Location of the Cannula of the Left Ventricular Assist Device in Explanted Hearts After Orthotopic Heart Transplantation

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Many patients having orthotopic heart transplantation (OHT) have previously had a left ventricular assist device (LVAD). Such a scenario allows the study of the position of the LVAD cannula in the explanted heart. We studied the explanted hearts in 105 patients who had had a LVAD inserted earlier and later underwent OHT at Baylor University Medical Center from January 2005 to September 2019, and compared the patients in whom the margins of the LVAD cannula contacted the mural endocardium with those in whom it did not. The margins of the orifice of the LVAD cannula contacted the left ventricular (LV) mural endocardium in 38 (36%) patients (considered potentially hazardous insertion) whereas in 67 (64%) patients there was no contact (considered "ideal" insertion). Comparison of the patients with ideal cannular insertion to those with potentially hazardous insertion disclosed insignificant differences in age at LVAD insertion or OHT; gender; interval between the LVAD insertion and OHT; body mass index; underlying cardiac disease; whether or not the heart floated in a container of formaldehyde, and the type of LVAD inserted. The margins of the LVAD cannula contacted the LV mural endocardium significantly more in patients with smaller mean heart weights than those with larger mean heart weights. In conclusion, of the 105 patients studied, the cannula of the LVAD resided in the LV cavity at an angle that allowed the margins of the orifice of the cannula to contact the mural endocardium in 38 (36%), a situation that at least potentially could cause partial obstruction of its orifice. Nevertheless, comparison of the 38 patients with nonideal cannular insertion to the 67 with ideal cannular insertion disclosed only 1 significant difference between the 2 groups. **(Am J Cardiol 2020;134:91−98)**

Many patients with left ventricular assist devices (LVADs) later have orthotopic heart transplantation (OHT), an occurrence which provides an opportunity to study the location of the cannula within the left ventricular (LV) cavity.[1−3] We recently described necropsy findings in 15 patients who previously had had an LVAD inserted.[4] In this report we describe cardiac findings in 105 patients who had OHT after a LVAD had been inserted at varying intervals earlier.

Methods

A total of 615 patients underwent OHT at Baylor University Medical Center from January 2005 to September 2019. Of the 615 hearts, 128 (21%) had had a LVAD inserted earlier: 118 at Baylor University Medical Center and 10 at 10 other hospitals. Of these 128 patients, 23 had the LVAD excised from the native heart before it reached the surgical pathology division of the department of pathology and therefore the location of the LVAD cannula in the LV cavity in them could not be determined. Consequently, these 23 cases were excluded from this study. Thus, this study is limited to the remaining 105 cases. All hearts were opened, described, weighed, and the official report provided by the same person (WCR), and the hearts were photographed by Ms. Saba Ilyas. The cardiac ventricles were cut in cross-section parallel to the posterior atrioventricular sulcus, the most apical one about 3 cm in thickness and the remaining ones about 1 cm in thickness. The medical records had been extensively reviewed when the explanted heart was initially examined (by WCR). The clinical records were reviewed later by NA.

The major purpose of this study was to examine the location of the LVAD cannula in the LV cavity, and specifically to determine if the margins of the cannula at its orifice contacted the LV mural endocardium. Such contact, depending on its extent, could result in varying degrees of obstruction to the orifice of the cannula. The LVADs were inserted in these 105 patients during a 14-year period (2005 to 2019) by 18 different surgeons.

Summary statistics including mean, range, standard deviation, frequency counts, and percentages were used to describe the study population. We utilized Q-Q plot[5] and Shapiro-Wilk test[6] for assessing the normality of continuous variables. The averages of continuous variables were compared between ideal and nonideal groups using either *t*

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test or Wilcoxon-Sum-Rank test[7–9] depending on the distribution of the outcome. Categorical variables were compared between the study groups using either chi-square test or Fisher exact test[10] whichever more appropriate.

Results

The findings in the patients are summarized in Table 1. The margins of the orifice of the LVAD cannula contacted the LV mural endocardium in 38 (36%) patients and there

Table 1
Baseline observations in patients undergoing orthotopic heart transplantation after insertion of a left ventricular assist device at Baylor University Medical Center between January 2005- September 2019

