers	Observational (Holter monitoring)	High altitude, acute exposure	Nocturnal QTc prolongation (despite RR shortening)	Autonomic modulation of repolarization	Small sample size; older methodology
Gudelunas et al., 2025	Healthy adults	Prospective study	4 days at high altitude	QTc prolongation >20 ms vs baseline	Subclinical repolarization changes	Short exposure duration
Liu et al., 2024	Adults (SCARF substudy)	Randomized trial (sub-analysis)	Acute exposure and reoxygenation	QTc and Tp–e prolongation; reversible after descent	Potential marker of arrhythmic susceptibility	Limited generalizability
Latshang et al., 2016	OSA patients	Randomized controlled trial	Moderate altitude exposure	Increased QTc during nocturnal hypoxia	Elevated arrhythmic risk in vulnerable populations	Specific clinical population
Aeschbacher et al., 2021	HAPH patients	Observational study	Chronic high-altitude exposure	QT prolongation and increased dispersion	Increased repolarization heterogeneity	Observational design
Batmaz et al., 2016	Pregnant women	Observational study	Moderate altitude	QT interval prolongation	Combined effect of hypoxia and physiological stress	Small cohort size

Abbreviations: QTc – corrected QT interval; Tp–e – Tpeak–Tend interval; OSA – obstructive sleep apnea; HAPH – high-altitude pulmonary hypertension.

Discussion

This review provides a comprehensive synthesis of current evidence regarding QT interval dynamics in high-altitude environments and highlights the complex interplay between hypoxia, autonomic regulation, and cardiovascular electrophysiology. The available literature consistently suggests that exposure to high altitude is associated with measurable changes in ventricular repolarization, particularly during acute exposure and early acclimatization phases.

One of the most important findings is the considerable heterogeneity across studies. Differences in altitude levels, duration of exposure, study populations, and methodological approaches—especially the use of different QT correction formulas and ECG acquisition techniques—limit direct comparability of results and complicate interpretation (Vandenberk et al., 2016). The current body of evidence remains limited by small

sample sizes, heterogeneous methodologies, and lack of standardized QT correction approaches, which significantly reduces the comparability and clinical interpretability of findings.

However, not all studies report consistent findings regarding QT interval changes at high altitude. While several investigations demonstrate QTc prolongation during acute exposure, others suggest minimal or clinically insignificant changes, particularly in well-acclimatized individuals or at moderate altitudes (Windsor et al., 2010). These discrepancies may reflect differences in study design, population characteristics, altitude level, and timing of measurements. Additionally, variability in QT correction formulas and ECG acquisition methods may further contribute to inconsistent results across studies (Vandenberk et al., 2016). This highlights the importance of cautious interpretation and the need for methodological standardization in future research.

Despite the observed prolongation of QT interval and QTc, current evidence indicates that in healthy individuals these changes are generally modest, transient, and rarely associated with clinically significant arrhythmias (Windsor et al., 2010; Woods et al., 2011). This supports the hypothesis that QT prolongation at high altitude may represent a physiological adaptive response rather than a direct marker of imminent cardiac risk.

However, this interpretation does not apply uniformly across all populations. Vulnerable individuals, including patients with obstructive sleep apnea, pulmonary hypertension, or underlying cardiovascular disease, appear to exhibit more pronounced disturbances in ventricular repolarization (Latshang et al., 2016; Aeschbacher et al., 2021). In these groups, hypoxia may act as an additional stressor, potentially unmasking latent arrhythmic susceptibility and increasing the clinical relevance of QT prolongation.

Importantly, the absence of large-scale prospective studies linking QT changes with hard clinical outcomes represents a major gap in the literature. Most available data are derived from observational or short-term studies, which limits the ability to determine the true prognostic significance of QT interval alterations in high-altitude environments.

Another key aspect of this review is the integration of digital health technologies into high-altitude cardiology. Wearable devices and mobile ECG systems offer new possibilities for remote cardiac monitoring, particularly in environments with limited access to healthcare infrastructure. Although current evidence demonstrates promising feasibility, the accuracy of QT interval measurement using wearable technologies remains variable and dependent on signal quality, device limitations, and user technique (Mannhart et al., 2022; Hoek et al., 2023). Despite technological enthusiasm, the current evidence does not support the use of wearable devices as a reliable standalone tool for QT assessment in high-altitude conditions. Therefore, these tools should be considered complementary rather than a replacement for standard 12-lead ECG.

