Identifying and troubleshooting low-frequency artifacts mimicking atrial flutter caused by deep brain stimulator

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Introduction

Electromagnetic interference from deep brain stimulators (DBS) is known to cause high-frequency artifact on some forms of cardiac telemetry.[1] Here, we (1) present a unique case in which a DBS caused a low-frequency artifact mimicking typical atrial flutter leading to referral to electrophysiology; (2) demonstrate a method to confirm this; and (3) provide recommendations of how to minimize artifact and work around this interaction in future rhythm monitoring attempts.

Case report

A 56-year-old man with history of Parkinson disease treated with a DBS was referred to electrophysiology for further evaluation for newly discovered atrial fibrillation on telemetry at the time of a routine preventative colonoscopy. A 12-lead electrocardiogram (ECG) obtained in the office revealed sinus rhythm with occasional premature atrial complexes (Figure 1). The patient had been asymptomatic from a cardiac standpoint, physical examination was within normal limits, and an echocardiogram revealed a structurally normal heart. The ECG recordings obtained prior to cancellation of his colonoscopy were not available for review, but we initially considered the possibility of Parkinson-related tremor artifact superimposed upon an irregular rhythm owing to his premature atrial complexes being mistaken for atrial fibrillation. However, he had no clinical tremor with his DBS (Activa 37601; Medtronic, Minneapolis, MN) and carbidopa-levodopa therapy, and no artifact was seen on the ECG obtained in our office. A 30-day event monitor (BioTel MCOT patch; BioTelemetry Inc, Eagan, MN) surprisingly reported a 9% atrial flutter burden. Initial review of the tracings suggested an apparent rate-controlled atrial flutter (Figure 2A). Despite visual resemblance to typical flutter, artifacts could not be ruled out.

KEY TEACHING POINTS

- While electrogram artifact caused by deep brain stimulators (DBS) is typically high frequency in nature, low-frequency artifact can also be encountered and mistaken for atrial flutter on ambulatory rhythm monitors, leading to misdiagnosis and incorrect therapy.
- Low-frequency artifact can be a result of aliasing occurring from a discrepancy between the stimulation frequency and the sampling rate of the ambulatory monitor. Real-time testing of the monitor while turning the DBS on and off can confirm this.
- Recognition of DBS-induced low-frequency artifact on ambulatory monitoring avoids misdiagnosis and guides future monitoring options by choosing monitors with higher sampling rates, including consumer-grade wearables.

Discussion

Despite a cycle length and morphologic appearance consistent with typical flutter (Figure 2C), the ECG raised suspicion for artifacts because of the dissociation of the "flutter waves" from the regular QRS complexes. Lack of relationship between flutter waves and QRS complexes would suggest complete heart block,[2] but the PR interval was normal during sinus rhythm, and no heart block events were otherwise recorded. Parkinsonian tremor has been implicated in causing artifact owing to baseline undulation mimicking atrial and

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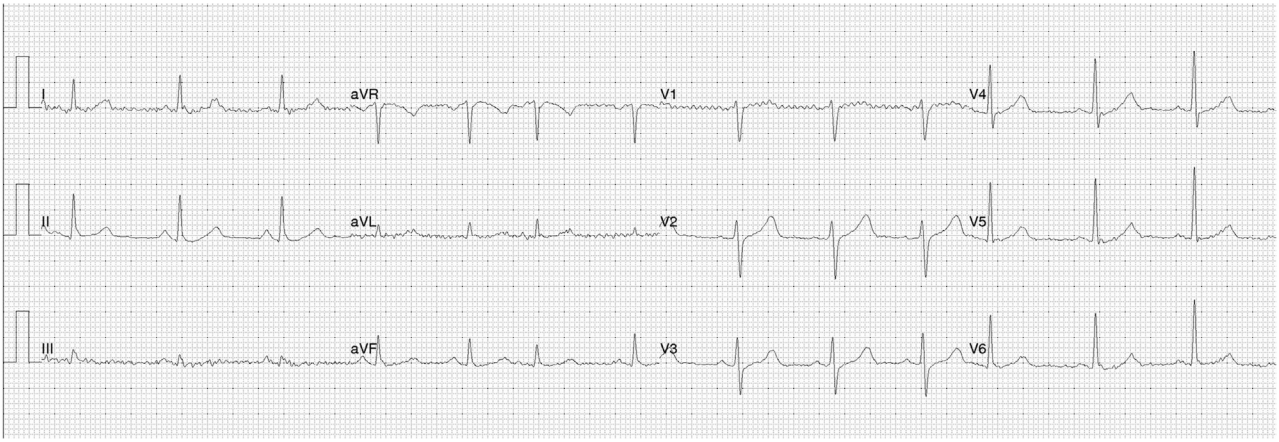

