Echocardiographic evaluation of atrial function after Senning and Mustard correction for transposition of the great arteries

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ABSTRACT Two groups of six children who had undergone either Senning or Mustard repair for uncomplicated transposition of the great arteries were studied with M mode echocardiography derived from a phased array sector scanner picture. The newly created atria were visualised from the subxiphoid region and the upper systemic venous inflow was selected for a simultaneous M mode registration with a subsequent wall motion analysis with a commercially available computer. In the Mustard group of patients the atrial walls seemed to move passively with the overall heart movements, while abrupt atrial wall excursions of both atria synchronous with heart action were noted in all patients after Senning repair. In this group also slow cyclic changes followed respiration. The atrial wall movements were significantly superior (p = 0.001) in the Senning group of patients. It is concluded that, in contrast to the Mustard method, the Senning operation seems to lead to a viable atrium with the capability of increasing and diminishing atrial diameter and with subsequent potential for growth.

In 1959 Albert’s experimental method for surgically correcting transposition of the great arteries was introduced into clinical practice by Senning. Generally, however, most centres preferred the repair introduced by Mustard and his colleagues in 1964, with diversion of atrial inflow by a pericardial or prosthetic baffle. Long term follow up after the Mustard procedure suggested a restriction of atrial development and function in growing patients resulting from the use of foreign material. These observations prompted renewed interest in the Senning operation with its theoretical advantages of potential atrial growth and contraction. Recently therefore several centres, including ours, have changed to the Senning operation or to modifications of Senning’s original procedure in the surgical management of transposition of the great arteries. Although discussed in published reports the theoretical advantages of potential atrial growth and normalisation of atrial contraction after Senning’s procedure have not been adequately documented.

The purpose of the present study was to compare atrial function after Senning and Mustard repairs by a combination of one dimensional and two dimensional echocardiography.

Patients and methods

Two groups, each consisting of six unselected patients treated by either the Mustard or the Senning method, were studied. The Mustard operations were carried out up to 1978, while five of the Senning patients were operated on in 1979. The mean age of the patients at the time of the study was in the Mustard group 8 years 4 months (range 2 years 10 months to 18 years 1 month) and in the Senning group 1 year 6 months (range 10 months to 2 years 4 months). The patients were followed up after an average interval of 67 months (range 21–138 months) in the Mustard group and of 12 months (range 7–18 months) in the Senning group. Of the 12 patients, eight were boys and they were equally distributed between the two groups. All patients were clinically well at the time of the study. One patient in the Senning group had a mild superior venous obstruction of diminishing clinical importance. All patients were in sinus rhythm, but the P

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Atrial function after correction for transposition of the great arteries

Echocardiographic findings in 12 paediatric patients who had either the Mustard or the Senning operation to correct simple transposition of the great arteries

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Operation</th>
<th>Time of study</th>
<th>Systemic venous atrium</th>
<th>Pulmonary venous atrium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
<td>Age (m)</td>
<td>Body surface area (m²)</td>
<td>Maximal diameter (mm)</td>
</tr>
<tr>
<td>MUSTARD OPERATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1974</td>
<td>21</td>
<td>98</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>1969</td>
<td>79</td>
<td>217</td>
<td>1.61</td>
</tr>
<tr>
<td>3</td>
<td>1977</td>
<td>11</td>
<td>47</td>
<td>0.62</td>
</tr>
<tr>
<td>4</td>
<td>1978</td>
<td>3 + 63</td>
<td>84</td>
<td>1.06</td>
</tr>
<tr>
<td>5</td>
<td>1972</td>
<td>18</td>
<td>120</td>
<td>0.99</td>
</tr>
<tr>
<td>6</td>
<td>1978</td>
<td>7</td>
<td>34</td>
<td>0.62</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>33</td>
<td>100</td>
<td>0.98</td>
</tr>
<tr>
<td>SD</td>
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<td>30</td>
<td>66</td>
<td>0.36</td>
</tr>
<tr>
<td>SENNING OPERATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1979</td>
<td>1</td>
<td>13</td>
<td>0.46</td>
</tr>
<tr>
<td>2</td>
<td>1980</td>
<td>3</td>
<td>10</td>
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<tr>
<td>6</td>
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<td>21</td>
<td>0.52</td>
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<tr>
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<td>0.51</td>
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<tr>
<td>SD</td>
<td></td>
<td>5</td>
<td>7</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\[ p = 0.02 \quad 0.001 \quad 0.001 \quad 0.066 \quad 0.001 \quad 0.001 \quad 0.001 \quad 0.001 \quad 0.090 \]

waves in the Mustard group were generally more flattened.

**Operative procedures**

In the Mustard group the first patient received a pericardial baffle, whereas a prosthetic baffle was used in the remaining patients. The surgical approach was changed in our institution in November 1978, when the Senning procedure was introduced and performed according to the modification described by Quagebeur et al. In the patients having the Senning operation no foreign material was used for atrial reconstruction as the septal defect after balloon septostomy could be sutured directly.

