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# Review of Pathologic Findings in Remnant Hearts Following Valve Donation

**ABSTRACT:** The failure of medical examiners/coroners (ME/C) to allow heart valve donation is a major problem encountered by tissue agencies. Even though many ME/C favor tissue donation they remain responsible for determination of cause and manner of death. In 2001, the Jesse E. Edwards Registry of Cardiovascular Disease was approached by one of the nation's largest tissue procurement agencies (The American Red Cross—ARC) for the purpose of performing cardiovascular pathologic examinations following valve donation. The affiliation existed from October 2001 to January 2005. This study was undertaken to review all 593 postvalve recovery heart remnants received during that time period to tabulate the abnormalities identified and to determine whether donation interfered with the determination of cause of death. For each case, a preliminary cause of death was provided by the ARC. The decedent's body height and weight were also provided. Using the preliminary cause of death, the 593 cases were divided into natural and nonnatural manner of death groups. This division of the cases resulted in 106 cases placed in the natural manner of death group and 487 cases in the nonnatural manner of death group. For each case, all cardiac findings including significant conditions, additional findings, incidental findings, and congenital abnormalities were tabulated. Within the natural manner of death group, 15 cases had a noncardiac cause of death and 91 cases had a cause of death suspected to be cardiac related. In the 91 cases, a total of 132 significant cardiac findings were identified and there were six structurally normal hearts including two infants. In the nonnatural manner of death group, 214 significant cardiac findings were identified and 222 cases had a structurally normal heart. In both natural and nonnatural groups, the most common cardiac abnormality was atherosclerotic coronary artery disease. Other frequently encountered conditions were also identified including 11 cases with acute angle of origin of a coronary artery (five cases natural group; six cases nonnatural group). An important feature of this review was the recognition of potentially inheritable conditions that were diagnosed in both natural and nonnatural manner of death groups. There were three cases of hypertrophic cardiomyopathy (one natural; two nonnatural), three cases of arrhythmogenic right ventricular cardiomyopathy (one natural; two nonnatural), and one case of mitral valve prolapse (natural). In reviewing these cases, we did not feel that valve donation severely impaired cardiac pathologic examination. The benefits of cardiovascular pathologic examination by a cardiac pathologist include the identification of significant and incidental findings and recognition of potentially inheritable conditions.

**KEYWORDS:** forensic science, cardiac pathology, cardiac valve donation, tissue donation, cardiovascular registry

Organ transplantation has made great advances and is generally well accepted as a life-saving procedure. A major issue that continually surrounds organ transplantation is the availability of organs and the constant often critical shortage. Previous articles have addressed the issue of chronic organ shortage and the need for improved donation practices (1–3).

The use of allograph tissues in treatment of various conditions has rapidly expanded over the last decade. The issues surrounding tissue donation are very similar to those surrounding organ donation. Two of the main obstacles encountered in tissue donation include the families of the decedent and the medical examiner/coroner. Although tissue donation has become more publicly accepted, obtaining consent for tissue and/or organ donation from families remains a hurdle.

The other major obstacle is the medical examiner/coroner (ME/C), as a large number of potential heart valve donors fall under the jurisdiction of the ME/C. There are several papers in the medical literature addressing these concerns as well as papers offering an opposing view as to why denials should not be allowed (4–7). ME/C may find themselves in a difficult position when considering donation. Many ME/C are in favor of tissue donation, but they are also responsible for determining the cause and manner of death and obtaining crucial evidence in criminal cases. Some of the major issues that the forensic pathologist faces are the potential interference with the determination of the cause and manner of death, interpretation of artifact caused by the donation procedure, and the loss of potential trace evidence.

An additional issue encountered with cardiac allograft donation is the belief of many forensic pathologists that removal of the heart will limit or even potentially inhibit the identification of underlying heart disease and the determination of the cause of death. This failure of forensic pathologists to allow valve donation is a major problem encountered by tissue agencies who supply manufacturers of cardiac valve allografts (4,7–11).