Figure 1 A 12-lead electrocardiogram exhibiting sinus rhythm and high-frequency artifact (most notable in lead V_1) typically seen with deep brain stimulator in situ.

ventricular tachyarrhythmias.[3–5] Hwang and colleagues[5] found that 89 of 100 patients with a Parkinson tremor at rest had ECG artifacts. Eleven of the 89 patients had an artifact mimicking atrial fibrillation, atrial flutter, or even ventricular tachycardia; and these patients had a significantly higher tremor score than the patients with an undulating baseline. The frequency of Parkinson rest tremor is approximately 5 Hz, which is similar to atrial flutter wave frequencies.[6,7] Although our patient's artifact frequency was consistent with Parkinsonian tremor artifact, lack of clinical tremors made it less likely. Thus, we considered DBS as the likely source of artifact despite the fact that the artifact encountered is typically very high-frequency distortion.[1]

Repeat testing was performed in the office with the same model of ambulatory monitor. Using the programmer for the DBS, several tracings were obtained by submitting "symptom events" in sitting, bending over, and supine positions with the DBS "on" (Figure 2A). Following this, tracings were similarly obtained in the same positions with the DBS "off" (Figure 2B). Visualization of the event recordings after immediate submission and post-processing confirmed our suspicion by reproduction of the artifact while DBS was on and loss of the artifact while DBS was off. Based on these findings, no further cardiac workup was warranted.

Why are the DBS-related artifacts low-frequency "flutter wave" in this case instead of the anticipated high-frequency signals? The low-frequency artifact may at least be partially explained by aliasing. The DBS pulse generator was implanted in the right infraclavicular space and lead electrodes were implanted in the left subthalamic nucleus in our patient. The DBS was programmed at 2.8 V at 60 ms pulse width and a stimulating frequency of 130 Hz in unipolar configuration.

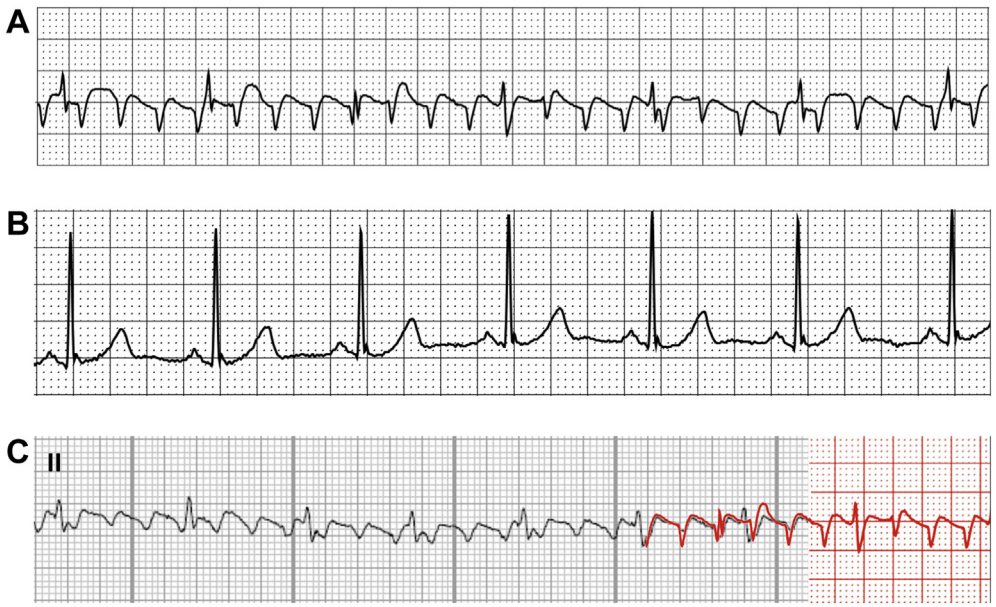

Figure 2 **A:** Low-frequency "flutter" artifact is visualized while deep brain stimulator (DBS) is on. **B:** Loss of "flutter" artifact is exhibited when DBS is turned off. **C:** For this tracing, the artifact is superimposed on an unrelated patient with actual typical atrial flutter to demonstrate the surprising similarity between the DBS-induced artifact and true clinical atrial flutter.

