LEFT VENTRICULAR STRUCTURES IN ATRIOVENTRICULAR SEPTAL DEFECT ASSOCIATED WITH ISOMERISM OF ATRIAL APPENDAGES COMPARED WITH SIMILAR FEATURES WITH USUAL ATRIAL ARRANGEMENT

In patients with isomeric atrial appendages, regurgitation of atrioventricular valves is recognized clinically as one of the risk factors that militate against successful achievement of definitive repairs. To determine whether this reflected anatomic features, we investigated 91 specimens with atrioventricular septal defect that had a common atrioventricular valve and biventricular atrioventricular connections. Of these specimens, 35 had isomeric right appendages, 23 showed isomeric left appendages, and 33 had usual atrial arrangement. We measured either the size or location of the supporting papillary muscles and the circumference of the mural leaflet within the morphologically systemic ventricle, as well as the length of outlet, inlet, and so-called scooped dimensions of the muscular ventricular septum. Presence of a solitary papillary muscle, or deviation of the attachments of the papillary muscles, was more frequent in hearts with isomeric right appendages. Values for the diameter and lengths of the papillary muscles were significantly smaller in hearts with isomeric right appendages compared with those with usual atrial arrangement ($p < 0.001$), as were the distances between the papillary muscles ($p < 0.002$) and the circumference of the mural leaflet ($p < 0.001$). The proportional length of ventricular outlet was longer in the setting of isomeric right appendages than in the other groups ($p < 0.001$), whereas the extent of septal scooping showed no differences among these three groups. We conclude that these structural features could be factors in the known insufficiency of the common atrioventricular valve and the ventricular dysfunction in patients with isomeric right appendages. (J THORAC CARDIOVASC SURG 1995;110:445-52)

Hideki Uemura, MD,^{a, b*} Robert H. Anderson, MD,^{a, c, d**} Siew Yen Ho, PhD,^a William A. Devine, BSc,^c William H. Neches, MD,^c Audrey Smith, PhD,^d Toshikatsu Yagihara, MD,^b and Yasunaru Kawashima, MD,^b
London and Liverpool, United Kingdom, Pittsburgh, Pa., and Osaka, Japan

In the attempt to establish better strategies for surgical treatment of hearts with isomerism of the atrial appendages, prevention of regurgitation across the atrioventricular valves is one of the factors most

likely to attract attention.¹⁻³ Our clinical experience in such patients indicates that insufficiency of the common atrioventricular valve and ventricular dysfunction are obvious risk factors in both the short and long terms. These deleterious features seem more frequent in patients with isomerism of the morphologically right appendages than in those with usual atrial arrangement. Furthermore, in our clinical series, either valvular regurgitation or ventricular dysfunction has been detected not only within the morphologically pulmonary ventricle, which could make it unsuitable for supporting the systemic circulation, but also within the morphologically systemic ventricle. To determine whether these functional observations might reflect different anatomic arrangements within the left ventricle, we investigated a series of autopsied specimens, and the morphologic findings support strongly our initial clinical impressions.

Material and methods

Material. From the hearts with isomeric atrial appendages among the cardiopathologic collections at the Na-

From the National Heart and Lung Institute,^a London, United Kingdom; Children's Hospital of Pittsburgh,^c Pittsburgh, Pa.; Royal Liverpool Children's Hospital,^d Liverpool, United Kingdom; and National Cardiovascular Center,^b Suita, Osaka, Japan.

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Address for reprints: Hideki Uemura, MD, National Heart and Lung Institute, Department of Pediatrics, Dovehouse St., London SW3 6LY, United Kingdom.

*Visiting fellow at the National Heart and Lung Institute from the National Cardiovascular Center.

**Visiting professor at Children's Hospital of Pittsburgh and Royal Liverpool Children's Hospital from the National Heart and Lung Institute.

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Table I. Materials chosen by the criteria of hearts with atrioventricular septal defect, a common atrioventricular valve, and balanced ventricles*

	No. of hearts				Concordant VA connections
	Discordant VA connections	Aorta from RV with pulmonary atresia	Double- outlet RV	Tetralogy of Fallot	
Right isomerism	3	15	17		
Left isomerism			11		12
Usual atrial arrangement	1	1	5	7	19

VA, Ventriculoarterial; RV, morphologically pulmonary ventricle.

*Excluded were those with separate atrioventricular valves or those with a common valve having two or more orifices.

