Cardiac rehabilitation for a skydiver after aortic valve replacement for pure aortic regurgitation and resection of the ascending aorta complicated by active infective endocarditis and heart block requiring a pacemaker

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A professional skydiver underwent aortic valve and ascending aorta replacement complicated by infective endocarditis with root abscess and pacemaker implantation. He then enrolled in the Baylor Heart and Vascular Hospital cardiac rehabilitation (CR) program as part of its specificity of testing and exercise training facility. He performed specific skydiving cardiovascular and muscular strength tests at the beginning and the end of the CR program. His pacemaker was interrogated to ascertain any arrhythmias or lead displacement over the course of the CR program. Daily exercise training was customized to match the physical demands of skydiving, including two sessions at iFLY Dallas. Upon completion of the daily exercise sessions, the patient performed a simulated free-fall drop test. He then performed a true jump at Dallas Skydive Center and subsequently traveled to Arizona for a skydiving competition, where he performed 35 true jumps with no adverse events or symptoms. This case illustrates how CR, tailored to a patient's specific needs, can aid in the return to rigorous activity.

A professional skydiver underwent aortic valve surgery, complicated by infective endocarditis with root abscess. He chose the Baylor Hamilton Heart and Vascular Hospital cardiac rehabilitation (CR) program because of its specificity of testing and exercise training facility. His particular goal was to participate in an Arizona skydiving competition in 1.5 months. This case report details the specific testing, exercise training, and pacemaker device interrogation that he underwent during CR.

CASE REPORT

The patient, a 39-year-old professional skydiver who had logged 2500 jumps, presented with severe aortic regurgitation and left ventricular dilation as a result of a bicuspid aortic valve. He underwent valve replacement and implantation of an aortic tube graft. The surgery was complicated by subsequent infective endocarditis and ascending aortic abscess, and he underwent further surgery on an emergency basis. A dual-chamber permanent pacemaker was implanted because of frequent manifestations of symptomatic bradycardia with periods of advanced atrioventricular block. The pacemaker was placed in the left mid chest wall so the patient would not suffer pressure generated by the chute-pack harness. The patient spent 74 days in the hospital.

During the recovery period and treatment of the endocarditis, the patient had venous thrombosis of the upper limbs and left jugular vein, requiring continuous use of anticoagulant therapy. He moved to a CR program in Rio de Janeiro, Brazil, during which he was limited in recovery by periods of atrioventricular block and bradycardia during exercise. The amiodarone and bisoprolol were suspended to promote improvement in cardiac performance and exercise tolerance. An echocardiogram showed good ventricular systolic function, and the aortic valve prosthesis was in good working condition. Due to his prolonged hospitalization, the patient was very weak and debilitated. The patient searched on the Internet for a facility that would provide specificity of testing and exercise training and subsequently enrolled in the Baylor Hamilton Heart and Vascular CR program in Dallas, Texas.

Upon entry to CR, the patient's body mass index was 26.5 kg/m^2, and his waist circumference was 36.5 inches; medications included both the rivaroxaban and losartan. Specific skydiving cardiovascular and muscular strength tests were performed at the beginning and the end of the CR program. The cardiovascular tests were performed on a treadmill while the patient wore a 20-pound chute-pack harness, helmet, and a calibrated desktop metabolic system (Fitmate MED, Cosmed USA Inc., Chicago, IL) *(Figure 1a)* that captured his oxygen consumption data. Protocols included 2-minute stages at speeds of 3.3 to 4.2 mph with changes in grade from 0% to 25%. The indications for terminating the test were those designated by the American College of Sports Medicine (1). The muscular strength tests (line gripping, line pulling, and abdominal core) were performed using a static force gauge that was attached to a multidimensional strength assessment system (IsoTrack Pro, JTECH Medical, Midvale, UT) *(Figure 1b)*.

The patient attended 25 CR exercise sessions, 3 times per week for 8 weeks. Exercise sessions were 75 minutes long and

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Figure 1. Specific skydiving testing and exercise training: **(a)** metabolic stress test wearing a helmet and a 20-pound chute-pack harness; **(b)** right arm line pull to measure muscular strength; **(c)** belly-fly exercise training drill.

customized to simulate the sport of skydiving *(Figure 1c)*. The patient's blood pressure was measured before and after exercise. In keeping with the standard protocol of our CR program, we used telemetry (TeleRehab VersaCare, ScottCare Corp., Cleveland, OH) to monitor the patient's electrocardiogram. The patient's pacemaker was evaluated 6 times over the course of CR by an electrophysiology nurse specialist. These device interrogations were done using the manufacturer's programmer (Biotronik PSW 1307.U, Biotronik, Inc., Lake Oswego, OR) to retrieve data and analyze the device settings. Each device interrogation consisted of a lead impedance test, an electrogram amplitude or sensing test, a capture threshold test, and retrieval of any recorded arrhythmias. The parameter criteria, according to the American College of Cardiology and the American Heart Association, were as follows: 1) the sensitivity threshold was 2.4 mV in the atrium (P waves) and 4.8 mV in the ventricle (R waves); 2) for pacing threshold, the loss of capture was 0.06 V at 0.4 ms in the atrium and 5.3 V at 1.0 ms in the ventricle; and 3) atrial lead impedance values were approximately 290 Ω and ventricular lead impedance was 312 Ω. The electrophysiology nurse specialist reviewed each transmission for proper functioning of the device and for the presence of arrhythmias.

