Functional Assessment of the Total Artificial Heart by Blood-Pool Radionuclide Angiography

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Blood-pool radionuclide angiography was used to image a patient with a Jarvik 7-(70) total artificial heart. Excellent delineation of the chambers was achieved, allowing assessment of the total artificial heart pumping function. Estimation of the left ventricular volumes, cardiac output, and filling rates by radionuclide angiography corresponded closely with those simultaneously obtained from the total artificial heart driving lines. Radionuclide angiography affords the unique possibility to assess the function of the artificial heart noninvasively.

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The Jarvik-7 total artificial heart (TAH) is capable of sustaining an effective circulation for prolonged periods of time (*1*). In the last few years, this TAH has been used with increasing success as a bridge to cardiac transplantation (*2,3*). The function of the TAH is currently monitored by continuous, on-line observation of the pressures in the ventricular drive lines. These pressure data are coupled with indirect information on the changes in ventricular volumes throughout the cardiac cycle, obtained from analysis of the volumetric changes in airflow (*4,5*). From these data, the stroke volume, cardiac output, and filling rates can be indirectly calculated for each ventricle. Assessment of the function of the TAH by noninvasive techniques would add yet another dimension to the physiologic monitoring of this life-preserving device.

In this case report, we have used blood-pool radionuclide angiography (RNA) to image the TAH and assess its function.

CASE REPORT

A 28-yr-old white male with severe aortic regurgitation and depressed left ventricular function underwent aortic valve replacement on 01/07/86. Postoperative echocardiogram revealed normal prosthetic valve function but a left ventricular ejection fraction of only 20%. Congestive heart failure persisted postoperatively and became refractory to intensive medical therapy. On 08/23/87 the patient underwent orthotopic cardiac transplantation. The initial postoperative course was uneventful and the patient was discharged on 09/18/87 on immunosuppressive therapy with cyclosporine-A, azathioprine and prednisone. His functional status steadily improved to New York Heart Association Class I and he remained asymptomatic during the subsequent 11 mo. One week prior to admission the patient competed in a tennis match that was part of a "Transplant Olympics".

On 09/19/88 he was readmitted for evaluation of nausea, vomiting and abdominal pain which had been present for the past 2 days. Echocardiography revealed moderate left ventricular hypertrophy and severely depressed left ventricular function, with an ejection fraction of < 20%. That afternoon he became hypotensive during endomyocardial biopsy. Despite steroid pulse therapy and increasing doses of immunosuppressive therapy, severe hypotension and low cardiac output ensued and became refractory to cardiac inotropic drugs and vasopressors.

On 09/21/88 a Jarvik-7(70) total artificial heart (TAH) was implanted. Pathologic examination of the explanted graft showed a large acute transmural infarction involving the posterolateral wall of the left ventricle, recent thrombosis of the left circumflex coronary artery, and fibrocellular intimal proliferation of the coronary arteries. Biventricular hypertrophy and grade 5 rejection were present. After implantation of the TAH, the patient's postoperative course was complicated by acute renal failure requiring hemodialysis and ultrafiltration, respiratory insufficiency necessitating prolonged intubation, and acute liver dysfunction. His mental status waxed and waned but he remained responsive to verbal commands and capable of moving all his extremities upon request.

On 10/05/88 blood-pool radionuclide angiography (RNA)

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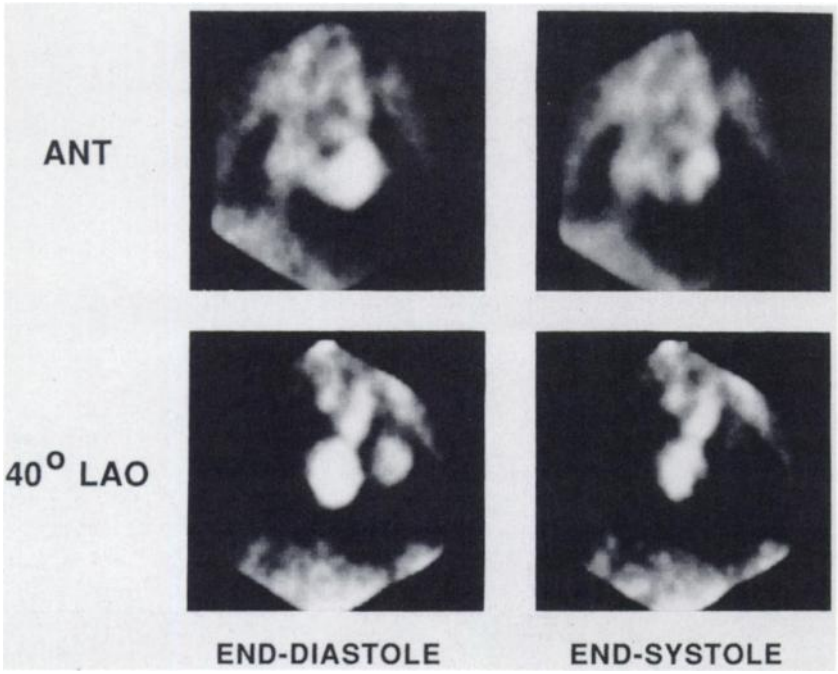

FIGURE 1
Blood-pool radionuclide angiography images of the total artificial heart. Good separation between the two ventricles is seen in the 40° LAO position. Notice the almost total obliteration of the left ventricular cavity during systole. Also note the prominent overlap between the right atrium and right ventricle. ANT = anterior, LAO = left anterior oblique.

