Ambulatory Electrocardiographic Monitoring between Artifacts and Misinterpretation, Management Errors of Commission and Errors of Omission

Nabil El-Sherif, M.D.,*† and Gioia Turitto, M.D.‡

From the *SUNY Downstate Medical Center, Brooklyn, NY; †NY Harbor VA Healthcare System, Brooklyn, NY; and ‡New York Methodist Hospital, Brooklyn, NY

Background: The aim of the study is to contrast the role of conventional ambulatory electrocardiographic monitoring (AEM) artifacts with a less emphasized problem with potentially more serious implications, that is, the failure to recognize, and therefore misinterpret, a genuine arrhythmia episode in the AEM recording.

Methods: The study material included 500 Holter recordings and 500 recordings from the cardiac telemetry unit.

Results: Electrocardiographic (ECG) artifacts were more common in telemetry recordings (5.6%) compared to Holter recordings (4%) for a total of 4.8%. There were 35 examples of misinterpretation of AEM recordings (3.5%). These were significantly more common in telemetry recordings (2.6%) compared to Holter recordings (0.9%). The most common ECG artifacts were examples of pseudo ventricular tachyarrhythmia (VT). The majority of misinterpretation (26 of 35 examples) were fast supraventricular tachyarrhythmias with aberrant QRS (including six examples of atrial flutter with periods of 1:1 atrioventricular conduction) that were misdiagnosed as ventricular VT. Other examples were misinterpretation of arrhythmic episodes consistent with sick sinus syndrome, pacemaker malfunction, and long QT syndrome. Only 5 of 48 examples of AEM artifacts resulted in management errors of commission or errors of omission compared to all 35 examples of misinterpretation.

Conclusions: Compared to conventional artifacts in AEM, misinterpretation of nonartifactual arrhythmic episodes consistently resulted in management errors. Misinterpretation was significantly more common with telemetry recordings compared to Holter ECG. This highlights the need for more appropriate training of the entire clinical team in charge of the management of the cardiac telemetry unit.

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There are several ambulatory electrocardiographic monitoring (AEM) devices that are used in clinical practice to detect and characterize cardiac arrhythmias.¹ AEM could be applied for few hours in an in-hospital telemetry unit or up to several years using portable analog or digital Holter recordings, event monitors, and implantable devices. The most commonly utilized procedures for cardiac rhythm detection are Holter recordings and in-hospital telemetry units. Since the introduction of Holter recording,² electrocardiographic (ECG) artifacts were known to occur and can result in

inappropriate management decisions that may lead to errors of commission and errors of omission. There are several reports in the literature that discuss AEM artifacts, their possible mechanisms, and their potential implications.^{3–11} A major goal of this report is to contrast the role of conventional AEM artifacts with a less emphasized problem with potentially more serious implications. This is the failure to recognize, and therefore misinterpret, a genuine arrhythmia episode in the AEM recording. This problem may highlight the need of improved targeted training in the detection and interpretation

Address for correspondence: Nabil El-Sherif, M.D., NY Harbor VA Healthcare System, 800 Poly Place, Brooklyn, NY 11209; Fax: 718-456-4002; E-mail: nelsherif@aol.com

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Figure 1. (A) The bottom channel shows recording artifact that may simulate atrial flutter/ fibrillation. However, careful analysis of the upper channel shows sinus rhythm with clear P waves. The presence of an irregular rhythm secondary to both sinus arrhythmia and occasional premature atrial beats adds to difficulty in making the correct diagnosis from the recording in the bottom channel alone. (B) and (C) two separate examples of artifacts from the same Holter recording that may simulate ventricular tachyarrhythmia. In both, tracings the artifacts are more prominent in one of the two illustrated channels. Normal QRS complexes are marked by arrows at the channel with prominent artifacts.

of AEM of the clinical staff in charge of this clinical service.

