A 57-year-old woman with atypical chest pain presented for exercise stress testing with myocardial single-photon emission computed tomography perfusion imaging. The patient had a history of hypertension and hypothyroidism but no other history of coronary disease or risk factors. The patient’s baseline ECG is shown in Figure 1, interpreted as incomplete right bundle-branch morphology. During exercise stress testing, apparent 2:1 A:V conduction occurred, as shown in Figure 2A. Physicians reading the exercise stress test also interpreted ST elevation most prominent in lead V1 as consistent with the type 1 Brugada ECG pattern. Intermittent 2:1 A:V block appeared to resolve at high heart rates in Figure 2B. The test was terminated, and the patient appeared to return to normal sinus rhythm conduction with resolution of the ST deviation, as in Figure 2C. She was referred to the electrophysiology service for consideration of pacemaker implantation.

This particular case demonstrates 2 separate artifacts of the signal averaging process used to display tracings for reading in the setting of significant ECG recording noise. One popular approach for averaging, as shown in this tracing, is known as “linked medians.” This algorithm attempts to find consecutive R waves and uses this as a matched point for the signal averaging process. The heart rate is estimated from these R waves, and the signal averaged tracing is then “linked” together for display at the calculated heart rate by joining together the R waves with the averaged recorded signal for a brief period before and after this time point.

The ECG tracing obtained shows noise artifact, as shown in Figure 2A and 2B (lead II rhythm strip at the bottom of the figure). This noise caused the algorithm to gate off of every second R wave. When joined together through the linked medians method, the intervening QRS complex is lost, making the reconstructed image appear to have 2:1 AV block. The algorithm and source of this artifact are detailed in Figure 3A. The artifact visible from “zeroing” of the TP segment to link successive beats is seen prominently in leads II and V3 (Figure 2A, arrows). Subsequent signal-averaged tracings that are properly gated and demonstrate an extremely similar noisy raw tracing appear to have a QRS complex rate of approximately 150 bpm but an absence of the apparent 2:1 block, with continued use of linked median reconstruction (Figure 2B). To model the effects of various degrees of right bundle-branch block with varying QRS width on signal-averaged tracings, a computer simulation of this effect was performed. A directly recorded, digitized tracing of the V1 ECG was obtained from a patient with right bundle-branch block (sampling frequency, 977 Hz; filtration bandpass between 0.5 and 100 Hz). This was expanded by 5%, 10%, 15%, and 20% in subsequent beats to simulate complete right bundle-branch block and was weighted in an exponentially decreasing manner using MATLAB (Mathworks, Inc, Natick, MA). The original recording is shown in blue, the time-dilated tracings are shown in green with the summation, representing the signal-averaged tracing, shown in red (Figure 3B). As demonstrated in this simulation, an appearance of ST elevation is apparent, as seen with our case patient.

This patient had normal perfusion images, with preserved ejection fraction of >65% with image gating. Two months later, the patient had no episodes of 2:1 AV block with repeat maximal exercise stress testing and remained free of any symptoms. There was no Brugada-type morphology in precordial leads observed at rest.

Signal averaging is extremely useful for reproduction of interpretable signal in the setting of large amounts of noise. With time-domain averaging, the algorithm must align fiducial time points (gating), and errors in this can have significant effects on the resultant averaged tracing. Additionally, signal-averaging algorithms do not account for interpretable changes in the signal over the time-averaged interval, and thus a rapidly changing signal may produce artifact in QRST morphology, as shown here. With increasing processing of any signal data, appropriate consideration must be made to potential signal artifact with examination and correlation with available raw data.

Disclosures
None.

References

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**Key Words**: arrhythmia ■ exercise ■ heart block ■ electrocardiography ■ pacemakers ■ Brugada syndrome

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**Figure 1.** ECG tracing of the patient before stress testing. A magnified section of V₁ is shown in the window. Although interpreted as incomplete right bundle-branch block by referring physicians, the QRS duration of <100 ms does not meet formal criteria for this diagnosis. The patient has an unusual precordial R-wave pattern with equiphasic RS complexes from V₃ to V₆.
Figure 2. **A.** ECG near maximum stress testing before termination. Note the appearance of apparent 2:1 AV dissociation at 70 bpm and nonreconstructed noisy ECG tracing with QRS at visible at 140 bpm (lead II at bottom, marked “raw data”). **Arrows** in **A** point to the “artificial zero” of the linking segments. A magnified view of lead V₁ is shown. **B.** Reconstructed linked medians are properly gated, displayed at the true rate of 110 bpm. The apparent ST elevation in V₁ remains, as shown in the magnified tracing. **C.** This is a directly recorded nonreconstructed tracing, with absence of both heart block artifact and ST elevation in V₁. Note that there is no “raw data” rhythm strip output by the automated machine, and there is significantly more low-frequency component to the signal “wavy baseline.” A magnified V₁ segment is shown.
Figure 2 (Continued).
Figure 3. A, "Linked medians" reconstruction and source of artifact. B, Simulation of varying degrees of right bundle-branch block morphology by computer model. In each tracing, blue is directly recorded signal, green is varying degrees of time dilation (up to 20%), and red is the weighted sum of all tracings, representative of gated signal-averaged ECG. As right bundle-branch block progresses, characteristic ST elevation is produced that may be confused with Brugada ECG pattern.

A

1) Machine detects R waves and calculates period of signal (T), equal to the cycle length of the QRS complexes.

2) Using R wave as the center of signal interval, algorithm gates off R wave and averages period +/-(T/2)

3) For display, machine "links" averaged intervals together to make appearance of continuous tracing. Linked segments are joined together by a brief period of zero electrical activity. In order to preserve cycle length T, the signal is truncated slightly, spanning from (-T/2 + ε) to (T/2 - ε).

4) In the presence of noise, the machine gates off alternate QRS complexes, and computes $T' = 2T$. These are averaged to produce a clean tracing.

5) Incorrectly gated segments are "linked" with period $T'$. The slight truncation during linking process removes the traces of the QRS complex of the adjacent beats but preserves its P and T waves, creating the appearance of 2:1 AV block when linked.

B

(mV)

100 200 300 400 500 600 (ms)
Pseudo–Heart Block and Pseudo-Brugada Morphology From Signal-Averaging Artifact During Exercise Stress Testing
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