Variable	Total (n=105)	Margins of the cannula of LVAD contact left ventricular endocardium		P value
		No (ideal) (n= 67)	Yes (n= 38)	
Age (years) (mean)				
at LVAD insertion	18-71 (54)	23-71 (55)	18-68 (52)	0.355
at OHT	19-73 (55)	26-73 (56)	19-69 (54)	0.381
Sex				
Men	89 (85%)	58 (65%)	31 (35%)	0.494
Women	16(15%)	9 (56%)	7 (44%)	
Interval LVAD insertion to OHT (days): range (mean)	6-1750 (490)	6-1706 (489)	84-1750 (492)	0.963
≤ 400	53 (50%)	33 (62%)	20 (38%)	0.739
>400	52 (50%)	34 (65%)	18 (35%)	
Interval LVAD insertion to OHT (years)				
≤ 1	48 (46%)	30(63%)	18(37%)	0.798
1-2	32(30%)	20(63%)	12(37%)	0.853
2-3	18(17%)	13(72%)	5(28%)	0.591
>3	7(7%)	4(57%)	3(43%)	0.702
Body mass index (kg/m^2) (mean)	21.0-44.4 (30.0)	21-44.4 (30.3)	21.2-39.6 (29.4)	0.389
≤ 25	22 (21%)	14 (64%)	8 (36%)	0.782
26-30	41 (39%)	25 (61%)	16 (39%)	0.356
31 - 39	37 (35)	24 (65%)	13 (35%)	0.895
≥ 40	5 (5%)	4 (80%)	1 (20%)	0.294
Underlying cardiac disease				
Ischemic cardiomyopathy	46 (44%)	31 (67%)	15 (33%)	0.500
Idiopathic dilated cardiomyopathy	43 (41%)	25 (58%)	18 (42%)	0.314
Hypertrophic cardiomyopathy	5 (5%)	4 (80%)	1 (20%)	0.651
Valvular heart disease	3(3%)	2 (67%)	1 (33%)	1.000
Adriamycin induced cardiomyopathy	2(2%)	1 (50%)	1 (50%)	1.000
Arrythmogenic right ventricular cardiomyopathy	1(<1%)	1 (100%)	0	1.000
Amyloidosis	1(<1%)	1 (100%)	0	1.000
Sarcoidosis	1(<1%)	1 (100%)	0	1.000
Non-compaction cardiomyopathy	1(<1%)	0	1 (100%)	0.362
Unclear	2(2%)	1 (50%)	1 (50%)	0.362
Heart weight (g): range (mean)	265-880 (485)	265-880 (498)	270-670 (459)	0.049
Men	270-880 (499)	285-880 (507)	270-670 (482)	0.198
Women	265-565 (408)	265-565 (441)	286-460 (365)	0.112
≤ 300	5/103*(5%)	2 (40%)	3 (60%)	0.096
301- 400	16/103* (16%)	10 (62%)	6 (38%)	0.906
401-500	40/103* (38%)	23 (58%)	17 (43%)	0.291
501-600	32/103* (31%)	25 (78%)	7 (22%)	0.043
601-700	8/103* (8%)	5 (63%)	3 (38%)	1.000
>700	2/103* (<2%)	2 (100%)	0	0.534
Hearts floated	44 (42%)	26 (59%)	18 (41%)	0.393
Type of LVAD inserted				
HeartMate I	1 (1%)	1 (100 %)	0	1.000
HeartMate II	84 (80%)	56 (67%)	28 (33%)	0.223
HeartMate III and heartware	20(19%)	10 (50%)	10 (50%)	0.153

Abbreviations: LVAD- left ventricular assist device; OHT- orthotopic heart transplant.
* - data missing in 2 men.

was no contact of any portion of the LVAD cannula in the other 67 (64%) patients. The insertion of the LVAD cannula in the latter 67 patients is considered "ideal." Views of the LVAD cannula within the LV cavity are illustrated in Figures 1 to 25.

Comparison of various variables between the patients having the LVAD cannula inserted ideally-vs-those inserted nonideally showed no significant differences in age at LVAD cannula insertion or at OHT; gender; interval between insertion of the LVAD cannula and the OHT; body mass index; underlying cardiac disease; whether or not the heart floated in a container of formaldehyde (a sign of massive cardiac adiposity), and type of LVAD inserted. The margins of the cannula contacted the mural endocardium more in patients with smaller mean heart weights than those with larger mean heart weights.

Discussion

The ideal left ventricle to insert a LVAD is one whose cavity is quite dilated and whose wall is not hypertrophied. The least favorable left ventricle to insert a LVAD is one whose cavity is not dilated and one whose wall is severely hypertrophied.[11] Additionally, the ideal ventricle also has no or little adipose tissue at its apex exteriorly and the least favorable one has huge quantities of subepicardial adipose tissue such that the LV apex is obscured. The obese patient is likely in this second category.[12,13]

The ideal location of the LVAD within the LV cavity is one in which the orifice of the cannula points toward the aortic valve, and the orifice of the cannula resides in or near the center of the cavity. Pointing the cannula toward the anterior, lateral or posterior wall or toward the ventricular septum can potentially be hazardous.[14,15] The more dilated the LV cavity the safer the insertion because contact of the margins of the mouth of the cannula is less likely. In 67 (64%) of the 105 patients included in this study, the cannula within the LV cavity did not contact the mural endocardium and therefore there was no possibility of its orifice being compromised by the LV wall. In contrast, the margins of the LVAD cannular contacted the mural endocardium in 38