Age at operation was significantly lower in the Senning group (p = 0.02), with only one patient operated on after the first year of life (table). In the Mustard group only two patients were operated on in infancy, while the third patient undergoing primary repair during infancy was studied after reoperation, which became necessary at the age of 5 years 3 months (patient 4).

**Methods of restudy**

The patients were studied from the epigastrium with M mode (TM) and two dimensional echocardiography using an interphased combination of Roche RT-400 phased array 80° sector scanner with line selection for TM on an Irex system II machine. This combination offers a pulse repetition rate of 750/s. The subxiphoidal approach was used to visualise the atrial part of the heart, the transducer being directed superiorly and slightly to the left. The direction of the transducer and the gain settings were adjusted until a picture of satisfactory quality appeared on the screen. The superior inflow of the systemic venous atrium was selected for visualisation, since it was placed more transversely to the ultrasonic beam and therefore was more likely to give registrations free from artefacts due to oblique beam penetration than was the inferior inflow. The superior inflow could be seen draining the systemic venous isthmus to the mitral valve and dividing the pulmonary venous atrium into a frontal and a dorsal segment. Anteriorly tricuspid valve fragments were observed (fig 1). An M mode line was selected and positioned through the walls of the upper limb of the systemic venous atrium just before it opened into the wider part of the atrium facing the mitral valve. Tricuspid valve fragments were touched anteriorly, and the posterior part of the pulmonary venous atrium was seen behind the borders of the upper systemic venous atrium limb. The TM echoes were recorded with a paper speed of 50 mm/s on black and white paper. In the anteroposterior direction the recordings (figs 2 and 3) showed fragments of the tricuspid valve, the anterior and posterior wall of the systemic venous atrium, and the posterior wall of the pulmonary venous atrium. The M mode recordings were analysed with a Kontron Cardio 80 computer system. Three or four cycles of typical curves were redrawn with a cursor. The changing distance between the anterior and posterior borders of the systemic...
Fig 1  Two dimensional echocardiographic presentation of the atrial part of the heart after the Mustard operation for transposition of the great arteries. The transducer was positioned in the subxiphoid region and directed superiorly and slightly to the left. The line selected for M mode registration was placed through the mouth of the superior venous inflow in both the Mustard and the Senning groups. The M mode registrations were recorded from the running two dimensional picture. Thus the position of the single beam could be observed to be steady. IVS—interventricular septum; LV—left ventricle; MV—mitral valve; PVA—pulmonary venous atrium; RV—right ventricle; SVA—systemic venous atrium; TV—tricuspid valve; UL—upper limb; VCS—superior caval vein.

Fig 2  Selected M mode registration from a patient after the Mustard operation for transposition of the great arteries. The aorta like band represents the margins of the upper limb of the systemic venous atrium. Abbreviations as in figure 1.

Fig 3  Selected M mode registration from a patient after the Senning operation. Cyclic changes in the distance between the two borders of the systemic venous atrium can be seen. AW—anterior wall; PW—posterior wall; other abbreviations as in figure 1.
Fig 4  Diagram of the systemic venous atrium after the Mustard operation, derived from the recording shown in figure 2. The upper line shows the instantaneous diameter measured, ranging from 12 to 14 mm; the lower line reflects the rate of change of atrial diameter. The rates are low but seem to be related to the heart cycle, the maximum value being found after the first third and the minimum after two thirds of the heart cycle. Vertical lines have been placed at the beginning of the Q waves of the electrocardiogram. The horizontal axis represents seconds.

Fig 5  Diagram analogous to figure 4, derived from the recording of the patient who had a Senning operation shown in figure 3. The diameter of the systemic venous atrium shows two peaks and two descents per cycle. The curve resembles an atrial pressure recording with its v and a waves and the corresponding troughs between them. The maximal rate of change seems to correspond to the P wave before atrial contraction and the minimal value coincides with the time of rapid ventricular filling. Note that the scale for rate of diameter change is different from that in figure 4.

venous atrium was printed out, as was the instantaneous rate of diameter change (figs 4 and 5). Measurements of the posterior part of the pulmonary venous atrium were performed in the same manner (figs 6 and 7).

STATISTICAL ANALYSIS
Statistical analyses were carried out with the Wilcoxon two sample test and differences were considered significant when \( p = 0.001 \).

Results

The optical impression from the curves indicated that in the group of patients who had the Mustard operation the systemic venous atrium walls moved only passively with the overall movements of the heart—that is, anteriorly during systole and posteriorly during diastole (fig 2). The anterior and posterior walls of the systemic venous atrium did not move relative to each other (fig 4), suggesting no change in atrial wall distance, and therefore no change in atrial volume. In the patients who had the Senning procedure, however, the systemic venous atrium walls displayed rapid excursions synchronous with the frequency of the heart (fig 3), and slower cyclic changes synchronous with respiration (fig 8). Moreover, the distance between the two walls showed appreciable variations, and in the typical case illustrated in figure 5 the instantaneous diameter curve showed a striking similarity to the normal atrial pressure curve with its two peaks at end systole and at the time of the P wave. All six patients in the Senning group had these two peaks, though in the patient with appreciable respiratory changes shown in figure 5 this "wave" was very small. In all cases the shortening fraction of the systemic...
Fig 8  M mode echocardiogram of another patient after Senning repair of transposition of the great arteries, showing considerable changes with respiration, particularly of the diameter of the systemic venous atrium. Cyclic changes corresponding to respiration changes were observed in addition to the movements that were synchronous with heart action.