To try to address the concerns of the forensic pathologist, several methods have been suggested. One method involves examination of the heart under sterile conditions at the time of initial heart procurement (12). Another method involves the use of pathologists contracted by the organ/tissue procurement agencies to examine the remnant heart following valve donation. One example of this method was the affiliation between the American Red Cross (ARC) and the Jesse E. Edwards Registry of Cardiovascular Disease (Registry). The Jesse E. Edwards Registry of Cardiovascular Disease was founded in 1960 by Dr. Edwards in St. Paul, MN. The Registry is a consult laboratory that contains over 20,000 cataloged hearts with various acquired and congenital diseases. In 2001, the Cardiovascular Registry by contract with the ARC began to examine remnant hearts following removal of valves for donation.

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The affiliation between the Cardiovascular Registry and the ARC existed from October 2001 to January 2005. This study was undertaken to review all of the postvalve recovery hearts in order to classify the type of conditions in these specimens.

## Materials and Methods

After procurement of heart valves, the remnant hearts were delivered to the Cardiovascular Registry in St. Paul, MN. Specimens were received after the initial donation procedure in a 10% formalin solution.

All specimens were accessioned with an "R" or Registry number and were numbered chronologically based on the year in which they were received. The Registry has developed a classification system and assigns cases a major class number based on the major cardiac pathologic finding. All remnant hearts from the ARC were assigned a major class number of 800. A search of the Registry's database was performed and all cases with a major class of 800 were included in the study.

All cases received a gross and microscopic examination. Gross examination included documentation of the size of the remnant heart and evaluation of the four cardiac chambers, remaining cardiac valves, myocardium, and coronary arteries. If the semilunar valves were not suitable for further processing, they were also examined.

During the initial gross dissection portions of the myocardium, cardiac valves, and coronary arteries were submitted for histological examination. The number of histologic sections depended on the presence of cardiac disease, and a minimum of three histologic sections were submitted in each case. Histologic slides were stained with hematoxylin and eosin, elastic van Gieson, and Mason trichrome stains.

Final reports were generated listing all cardiac findings, included pathologic conditions, incidental findings, and variations in normal anatomy. A final report, was generated within an average time of 5–7 business days. Following examination and completion of the final report the remnant hearts were returned to the ARC and then returned to the ME/C if requested.

Included in the reports was information supplied by the ARC in association with the ME/C indicating the decedent's height, body weight, and preliminary cause of death.

The cause of death and all diagnoses were tabulated for each case. Diagnoses were separated by significant findings, additional findings, incidental findings, and congenital abnormalities, or as structurally normal hearts. In cases with more than one significant finding, all diagnoses were included in the tabulation. The number of cases with more than one significant finding was recorded.

Cases with a natural cause of death were separated from the remaining cases. The cases placed in this group had a preliminary cause of death reported as myocardial infarction, cardiopulmonary arrest, cardiac arrest, cardiac insufficiency, cardiac related, or a specific natural condition.

The number of pediatric cases (ages $<18$ years) was also tabulated.

## Results

During the study period of 40 months (October 2001–January 2005), a total of 593 remnant hearts were examined. Division of the cases by preliminary manner of death into natural or nonnatural groups resulted in 106 cases in the natural group (17.9%) and 487 cases in the nonnatural manner of death group (82.1%).

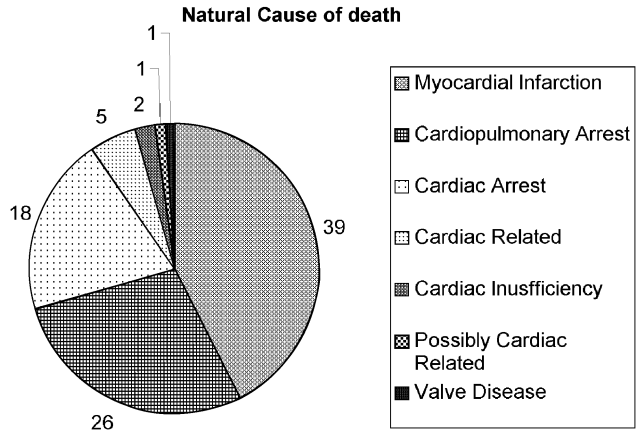


FIG. 1—*Natural manner of death group with distribution of reported preliminary cause of death. Total number of cases = 91.*