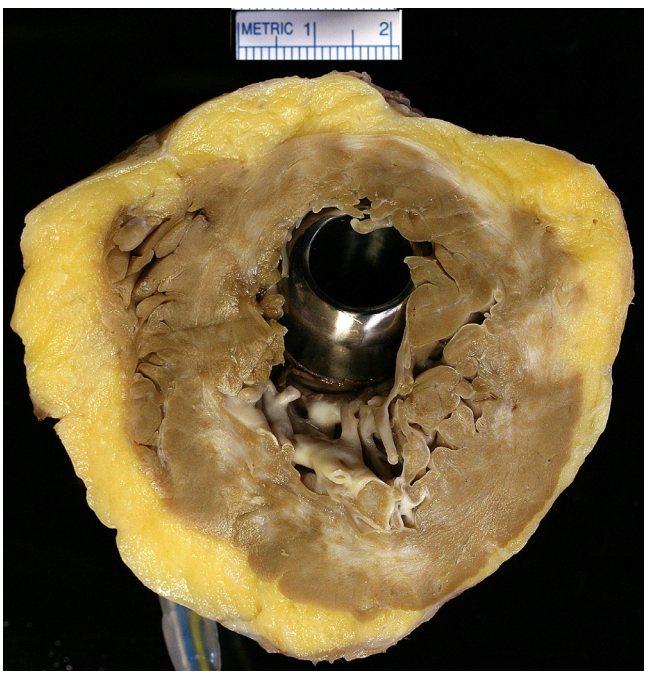

Figure 1. Shown here is a LVAD inserted into a dilated LV cavity of a 62-year-old man who underwent OHT 35 days after LVAD insertion. Although the cannula points to the anterior wall, its margin did not touch the mural endocardium. Multiple scars are present in the LV wall. The subepicardial adipose tissue totally surrounds the ventricle. The heart weighed 463 g and the body mass index was 21 kg/m^2. This patient had an acute myocardial infarction at age 42 followed by a coronary by-pass at age 49.

Figure 2. Shown here are the cardiac ventricles of a 45-year-old man with ischemic cardiomyopathy. The cannula faces the anterior wall and the margins of the cannula contact the ventricular septum. Adipose tissue covers the right ventricle anteriorly. The body mass index was 38 Kg/m^2. The heart weighed only 270 g. The LVAD with the pump weighed 255 g. The patient underwent OHT 98 days after LVAD insertion and died 46 days after OHT.

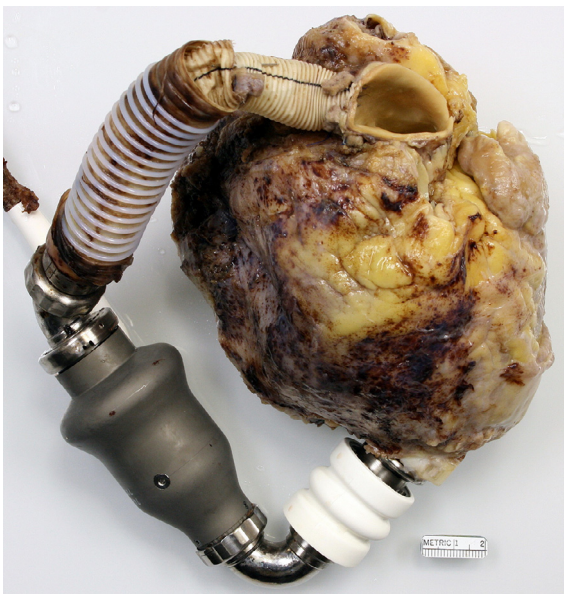

Figure 3. This is a heart of a 67-year-old man with ischemic cardiomyopathy who underwent LVAD insertion with a HeartMate II device followed by OHT 154 days later. The heart weighed 330 g and body mass index was 25 Kg/m^2.