Several limitations of the available literature should be acknowledged. First, many studies investigating QT interval changes at high altitude involve relatively small sample sizes, which may limit statistical power and generalizability. Second, there is substantial heterogeneity in study design, including differences in altitude exposure, duration of observation, and participant characteristics, making direct comparisons challenging. Third, methodological variability in QT measurement and correction formulas introduces potential measurement bias and affects the consistency of reported results (Vandenberk et al., 2016).

Future research should focus on well-designed prospective studies with standardized methodologies, including consistent QT correction approaches and uniform altitude exposure protocols. Further validation of wearable technologies in extreme environments is also necessary, particularly with the integration of artificial intelligence to improve measurement accuracy. Such efforts may help clarify the clinical significance of QT interval changes and support the development of effective risk stratification strategies.

Conclusions

High-altitude exposure is associated with measurable changes in ventricular repolarization, including prolongation of the QT interval and QTc, particularly during acute exposure and early phases of acclimatization. In healthy individuals, these changes are generally modest, transient, and unlikely to result in clinically significant arrhythmias.

However, in vulnerable populations, including individuals with underlying cardiopulmonary conditions or impaired oxygenation, QT interval alterations may have greater clinical relevance and may reflect increased arrhythmic susceptibility. In such cases, individualized risk assessment and targeted monitoring should be considered.

Wearable technologies represent a promising approach to remote cardiac monitoring in high-altitude environments, offering potential benefits for early detection and risk stratification. Nevertheless, current

limitations in QT measurement accuracy require cautious interpretation, and confirmatory assessment using standard electrocardiography remains essential when clinically significant abnormalities are suspected.

Clinically, QT interval monitoring at high altitude should be considered in individuals with known cardiovascular disease, sleep-disordered breathing, or other conditions associated with impaired oxygenation. A risk-based and individualized approach to cardiovascular assessment is therefore recommended, particularly in the context of increasing accessibility of high-altitude travel and the growing use of digital health technologies.

Further research is needed to clarify the prognostic significance of QT interval changes at high altitude and to establish the role of wearable technologies in improving cardiovascular safety in extreme environments.

Conflict of Interest: The authors declare no conflict of interest.
Funding Statement: This study did not receive any specific funding.
All authors have reviewed and consented to the publication of the final version of the manuscript**.**