METHODS

The study material included 500 Holter ECG recordings and 500 recordings from cardiac arrhythmia telemetry unit. Although the recordings were not consecutively obtained, they were mostly within a 2-year period and were carefully scrutinized by the coauthors. Some of the recordings were retrieved and reanalyzed for the sake of this report. Holter recordings were ordered by attending physicians. To be consistent with clinical practice, Holter tracings were reviewed by the coauthors. No commercial or research-based algorithm was used to identify events and

Figure 2. (A) Pseudo-pauses in the top channel of a two-channel of sinus rhythm and unifocal ventricular premature beats, (VPC). It is interesting that a distorted deflection was only recorded in the top channel during the VPC. This may be due to a change in the pattern of ventricular contraction during the VPC possibly resulting in partial skin-electrode contact as compared to total skin-electrode contact failure during sinus rhythm. (B) Pseudo pacemaker failure due to temporary loss of skin-electrode contact. The arrows show, that failure of contact can develop during any part of the paced QRS-T complex. The pauses are exact multiple of the paced cycle length.

pseudo-events. Although more than one type of Holter recorders were utilized, the majority (484 of 500) were digital with 24-hour full disclosure, three-channel data, ETL listed 8-bit resolution. The telemetry unit is manned by dedicated nurses, rotating medical residents, cardiology fellows, and cardiology attending. The telemetry clinical team reviewed the tracings and advised a course of action. The coauthors independently reviewed the telemetry records and later conferred with the clinical team to compare the results and advise accordingly.

RESULTS

ECG Artifacts

ECG artifacts were originally classified as pseudo-arrhythmias and nonarrhythmia artifacts by Krasnow and Bloomfield.³ For the sake of this study, pseudo-arrhythmias were classified into pseudo-tachyarrhythmias and pseudo-bradyarrhythmias. Pseudo-tachyarrhythmias included pseudo atrial tachyarrhythmias (atrial tachycardia, atrial flutter, and atrial fibrillation), and pseudo-ventricular tachyarrhythmias (VT, monomorphic

Table 1. Artifacts and Misinterpretations of Ambulatory ECG Recordings

A. Artifacts (48/1000 recordings; 4.8%)		
	Holter Recordings (20/500; 4%)	Telemetry Recordings (28/500; 5.6%)
Pseudo-atrial tachyarrhythmia	2	3
Pseudo-ventricular tachyarrhythmia	10	16
Pseudo sinus arrest	4	5
Pseudo AV block	4	4
B. Misinterpretations (35/1000 recordings; 3.5%)		
	Holter Recordings (9/500; 1.8%)	Telemetry Recordings (26/500; 5.2%)
Fast SVT with aberrant QRS misinterpreted as VT	3	17
Atrial flutter with periods of 1:1 AV conduction and aberrant QRS	3	3
Sick sinus syndrome	1	2
Pacemaker malfunction	1	2
Long QT syndrome	1	2

AV = atrioventricular; ECG = electrocardiogram; SVT = supraventricular tachyarrhythmia; VT = ventricular tachyarrhythmia.

Figure 3. Recording artifact simulating high-degree AV block. The small complexes that may be misinterpreted as P waves, are infact diminutive QRS complexes. A closer look will reveal traces of T-wave artifacts following the simulated “P” deflections. Other evidences of artifacts are the third complex in the bottom tracing and the abbreviated PR interval of the fourth complex. The tracings were obtained from a Holter ECG of a 65-year-old male with history of frequent dizzy spells. A preliminary report of high-degree AV block was sent to the responsible cardiologist, who promptly scheduled the patient for a permanent pacemaker procedure. The scheduled procedure was cancelled in the last minute when the artifactual nature of the recording was recognized.

ventricular tachycardia and fast polymorphic ventricular tachycardia/ventricular fibrillation). Pseudo-bradyarrhythmias included pseudo sinus pause/sinus arrest, and pseudo atrioventricular (AV) block. On the other hand, nonarrhythmia

artifacts included primarily pseudo-ST segment/T-wave changes. Other nonarrhythmia artifacts like tape reversal and polarity reversal³ are considered very rare with current Holter technology. Nonarrhythmia artifacts were not considered in

Figure 4. Ambulatory telemetry recording of a 72-year-old male, who was admitted to the service with a history of palpitation and presyncope. The recording was misinterpreted by the clinical team as fast monomorphic ventricular tachycardia (VT). The presence of an early premature P wave initiating the wide QRS tachycardia (marked by an arrow), of fusion QRS complex (marked by X), and the normalization of the wide QRS before the termination of the tachycardia (first half of the middle tracing) are all evidence of fast supraventricular tachycardia with prolonged periods of aberrant intraventricular conduction.