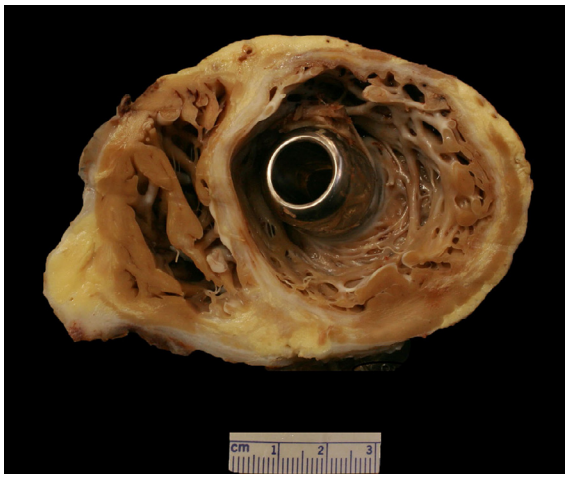

Figure 4. Shown here is a hugely dilated LV cavity with a properly inserted LVAD in a 57-year-old man with ischemic cardiomyopathy who 199 days later underwent OHT. The LV wall is extensively scarred and all epicardial coronary arteries are severely narrowed by atherosclerotic plaque. The heart weighed 435 g and the body mass index was 24 Kg/m^2.

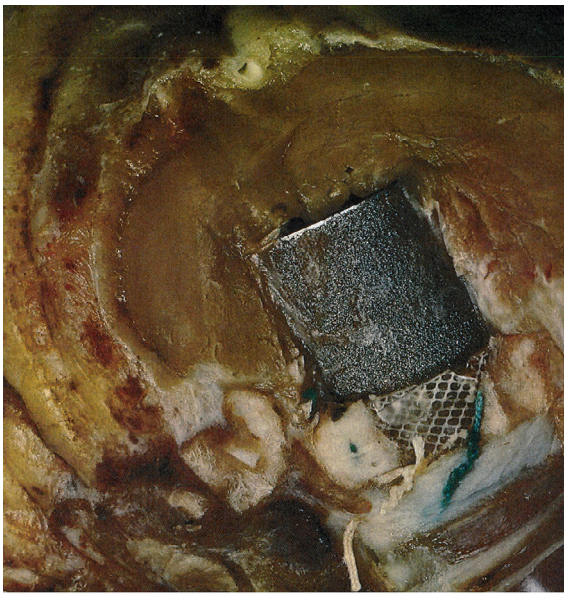

Figure 6. Shown here is the LVAD cannula directed towards the anterior wall of the left ventricle in a way that the orifice of the cannula is right against the LV wall. This 69-year-old man with idiopathic dilated cardiomyopathy underwent OHT 216 days after LVAD insertion. The heart weighed 410 g and the body mass index was 29 Kg/m^2.

patients, a circumstance which at least potentially could prevent ideal function of the device. The duration that the LVAD had been in place was no different in the group with contact or in the group without contact: a total of 53 patients had it in place ≤400 days, including 33 (50%) of the 67 patients with ideal insertion and 20 (53%) of those where the insertion caused contact.[16] Other factors including gender, body mass index, and cardiac adiposity were also insignificantly different between the 2 groups.

Other than the previous publication describing 15 patients at necropsy with an LVAD,[4] we have not found any other publication on this topic. A limitation of this report is that it does not describe the clinical or hemodynamic findings in these patients. Despite the fact that some of the photographs enclosed herein demonstrate partial occlusion of the cannula of the LVAD, the long intervals between the LVAD insertion and the OHT suggest that clinically cannular obstruction did not occur or the degree of obstruction was insufficient to cause functional abnormality. Whether the patients clinically improved with the LVAD insertion is unclear. Some clinicians have suggested that the position of the LVAD cannula within the LV cavity may change over time, possibly affecting its function, but we have no information on how the LVAD cannula resided in the LV cavity at the time of its insertion versus

