Characterization of Arrhythmia Occurrence During Sleep and Activity in Patients Undergoing Long-Term Continuous Ambulatory ECG Monitoring

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Background

- Circadian patterns of arrhythmias based on time of occurrence have been described in small datasets, but there is little information on the relationship of arrhythmia occurrence to sleep and activity.

Objectives

- We sought to quantify the occurrence of arrhythmias detected by long-term (≤14 days) continuous ambulatory ECG monitoring (LTCM) during periods of sleep, wake, activity and inactivity.

Methods

- We performed a retrospective analysis of patients who underwent LTCM in the United States for clinical indications with an FDA-cleared device that features an embedded accelerometer (Zio® monitor, iRhythm Technologies, Inc; San Francisco, CA).
- We used deidentified data from iRhythm's Clinical Research Data Warehouse; analysis was performed under an IRB-exempted protocol (Advarra; Columbia, MD).
- Building on the initial LTCM ECG data analysis of 3,840 patients from a single day (February 1, 2024), the current analysis features a larger nationwide dataset encompassing patients whose LTCM ECG data were processed between August 2023 and July 2024, including approximately 2,000 randomly sampled cases from each month.
- Devices with average daily sleep <4 hours or >12 hours were excluded. Early wear discontinuations (≤5 days wear time) or high signal artifact (≤90% analyzable time) were also excluded.
- Rhythms were classified using an FDA-cleared deep learning algorithm and reviewed by a certified cardiographic technician.
- A validated support vector machine algorithm was used to classify periods of sleep, wake, activity (≥2 mph walking), and inactivity based on accelerometry data. Algorithm sensitivity (SE) and specificity (SP) in sleep detection were 88.8% and 54.0%, respectively (over 1-minute epochs vs. polysomnography reference). SE and SP were 97.0% and 100% in activity detection, respectively (over 1-minute epochs vs. wrist-worn actigraphy reference).
- Rhythm classifications were time-aligned to sleep, wake, activity, and inactivity labels. Active and inactive states together constitute time in wake. The percentage of total time spent in rhythm across periods of sleep/wake and inactivity/activity was calculated for each arrhythmia type.
- Odds ratios (OR) associated with time in arrhythmia for sleep and activity periods were calculated by rhythm type.

Table 1: Patient Demographics

Characteristic	Value (n=23,962)
Gender	
Female, n (%)	13,824 (57.7%)
Male, n (%)	10.138 (42.3%)
Age	
Age (years), Mean ± SD	60.9 ± 18.0
18 to 65, n (%)	11,711 (48.9%)
>65 years, n (%)	12,251 (51.1%)

Table 2: Wear Metrics and Monitoring Indication

Characteristic	Value (n=23,962)
Device Wear	
Wear time (days), Median (IQR)	13.7 (7.2 - 14.0)
Indications for Monitoring (Top 3)	
Palpitations, n (%)	8,221 (34.3%)
Paroxysmal Afib, n (%)	2,232 (9.3%)
Syncope, n (%)	2,002 (8.4%)

Table 3: Likelihood of Arrhythmia Associated with Sleep and Activity (N = 23,962)