the analysis. Pseudo-tachyarrhythmias artifacts are most probably related to body movement, temporary impairment of skin-electrode contact, loose electrode connections, broken leads, skeletal myopotentials, and ambient noise.¹⁰ These can generate deflections that can simulate pseudo-atrial arrhythmias (Fig. 1A) or pseudo-VT (Fig. 1B). Pseudo-bradyarrhythmias artifacts are most probably related to intermittent impairment of electrode contact or recorder problems that can result in tape slowing or intermittent stoppage including in some older models sticking to scanning head.^{3,10} These artifacts result in pseudo-pauses that can simulate sinus arrest (Fig. 2A), pacemaker malfunction (Fig. 2B), or high degree AV conduction block (Fig. 3). The majority of artifacts can be easily recognized if the reviewer takes the time to analyze the simultaneous tracings in more than one lead (Figs. 1A and 2). Few artifacts, especially if only one tracing is available for analysis, may be difficult to recognize and these are the ones that most likely result in management errors (Fig. 3).

Table 1A shows that artifacts were more common in telemetry recordings (28 of 500 recordings) compared to Holter EKG (20 of 500 recording) for a total of 48 recordings with artifacts out of 1000 total recordings or 4.8%. Five of the 48 recordings with artifacts resulted in errors of commission. In three patients a diagnosis of VT was made and prompted an electrophysiological study. In two of the three patients there was no inducible VT. The third patient had inducible

ventricular fibrillation and because of symptoms simulating presyncope and a moderately depressed left ventricular ejection fraction (40%) he was seriously considered for implantable defibrillator. The procedure was halted when the artifactual nature of the arrhythmia was recognized. The remaining two patients had artifacts simulating high-degree AV block. One of the patients who complained of frequent lightheadedness was scheduled for a permanent pacemaker by his attending. The procedure was halted, literally a couple of hours earlier, by the implanting physician when the nature of the artifacts was recognized.

Misinterpretation of Ambulatory EKG Recordings

Table 1B shows that 35 of 1000 ambulatory telemetry recordings were misinterpreted. These included 5 examples in which an arrhythmia episode was missed on initial analysis to be picked up later on reanalysis of the recording that was prompted by patients suggestive symptoms. The remaining 30 examples were arrhythmic episodes that were detected and recorded/printed but were misinterpreted by the clinical team in charge of the service. Misinterpretation was decidedly more common with telemetry EKG recordings as compared to Holter ECG (26 vs. 9 examples). The majority of misinterpretation (26 of 35 recordings) were examples of fast supraventricular tachycardia (SVT) with aberrant wide QRS complexes that

Figure 5. Ambulatory Holter recording from a 45-year-old male athlete, who had successfully run the New York Marathon for the previous 4 years. He presented with recent onset of atypical chest pain, palpitation, and presyncope during training for the next marathon and was provided with a 24-hour Holter recording to be worn during his routine training runs. The selected tracings illustrate: (A) recording at rest showing sinus arrhythmia and occasional atrial and ventricular premature beats; (B) recording obtained during exercise showing the onset of a wide QRS tachyarrhythmia that simulates polymorphic VT in the first half of the tracing before accelerating into a monomorphic VT at approximately 295 beats/min. The wide QRS tachycardia persisted for 2 minutes and was followed by a narrow QRS tachycardia at approximately the same rate of 295 beats/min (C). The last tracing (D) was obtained 2 minutes later and shows atrial flutter with 2:1 AV conduction. The patient who had normal ventricular function at the time of the recording, underwent successful radiofrequency ablation of the atrial flutter circuit. Two years later, the patient developed nonischemic cardiomyopathy.

were misinterpreted as VT (Fig. 4). These include a subgroup of six patients who presented with atrial flutter and periods of 1:1 AV conduction and aberrant QRS (Fig. 5). Three examples of sick sinus syndrome were first ignored as pause artifacts (Fig. 6). Three additional examples of pacemaker malfunction were also misinterpreted (Fig. 7). The last three examples were recordings from one patient with congenital long QT syndrome (LQTS) and 2 patients with acquired LQTS in whom the diagnosis was missed in spite of significant clues (Fig. 8).

DISCUSSION

Since the introduction of ambulatory ECG recordings, there have been major advances in recording and playback techniques resulting in better recording fidelity and more sophisticated analysis software. However, recording artifacts

continue to occur in spite of continuous technological research to reduce artifacts due to motion and impaired skin-electrode contact. Recent techniques include a frequency filter and time window interconnected in series¹² and real-time digitally assisted analog motion artifact reduction.¹³ Although the present report did not analyze consecutive recordings, the 4.8% of recording artifacts is comparable to earlier reports.⁴ The table shows that both recording artifacts and especially misinterpretation of nonartifactual recordings are significantly more common in telemetry recordings compared to Holter ECG.