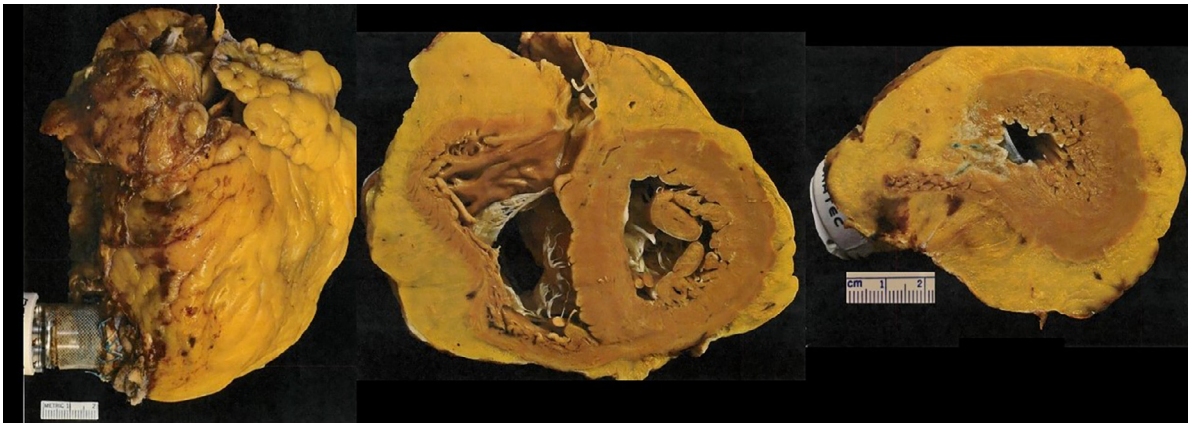

Figure 5. The cannula here was inserted into the apex of right ventricle and thereafter coursed through the ventricular septum into the LV cavity. The massive quantity of subepicardial adipose tissue presumably obscured the LV apex from view of the surgeon. The cannula points toward the LV lateral wall. This 44-year-old man underwent OHT 201 days after LVAD insertion. The heart weighed 470 g and body mass index was 29 Kg/m^2. The cardiac diagnosis clinically was idiopathic dilated cardiomyopathy. At heart examination, the major epicardial coronary arteries had no luminal narrowing. Whether the massive quantity of adipose tissue played an etiological role in his heart disease is unclear.

Figure 7. Here the cannula of the LVAD is directed towards the antero-lateral wall of the left ventricle such that part of the cannula margin touches the LV free wall. Subepicardial adipose tissue surrounds the ventricles completely. The heart weighed 460 g and the body mass index was 22 Kg/m^2. This 67-year-old woman with idiopathic dilated cardiomyopathy underwent OHT 250 days after LVAD insertion and died 18 days after OHT.

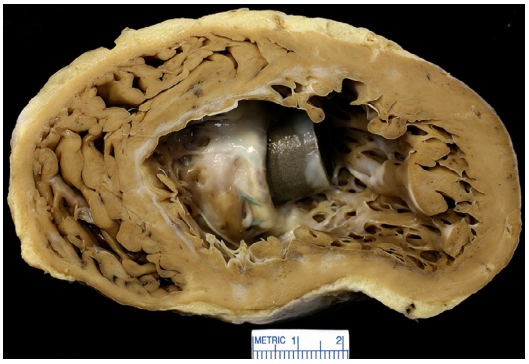

Figure 8. Shown here are cardiac ventricles of a 68-year-old-man with ischemic cardiomyopathy who underwent OHT 255 days after LVAD insertion. The cannula points towards the lateral free wall and white fibrous tissue is present around the cannula in the left ventricle. Subendocardial scarring is present in the ventricular septum. The heart weighed 455 g and the body mass index was 29 Kg/m^2.

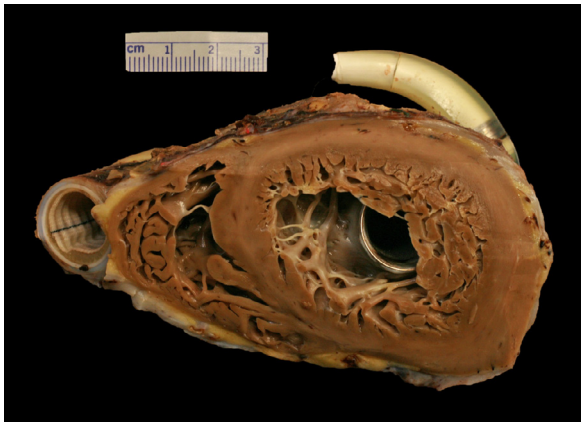

Figure 9. Shown here is a LVAD inserted in a 54-year-old woman who underwent OHT 263 days after LVAD insertion. Although the cannula is pointed towards the posterolateral free wall of the left ventricle, its margins did not touch the mural endocardium. The underlying cardiac diagnosis is unclear, the heart weighed 365 g and the body mass index was 29 Kg/m^2.

Figure 10. Here is an LVAD cannula directed toward the ventricular septum and partially embedded without causing a significant obstruction to the blood flow in a 35-year-old man who underwent OHT 284 days after LVAD insertion due to Adriamycin-induced cardiomyopathy. The heart is mildly deformed and weighed 360 g. The body mass index was 35 Kg/m^2.

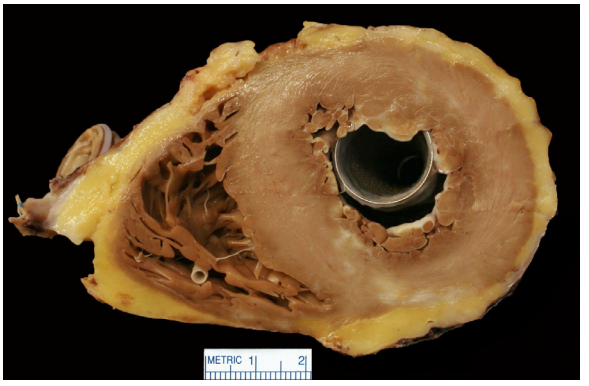

Figure 11. Shown here is a LVAD cannula opening directed towards the posterior LV free wall in a 58-year-old-man who had OHT 355 days after LVAD insertion. Thick layer of subepicardial adipose tissue surrounds the heart with scarring present in the LV wall anteriorly. The heart weighed 530 g and the body mass index was 27 Kg/m^2. The patient had ischemic cardiomyopathy.