Rhythm	Patients n (%)	% Time in Rhythm				Odds Ratio (95% CI)	
		% in Sleep	% in Wake			[1]Sleep:Wake*	[2]Active:Non-active*
				% In Active	% in Inactive		
Atrial Fibrillation	2,811 (11.7%)	32.7%	67.3%	1.0%	66.3%	1.024 (1.024 - 1.024)	0.608 (0.608 - 0.609)
Supraventricular Tachycardia	15,622 (65.2%)	22.8%	77.2%	1.9%	75.3%	0.623 (0.622 - 0.624)	1.063 (1.060 - 1.066)
Ectopic Atrial Rhythm	20,288 (84.7%)	33.6%	66.4%	0.8%	65.6%	1.096 (1.095 - 1.097)	0.347 (0.346 - 0.348)
Idioventricular Rhythm	771 (3.2%)	41.2%	58.8%	0.3%	58.5%	1.480 (1.468 - 1.492)	0.199 (0.186 - 0.213)
Junctional Rhythm	7,276 (30.4%)	24.6%	75.4%	1.4%	73.9%	0.698 (0.698 - 0.699)	0.711 (0.709 - 0.714)
Pause	874 (3.6%)	55.6%	44.4%	0.1%	44.3%	2.577 (2.550 - 2.603)	0.052 (0.044 - 0.063)
2nd Degree AV Block Mobitz Type I (Wenckebach)	1,281 (5.3%)	48.8%	51.2%	0.4%	50.8%	2.119 (2.117 - 2.120)	0.164 (0.163 - 0.165)
2nd Degree AV Block Mobitz Type II	225 (0.9%)	28.7%	71.3%	1.5%	69.8%	0.829 (0.827 - 0.831)	0.930 (0.922 - 0.939)
3rd Degree AV Block (CHB)	112 (0.5%)	41.2%	58.8%	2.0%	56.6%	1.371 (1.369 - 1.374)	1.640 (1.629 - 1.652)
Ventricular Tachycardia	5,764 (24.1%)	19.4%	80.6%	3.2%	77.5%	0.506 (0.503 - 0.509)	1.966 (1.943 - 1.989)
Bigeminy	7,591 (31.7%)	26.2%	73.8%	1.6%	72.1%	0.748 (0.747 - 0.748)	0.977 (0.975 - 0.979)
Trigeminy	7,612 (31.8%)	28.7%	71.3%	1.6%	69.7%	0.853 (0.853 - 0.854)	0.948 (0.946 - 0.9500)
Total	23,962 (100.0%)†	32.3%	67.7%	1.6%	98.4%	-	-

Odds Ratio is a measure of association between an exposure (vs. non-exposure) and an outcome. Two exposure models are examined with each arrhythmia outcome: [1] Sleep (vs. Wake) and [2] Active (vs. Non-active). Non-active represents Inactive or Sleep.
* Denotes P < 0.05 for all odds ratios
† Multiple arrhythmias occur in certain patients; summations represent entire population analyzed. Analysis reflects total time in rhythm among sleep, wake, active or inactive periods. Therefore, a single arrhythmia episode could be classified across all states.

Results and Discussion

Demographics and Device Metrics

- N=23,962 patients (57.7% female, age 60.9±18.0 yrs.; Table 1).
- Median wear time was 13.7 days; IQR (7.2 - 14.0) and the top indications for monitoring included palpitations, known AF and syncope (Table 2).
- Per patient median time in sleep was 30.4% (IQR 26.5–34.9) and 69.6% (IQR 65.1–73.5) in wake; periods of activity accounted for a median of 2.1% (IQR 0.5–4.8) of all waking hours.

Rhythm Characterization

- Among rhythms with the highest % time associated with sleep (vs. wake) were pause (OR=2.577; 95% CI 2.550-2.603) and 3rd degree block (OR=1.371; 95% CI 1.369-1.374; Table 3).
- VT was the arrhythmia least likely to occur during sleep (OR=0.506; 95% CI 0.503-0.509).
- VT and 3rd degree block had the highest OR associated with activity.

Limitations

Analysis focused on epochs and overall burden, rather than the onset of episodes. Examining the onset of episodes specifically could provide clearer insights into timing and progression.

Conclusions

- This study is the largest to characterize sleep, wake, and activity in patients undergoing ambulatory monitoring.
- 41% of complete heart block, 56% of pauses, 33% of atrial fibrillation, and 19% of VT occurred during sleep.
- Correlating physiological states with arrhythmia events or burden has the potential to provide context to arrhythmia management that could have clinical implications and could help with AI-based risk stratification or classification of arrhythmia etiology and disease states.

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