Within the natural manner of death group, 15 of the cases (14.2% of the cases in this category; 2.5% of the total cases) had a noncardiac cause of death. These 15 cases included six cases with a cerebral vascular event, three cases with a seizure disorder, three cases with primary pulmonary disease, two cases of pulmonary thromboembolus, and one case of a complication following gastric bypass surgery. The remaining 91 cases (85.8% of the cases in this group; 15.3% of the total number of remnant hearts examined) had a preliminary cause of death suspected to be cardiac related. The distribution of the preliminary cause of death is shown in Fig. 1.

In the 91 cases in which the cause of death was suspected to be cardiac related, 132 significant cardiac findings were identified. The significant cardiac abnormalities identified are listed in Table 1. The significant cardiac abnormalities included atherosclerotic coronary artery disease with $\geq 75\%$ luminal stenosis of an epicardial coronary artery with or without myocardial infarction, cardiomegaly, anomalous origin of a coronary artery, myocarditis, hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, stenotic dysplastic intramyocardial arteries, acute aortic dissection, mitral valve prolapse, aortic valve stenosis, mechanical valve replacement, and left ventricular hypertrophy.

Fifty-eight additional cardiac findings were identified in this group and are listed in Table 2. These findings included atherosclerotic coronary artery disease with $<75\%$ luminal stenosis of

TABLE 1—*Number of significant cardiac abnormalities in natural manner of death group.*

| | |
|---|---|
| ASCAD $\geq 75\%$ stenosis with infarction | 34 |
| ASCAD $\geq 75\%$ stenosis without infarction | 34 |
| Cardiomegaly | 43 |
| Anomalous origin of coronary artery | 5 |
| Myocarditis | 4 |
| Acute aortic dissection | 3 |
| Bicuspid aortic valve, with stenosis | 3 |
| Left ventricular hypertrophy | 2 |
| Hypertrophic cardiomyopathy | 1 |
| Arrhythmogenic right ventricular cardiomyopathy | 1 |
| Dysplastic intramyocardial arteries, with stenosis | 1 |
| Mitral valve prolapse | 1 |
| Mechanical valve replacement | 1 |
| Total significant cardiac abnormalities | 132 |

Total number of cases = 91 (some cases had more than one significant cardiac abnormality).

TABLE 2—*Number of additional findings in the natural manner of death group.*

| | |
|---|---|
| Myxomatous thickening of atrioventricular valves | 30 |
| Borderline cardiomegaly | 11 |
| ASCAD <75% stenosis | 8 |
| Possible myocarditis | 4 |
| Increased right ventricular fat | 3 |
| Borderline left ventricular hypertrophy | 1 |
| Myocyte disarray | 1 |
| Total additional findings | 58 |

Total number of cases = 91 (some cases had more than one additional finding and some did not have any).

an epicardial coronary artery, myxomatous change of an atrioventricular valve, borderline cardiomegaly, increased right ventricular fat deposition, possible myocarditis, borderline left ventricular hypertrophy, and myocyte disarray. Fourteen incidental findings were identified: six with a patent foramen ovale, five with lipomatous hypertrophy of the atrial septum, and three with a myocardial bridge of the left anterior descending coronary artery. Three cases had a congenitally bicuspid aortic valve (Table 3).

There were 12 structurally normal hearts in the natural manner of death group, comprising 13.2% of cases. Six cases were from the noncardiac cause of death group. Therefore, 6.6% of hearts in the suspected cardiac cause of death group had structurally normal hearts.