CR staff (registered nurses and exercise physiologists) provided telemetry monitoring, testing, and exercise training. The testing and exercise training were symptom regulated, and as such were monitored for the peak rate-pressure product threshold (>36,000) (2), angina pectoris, dizziness, pain, dyspnea, lead displacement, and arrhythmias. Peak heart rate and blood pressure measurements were successfully recorded (18 out of 25 sessions). During the sessions, the patient's heart rate, blood pressure, and rating of perceived exertion remained within acceptable ranges (means, 153 beats/min, 160/73 mm Hg, and 7, respectively). His mean peak rate-pressure product value (24,624) was consistent with the 36,000 threshold. The patient achieved 9.65 metabolic equivalents (METS, defined as the energy cost of exercise, where 1 MET = 3.5 mL O_2 per kg of body weight per minute) on the post-CR program metabolic stress test. He also demonstrated gains in muscular strength (mean change = 22.5%) on the post-CR program static force gauge tests. Physiological data obtained during these tests are shown in the *Table.* Over the course of the exercise sessions, various arrhythmias were noted: occasional preventricular contractions, couplets and triplets, and one 4-beat run of preventricular contractions; all were deemed clinically insignificant by the CR staff. The patient had no adverse events or symptoms that required the discontinuation of any exercise session.

The patient attended iFLY Dallas during exercise sessions 10 and 14, where he performed skydiving maneuvers including the belly-fly *(Figure 2a),* sit-fly, and head-up. There were no adverse events or symptoms during the performance of these maneuvers.

To simulate the force of the chute-pack harness on his torso and, thus, the pacemaker leads, the patient reported to CR on exercise session 23 to perform a simulated free-fall drop test *(Figure 2b).* Before the test began, an electrophysiology nurse specialist performed a device interrogation in which appropriate lead placement was confirmed. The patient and CR staff then

Table. Physiological data from pre- and post–cardiac rehabilitation program tests designed to replicate the patient's specific skydiving goal activities

Category	Test	Pre	Post	Change
Muscular strength test: Line grip (lb)	Left maximum grip	82.9	86.4	4%
	Right maximum grip	93.2	97	4%
	Left sustained grip	79.9	82.1	3%
	Right sustained grip	76.7	89.6	17%
Muscular strength test: Line pull (lb)	Right line pull	67	82	22%
	Left line pull	54	89	65%
Muscular strength test: Fly position (lb)	Abdomen extension	91	139	53%
	Rotate right	34	41	21%
	Rotate left	31	36	16%
Skydiving cardiovascular treadmill tests	Oxygen volume (mL/kg/min)	33	33.8	2%
	Metabolic equivalents	9.42	9.65	2%

Figure 2. Skydiving performance and outcome: **(a)** belly-fly maneuver at iFLY Dallas; **(b)** free-fall drop test, designed to simulate the force of the chute-pack harness on the torso; **(c)** true jump at Dallas Skydive Center.

walked to the nearby fitness center where he put on his chute-pack harness. Two sets of 5 carabineers were linked together and attached to handles on an 8-foot squat rack platform. The bottom carabineers on each side were attached to each side of the top of the patient's chute-pack harness. The patient was asked to hold the handles on the squat rack while two CR staff members pushed his legs and body horizontally until he was parallel to the floor. The patient was asked to release the handles while the CR staff simultaneously let go of his legs. Before being stopped by the carabineers, this maneuver resulted in a 0.35 second free-fall drop at a speed of 11.3 feet per second and was repeated five consecutive times. Immediately following the test, the patient returned to CR, where the electrophysiology nurse specialist performed a device interrogation and confirmed that no change in lead status had occurred during the simulated free-fall drop test.

The patient was released to perform one true jump at the Dallas Skydive Center *(Figure 2c).* He subsequently traveled to Arizona 10 days later for a skydiving competition, during which he successfully jumped 35 times. He then returned to the Baylor CR facility where a final device interrogation was performed. One arrhythmia was noted: a single 6-beat run of nonsustained supraventricular tachycardia that was deemed clinically insignificant by the supervising electrophysiology nurse specialist. No change in lead status had occurred during the jumps.

DISCUSSION

The sport of skydiving requires specific cardiovascular endurance and muscular strength. A skydiver "free falls" after he leaves the aircraft, reaching speeds of 100 miles per hour in about 15 seconds. After the lines are pulled and the parachute opens, the force on the skydiver is approximately 4 times the force of gravity (4 "g's") (3). Patients who have endured pacemaker implementation may be precluded from skydiving due to the risk of arrhythmias and the potential for pacemaker lead displacement. On the simulated free-fall drop test, the patient endured five consecutive free-fall stop forces, calculated to be 175% of the "g" force one endures during an actual parachute jump. From device interrogation reports obtained over the course of the CR program, no recurrent sustained arrhythmias or lead displacement had occurred. Approximately 17 months after completion of CR, the patient had performed 800 true skydiving jumps without any adverse events, symptoms, or lead displacement.

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1. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription,* 9th ed. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health, 2014.
2. Adams J, Cline MJ, Hubbard M, McCullough T, Hartman J. A new paradigm for post-cardiac event resistance exercise guidelines. *Am J Cardiol* 2006;97(2):281–286.
3. Parks College Parachute Research Group. *Parachute Opening Shock Basics*. Available at https://www.pcprg.com/sym01out.htm/; accessed November 15, 2016.