Table II. Splenic status and venoatrial connections

	No. of hearts		
	Right isomerism	Left isomerism	Usual atrial arrangement
Splenic status			
Absent	18	1	0
Multiple	0	15	0
Solitary	5	1	24
Not known	12	6	9
Venoatrial connections			
Normal pattern or mirror image	0	2	29
Abnormal systemic venous drainage	2	2	4
Abnormal pulmo- nary and systemic venous drainages	23	19	0
Abnormal pulmo- nary venous drain- age	10	0	0

tional Heart and Lung Institute in London, at Children's Hospital of Pittsburgh, at the National Cardiovascular Center in Osaka, and at the Royal Liverpool Children's Hospital, we selected all those specimens with Ambiguous and biventricular atrioventricular connections guarded by a common atrioventricular valve with, at the same time, balanced ventricular structure. Out of 125 specimens with isomeric right appendages and 58 with isomeric left appendages in these combined series, 35 specimens with right and 23 with left isomerism matched these criteria; those unsuitable for precise measurements were excluded. Isomerism of the atrial appendages was determined according to the extent of the pectinate muscles around the atrioventricular junctions. Among the group of hearts with isomeric right appendages, discordant ventriculoarterial connections were seen in 3, single-outlet right ventricle with pulmonary atresia in 15, and double-outlet right ventricle in 17. As for left isomerism, double-outlet connections from the right ventricle were found in 11 hearts and concordant ventriculoarterial connections in the remaining 12 (Table I).

As a control group, we selected all hearts with usual atrial arrangement, concordant atrioventricular connec-

tions, atrioventricular septal defect with common atrioventricular valve, and abnormal ventriculoarterial connections, the number of such hearts being 14, and randomly selected 19 specimens with exactly comparable morphologic features but with concordant ventriculoarterial connections (Table I). We excluded, therefore, all hearts with a dominant right or left ventricle, those with separate right and left atrioventricular valves ("ostium primum" defects), and those with dual or multiple orifices in a common valve.

Venoatrial connections were frequently abnormal in the setting of isomeric atrial appendages. Splenic status could be determined from autopsy records in 64 cases (Table II).

Methods. Anatomic measurements were made of the ventricular lengths between the apex and the crux of the heart, between the apex and the aortic valvular attachment, and between the apex and the depth of the so-called scooped septum.⁴ Then, the number of the major papillary muscles, as well as their location, were examined within the morphologically systemic ventricle and measurements were made of the distance between the two major papillary muscles, if dual in the left ventricle, together with the diameter or length of these papillary muscles (Fig. 1). In this investigation, we defined the major papillary muscles as those tethering the marginal tendinous cords of the leaflets. If the cross-sectional shape of the papillary muscle was oval, we used a calculated diameter of a circle with the corresponding cross-sectional area to that of an ellipse. Other additional small muscles that had no relation to the marginal cords were not measured. The circumferential angle of the mural leaflet on its morphologically left ventricular side was calculated according to the method used by Penkoske and colleagues⁴ (Fig. 1).

For standardization, all parameters except the circumference of the mural leaflet were divided by the value of the ventricular inlet dimension measured from the crux to the apex. Although in previous investigations it was the length of the ventricular outlet that was used for standardization,⁴⁻⁶ we used the inlet instead of the outlet length for our study, because the tension apparatus is mainly an inlet component of ventricular structures. These standardized values and the calculated circumferences were compared among three groups, namely the groups of hearts with right or left isomerism and those with usual atrial arrangement. The χ^2 and *t* tests combined with a test for variance (F test) were used for statistical analyses.

Fig. 1. Morphologic measurements were done on the papillary muscles within the morphologically left ventricle and the morphologically left component of the common atrioventricular valve and for ventricular lengths. Length of the ventricular inlet was used for standardization of all measured values except for the circumferential angle of the mural leaflet, which was calculated from the formula shown. SB, Superior bridging; IB, inferior bridging; M, mural.

Results

Among all 91 specimens, a solitary papillary muscle within the morphologically left ventricle was seen in nine hearts with right isomerism, in three with left isomerism, and in one with usual atrial arrangement, with the prevalence being significantly higher in the group of hearts with right isomerism (χ^2 test, $p < 0.01$). The solitary structure was suspected to be a result of fusion of dual papillary muscles located adjacent to one another in two hearts with right isomerism. In the other 11 specimens, either the anterior or posterior papillary muscle was deemed to be lacking (Fig. 2). In this setting, some of the marginal cords for the morphologically left component of the atrioventricular valve, instead of being connected to the solitary papillary muscle, were directly attached to the ventricular septal crest or to the ventricular wall. Among 78 hearts with paired major papillary muscles, the ventricular mural origins were deviated anteriorly in 9 and posteriorly in 3 (Fig. 2). Such deviations were more frequent, with statistical significance (χ^2 test, $p < 0.05$), in the group of hearts with right isomerism as compared with the fre-

quency in the other two groups. The distance between the two papillary muscles was significantly smaller in hearts with right isomerism than in either those with left isomerism or those with usual atrial arrangement (Fig. 3, A).