REFERENCES

1. Aeschbacher, S. S., Latshang, T. D., Sheraliev, U., Marazhapov, N. H., Mirrakhimov, E., Sooronbaev, T. M., Ulrich, S., Furian, M., Bloch, K. E., & Duru, F. (2021). Altered cardiac repolarisation in highlanders with high-altitude pulmonary hypertension during wakefulness and sleep. *Journal of Sleep Research, 30*(3), e13153. https://doi.org/10.1111/jsr.13153
2. Batmaz, G., Aksoy, A. N., Aydin, S., Ay, N. K., & Dane, B. (2016). QT interval changes in term pregnant women living at moderately high altitude. *Nigerian Journal of Clinical Practice, 19*(5), 611–615. https://doi.org/10.4103/1119-3077.188707
3. Bärtsch, P., & Gibbs, J. S. R. (2007). Effect of altitude on the heart and lungs. *Circulation, 116*(19), 2191–2202. https://doi.org/10.1161/CIRCULATIONAHA.106.650796
4. Couderc, J. P. (2010). Measurement and regulation of cardiac ventricular repolarization: From QT interval to T-wave morphology. *Annals of Noninvasive Electrocardiology, 15*(3), 209–215. https://doi.org/10.1111/j.1542-474X.2010.00367.x
5. Drew, B. J., Califf, R. M., Funk, M., Kaufman, E. S., Krucoff, M. W., Laks, M. M., Macfarlane, P. W., Sommargren, C., Swiryn, S., & Van Hare, G. F. (2010). Practice standards for electrocardiographic monitoring in hospital settings: An American Heart Association scientific statement. *Circulation, 122*(24), 272–292. https://doi.org/10.1161/CIR.0b013e3181f96b4c
6. Duncker, D., Ding, W. Y., Etheridge, S., Noseworthy, P. A., Veltmann, C., Yao, X., Bunch, T. J., & Gupta, D. (2021). Smart wearables for cardiac monitoring—Real-world use beyond atrial fibrillation. *Sensors, 21*(7), 2539. https://doi.org/10.3390/s21072539
7. Furian, M., Latshang, T. D., Aeschbacher, S. S., Sheraliev, U., Marazhapov, N. H., Mirrakhimov, E., Ulrich, S., Sooronbaev, T. M., & Bloch, K. E. (2021). Markers of cardiovascular risk and their reversibility with acute oxygen therapy in Kyrgyz highlanders with high altitude pulmonary hypertension. *Pulmonology, 27*(5), 394–402. https://doi.org/10.1016/j.pulmoe.2021.02.001
8. Goldenberg, I., Moss, A. J., & Zareba, W. (2006). QT interval: How to measure it and what is "normal." *Journal of Cardiovascular Electrophysiology, 17*(3), 333–336. https://doi.org/10.1111/j.1540-8167.2006.00408.x
9. Gudelunas, K., Chinn, G. A., Barreto-Chang, O. L., Campbell, L., & Sall, J. W. (2025). A 4-day exposure to high altitude prolongs QTc in healthy human subjects. *Wilderness & Environmental Medicine, 36*, 176–181. https://doi.org/10.1177/10806032251314740
10. Hoek, L. J., Brouwer, J. L. P., Voors, A. A., & Maass, A. H. (2023). Smart devices to measure and monitor QT intervals: A systematic review. *Frontiers in Cardiovascular Medicine, 10*, 1172666. https://doi.org/10.3389/fcvm.2023.1172666
11. Horii, M., Takasaki, I., Ohtsuka, K., Tsukiyama, H., Takahashi, A., & Doi, Y. (1987). Changes of heart rate and QT interval at high altitude in alpinists: Analysis by Holter ambulatory electrocardiogram. *Clinical Cardiology, 10*(4), 238–242. https://doi.org/10.1002/clc.4960100406
12. Karliner, J. S., Sarnquist, F. F., Graber, D. J., Peters, R. M., Jr., & West, J. B. (1985). The electrocardiogram at extreme altitude: Experience on Mt. Everest. *American Heart Journal, 109*(3), 505–513. https://doi.org/10.1016/0002-8703(85)90555-1
13. Koshy, A. N., Sajeev, J. K., Nerlekar, N., Brown, A. J., Rajakariar, K., Zureik, M., Wong, M. C., Roberts, L., Street, M., Cooke, J., Teh, A. W., & Sanders, P. (2018). Smart watches for heart rate assessment in atrial arrhythmias. *Heart, Lung and Circulation, 27*(2), 132–138. https://doi.org/10.1016/j.hlc.2017.05.129
14. Latshang, T. D., Kaufmann, B., Nussbaumer-Ochsner, Y., Ulrich, S., Furian, M., Kohler, M., Thurnheer, R., Saguner, A. M., Duru, F., & Bloch, K. E. (2016). Patients with obstructive sleep apnea have cardiac repolarization disturbances when travelling to altitude: Randomized, placebo-controlled trial of acetazolamide. *Sleep, 39*(9), 1631–1637. https://doi.org/10.5665/sleep.6080