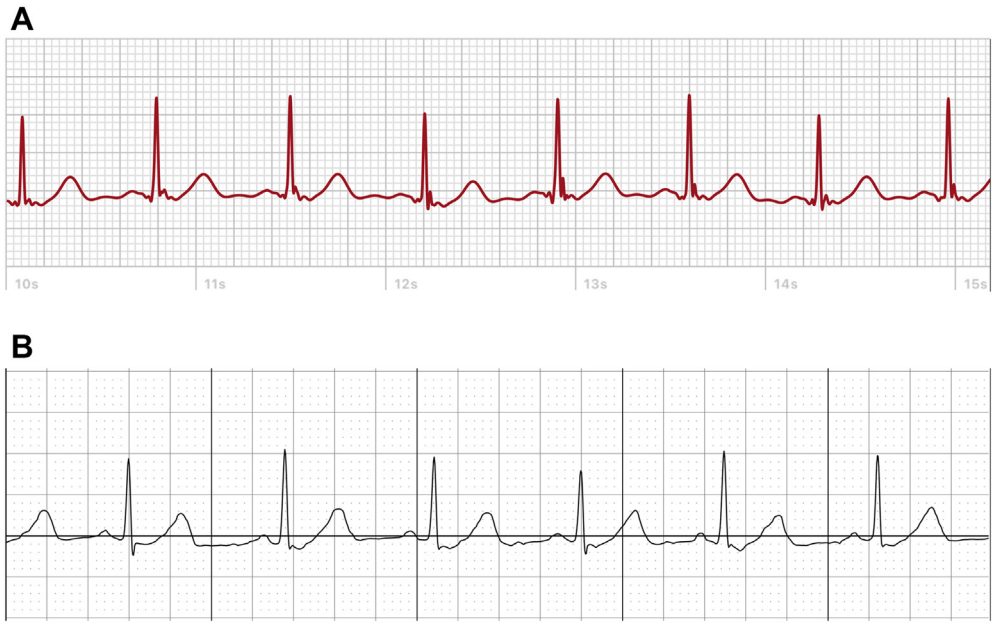

Figure 3 **A:** Apple Watch (Apple, Cupertino, CA) tracing performed with deep brain stimulator on reveals no identifiable electrogram artifact. **B:** KardiaMobile 6L (AliveCor, Mountain View, CA) tracing obtained in single-lead mode also reveals no evidence of identifiable electrogram artifact. This holds true for 6-lead mode as well.

The event monitor was placed in the left parasternal region per manufacturer recommendations and samples at a rate of 250 Hz, exhibiting a Nyquist frequency of 125 Hz (half the sampling rate). In this case, the DBS stimulation frequency of 130 Hz (source) exceeds the Nyquist frequency by 5 Hz. This discrepancy, potentially compounded by proprietary signal processing algorithms and filters used by the monitor, likely results in the low-frequency aliasing artifact. This would also explain why low-frequency artifact is not encountered on recordings obtained at a higher sampling rate such as the 12-lead ECG machine (sampling rate 500 Hz). If any artifact is encountered on ECG, it is usually very low-amplitude, high-frequency noise, as exemplified in Figure 1 (notably leads I, III, AVL, and V_1). It is unclear why the artifact was only encountered 9% of the time. We initially considered positional change as an etiology; however, position did not affect presence of artifact during reproducibility testing. Only the stimulator being on or off determined artifact presence. Because polarity (unipolar vs bipolar), DBS programming (pulse amplitude and pulse width), proximity of the stimulator to recording device, and orientation of recording leads may all affect the degree of electromagnetic interference, it is likely that these factors influence the consistency and amplitude of the identified artifact.[1]

While the artifact in this case was encountered on a BioTel platform, these findings raise questions regarding which other commercially available monitors may be susceptible to such artifact. Beyond any proprietary filtering algorithms, most platforms exhibit a band-stop filter for excluding 50 Hz or 60 Hz noise, a low-pass filter, and a high-pass filter. For instance, iRhythm Zio Patch (iRhythm Technologies, San Francisco, CA) exhibits common mode rejection at 60 Hz, a high-pass filter at 0.5 Hz, and a low-pass filter at either 30 Hz or 40 Hz based on the specific patch applied.