was performed. Because of the possibility that the in vivo red cell labeling might be compromised by the presence of circulating heparin and that the plastic components of the TAH might adsorb the stannous pyrophosphate used for red cell labeling, human serum albumin labeled with technetium-99m (^{99m}Tc) (20 mCi) was selected as the imaging agent. Because the patient did not have an intrinsic electrocardiographic signal, the TAH cyclic driving electrical signal was used to gate the RNA acquisition through an input cable with a series of resistors that decreased the 5V signal by tenfold. Images were performed on a portable, computerized single crystal gamma camera (Technicare 420/550 System, General Electric Co., Milwaukee, WI) using a general purpose, parallel-hole collimator. Twenty-four frames were acquired on each cardiac cycle, to a total of 200 counts/pixel over the left ventricular chamber in the anterior and 40° left anterior oblique projections. Left ventricular volumes were calculated using a geometry-independent technique previously validated in our laboratory (*6*). The left ventricular ejection fraction was calculated using a semi-automatic method with variable regions of interest (*6*).

The images of the TAH were of high quality and allowed excellent visualization of the cardiac chambers, and resembled the RNA studies of human subjects (Fig. 1). In the anterior projection, the right atrium appeared dilated and akinetic and the two ventricles overlapped to a great extent. There was a wide halo surrounding the cardiac chambers, possibly due to incomplete filling of the space previously occupied by the patient's dilated graft. In the 40° left anterior oblique projection, the two ventricular chambers were clearly separated. There was, however, marked right atrial/right ventricular overlap in this projection, which persisted even at steeper obliquities of the camera.

The left ventricular hemodynamics are displayed in Table 1. The variables calculated by RNA were similar to those simultaneously obtained from the TAH drive system (Utah-drive System, Symbion, Inc., Salt Lake City, UT). The left ventricular time-activity (volume) curve is shown in Figure 2. The peak filling rate was 4.5 EDV/sec by RNA and 4.7 EDV/sec in the drive system. Fourier-transform and phase analysis indicated that the systolic motion of the left ventricular diaphragm initiated in the inferolateral wall and proceded superiorly and medially, toward the septal wall.

DISCUSSION

We herein report the use of blood-pool RNA to assess the function of the TAH. This technique allowed excellent anatomic visualization of the beating TAH in situ. Left ventricular ejection fraction, volumes, stroke volume, cardiac output, and peak filling rate, were calculated and corresponded closely with the values simultaneously obtained from the TAH drive system. The latter, however, are obtained indirectly through

TABLE 1
Hemodynamic Data

	RNA	TAH console
LV stroke volume (ml)	55	52.6
LV cardiac output (ml/min)	5,770	5,500
LV end-diastolic volume (ml)	68	70*
LV end-systolic volume (ml)	13	17.4*
LV ejection fraction (%)	82	75.1*
LV peak filling rate (EDV/sec)	4.5	4.7*

* Calculated using the capacity of the pump (70 ml) as the end-diastolic volume.

Abbreviations: EDV = end-diastolic volume; LV = left ventricular; RNA = radionuclide angiography; TAH = total artificial heart.

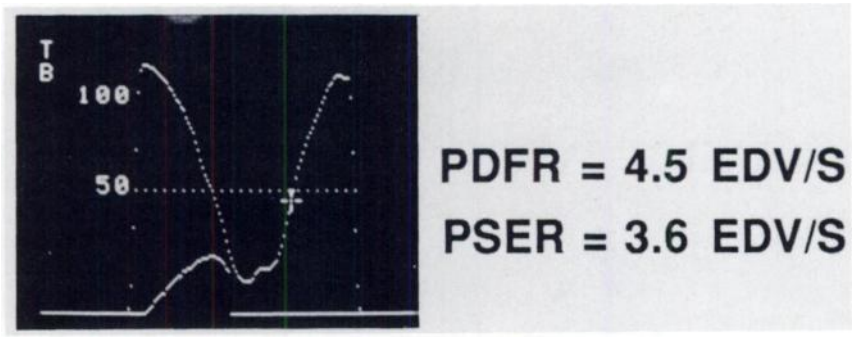

FIGURE 2
Left ventricular time-activity curve of the total artificial heart. Notice the high filling and ejection rates. The filling slope decreases in the second half of diastole. EDV/S = end-diastolic volume/seconds; PDFR = peak diastolic filling rate; PSER = peak systolic ejection rate.

pneumatographic measurements of the airflow into the ventricular chambers (*4*). The RNA technique, in contrast, provides a direct assessment of the function of the TAH by monitoring the count-rate of the radioactivity in the ventricular chamber throughout the cardiac cycle. In this respect, RNA may be one of the few, if not the only, alternative technique capable of assessing the TAH, other than the TAH drive system itself. Such an assessment may be important in detecting malfunction of the TAH, wherein the left ventricular volumes and output may differ from the values initially set for the pump. Furthermore, RNA may also prove to be of unique value in the assessment of totally implantable, self-contained, artificial hearts, which are presently being developed.

To the best of our knowledge, only two instances of the use of RNA to assess the TAH have been reported previously. Datz et al. (*7*) calculated the left ventricular ejection fraction and inferred the motion pattern of the left ventricular diaphragm using phase analysis. Zenger and DeVries (*8*) have assessed the ejection fraction of the right and left ventricular chambers by first-pass RNA on a patient with an implanted TAH. The authors found a close correlation between ejection fractions assessed by the first-pass RNA and the values predicted from the pump data. These authors, however, did not measure the left ventricular volumes nor the output of the TAH.

As demonstrated in the case herein reported, RNA provides important physiologic information concerning the function of the TAH. Such information may allow a noninvasive, comprehensive assessment of the TAH and may even assist in diagnosing certain malfunctions of the artificial heart.

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