Forty-four of the 91 cases had only one significant finding. Thirty-eight cases had at least two major diagnoses. Atherosclerotic coronary artery disease and cardiomegaly were the diagnoses in 29 of the 38 cases. Two cases had myocarditis and cardiomegaly, and there was one case of each of the following combination of major diagnoses: atherosclerotic coronary artery disease and anomalous coronary artery, aortic valve replacement and cardiomegaly, atherosclerotic coronary artery disease and left ventricular hypertrophy, aortic dissection and cardiomegaly, arrhythmogenic right ventricular cardiomyopathy, and cardiomegaly, and mitral valve prolapse and cardiomegaly. Three of the 91 cases had three major diagnoses. There were two cases with coronary artery anomalies, atherosclerotic coronary artery disease, and cardiomegaly and one case with aortic dissection, bicuspid aortic valve, and cardiomegaly. There was one case with four major diagnoses (aortic dissection, bicuspid aortic valve, atherosclerotic coronary artery disease, and cardiomegaly).

In the remaining 487 cases, the preliminary cause of death was specified as noncardiac related. The distribution of the preliminary cause of death in these cases is listed in Table 4. Within this group, 214 significant cardiac findings were identified. The list of these findings is given in Table 5. The significant cardiac findings in this group included atherosclerotic coronary artery disease with ≥75% stenosis in at least one major epicardial coronary artery,

TABLE 3—*Incidental findings and congenital abnormalities in the natural manner of death group.*

| | |
|---|---|
| Incidental findings (total) | 14 |
| Patent foramen ovale (normal) | 6 |
| Lipomatous atrial septum | 5 |
| Myocardial bridge | 3 |
| Congenital (total) | 3 |
| Bicuspid aortic valve | 3 |

Total number of cases = 91.

TABLE 4—*Nonnatural manner of death group showing distribution of reported preliminary cause of death.*

| | |
|---|---|
| Motor vehicle accident | 165 |
| Pending | 113 |
| GSW | 59 |
| Trauma NOS | 36 |
| Head injury | 22 |
| Hanging | 20 |
| Overdose | 11 |
| Drowning | 11 |
| Asphyxiation | 9 |
| CO | 6 |
| Respiratory arrest | 5 |
| Smoke inhalation | 4 |
| Suicide NOS | 3 |
| Anoxic brain injury | 3 |
| Anoxia | 3 |
| COD not specified | 2 |
| Choking/aspiration | 2 |
| Electrocution | 2 |
| Accidental hanging | 2 |
| Traumatic asphyxiation | 1 |
| Anaphylaxis | 1 |
| Dislodged tracheotomy tube | 1 |
| Airplane crash | 1 |
| Ethylene glycol | 1 |
| Trauma | 1 |
| Jump | 1 |
| Suicide euthanasia | 1 |
| Hepatic failure | 1 |

Total number of cases = 487.

cardiomegaly, myocarditis, mitral valve prolapse, acute angle of origin of coronary artery, left ventricular hypertrophy, bicuspid aortic valve, hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, histiocytoid cardiomyopathy, rhabdomyoma, noninfective endocarditis, coarctation of aorta, coronary artery thromboembolus, and stenotic dysplastic intramyocardial arteries.

Two hundred additional findings were identified in this group and are listed in Table 6. These conditions included athero sclerotic coronary artery disease with <75% luminal stenosis, myxomatous thickening of an atrioventricular valve, borderline cardiomegaly, myocyte disarray, possible myocarditis, increased right ventricular fat, interstitial fibrosis, borderline left ventricular hypertrophy, mitral valve annular calcification, nonstenotic

TABLE 5—*Number of significant cardiac abnormalities in the nonnatural manner of death group.*

| | |
|---|---|
| ASCAD ≥75% stenosis <25 years of age | 12 |
| ASCAD ≥75% stenosis >25 years of age | 93 |
| Cardiomegaly | 57 |
| Myocarditis | 24 |
| Mitral valve prolapse | 6 |
| Acute angle origin coronary artery | 6 |
| Left ventricular hypertrophy | 4 |
| Bicuspid aortic valve | 2 |
| Hypertrophic cardiomyopathy | 2 |
| Arrhythmogenic right ventricular cardiomyopathy | 2 |
| Histiocytoid cardiomyopathy | 1 |
| Rhabdomyoma | 1 |
| Noninfective endocarditis | 1 |
| Coarctation of aorta | 1 |
| Coronary artery thromboembolus | 1 |
| Dysplastic intramyocardial arteries with stenosis | 1 |
| Total significant cardiac findings | 214 |

Total number of cases = 487.