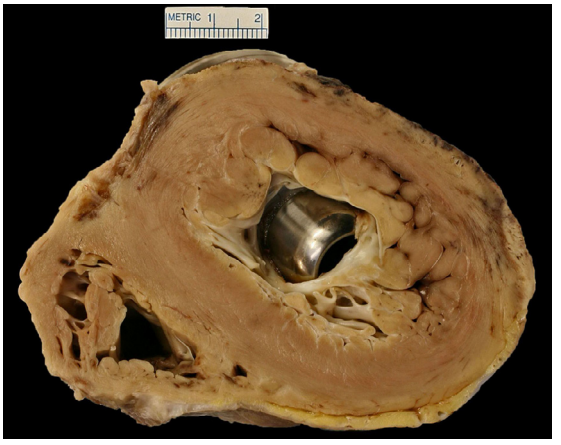

Figure 12. Shown here is a LVAD cannula pointing towards the posterolateral wall such that the opening is almost obstructed by the LV free wall. This 20-year-old man had OHT almost a year (361 days) after LVAD insertion due to idiopathic dilated cardiomyopathy. The body mass index was 25 Kg/m^2.

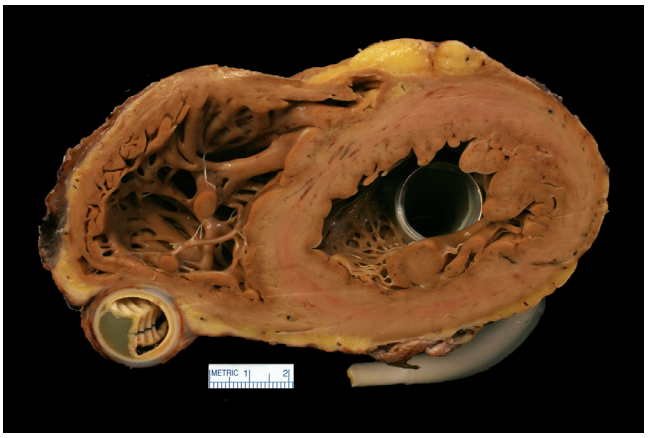

Figure 13. Shown here are dilated ventricles with a properly inserted LVAD in a 24-year-old man with idiopathic dilated cardiomyopathy who underwent OHT 397 days after LVAD insertion. The conduit of the LVAD is partially obstructed with fibrinous material. The heart weighed 420 g and the body mass index was 40 Kg/m^2.

Figure 14. Shown here is a LVAD cannula in a dilated LV cavity of a 65-year-old man with ischemic cardiomyopathy who underwent OHT 426 days after LVAD insertion. Although the opening of the cannula is directed towards the anterolateral LV wall, its margins do not touch the mural endocardium. Extensive scarring of the anterior, lateral and septal walls is present. Diffuse endocardial thickening is present in the LV cavity particularly around the cannula. The heart weighed 500 g and the body mass index was 32 Kg/m^2.

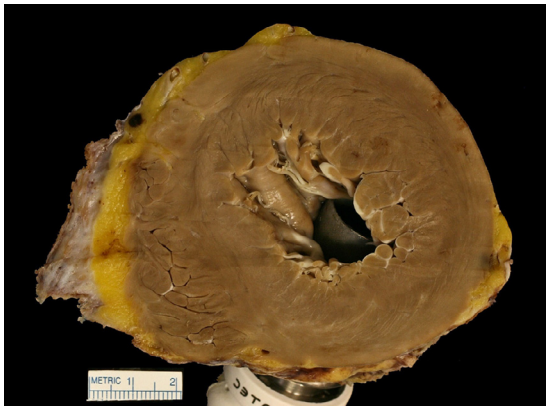

Figure 15. Shown here is a LVAD cannula opening facing the lateral LV wall and partly obstructed by it. The walls of the ventricles are thick without any scarring. The heart weighed 460 g in this 59-year-old man with idiopathic dilated cardiomyopathy who underwent OHT 432 days after LVAD insertion. The body mass index was 27 Kg/m^2.

Figure 16. Here the LVAD cannula is directed toward the lateral LV wall such that its opening is severely obliterated by the wall. The LV walls is very thick. This 61 year-old man who underwent OHT 434 days after LVAD insertion. A scar is present in the posterior LV wall. The underlying cardiac diagnosis was ischemic cardiomyopathy. The heart weighed 495 g and the body mass index was 26 Kg/m^2.

