Usefulness of Extended Holter ECG Monitoring for Serious Arrhythmia Detection in Patients with Heart Failure and Sleep Apnea

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Background: In patients with systolic heart failure (HF), coexisting sleep apnea may promote arrhythmia. Ambulatory Holter electrocardiogram (ECG) monitoring (AECG) is a method of arrhythmia and apnea evaluation. We hypothesized that 24-hour AECG in patients with HF who have a high risk of serious arrhythmia may be less accurate than AECG extended to 48 hours and that, moreover, arrhythmia may be related to apnea.

Methods: Eighty-four recordings of 48-hour AECG in 84 patients with ischemic HF (mean ejection fraction $34 \pm 7\%$) were analyzed. Day 1, Day 2 were checked for ventricular tachycardia (VT) and supraventricular tachycardia (SVT). Estimated apnea-hypopnea index (est.AHI) was calculated using Holter monitoring where est.AHI > 15 indicates apnea.

Results: In 48-hour AECG, VT occurred in 34 patients (40.5%) whereas SVT in 17 patients (20.2%), and patients with est.AHI > 15 had higher VT occurrence. In two-sample one-sided test for proportions, 24-hour AECG from Day 1 showed a significantly lower percentage of patients with detected VT than 48-hour AECG—it was 23.8% (20 patients), meaning a significant underestimation with $P = 0.0089$. We assessed VT underestimation in the subgroups with regard to est.AHI, and found that it was present in Day 1 monitoring in the subgroups with est.AHI > 15. It was absent in the subgroups with est.AHI ≤ 15 and also in Day 2 monitoring.

Conclusions: In patients with systolic HF, 24-hour AECG may have insufficient sensitivity regarding serious arrhythmia occurrence. If significant apnea was detected in the first day, extending the monitoring may be recommended.

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Heart failure (HF) and sleep apnea are two quite common health problems, which, additionally, often coexist. In the Framingham Heart Study, the risk of developing congestive HF was estimated as 20%.¹ Sleep disorders are now widely studied, as they seem to coexist with various cardiovascular conditions.² The prevalence of obstructive sleep apnea syndrome in general population aged 30–

60 years is assessed as 2–4%, but it rises with age.³ It has been reported that coronary artery disease is related to increased prevalence of sleep-disordered breathing.⁴ Moreover, many reports indicate very high prevalence of sleep-disordered breathing in HF patients. It seems that the majority of them experience different forms of the problem—central or obstructive apnea.⁵

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In the population of systolic HF patients, mortality is high, and one of the reasons is sudden cardiac death due to arrhythmia. Another recently recognized factor that might be affecting prognosis is sleep apnea, which also promotes heart rhythm disturbances—the prevalence of arrhythmia increases with the severity of apnea. Wang et al.⁵ demonstrated that in HF patients (with ejection fraction $\leq 45\%$, and with similar percentages of ischemic cardiomyopathy in subsets) in follow-up of 2.9 ± 2.2 years those with untreated obstructive sleep apnea had a higher mortality rate than those without apnea.

With advanced software, ambulatory Holter electrocardiogram (ECG) monitoring (AECG) can be a method of both arrhythmia and apnea evaluation. The method of apnea assessment used in our study has been previously presented by de Chazal.⁷ Briefly, since apnea triggers nervous modulation of the heart rhythm, it is possible to calculate the probability of an apneic event on the basis of changes of the time distance between heart beats. Moreover, in body-surface ECG, modulations of the amplitude of the R waves during the breathing cycle can be detected. The effect is caused by the electrode motion relative to the heart, and by changes in thoracic electrical impedance. Analyzing these two features, we can calculate the probability of apneic sleep for consecutive 1-minute intervals and then for longer intervals, with the final result for the entire sleep period given as the estimated apnea-hypopnea index (est.AHI). Similarly to polysomnographic AHI, this index represents the number of events per hour of sleep. Results of est.AHI ≤ 5 are regarded as normal, while est.AHI > 5 but ≤ 15 is considered to be borderline, and est.AHI > 15 is regarded as apnea. This program is designed to detect obstructive and mixed apnea.

We hypothesized that 24-hour AECG in patients with HF who have a high risk of serious arrhythmia may be less accurate than the monitoring extended to 48 hours. We also suspected that the occurrence of serious arrhythmia may be related to coexisting apnea.

METHODS

We analyzed 84 recordings of 48-hour ambulatory Holter electrocardiogram (ECG) monitoring, obtained from 84 patients. The patients included in the study had ischemic heart disease and systolic

left ventricular dysfunction understood as ejection fraction $< 45\%$. At the time of the recordings, the patients were in NYHA II class, their mean ejection fraction was $34\% \pm 7$, and their mean age was 60 ± 8 years. Ten recordings belonged to women.