This study was specifically designed to highlight the extent and potential clinical implication of the less frequently emphasized problem of misinterpretation of nonartifactual ambulatory ECG recordings. This problem is significantly more common in the cardiac telemetry service and involves specially trained cardiac nurses, as well

Figure 6. Selective tracings of a cardiac telemetry recording of a 64-year-old male with history of palpitation and presyncope. Analysis of a 24-hour recording showed three long episodes of paroxysmal atrial fibrillation (AF) with fast ventricular response. Two periods of approximately 4.6 second flat line pauses were recorded following abrupt termination of AF. The A tracing shows immediate resumption of AF following what looks like an escape atrial beat. The pause in (A) was attributed to a recording artifact. No attention was originally paid to the continuous tracing in (B), which shows typical tracing of overdrive suppression of sinus node activity followed by the emergence of slow low atrial/AV junctional rhythm before resumption of normal sinus rhythm. The patient was discharged after 24 hours hospitalization and was prescribed a β -blocker for control of ventricular rate during AF and started on anticoagulation. Patient was readmitted 48 hours later after sustaining soft tissue injury during a syncopal episode. The diagnosis of sick sinus syndrome was recognized and the patient received a permanent pacemaker.

Figure 7. A continuous tracing obtained from an ambulatory Holter ECG of a 72-year-old male who had a recent single chamber ventricular pacemaker for symptomatic complete AV block. The recording was ordered 2 weeks after device implantation when the patient complained of presyncope and the resting ECG showed normal paced rhythm. The tracing was initially interpreted as ventricular paced rhythm alternating with AV junctional rhythm. A critical analysis revealed what was misinterpreted as narrow QRS complexes were in fact pacing spike artifacts. The continuous tracing reveals that it took approximately 28 seconds before the escape of a slow idioventricular rhythm in the lower tracing. The patient was readmitted and underwent repositioning of the ventricular lead.

as medical residents, cardiology fellows, and cardiology faculty who represent the team in charge of the service.

A significant percentage of misinterpretation involves examples of fast SVT with aberrant conduction that are misdiagnosed as VT. Admit-

tedly some of the recordings may be challenging, for example cases of atrial flutter with 1:1 AV conduction. Although this is a relatively uncommon arrhythmia, it can result in significant errors of commission and errors of omission as has been previously reported.¹⁴ The majority of

Figure 8. Two recordings obtained during two separate admissions to the telemetry service of a 23-year-old female who complained of frequent presyncopal episodes. (A) The first recording showed frequent episodes of short nonsustained supraventricular tachycardia, followed after a bradycardic pause with a normal sinus beat with bizarre giant TU wave (marked by arrow). Several giant TU waves were seen following similar sequences during the 1 day recording and were attributed to recording artifact. The patient was discharged on no medication and was scheduled for a tilt table test to rule out neurocardiogenic syncope. The patient was readmitted 2 days later to the telemetry service following an episode of syncope. This time there was evidence of prolonged QT interval during normal sinus rhythm (B). The patient continued to develop short episodes of nonsustained SVT followed after the bradycardic pause by a sinus beat with more prolonged QT interval and the onset of episodes of torsade de pointes ventricular tachyarrhythmia.

examples highlighted in this report requires a basic degree of knowledge of arrhythmia interpretation, for example, the concept of overdrive suppression of the sinus node (Fig. 6). Other examples probably require a relatively more broad expertise, for example, the post-pause development of "bizarre" giant TU wave in patient with congenital or acquired LQTS¹⁵ (Fig. 8). The clinical implication of mistaken interpretation of ambulatory ECG recordings could result in errors of commission and errors of omission. Errors of commission include, but are not confined, to recommending the wrong medication (Figs. 6 and 8) or potentially harmful and unnecessary interventional procedures like

cardiac catheterization, electrophysiological study, or implantation of arrhythmia devices. Errors of omission include failure to properly address patient with sick sinus syndrome (Fig. 6), pacemaker malfunction (Fig. 7), or LQTS (Fig. 8). As previously reported, board certification in medicine, cardiology, or even cardiac electrophysiology is not a guarantee of better interpretation of ambulatory recordings.⁹

In summary, this report is a plea for improved "targeted" training of clinical personnel involved in the diagnosis and management of ambulatory ECG recordings especially in the cardiac telemetry service.

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