Figure 17. Shown here is a perfectly inserted LVAD cannula in a dilated LV cavity of a 54-year-old man with ischemic cardiomyopathy who underwent OHT 435 after LVAD insertion. The posterior wall is scarred. The heart weighed 545 g and the body mass index was 25 Kg/m^2.

its position in the explanted heart. Our hope is that there might be a bit more attention given to the angle at which the LVAD is inserted into the LV cavity. We suspect that the findings reported herein also are seen at most other OHT centers.

DisclosuresThe authors have no conflicts of interest to disclose.

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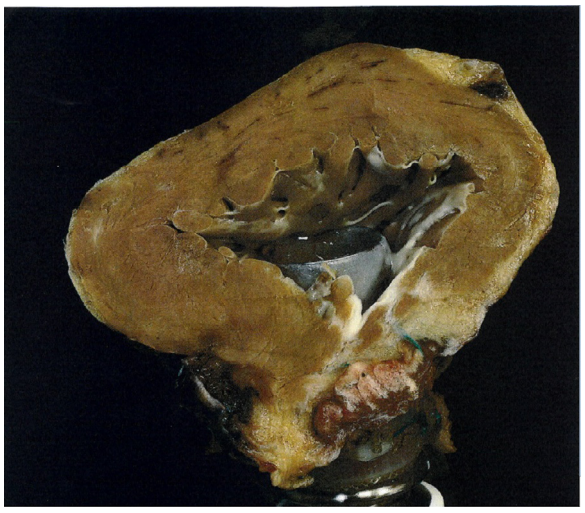

Figure 18. Shown here is a dilated LV cavity with the LVAD cannula pointing towards the anterior LV wall and partially touching it, without obstructing any blood flow in a 62-year-old man with idiopathic dilated cardiomyopathy who underwent OHT 453 days after LVAD insertion. The heart weighed 560 g and the body mass index was 31 Kg/m^2.

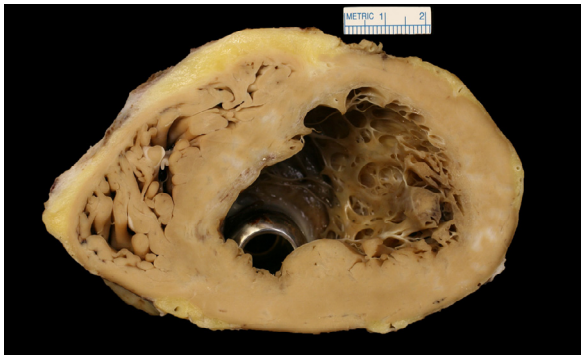

Figure 19. Shown here is a LVAD cannula pointing towards the posterior wall of a greatly dilated LV cavity in a 61-year-old man who underwent OHT 477 days after LVAD insertion. Scars are present in the LV free wall and in the ventricular septum. The heart weighed 595 g and the body mass index was 27 Kg/m^2. The underlying cardiac diagnosis was ischemic cardiomyopathy.

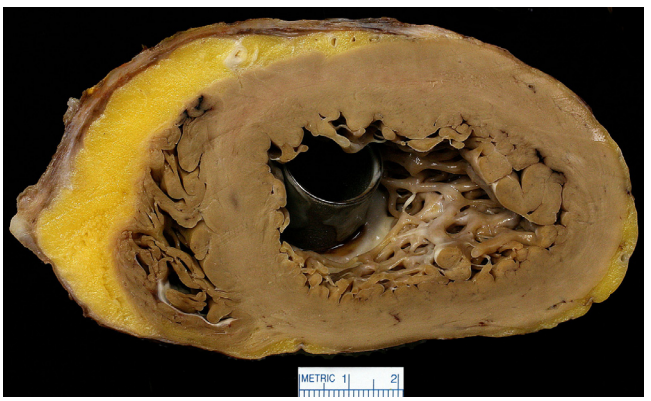

Figure 20. Shown here is an anteriorly directed LVAD cannula in a greatly dilated LV cavity of a 62-year-old man who underwent OHT 685 days after LVAD insertion. Thick adipose tissue surrounds the right ventricle. The heart weighed 607 g and the underlying cardiac diagnosis is ischemic cardiomyopathy. The body mass index was 30 Kg/m^2.