TABLE 6—*Number of additional findings in the nonnatural manner of death group.*

| | |
|---|---|
| ASCAD <75% stenosis <25 years of age | 11 |
| ASCAD <75% stenosis >25 years of age | 24 |
| Myxomatous thickening of atrioventricular valves | 89 |
| Borderline cardiomegaly | 38 |
| Myocyte disarray | 9 |
| Possible myocarditis | 9 |
| Increased right ventricular fat | 6 |
| Increased interstitial fibrosis | 5 |
| Borderline left ventricular hypertrophy | 4 |
| Mitral valve annular calcification | 2 |
| Dysplastic intramyocardial arteries without stenosis | 2 |
| Right atrial appendage thrombosis | 1 |
| Total additional findings | 200 |

Total number of cases = 487.

dysplastic intramyocardial arteries, and right atrial appendage thrombosis. Ninety-two incidental findings were identified in this group including 55 cases with patent foramen ovale, 17 cases of myocardial bridge, 13 cases with lipomatous hypertrophy of the atrial septum, and seven cases with a Chiari network. Eighteen congenital abnormalities were found including seven atrial septal defects, five bicuspid aortic valves, three bicuspid pulmonary valves, and one each of quadracuspid pulmonary valve, spontaneously sealed ventricular septal defect, and aberrant origin of the right subclavian artery.

Traumatic injuries are identified in 26 cases within this group and all were from cases with a preliminary cause of death related to trauma: motor vehicle collision, head injury, or trauma not otherwise specified. Eight structurally normal hearts had contusions and 10 had lacerations. Three hearts with other cardiac findings had contusions and five had lacerations.

Two hunderd and twenty-two of the cases or 45.6% had a structurally normal heart; 54.4% of the cases had a cardiac abnormality. All incidental findings were considered variations of normal anatomy, and these cases were considered structurally normal hearts.

A total of 139 cases (23.4%) were within the pediatric age group (<18 years of age). There were six cases in which the preliminary cause of death was due to a natural event. These six cases included a 1-day-old infant, with the cause of death listed as cardiopulmonary arrest, a 2-month-old with cardiac arrest, a 23-month-old with a seizure disorder and hydrocephalus, a 6-year-old with cystic fibrosis, a 10-year-old with lymphoid pneumonitis, and a 16-year-old with a ruptured berry aneurysm. All six of these cases had structurally normal hearts.

The remaining pediatric cases were in the nonnatural manner of death group, and the distribution of the preliminary cause of death in pediatrics cases is illustrated in Fig. 2. There were 41 cases in which the preliminary cause of death was motor vehicle collision (MVC) ages 20 months to 17 years. There were 28 cases with a preliminary cause of death listed as pending and these cases ranged from 6 weeks to 17 years of age. There were 12 cases following trauma and eight cases due to head injury. There were 12 cases of gun shot wounds, seven drownings, five hangings, four deaths due to asphyxia and respiratory arrest, two cases each of smoke inhalation and overdose, and one case each of anaphylaxis, choking, dislodged tracheal tube, airplane crash, carbon monoxide intoxication, ethylene glycol intoxication, anoxia, and one in which the preliminary cause of death was not specified.

Twenty-two cases were from infants (<12 months in age), constituting 15.8% of cases in the pediatric group.