Using the Pathfinder (Spacelabs Healthcare, Issaquah, WA) software, we checked each day of the recording (Day 1, Day 2) for the occurrence of serious arrhythmia—ventricular tachycardia (VT), and also supraventricular tachycardia (SVT). Tachycardia was defined as at least three consecutive nonsinus beats with the rate > 100 bpm. The estimated apnea-hypopnea index was calculated by means of Holter monitoring (Lifescreeen Apnea, Spacelabs Healthcare). We were able to obtain est.AHI from Day 1 in all patients, and from Day 2 in 80 cases, and thus we were able to divide our study group into subsets with regard to the est.AHI from Day 1, Day 2, the maximal est.AHI and the mean est.AHI, with cutoff value of 15.⁸

We conducted intersubgroups comparisons of the percentages of patients with arrhythmia. For the purpose of further analysis, we took potential detection of arrhythmia during the whole 48-hour AECG as a reference, and compared the outcomes from single day monitoring to the findings from the extended examination. In the whole group and in the subsets chosen, we investigated if the percentage of patients with arrhythmia was comparable between one-day monitoring and 48-hour recording.

Two-sample two-sided tests for proportions were employed to determine whether the proportion of patients with arrhythmia was different in the subsets with est.AHI ≤ 15 than in subsets with est.AHI > 15 . Two-sample one-sided tests for proportions were used to determine whether the proportion of patients with arrhythmia found in one-day monitoring was significantly smaller than the proportion found in 48-hour monitoring. Probability values < 0.05 were considered to be statistically significant.

RESULTS

Arrhythmia Detection in Patients with Systolic Heart Failure

In our group of patients with systolic HF with mean left ventricular ejection fraction 34%, we observed a significant underestimation of a serious and possibly life-threatening arrhythmia (VT) in

Table 1. Inter-Subgroups Differences in Ventricular Tachycardia VT Occurrence

Subgroups		48-hour VT N (%)	P	Day 1 VT N (%)	P	Day 2 VT N (%)	P
Day1 est.AHI ≤ 15	N = 31	8 (25.81)	0.0191*	4 (12.90)	0.0386*	5 (16.13)	0.0168*
Day1 est.AHI > 15	N = 53	26 (49.06)		16 (30.19)		20 (37.74)	
Day2 est.AHI ≤ 15	N = 34	10 (29.41)	0.0296*	5 (14.71)	0.0544	6 (17.65)	0.0141*
Day2 est.AHI > 15	N = 46	23 (50.00)		14 (30.43)		19 (41.30)	
Maximal est.AHI ≤ 15	N = 25	6 (24.00)	0.0246*	3 (12.00)	0.0475*	3 (12.00)	0.0108*
Maximal est.AHI > 15	N = 59	28 (47.46)		17 (28.81)		22 (37.29)	
Mean est.AHI ≤ 15	N = 32	8 (25.00)	0.0117*	5 (15.63)	0.0879	5 (15.63)	0.0160*
Mean est.AHI > 15	N = 52	26 (50.00)		15 (28.85)		20 (38.46)	

The P values represent significant*/insignificant differences between the subsets.

recordings limited to standard 24-hour length. During 48-hour AECG, VT occurred in 34 patients (40.5%) and SVT in 17 (20.2%). In the two-sample one-sided test for proportions, 24-hour AECG from Day 1 showed a significantly lower percentage of detected VT than 48-hour AECG—it was 23.8% (20 patients), meaning a significant underestimation with $P = 0.0089$ and in Day 2 monitoring it was 29.8% (25 patients), which means only an insignificant tendency to underestimation with $P = 0.0871$.

Arrhythmia Detection in Patients with Systolic Heart Failure and Apnea

In 48-hour AECG, there was a higher VT occurrence in the subgroups with est.AHI > 15—from Day 1, from Day 2, maximal or mean—than in the subgroups with est.AHI ≤ 15. For example, with regard to the maximal est.AHI, the difference was 47.5% versus 24%, $P = 0.0246$ and, similarly, with regard to the mean est.AHI, the difference was 50% versus 25%, $P = 0.0117$. The results for SVT detection are less conclusive, but still, if there was a significantly higher prevalence of SVT, it was

observed in the subsets with higher est.AHI. The differences between the subsets with respect to VT and SVT occurrence are presented in Tables 1 and 2.