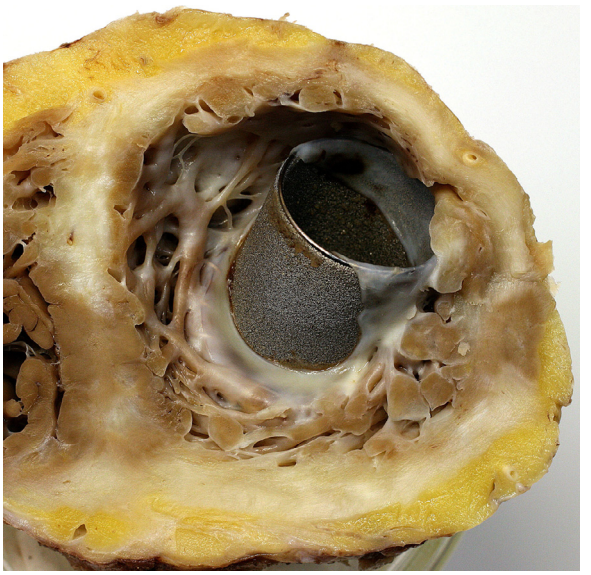

Figure 21. Here is a close up of the left ventricle showing the cannula opening directed towards the LV anterior free wall with fibrous tissue in and around it, without causing obstruction to blood flow. Extensive scarring is present in all the walls of the left ventricle with subepicardial adipose tissue surrounding it. This 48-year-old man with ischemic cardiomyopathy underwent OHT 869 days after LVAD insertion. The heart weighed 442 g and body mass index was 31 Kg/m^2.

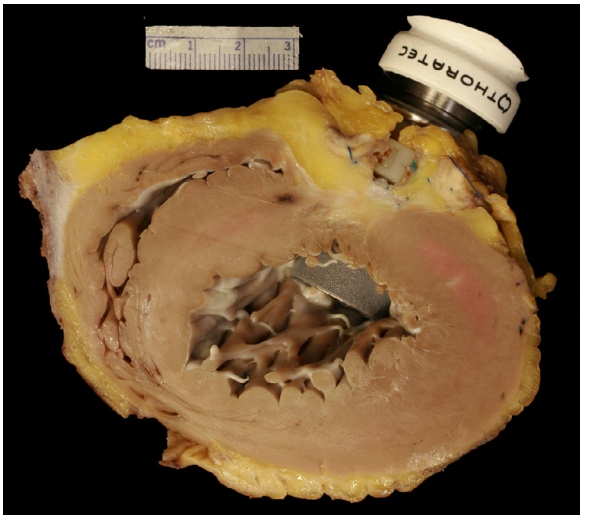

Figure 22. Shown here is a LVAD inserted into the anterior LV wall such that the opening is directed towards the posterior LV wall. The cannula does not obstruct the blood flow. The ventricles are surrounded by adipose tissue. This 49-year-old man underwent OHT 930 days after LVAD insertion. The heart weighed 670 g, the underlying cardiac diagnosis was idiopathic dilated cardiomyopathy and the body mass index was 38 Kg/m^2.

Figure 23. Here the LVAD cannula is directed toward the left lateral ventricular wall such that the opening of the cannula is partially obstructed by it. This 59-year-old man with idiopathic dilated cardiomyopathy had LVAD for 1,074 days before he underwent OHT. The heart weighed 465 g and the body mass index was 32 Kg/m^2.

Figure 24. Shown here is a posteriorly directed LVAD such that its opening touches the ventricular septum. Extensive white fibrous plaques are seen in the mural endocardium particularly around the cannula. The LVAD was present for 1,270 days before this 53-year-old man with idiopathic dilated cardiomyopathy underwent OHT. The heart was deformed and it weighed 605 g. The body mass index was 26 Kg/m^2.

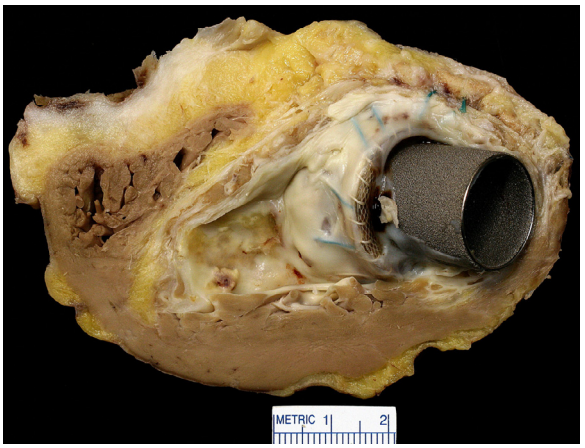

Figure 25. Shown here is a dilated LV cavity with a LVAD cannula directed towards the lateral free wall. The ventricular septum and anterior LV wall are completely scarred. Thick white fibrous plaques are present in the mural endocardium particularly surrounding the LVAD cannula. The subepicardial adipose tissue is excessive. This 48-year-old man with ischemic cardiomyopathy underwent OHT 1,355 days after LVAD insertion. The heart weighed 555 g and the body mass index was 34 Kg/m^2.

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