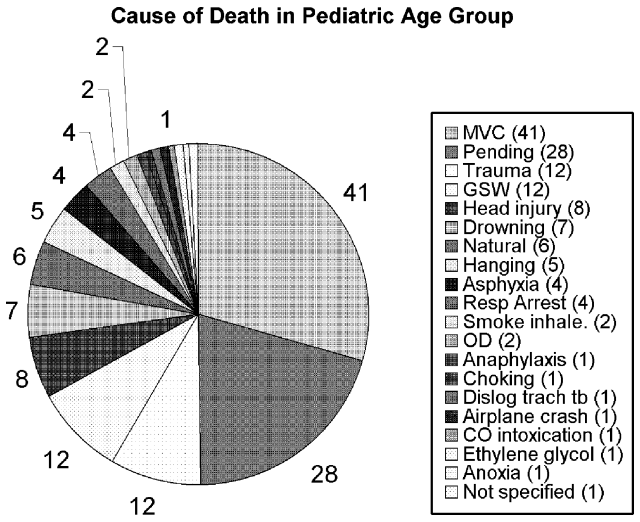


FIG. 2—*Pie chart from the pediatric age group (<18 years of age) showing distribution of reported preliminary cause of death. Total number of cases = 139.*

## Discussion

Because there is a chronic shortage of organs and tissues, it is our responsibility as health care professionals to optimize the number of tissues and organs available while continuing to address the concerns of all parties involved. The majority of the medical literature available on this subject addresses the issues of the organ and tissue agencies and those of the ME/C (4–7,9,10). There are few articles in the literature addressing ways in which to encourage heart valve tissue donation (12–14). One article discusses a procedure involving examination of the heart at the time of procurement (12). The National Association of Medical Examiners (NAME) recently released a position paper on the role of the ME/C and the release of organs/tissues for donation (14). The majority of the organ and tissue agencies provide a review of remnant hearts after valve donation. This paper reviewed the findings in remnant hearts sent to the Jesse E. Edwards Registry of Cardiovascular Disease by the ARC during the time period from October 2001 to January 2005. This affiliation was initiated by the ARC in order to increase consent for donation by the use of cardiovascular pathologists to review remnant hearts.

The chronic shortage of heart valves is of particular concern in the pediatric population in which allograft valves are the graft of choice. A previous study addressed the concerns of releasing hearts in this age group by reviewing the significant cardiac findings in the pediatric deaths and concluded that there were few conditions that would be missed by the donation procedure (13).

In the time period of the affiliation between the ARC and the Jesse E. Edwards Registry of Cardiovascular Disease, 593 cases were reviewed. The main focus of this review was to tabulate the number of cases in which donation was allowed when the suspected cause of death was cardiac related and to determine whether donation interfered with the determination of cause of death. To answer these questions, the cases were divided into two groups: natural and nonnatural manners of death based on preliminary cause of death information provided by the ARC. Of the 593 cases, 106 cases had a preliminary natural manner of death. Further division in this category identified 15 cases in which the cause of death was noncardiac related, leaving 91 suspected cardiac-related cases.

All significant cardiac abnormalities were tabulated in this group and 132 significant abnormalities were identified. The vast majority of these cases had significant atherosclerotic coronary artery disease defined as $\geq$75% luminal stenosis in at least one major epicardial coronary artery. In the cases with significant atherosclerotic coronary artery disease, 50% had no evidence of infarction and the remaining 50% had areas of acute myocardial infarction. Additional significant findings in this group included cardiomegaly, myocarditis, aortic dissection, aortic valve stenosis, valvular heart disease, and left ventricular hypertrophy. There were five cases with a diagnosis of an anomalous origin of a coronary artery. In order to make this diagnosis, the aortic valve had not been used and it was submitted with the remnant heart for examination.

Potentially inheritable conditions were identified in three cases. There was one case each of hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, and mitral valve prolapse. The importance of these diagnoses is the genetic implication for surviving family members.

Potentially inheritable conditions were also diagnosed in the nonnatural manner of death group. There were two cases of hypertrophic cardiomyopathy: one in a 32-year-old male with cause of death listed as pending, and the second in a 54-year-old male with cause of death listed as suicide. Also there were two cases of arrhythmogenic right ventricular cardiomyopathy: one in a 54-year-old female with the fibrofatty variant and cause of death listed as suicide, and the second from a 51-year-old female with cause of death listed as jumping from a height. The importance of the recognition of these cases is again the implication for family members, as both conditions are potentially inheritable and may be transmitted in an autosomal dominant fashion. Three of the potentially inheritable conditions were found in suicides. A complete autopsy with histologic examination of the heart is not always routinely performed in all suicides; therefore, these conditions may have been missed if not for valve donation and the examination of the remnant heart.

