Inverse decremental conduction heralds complete atrioventricular block following transcatheter aortic valve replacement

Gan-Xin Yan, MD, PHD

From Lankenau Medical Center, Main Line Health, Wynnewood, Pennsylvania; Fuwai Huazhong Hospital, Zhengzhou, China; and Sidney Kimmel Medical College at Thomas Jefferson University, Philadelphia, Pennsylvania.

Introduction

Transcatheter aortic valve replacement (TAVR) is a minimally invasive therapy for patients with symptomatic severe aortic stenosis and has become popular in the past decade. However, TAVR can result in high-degree atrioventricular (AV) block requiring pacemaker implantation.[1,2] Preexisting complete right bundle branch block (C-RBBB) is an independent risk factor for development of advanced AV block following TAVR.[3] I present a case in which prolongation of the PR interval with lengthening of the RP interval, which likely reflects inverse decremental conduction in left bundle branch (LBB) in a patient with preexisting C-RBBB, heralds sudden cardiac arrest owing to complete AV block and asystole.

Case report

An 87-year-old male patient with severe symptomatic aortic stenosis underwent TAVR with a balloon-expandable valve. His pre-TAVR electrocardiogram (ECG) showed sinus rhythm with sinus arrhythmia, C-RBBB, and a normal PR interval. On pre-TAVR telemetry monitoring, the PR interval shortened with lengthening of the preceding RP interval after a compensatory pause following a premature atrial complex (PAC), a property consistent with decremental conduction in the AV node (Figure 1A, upper panel). Surprisingly, the PR interval paradoxically prolonged in response to an increase in the preceding RP interval after a PAC-related compensatory pause on day 2 post TAVR (Figure 1A, lower panel).

KEY TEACHING POINTS

- Transcatheter aortic valve replacement (TAVR) may cause injury in the left bundle branch (LBB), resulting in inverse decremental conduction.
- Inverse decremental conduction in the LBB in the setting of preexisting complete right bundle branch block or in the His bundle, which may manifest as positive correlation of the PR interval with the preceding RP interval on the electrocardiogram (ECG), heralds complete atrioventricular (AV) block.
- Continuous periprocedural ECG monitoring for the PR interval behaviors in response to change in heart rate could provide an early ECG warning signal for TAVR-related AV block.

The relationships between the PR and the preceding RP intervals reveal that the pre-TAVR PR interval was negatively correlated with the preceding RP interval (r: -0.87, $P < .01$), whereas, the post-TAVR PR interval was positively correlated with the RP interval (r: 0.95, $P < 0.01$; Figure 1B), a phenomenon of inverse decremental conduction. Frequent episodes of paroxysmal AV block, which were initiated by a longer RP interval following a PAC (arrow), occurred a few hours after the phenomenon of inverse decremental conduction was observed (Figure 2). It is also noted that the PR interval remained to be positively correlated with the RP interval post paroxysmal AV block. Sudden cardiac arrest owing to complete AV block and asystole, which required cardiopulmonary resuscitation and external transcutaneous pacing, developed subsequently. The patient underwent emergent implantation of a dual-chamber pacemaker.

Discussion

New-onset left bundle branch block (LBBB) is the most frequent complication of TAVR, with a mean incidence of