As to arrhythmia underestimation in 24-hour AECG, detailed results of VT detection in the est.AHI subsets are presented in Table 3. Importantly, in the subgroups with est.AHI > 15—from Day 1, from Day 2, maximal or mean—there was a significant underestimation of VT in the recordings limited to the first 24 hours, whereas in the corresponding subgroups with est.AHI ≤ 15 this was absent. Interestingly, such underestimation was not found during the second day of the recording. These findings are reflected in the sensitivity and negative predictive value that are higher for the second day monitoring (Table 4). Thus, in patients with est.AHI > 15, it made sense to extend the monitoring to 48 hours.

Detailed results of SVT detection in the subgroups with different est.AHI are presented in Table 5. There was no significant underestimation, though there was a tendency towards underestimation of SVT during Day 1 in the subsets with est.AHI > 15 from Day 2, maximal and mean.

Table 2. Inter-Subgroups Differences in Supraventricular Tachycardia SVT Occurrence

Subgroups		48-hour SVT N (%)	P	Day 1 SVT N (%)	P	Day 2 SVT N (%)	P
Day1 est.AHI ≤ 15	N = 31	5 (16.13)	0.3515	2 (6.45)	0.1076	4 (12.90)	0.3226
Day1 est.AHI > 15	N = 53	12 (22.64)		8 (15.09)		9 (16.98)	
Day2 est.AHI ≤ 15	N = 34	3 (8.82)	0.0177*	2 (5.88)	0.1033	1 (2.94)	0.0270*
Day2 est.AHI > 15	N = 46	13 (28.26)		7 (15.22)		11 (23.91)	
Maximal est.AHI ≤ 15	N = 25	2 (8.00)	0.0374*	1 (4.00)	0.0760	1 (4.00)	0.0311*
Maximal est.AHI > 15	N = 59	15 (25.42)		9 (15.25)		12 (20.34)	
Mean est.AHI ≤ 15	N = 32	4 (12.50)	0.0926	3 (9.38)	0.2882	2 (6.25)	0.0318*
Mean est.AHI > 15	N = 52	13 (25.00)		7 (13.46)		11 (21.15)	

The P values represent significant*/insignificant differences between the subsets.

Table 3. Detection of VT during Single Day versus 48-hour Monitoring in Different Subgroups

Group	48-hour VT N (%)	Day 1 VT N (%)	p	Day 2 VT N (%)	p
ALL N = 84	34 (40.48)	20 (23.81)	0.0089*	25 (29.76)	0.0871
Day1 est.AHI $\leq$ 15 N = 31	8 (25.81)	4 (12.90)	0.0982	5 (16.13)	0.1669
Day1 est.AHI $>$ 15 N = 53	26 (49.06)	16 (30.19)	0.0443*	20 (37.74)	0.1664
Day2 est.AHI $\leq$ 15 N = 34	10 (29.41)	5 (14.71)	0.0817	6 (17.65)	0.1424
Day2 est.AHI $>$ 15 N = 46	23 (50.00)	14 (30.43)	0.0251*	19 (41.30)	0.1930
Maximal est.AHI $\leq$ 15 N = 25	6 (24.00)	3 (12.00)	0.1347	3 (12.00)	0.1347
Maximal est.AHI $>$ 15 N = 59	28 (47.46)	17 (28.81)	0.0220*	22 (37.29)	0.1356
Mean est.AHI $\leq$ 15 N = 32	8 (25.00)	5 (15.63)	0.1863	5 (15.63)	0.1863
Mean est.AHI $>$ 15 N = 52	26 (50.00)	15 (28.85)	0.0142*	20 (38.46)	0.1088

The P values represent significant*/insignificant underestimation of arrhythmia in single-day monitoring in comparison with extended 48-hour monitoring. Day1 = the first day; Day2 = the second day; VT = ventricular tachycardia, est.AHI = estimated apnea-hypopnea index.

Table 4. Sensitivity and Negative Predictive Value of Ventricular Tachycardia (VT) Detection Obtained in 24-hour Monitoring (Day 1, Day 2) for Different Apnea Subgroups

Group	Day 1 sensitivity for VT [%]	Day 1 negative predictive value for VT [%]	Day 2 sensitivity for VT [%]	Day 2 negative predictive value for VT [%]
ALL N = 84	59	78	74	85
Day1 est.AHI $\leq$ 15 N = 31	50	85	63	88
Day1 est.AHI $>$ 15 N = 53	62	73	77	82
Day2 est.AHI $\leq$ 15 N = 34	50	83	60	86
Day2 est.AHI $>$ 15 N = 46	61	72	83	81
Maximal est.AHI $\leq$ 15 N = 25	50	86	50	86
Maximal est.AHI $>$ 15 N = 59	61	74	79	84
Mean est.AHI $\leq$ 15 N = 32	63	89	63	89
Mean est.AHI $>$ 15 N = 52	58	70	77	81