The circumference of the mural leaflet in the morphologically left ventricle was smaller in hearts with either right or left isomerism than in those with usual atrial arrangement (Fig. 3, A). The values for circumference were correlated significantly to the distance between the two papillary muscles (Fig. 3, B), with a correlation coefficient of 0.73.

The diameter of the papillary muscles, standardized by the ventricular inlet length, was smaller in hearts with either right or left isomerism than in those with usual atrial arrangement ($p < 0.001$ and $p < 0.05$, respectively). The proportional length of the papillary muscles was significantly shorter in those with right isomerism than in those with either left isomerism or usual atrial arrangement (Fig. 4, A). These ratios of papillary muscular diameter and length to the ventricular inlet length showed no correlation with either the size of the ventricle or with age at death. In addition, no significant influ-

Fig. 2. Prevalence of hearts with a solitary papillary muscle (PM) was significantly higher in the setting of right isomerism ($p < 0.01$ by χ^2 test). When a heart had paired papillary muscles, anterior or posterior deviations of the structures were also more frequent in hearts with right isomerism ($p < 0.05$, χ^2 test).

ences on these values were detected in terms of patterns of venoatrial connections of which there was a great diversity. The plots of diameter versus length for each papillary muscle demonstrate that, in the group of hearts with isomerism of atrial appendages, 21 dots (20%) of the total of 104 fell outside the range of 95% confidence for the papillary muscles in hearts with usual atrial arrangement (Fig. 4, B). This indicates that some papillary muscles possess disproportional diameter-to-length ratios in hearts with isomeric atrial appendages compared with those found in the setting of usual atrial arrangement.

The ventricular outlet dimension was proportionally longer in hearts with right isomerism than in either those with left isomerism or usual atrial arrangement, but no significant differences were detected in the degree of scooping of the ventricular septum among the three groups (Fig. 5).

Discussion

Papillary muscular dysfunction is known to be one of the major causes of mitral insufficiency.⁷ It has also been established that the tension apparatus of the mitral valve has a crucial influence on left ventricular contractility^{8,9} and that, if this apparatus is preserved, there is the potential for better ventricular function after a valvular operation.^{10,11} The quest for better understanding of these functional roles has promoted detailed morphologic investigations of all components of the left atrioventricular valve in the normal heart.¹² In contrast, detailed

descriptions of the valvular tension apparatus in complicated cardiac malformations are few, although the functional implications are undoubtedly of equal significance.

In hearts with atrioventricular septal defect with usual atrial arrangement, it is the rule to find an abnormal orientation of the papillary muscles in comparison with that of the normal heart.⁴ The orientation in the malformed hearts is nearly parallel to the plane of the muscular ventricular septum, which almost certainly reflects the size and the shape of the mural leaflet (Fig. 6). As has been described, a solitary papillary muscle is occasionally found as one of the abnormalities within this characteristic cardiac malformation.^{5,13} The seminal article by Rastelli, Kirklin, and Titus¹⁴ also emphasized the variability in valvular structure in this lesion, but concentrated on the morphologically right side.

Although regurgitation of the atrioventricular valve is recognized clinically as one of the major risk factors for poor surgical outcome in patients with isomeric atrial appendages (visceral heterotaxy),^{1,2} so far as we know no detailed morphologic investigations have been performed on the valves and their tension apparatus in this setting. This might, in part, be due to the marked diversity of ventricular morphologic features and atrioventricular connections in such hearts. The atrioventricular connections are biventricular and ambiguous in some hearts, but univentricular in others, and the latter subset consists of a double inlet and absence of the right-sided

Fig. 3. A, Distance between two major papillary muscles (PMs) and circumference of the morphologically left mural leaflet. Areas demonstrated by *shadow* indicate the range within mean ± 1 standard deviation for the control group of hearts with usual atrial arrangement. VA, Ventriculoarterial; RV, right ventricle; PA atresia, pulmonary atresia. B, Correlation between papillary muscular distance and circumference of the mural leaflet. The distance of zero was substituted for hearts with a solitary papillary muscle and circumference of zero indicates that the mural leaflet is lacking.

or left-sided connections. We selected just one of these subgroups as our focus so as to simplify anatomic measurements. The results of this study, therefore, are unlikely to be characteristic for the entire group of hearts unified by the presence of isomeric atrial appendages. Furthermore, our control group is composed not of normally structured hearts, but of unequivocally abnormal hearts with a

common atrioventricular valve. It should be remembered, therefore, that this group of control hearts intrinsically possesses either longer outlet lengths or a higher prevalence of a solitary papillary muscle within the morphologically left ventricle than do normal hearts.⁴⁻⁶ If we compared hearts with isomerism of atrial appendages with the normal heart, therefore, our demonstrated differences in anatomic