15. Liu, Z., Yang, J., Yang, B., Sun, M., Ye, X., Yu, S., Tan, H., Hu, M., Lv, H., Wu, B., Gao, X., & Huang, L. (2024). Effect of ubiquinol on electrophysiology during high-altitude acclimatization and de-acclimatization: A substudy of the Shigatse CARdiorespiratory fitness (SCARF) randomized clinical trial. *International Journal of Cardiology, 401*, 131817. https://doi.org/10.1016/j.ijcard.2024.131817
16. Maille, B., Wilkin, M., Million, M., Rességuier, N., Franceschi, F., Koutbi-Franceschi, L., Hourdain, J., Martinez, E., Zabern, M., Gardella, C., Tissot-Dupont, H., Singh, J. P., Deharo, J.-C., & Fiorina, L. (2021). Smartwatch electrocardiogram and artificial intelligence for assessing cardiac-rhythm safety of drug therapy in the COVID-19 pandemic: The QT-logs study. *International Journal of Cardiology, 331*, 333–339. https://doi.org/10.1016/j.ijcard.2021.01.002
17. Mannhart, D., Hennings, E., Lischer, M., Vernier, C., Du Fay de Lavallaz, J., Knecht, S., Schaer, B., Osswald, S., Kühne, M., Sticherling, C., & Badertscher, P. (2022). Clinical validation of automated corrected QT-interval measurements from a single-lead electrocardiogram using a novel smartwatch. *Frontiers in Cardiovascular Medicine, 9*, 906079. https://doi.org/10.3389/fcvm.2022.906079
18. Perez, M. V., Mahaffey, K. W., Hedlin, H., Rumsfeld, J. S., Garcia, A., Ferris, T., Balasubramanian, V., Russo, A. M., Rajmane, A., Cheung, L., Hung, G., Lee, J., Kowey, P., Talati, N., Nag, D., Gummidipundi, S. E., Beatty, A. L., Hills, M. T., Desai, S., & Turakhia, M. P. (2019). Large-scale assessment of a smartwatch to identify atrial fibrillation. *New England Journal of Medicine, 381*(20), 1909–1917. https://doi.org/10.1056/NEJMoa1901183
19. Roden, D. M. (2004). Drug-induced prolongation of the QT interval. *New England Journal of Medicine, 350*(10), 1013–1022. https://doi.org/10.1056/NEJMra032426
20. Saghir, N., Aggarwal, A., Soneji, N., Valencia, V., Rodgers, G., & Kurian, T. (2020). A comparison of manual electrocardiographic interval and waveform analysis in lead I of 12-lead ECG and Apple Watch ECG: A validation study. *Cardiovascular Digital Health Journal, 1*(1), 30–36. https://doi.org/10.1016/j.cvdhj.2020.07.002
21. Sana, F., Isselbacher, E. M., Singh, J. P., Heist, E. K., Pathik, B., & Armoundas, A. A. (2020). Wearable devices for ambulatory cardiac monitoring: JACC state-of-the-art review. *Journal of the American College of Cardiology, 75*(13), 1582–1592. https://doi.org/10.1016/j.jacc.2020.01.046
22. Saurenmann, P., & Koller, E. A. (1984). The ECG changes due to altitude and to catecholamines. *European Journal of Applied Physiology, 53*(1), 35–42.
23. Schwartz, P. J., Crotti, L., & Insolia, R. (2012). Long QT syndrome: From genetics to management. *Circulation, 126*(9), 1047–1058. https://doi.org/10.1161/CIRCULATIONAHA.111.060061
24. Somers, V. K., Mark, A. L., & Abboud, F. M. (1993). Sympathetic activation by hypoxia and sleep apnea. *Circulation, 87*(1), 189–197.
25. Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). The emerging field of mobile health. *Science Translational Medicine, 7*(283), 283rv3. https://doi.org/10.1126/scitranslmed.aaa3487
26. Tison, G. H., Sanchez, J. M., Ballinger, B., Singh, A., Olgin, J. E., Pletcher, M. J., & Marcus, G. M. (2018). Passive detection of atrial fibrillation using a commercially available smartwatch. *JAMA Cardiology, 3*(5), 409–416. https://doi.org/10.1001/jamacardio.2018.0136
27. Vandenberk, B., Vandael, E., Robyns, T., Vandenberghe, J., Garweg, C., Ector, J., Willems, R., & Foulon, V. (2016). Which QT correction formulae to use for QT monitoring? *Journal of the American Heart Association, 5*(6), e003264. https://doi.org/10.1161/JAHA.116.003264
28. West, J. B. (2012). High-altitude medicine. *American Journal of Respiratory and Critical Care Medicine, 186*(12), 1229–1237. https://doi.org/10.1164/rccm.201207-1323CI
29. Windsor, J. S., Rodway, G. W., & Montgomery, H. E. (2010). A review of electrocardiography in the high altitude environment. *High Altitude Medicine & Biology, 11*(2), 51–60. https://doi.org/10.1089/ham.2009.1065
30. Woods, D. R., Begley, J., & Stacey, M. (2011). Cardiac arrhythmias at high altitude. *High Altitude Medicine & Biology, 12*(1), 35–41. https://doi.org/10.1089/ham.2010.1057