Many monitoring platforms have also transitioned to a single hardware device for simplicity. Both BioTel MCOT patch and iRhythm Zio Patch models are placed in the left parasternal region. While the BioTel MCOT samples at 250 Hz and provides 2 modified lead I channels, the iRhythm Zio Patch samples at 200 Hz and provides a single modified lead II channel. In contrast, the Preventice (Houston, TX) Bodygaurdian Mini is preferentially placed in vertical orientation at the manubrium or alternatively in a horizontal (perpendicular) orientation at the same level based on body habitus. While capable of sampling at 125 Hz, 250 Hz, 500 Hz, and even 1000 Hz, the default sampling rate of all Preventice hardware is 250 Hz. This is because rhythm identification and filtering algorithms have all been optimized for 250 Hz. A rate of 125 Hz does not sample frequently enough to allow sufficient fidelity, whereas higher frequencies may allow increased fidelity at the cost of battery life. Sampling at 1000 Hz only allows 1 channel vs 3 channels at sampling rates of 500 Hz or lower. If a higher sampling frequency is desired, this must be specified and programmed into the hardware by the platform holder prior to application.

Taking platform-specific proprietary filters and signal processing and standard hardware limitations into consideration, most commercially ambulatory monitors likely exhibit varying degrees of susceptibility to DBS-induced artifact. If the artifact can be attributed primarily to aliasing from sampling rate, then coordinating with the desired monitoring platform to choose hardware that offers a higher sampling rate could potentially resolve the issue. However, if the artifact is due to more platform-specific proprietary filtering or signal

processing algorithms, then use of an alternate platform or even a consumer-grade device may be a more viable option.

Moreover, many patients already monitor their own heart rhythms using consumer-grade wearable cardiac devices, and the potential interaction of these wearables with DBS has not been fully explored. To that end, we performed additional recordings with the patient's permission to obtain both single-lead and 6-lead tracings on a KardiaMobile 6L (AliveCor, Mountain View, CA) device and also on an Apple Watch (Apple, Cupertino, CA). No low- or high-frequency artifacts were visualized on either device while the patient's DBS was on (Figure 3A and 3B). While this may be partially owing to the proximity of the devices relative to the DBS and orientation of the leads being used (both devices provide a lead I equivalent), the lack of artifact is likely also owing to these devices using a higher sampling rate. The sampling rate of the Apple Watch is 512 Hz, and the KardiaMobile 6L samples at a rate of 300 Hz. Thus, both devices exhibit a Nyquist frequency well above the DBS-stimulating frequency of 130 Hz.

Encountering this artifact in the clinical setting raises the concern that there may be other patients with DBS therapy who may be misidentified as having atrial tachyarrhythmias, which could result in incorrect diagnosis and possible antiarrhythmic and anticoagulant therapy. It is estimated that greater than 100,000 patients worldwide are currently being treated with DBS.[1] Oral anticoagulation in particular poses a high risk in this patient population owing to the elevated incidence of dysautonomia and gait instability contributing to an elevated fall risk. While reprogramming the patient's DBS to bipolar setting may minimize the artifact for future rhythm monitoring attempts in some patients, many patients, including ours, had inadequate therapy and significant discomfort when tried on bipolar settings during their initial post-implant calibrations, making this a nonviable option for troubleshooting. Rather than changing DBS settings, choosing a wearable monitor or even a consumer-grade rhythm monitoring device that exhibits a higher sampling rate with Nyquist frequency that exceeds the DBS-stimulating frequency should exclude this artifact.

Conclusion

Deep brain stimulators can cause aliasing artifact that mimics typical atrial flutter on wearable cardiac monitors, which can lead to misdiagnosis and potentially harmful unintended medical therapy. Recognition of this artifact and the mechanism behind it avoids misdiagnosis and allows for more accurate rhythm monitoring in the future via appropriate device selection.

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