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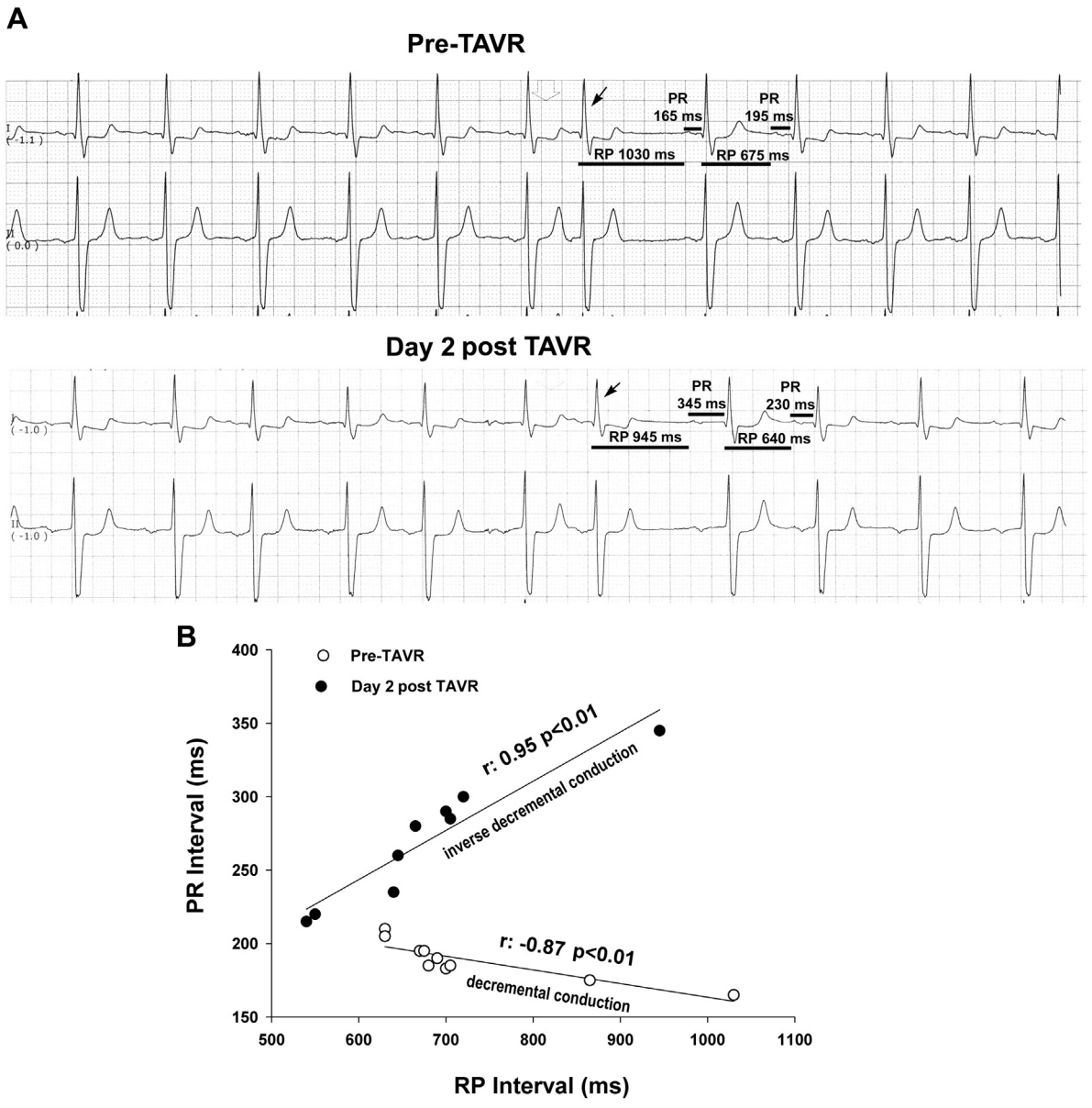

Figure 1 **A:** The telemetry electrocardiograms of the patient with preexisting complete right bundle branch block (C-RBBB) showed that the PR interval shortened after a compensatory pause after premature atrial complex (*arrow*) prior to transcatheter aortic valve replacement (TAVR) but significantly lengthened on day 2 post TAVR. **B:** Comparison of the relationships between the PR and RP intervals prior to and post TAVR in this patient.

approximately 40%.[4,5] This may explain why preexisting C-RBBB is a predictor for development of high-degree AV block following TAVR.[3] My associates and I recently reported 2 cases[6,7] in which patients developed LBBB at varying degrees following TAVR, which are related to either the preceding R-R intervals during atrial fibrillation or the preceding RP intervals in sinus rhythm with PACs. In the patient with sinus rhythm who had PACs, the QRS duration is positively correlated with the preceding RP interval.[6,7] In the patient with irregular R-R intervals during atrial fibrillation, on the other hand, the QRS duration is positively correlated with the preceding RR interval.[7] Both cases indicate inverse decremental conduction in the LBB following TAVR. In other words, although LBBB is called "conduction block" in the LBB, it may actually be slow conduction at different velocities, which is influenced by the impulse frequency from the upstream source, in many of the TAVR cases.