Another potentially inheritable condition is mitral valve prolapse. In the nonnatural manner of death category, there were six cases of mitral valve prolapse: two from motor vehicle collisions, two from unspecified trauma, and two suicides.

Fifty-eight additional findings were identified in the natural manner of death group including atherosclerotic coronary artery disease with $<$75% luminal stenosis, borderline cardiomegaly, borderline left ventricular hypertrophy, and possible myocarditis. The most common additional finding in this group was myxomatous thickening of the atrioventricular valves, which is a frequent age-related finding. There were three cases with a significant increase in fat deposition within the right ventricle and one case with focal areas of myocyte disarray.

Cases with focal myocyte disarray and increased right ventricular fat were also found in the nonnatural manner of death group. Nine cases with myocyte disarray were identified in this group. Myocyte disarray may be seen in several conditions including hypertension and certain congenital heart diseases. In addition, it is a normal finding in certain areas of the heart including at the juncture of trabeculae with the compact myocardium, at the curves of the ventricles, and around vessels. In these cases, the myocyte disarray was in unexpected areas of the compact myocardium. The diagnosis of hypertrophic cardiomyopathy could not be made in these cases based on the extent of the myocyte disarray within the myocardium. In these cases, the finding was specified in the diagnoses as foci of myocyte disarray.

Fat deposition is a normal finding in certain areas of the right ventricle, but increased fat deposition in the right ventricular outflow tract and posterior wall is not normal (15,16). The presence of fat deposition alone in the absence of myocyte injury is not sufficient for a diagnosis of the fatty variant of arrhythmogenic right ventricular cardiomyopathy. Six cases in the nonnatural manner of death group had increased fat deposition in the anterior wall of the right ventricular outflow tract. These six cases included a 41-year-old male with trauma, a 37-year-old female in an MVC, 53- and 35-year-old males with preliminary cause of death as pending, and two 45-year-old female suicidal hangings. Histologically, in each of the cases, there was an increase in fat deposition in the anterior wall of the right ventricle without fibrosis or myocyte injury. The absence of myocyte injury, combined with the extent of the fat deposition, excluded the diagnosis of arrhythmogenic right ventricular cardiomyopathy. As with myocyte disarray, this is an abnormal finding, and was therefore reported as an abnormality. Even though these findings are mainly descriptive and not associated with a significant condition, they were recorded in the event that their significance could be established in future research or should molecular testing become more widely available.

There were 12 structurally normal hearts in the natural manner of death group. Of the 12 cases in which no structural heart disease was identified, six of the cases had a noncardiac cause of death. Two of the remaining six cases were infants ages 2 months and 1 day. The remaining four cases were a 54-year-old with cause of death listed as cardiac related, 46- and 22-year-old females with cause of death listed as cardiopulmonary arrest, and a 29-year-old female with the cause of death listed as cardiac arrest. The aortic valve with adjacent tissues was not available for examination in any of these six cardiac-related cases. It is also worth reiterating that the information used to separate these cases into natural and nonnatural groups was provided by the ARC and in most cases was before the autopsy, and so toxicology and autopsy findings were not available. The information was preliminary only, and follow-up details were not provided.

There are potential cardiac findings that can be missed in hearts after valve donation including focal, proximal atherosclerotic coronary artery disease, anomalous origin of a coronary artery, and conduction system abnormalities. The donation process does interfere with examination of these regions; however, it is important to note that only 6.6% of cases in the suspected cardiac cause of death group did not have a cardiac abnormality, and if the two infants were excluded, only 4.4% of cases were found to be structurally normal. Unfortunately, in the United States, molecular testing for conditions such as ion channelopathies is not widely available, and they are not tested for at our facility.