Table 5. Detection of SVT during a Single Day versus 48-hour Monitoring in Different Subgroups

Group	48-hour SVT N (%)	Day 1 SVT N (%)	P	Day 2 SVT N (%)	P
ALL N = 84	17 (20.24)	10 (11.90)	0.0786	13 (15.48)	0.1969
Day1 est.AHI $\leq$ 15 N = 31	5 (16.13)	2 (6.45)	0.1041	4 (12.90)	0.3686
Day1 est.AHI $>$ 15 N = 53	12 (12.64)	8 (15.09)	0.1469	9 (16.98)	0.2200
Day2 est.AHI $\leq$ 15 N = 34	3 (8.82)	2 (5.88)	0.3296	1 (2.94)	0.1551
Day2 est.AHI $>$ 15 N = 46	13 (28.26)	7 (15.22)	0.0607	11 (23.91)	0.3194
Maximal est.AHI $\leq$ 15 N = 25	2 (8.00)	1 (4.00)	0.2758	1 (4.00)	0.2758
Maximal est.AHI $>$ 15 N = 59	15 (25.42)	9 (15.25)	0.0873	12 (20.34)	0.2577
Mean est.AHI $\leq$ 15 N = 32	4 (12.50)	3 (9.38)	0.3256	2 (6.25)	0.1955
Mean est.AHI $>$ 15 N = 52	13 (25.00)	7 (13.46)	0.0594	11 (21.15)	0.3140

The P values represent significant*/insignificant underestimation of arrhythmia in single-day monitorings in comparison with extended 48-hour monitoring. Day 1 = the first day; Day 2 = the second day; SVT = supraventricular tachycardia; est.AHI = estimated apnea-hypopnea index.

DISCUSSION

In this study we demonstrated how standard 24-hour AECG monitoring may be insufficient for the assessment of VT occurrence in patients with systolic HF and apnea (detected on the

basis of the electrocardiographic method). Patients with apnea were more likely to have serious arrhythmia, and monitoring limited to the first 24 hours was more likely to fail to detect it in these patients. Our results indicate significant superiority of monitoring extended to 48 hours.

Holter ECG Monitoring for Apnea Detection

Although it has to be stated that polysomnography remains the "gold standard" for apnea detection and for further therapeutic decisions, simplified methods of preliminary diagnosis based on AECG are now widely introduced. Despite their obvious advantages like the low cost of the examination or availability, they needed to be tested for their reliability. Specifically, Lifescreen Apnea was confirmed to be reliable. The authors of this method reported 92% sensitivity and 69% specificity of the Holter screening test in comparison with the reference outcome of polysomnography, when est.AHI cutoff value of 15 was used for apnea confirmation.⁸ Ożegowski et al.⁹ conducted simultaneous polysomnography and 24-hour AECG in 74 patients. Regarding the polysomnographic apnea-hypopnea index value as a reference parameter which discriminates individuals with and without sleep-disordered breathing, they calculated the number of false positive and false negative results for detecting sleep-disordered breathing using est.AHI. On the basis of est.AHI, 68% patients were diagnosed correctly. The ROC analysis showed high accuracy with sensitivity 91.2%, and specificity—87.5%. In this study the est.AHI cutoff value of 17 was optimal for the differentiation between patients with or without sleep-disordered breathing. On the basis of our previous study,¹⁰ we also know that the results obtained by means of Lifescreen Apnea show good repeatability during consecutive nights of the monitoring, which confirms the reliability of the method.

Arrhythmia in Heart Failure and Sleep Apnea

It is known that in two AECGs conducted on the same patient, there will probably occur a spontaneous variability of arrhythmia. Because of these natural fluctuations in heart rate disturbances, the ACC/AHA Guidelines for Ambulatory Electrocardiography from 1999¹¹ recommend that nothing less than obtaining a 65–95% reduction in arrhythmia frequency should be regarded as a marker of treatment effectiveness. Our results suggest that in a population of patients with systolic HF, due to this spontaneous variability, 24-hour

AECG may in fact be insufficient for serious arrhythmia detection.