If there is complete conduction block in the right bundle branch (ie, C-RBBB), inverse decremental conduction in the LBB would alter not the QRS morphology and duration but the infra-Hisian conduction time of the His-Purkinje system, which would be expected to translate into changes in the PR interval on the body surface ECG. This is also the case for inverse decremental conduction in the His bundle. However, because the AV node and the His-Purkinje system are connected in series, inverse decremental conduction in the LBB in the setting of C-RBBB or in the His bundle may be offset by decremental conduction in the AV node, so a

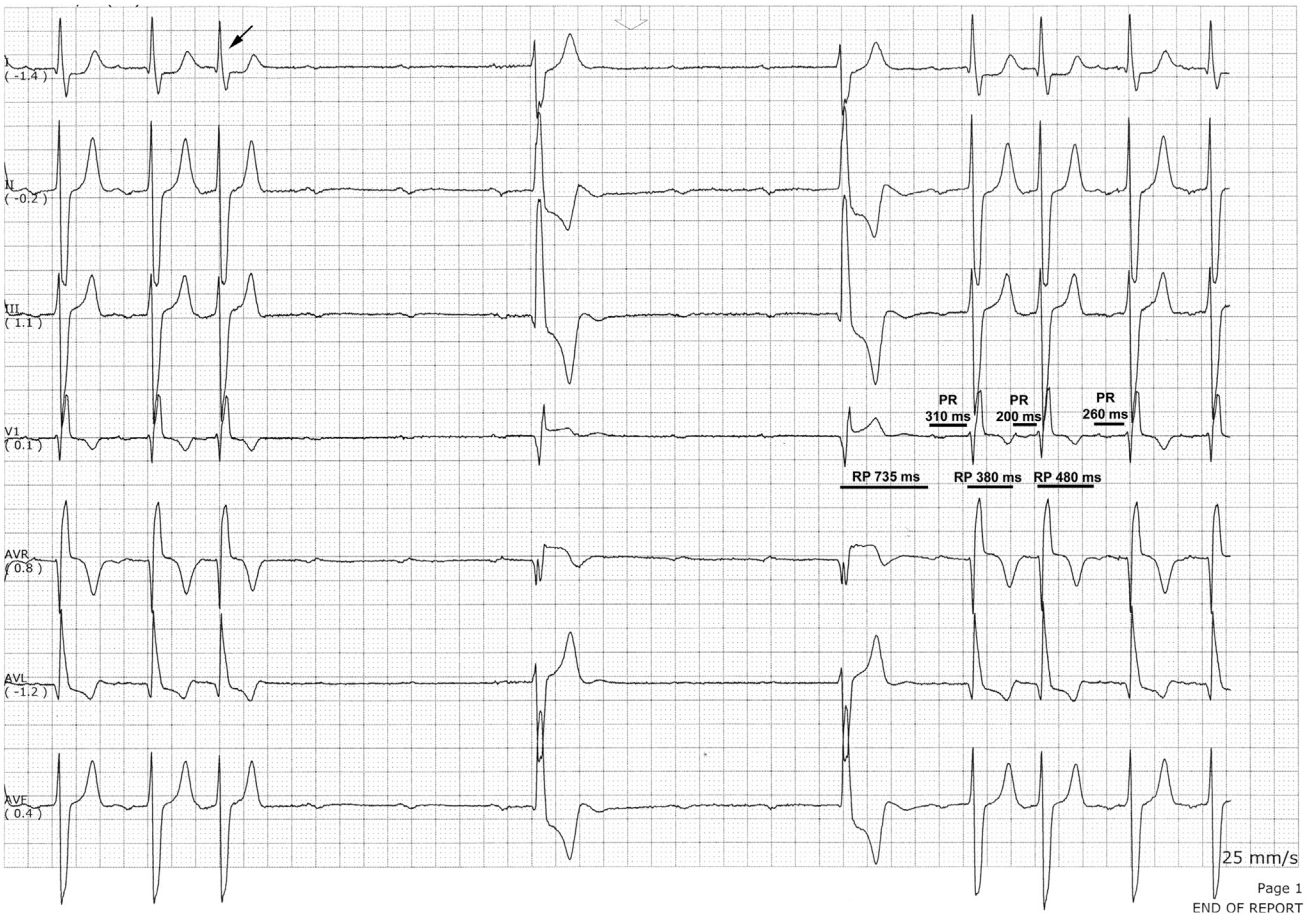

Figure 2 Paroxysmal atrioventricular (AV) block occurred after a compensatory pause resulting from a premature atrial complex (*arrow*). Note that the PR interval remained to be positively correlated with the preceding RP interval post paroxysmal AV block.

change in the PR interval change reflecting inverse decremental conduction in the injured LBB or His bundle can be trivial or be totally masked. If the injury of the LBB or His bundle by TAVR is severe enough, inverse decremental conduction may exceed the counteraction of decremental conduction in the AV node, manifesting as pause-dependent PR prolongation. It should be emphasized that it is indistinguishable on the body surface ECG between inverse decremental conduction in the His bundle and that in the LBB with preexisting C-RBBB. Because TAVR injures the LBB more commonly, I believe that inverse decremental conduction in the LBB contributes to varying degrees of AV block in the majority of patients with preexisting C-RBBB who underwent TAVR. However, the validity of this assumption needs to be tested in focused electrophysiological study: the HV interval, which reflects infra-Hisian conduction through the His-Purkinje system, would increase following a compensatory pause or a relatively longer RP interval if the TAVR-related injury is limited to LBB in a patient with preexisting C-RBBB.