Many cases had more than one significant finding. The most common combination of diagnoses was atherosclerotic coronary artery disease with cardiomegaly and valvular heart disease with cardiomegaly. It was not surprising to see more than one significant finding in many cases as some conditions are known to be associated with each other.

There have been reports suggesting that myocardial bridge can cause cardiac insufficiency, even during diastole (17). A myocardial bridge was considered an incidental finding in this review. We found 20 cases (or 3.4% of all cases) that had a myocardial bridge: three cases in the natural manner of death group and 17 in the nonnatural manner of death group. In the natural group, two cases had severe atherosclerotic coronary artery disease and in the third the death was due to subarachnoid hemorrhage. None of the 12 normal hearts found in this group had a myocardial bridge. It is possible that cardiac insufficiency may occur due to a myocardial bridge, but this was not a finding of our study.

A second focus of this review was to evaluate the percentage of valve donors in the pediatric age range (age $<18$ years). This group is in particular demand because tissue allografts are the preferred graft. Of the 593 cases, 139 (23.4% of all cases) were within the pediatric population. Twenty-two of the 139 (15.8%) were $<12$ months of age. In separating this group based on preliminary manner of death into natural and nonnatural, there were six cases with a natural cause of death, and all of these cases had a structurally normal heart.

There were 133 pediatric cases in which the case of death was not related to a natural event. Of these 133 cases, 97 of them had a structurally normal heart. Ten cases had myxomatous change of an atrioventricular valve and seven had foci of myocarditis. The diagnosis of myocarditis was made only when definite myocyte injury was present in association with an interstitial inflammatory cell infiltrate. Molecular testing for viral genome is not available at our facility and was not performed. In the seven cases of myocarditis, there was one drowning (2 years), one hanging (12 years), one nonspecified trauma (13 years), two motor vehicle collisions (15 and 17 years), and two with cause of death listed as pending (11 and 12 years). There were four hearts with cardiomegaly, four had borderline cardiomegaly, and four had possible myocarditis (no definite myocyte injury). There were three cases of anomalous origin of a coronary artery: one case with head injuries and two motor vehicle collisions. There were two pediatric cases with significant atherosclerotic coronary artery disease with >75% narrowing of a coronary artery (10 and 16 years), both in motor vehicle collisions. Two hearts had significant left ventricular hypertrophy. There were two hearts with myocyte disarray: one a 12-year-old with respiratory arrest and the second a 17-year-old in a motor vehicle collision. One heart had mitral valve prolapse (a 17-year-old involved in a motor vehicle collision). In the 22 cases $<12$ months in age, 19 had a structurally normal heart.

## Conclusions

This review has implications for tissue donation. In reviewing these cases, we did not find that the valve donation procedure severely impaired cardiopathologic examination. There are several conditions that may be affected by valve removal including isolated proximal coronary artery stenosis by atherosclerotic disease, acute angle of origin of a coronary artery, anomalous origin of a coronary artery, or conduction system abnormalities. In only six cases in which the cause of death was thought to be cardiac related was there no structural finding, and two of these cases were infants. It is also important to stress in this review study that the information provided to our facility was from the ARC. The information provided was preliminary, usually before the autopsy; therefore, toxicology and autopsy results were not available during the remnant heart examination. Molecular testing for ion channelopathies is also not available at our institution; hopefully, these tests will become more widely commercially available in the future.

In this study, 11 cases with anomalous or acute angles of origin of coronary arteries were identified. Potentially more cases with this finding could be identified by the use of photographic documentation of the aortic root during initial valve processing. The ARC did provide descriptions of the origins of the coronary arteries with each case.

The one condition that will be affected by the donation procedure is conduction system abnormalities. Cases of sudden cardiac death due solely to conduction system abnormalities are relatively uncommon (2.9% of cases of sudden cardiac death in one study) (18).

The benefits of remnant heart review by a cardiac pathologist include the recognition of potentially inheritable conditions such as hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, and mitral valve prolapse, and the identification of findings that require further research or investigation.

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