It is uncertain what sort of length of the AECG would guarantee the best reliability in arrhythmia assessment without a needless increase of the cost or the involvement of the patients and the medical care system. This problem concerns, for example, patients evaluated for syncope, in whom 24-hour AECG may fail to identify all potentially important arrhythmias.¹² Simantirakis et al., in a study on a small group of 23 subjects with moderate or severe obstructive sleep apnea syndrome, demonstrated that short-term monitoring may be misleading when compared to monitoring with implantable loop recorders.¹³ This study, however, addressed mainly bradyarrhythmias, while in our material the events were tachyarrhythmic.

The question is also unanswered in HF patients. In the MADIT II study, in the population of patients after myocardial infarction with ejection fraction $\leq 30\%$, even 10-minute AECG delivered important information.¹⁴ Patients who died or who had an appropriate ICD therapy for ventricular tachycardia/fibrillation during the follow-up, had significantly more ventricular arrhythmias or more often had VT in the recording. On the other hand, Pastor-Pérez et al. reported that in HF patients (both of non-ischemic and ischemic causes) with ejection fraction $\leq 50\%$, AECG extended to 7 days instead of 1 day improved the detection of VT. In that study the incidence of VT increased in nonischemic patients from 35.1% on day 1 to 54.1% on day 7 ($P = 0.01$), and in ischemic patients from 11.5% to 46.2%, respectively ($P = 0.004$).¹⁵

Our findings indicate that not only was extended monitoring better in terms of VT detection, but also Day 2 monitoring showed better agreement with extended AECG than Day 1 monitoring alone. We have found no literature covering the matter of the superiority of that particular day of AECG, and we cannot fully explain this interesting observation. We can only speculate that the emotional stress connected with the upcoming termination of AECG and anxiety about the results might play a role in promoting arrhythmia.

The same ACC/AHA document¹¹ contained guidelines for using AECG to assess the risk of future cardiac events in patients without symptoms from arrhythmia, and, in these guidelines, patients with LV dysfunction after myocardial infarction with ejection fraction below 40% as well as patients with congestive HF were given class IIb

of indications. Surprisingly, sleep apnea patients were mentioned in class III, which seems rather controversial compared to more recent studies. There are now many reports that focus on the proarrhythmic influence of sleep apnea. Thus it seems that in patients in whom sleep-disordered breathing is suspected, AECG may serve well not only as a diagnostic tool for the detection of apnea as discussed above, but also for the detection of dangerous arrhythmias caused by apnea. In obstructive sleep apnea, various forms of arrhythmia were described: ventricular beats with nonsustained VT as well as bradyarrhythmias like sinus arrest or second-degree atrioventricular conduction block.¹⁶ It is known that apnea is related to atrial fibrillation.¹⁷ In a large cohort, it has been shown that in older men sleep-disordered breathing promotes atrial fibrillation and complex ventricular ectopy, with complex ventricular arrhythmia associated rather with obstructive apnea and hypoxia, whereas atrial fibrillation is associated rather with central apnea.¹⁸ Not surprisingly then, sleep-disordered breathing—both obstructive and central apnea—is recognized as a risk factor of more frequent appropriate implantable cardioverter-defibrillator discharges in HF patients.^{19–21} This arrhythmogenic impact of apnea is also represented by a shift in the hours when most of the sudden cardiac deaths or appropriate implantable cardioverter-defibrillator discharges occur.² In apnea patients these events are more frequent during sleep time.

Our findings also suggest an arrhythmogenic impact of apnea. As presented above, in patients with est.AHI >15 the occurrence of VT is higher and, despite less conclusive results for SVT, the relationship is also noticeable. Moreover, we demonstrated how one-day AECG might be insufficient in screening for VT in HF patients, and we found that AECG lasting only 24 hours had a particularly limited value in patients with est.AHI >15. According to our results, the detection of apnea represented by est.AHI >15 during the first day of AECG with simultaneous negative tracing for serious arrhythmia, may raise suspicions that perhaps arrhythmia is underrated and that extending the monitoring for at least another day would be beneficial.

In patients with systolic HF, 24-hour Holter ECG monitoring may have insufficient sensitivity with regard to VT occurrence. Especially in patients with coexisting significant apnea detected in the

first 24 hours of examination and with simultaneous negative tracing for serious arrhythmia, extending the monitoring for another day may be recommended.

Our findings may be easily applied to everyday practice, allowing better application of diagnostic tools.

Limitations

We are aware that even 48-hour AECG may—in the case of some patients—fail to detect serious arrhythmia, which these patients in fact have. Still, we have demonstrated that extended AECG has better sensitivity than a standard single-day recording. Perhaps if we juxtaposed single-day recordings with monitoring longer than 48 hours, the difference in favor of extended monitoring would be even greater.

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