It is well known that the AV node commonly displays decremental conduction and that conduction in the His-Purkinje system behaves in an all-or-none fashion. Decremental conduction assures that as the frequency of supraventricular stimulation to the AV node increases, the conduction slows. On the other hand, an electrical impulse conducts through the His-Purkinje system either at its full velocity ("all") or at zero velocity ("none"). However, an injured His-Purkinje system may lose such all-or-none conduction property and display inverse decremental conduction, a special conduction pattern in contrast to decremental conduction in AV node, wherein the less frequently the His-Purkinje fiber is stimulated the slower it conducts. The mechanism of inverse decremental conduction in the LBB with or without C-RBBB, similar to that of phase 4 block,[6] is illustrated in Figure 3. Conduction velocity in His-Purkinje fibers is a function of the upstroke (phase 0) velocity of action potential (AP) that is dependent on the level of the resting membrane potential upon arrival of a new electrical impulse. This is because the number of available voltage-gated sodium channels for AP phase 0 upstroke is determined by the resting membrane potential. When the LBB or His bundle is injured by TAVR, gradual spontaneous depolarization of injured His-Purkinje fibers during AP phase 4 shifts the resting membrane potential to a more positive level. Thus, a reduction of membrane potential at the time of excitation diminishes AP upstroke velocity owing to fewer available voltage-gated sodium channels, resulting in slower