Fig. 4. A, Diameter and length of papillary muscles (PM). Shadowed ranges correspond to those shown in Fig. 3. A. B, Correlation between diameter and length of each papillary muscle (PM). Shadowed areas indicate the range of 95% confidence interval around the regression line for papillary muscles in the setting of usual atrial arrangement.

features would be even more prominent. It seems more reasonable, nonetheless, to compare hearts having isomeric atrial arrangement with those possessing similar intracardiac malformations in the setting of usual atrial arrangement.

Our anatomic results are obviously supportive of our clinical impression. We found the papillary muscles to be hypoplastic, disproportional, or even absent, as well as malpositioned, in a higher proportion of hearts with right isomerism than was found in those with usual atrial arrangement. The corre-

spondingly smaller sizes of the morphologically left mural leaflets in the setting of right isomerism probably reflect this markedly abnormal orientation of papillary muscular attachments. Although similar tendencies were observed in the setting of left isomerism, the differences were not as prominent as those detected between hearts with right isomerism and those with usual atrial arrangement.

On account of either the small circumference of the mural leaflet, or because of the anomalous nature of the tension apparatus supporting the left

Fig. 5. Proportional length of ventricular outlet and scooped ventricular septum versus ventricular inlet length. *Shaded ranges* correspond to those in Fig. 3, *A*. Note that abnormal ventriculoarterial connections are not the factor producing statistically significant differences in ventricular outlet length among three groups. *VA*, Ventriculoarterial; *RV*, right ventricle; *PA atresia*, pulmonary atresia.

component of the common atrioventricular valve, it may well be that most hearts with right isomerism, and some of those with left isomerism, are unsuitable for anatomic biventricular surgical repair. Even when such definitive procedures could be accomplished, progressive atrioventricular insufficiency, if once instituted, would be difficult to treat by preserving the native atrioventricular valve in continuity with its own tension apparatus. In other words, optimal timing for replacement of the regurgitant valve could be of major importance in avoiding irreversibly impaired function of the morphologically left ventricle. In light of the contribution of the papillary muscles to ventricular contractility, the surgical option in which the stumps of incised papillary muscles are sutured to the base of the heart at the time of atrioventricular valvular replacement¹⁰ would be the procedure of choice for valvular replacement. This must, of course, be weighed against the additional technique that produces undesirable limitations in either the sizes of available prosthetic valves or their postoperative function. When anatomic biventricular repair without a prosthesis is planned, augmentation of the leaflets, by methods such as proposed by Kawashima and colleagues,¹⁵ might prove helpful. Not only the mural leaflet, however, but also the superior or inferior bridging leaflets may have a markedly smaller size in

Fig. 6. Attachments of the major papillary muscles in the left ventricle are abnormal in hearts with atrioventricular septal defect guarded with a common valve, even in the setting of usual atrial arrangement, and the orientation is nearly parallel to the ventricular septum and markedly different from that in the normal heart.

consequence of the deviation of papillary muscles or the presence of a solitary papillary muscle. In such circumstances with imbalance in the size of the bridging leaflets, use of additional techniques may be necessary to minimize postoperative valvular regurgitation¹⁶ and, at the same time, to avoid orificial stenosis.

The proportionally longer outlet from the morphologically left ventricle to the aortic valve in hearts with right isomerism can also be potentially hazardous when one seeks to achieve anatomic biventricular repair. The newly constructed pathway for the left ventricular outflow tract is potentially obstructive. Because the presence of obstruction within the ventricular outflow tract and inlet valvular regurgitation are recognized harbingers of reduced systemic ventricular ejection, careful follow-up is needed after definitive anatomic repair. We predict that such deleterious sequelae could probably remain even after operations for bypass of the right side of the heart.

With these considerations in mind, preoperative and postoperative echocardiography could prove crucial in the establishment of optimal surgical strategies. The measurements achieved in our series of specimens should readily be obtained during life.^{16,17} On the basis of our morphologic findings, we predict that such echocardiographic studies will clarify the significance of the structural abnormalities noted within the morphologically left ventricle. Although statistical tendencies for given morphologic features were demonstrated among our three groups of hearts, the relatively extended ranges of the plotted data show that a variety of minor differences exist within each group. Our recommendation, therefore, is to recognize the characteristic features of each group and to estimate them quantitatively for each individual patient seen in the clinical setting.

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