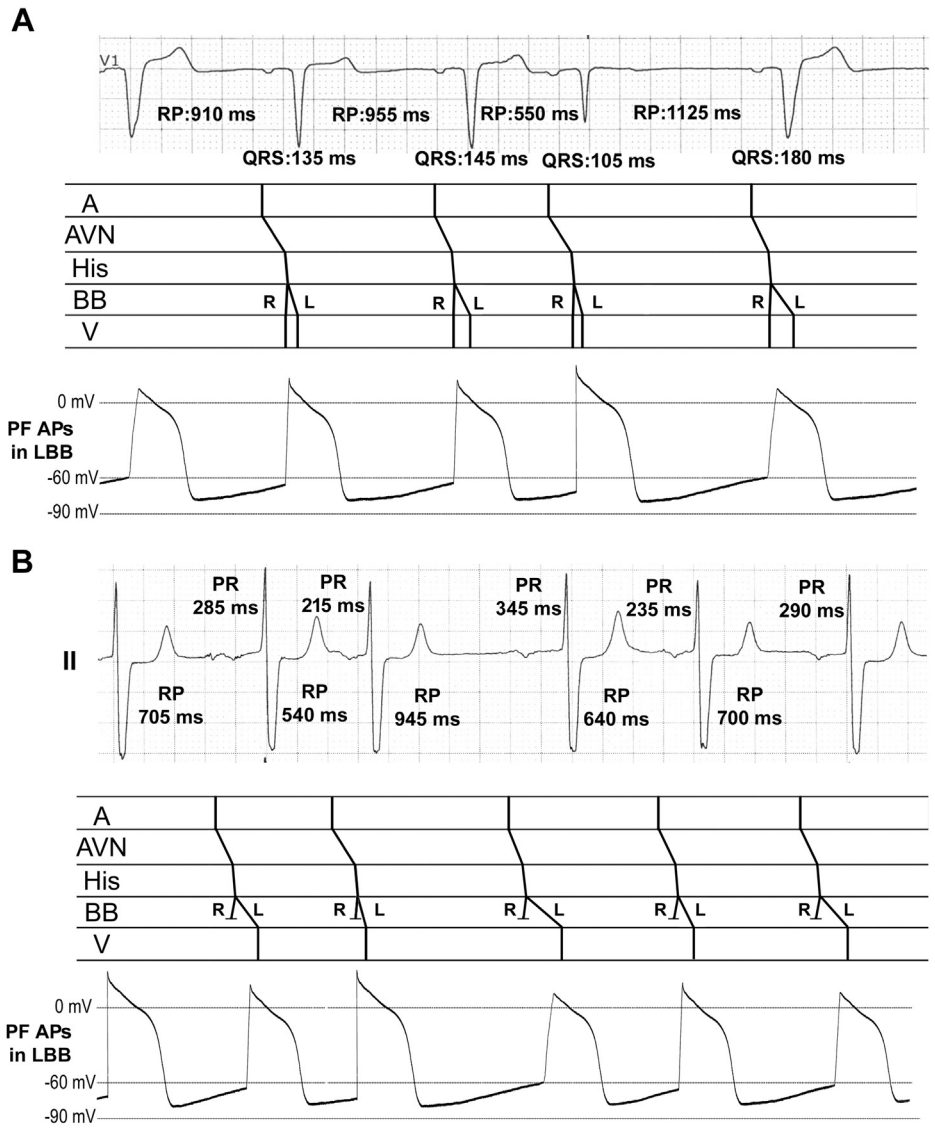

Figure 3 The proposed mechanism for transcatheter aortic valve replacement (TAVR)-induced inverse decremental conduction in the left bundle branch (LBB) with or without preexisting complete right bundle branch block (C-RBBB). **A:** An 87-year-old man with a baseline narrow QRS on electrocardiogram developed LBB block at varying degrees that positively correlated with the preceding RP interval on day 1 post TAVR. **B:** The patient in this case report with preexisting C-RBBB developed bradycardia-dependent PR prolongation on day 2 post TAVR. A = atria; APs = action potentials; AVN = atrioventricular node; BB = bundle branches; His = His bundle; L = left bundle branch; PF = Purkinje fiber; R = right bundle branch; V = ventricles.

conduction.[6] When AP phase 4 is long enough, the number of voltage-gated sodium channels ready for opening reduces to a critical number insufficient to produce a conductible AP and complete AV block (ie, conduction at a zero velocity) will occur. Therefore, the major difference between inverse decremental conduction and phase 4 block is as follows: inverse decremental conduction displays a continuing change in the conduction velocity in the injured or diseased His-Purkinje system that is determined by the frequency at which the system is stimulated, whereas phase 4 block represents a zero conduction velocity following a sufficiently long pause. In the case of phase 4 block, the electrical impulse either conducts at its baseline speed or ceases at the site of the block. Inverse decremental conduction in the LBB or His bundle may be a transitional pathologic state shortly post TAVR or other injury insults that can evolve into 1 of the 2 consequences: (1) cells gradually recovering from the injury and subsequently resuming their all-or none conduction; or (2) development of complete AV block, as demonstrated in this report.

Conclusion

Inverse decremental conduction in the LBB in the presence of preexisting C-RBBB, which manifests as positive correlation of the PR interval with the preceding RP interval, heralds development of complete AV block and asystole.

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