Fig 9  Systemic venous atrial diameter shortening fraction in the Mustard and Senning groups of patients. There is no overlap between the two groups.

Fig 10  Systemic venous atrial maximal and minimal diameter related to body surface area of the patients. The three least distended atria belong to patients in the Mustard group; five of the atria in the Senning group were bigger than five of those in the Mustard group. The minimum values do not differ significantly.

The first derivative of the instantaneous change of diameter, dD/dt, of the systemic venous atrium was significantly higher in the Senning than in the Mustard group (fig 9). The maximal and minimal diameter of the upper systemic inflow was significantly wider in the atria of the Mustard than of the Senning group (table). If we correct for the body surface area of the patients, however, there was no difference, although the three least distended atria were all in patients who had had the Mustard operation (fig 10). The actual measurements confirmed the impression of a significant difference in atrial action between the two groups of patients, as depicted in the table.
Discussion

By combining two dimensional echocardiography with simultaneous M mode line selection from the running two dimensional picture, it became possible to obtain M mode recordings from previously impractical angles. Whereas previously the TM echo was limited to a few beam directions from the precordial area, recordings could be made in the present study through other echo windows at well defined positions. Although the two dimensional picture would have allowed a broader visualisation of the venous inflow, the M mode recording with its higher time resolution was superior to the two dimensional technique in evaluating motion patterns. The combination of the two echocardiographic methods widened the application of M mode recordings, optimising distance measurements and information from moving echoes.

Baffle movements of patients undergoing Mustard repair for transposition of the great arteries have previously been studied with M mode recordings from the precordium.9-11 The baffle was generally seen behind the pulmonary artery, but was interrogated much closer to the mitral valve than in the present study. The movements resembled that of a stenotic atioventricular valve12—that is, baffle movements were originating from structures to which it had been sutured, mainly the region adjacent to the mitral valve ring, suggesting that the baffle has little intrinsic movement because of changes in atrial volume.13 A typical a wave motion pattern of the baffle, suggesting genuine baffle movements, was observed only in cases of baffle detachment.12 Similar observations were made by us with precordial M mode echo before this study. By combining two dimensional and simultaneous TM echo from the subxiphoid approach we could not only observe the atrial walls with their relative movements but also pick up one M mode line from a well defined position, and secure steady positioning throughout the recording. The TM recordings were used to study the distances between the atrial walls and their motion patterns. The superior systemic venous inflow, just before it opened into the portion of the systemic venous atrium superior to the mitral valve, was selected for the measurements because this position could be picked out equally after both types of procedure. The distance between the two atrial borders is considered to represent the true size of the venous inflow diameter. In the present study, the change in size of the upper inflow diameter of the Mustard group was about 15–25% of the maximal diameter. This minor change might even have been caused partly by the cyclic overall heart movements and by the M mode beam penetrating slightly different diameters of the venous inflow during one cardiac cycle. In any case, the registered change was considered to represent the maximum of possible movements. The diameter shortening fraction in the Senning group, however, was superior in all cases, varying from 29% to 64% (p = 0.001).

All Mustard operations were carried out before the first Senning operation. There is therefore a considerable difference between the two groups of patients both in age and in the time that has elapsed since operation. The longest observation time in the Senning group was 18 months whereas the shortest observation time in the Mustard group was 27 months. This particular patient, however, is not different from the other patients who had Mustard operations. Furthermore, the largest systemic venous atrium shortening fraction was found in the oldest patient with the longest interval since surgery. Evidently therefore in the Mustard group time has no influence on the measurements. Although the shortening fractions were more scattered in the Senning group there was no change related to the time that had elapsed since operation. Consequently, although the groups are different in age and interval since operation there is no evidence to suggest that these differences have influenced the observed values.

In 1977 Silverman et al14 reported that baffle movements after Mustard repair could be seen by two dimensional echo. Recently Wyse et al15 showed differences between the blood flow patterns of the superior vena cava after Senning and Mustard operations by means of Doppler blood flow velocity measurements. They noted that forward superior caval vein inflow was absent or diminished during systole in all patients after Mustard repair, indicating that in patients who had had the Mustard operation the atrium had lost its distensibility and that no blood entered it so long as the mitral valve was closed. Patients who had had the Senning operation were seen to have a greater peak velocity of blood entering the atrium and superior atrial filling. Our results confirm the conclusions by a different method of study—that is, the diameter of the systemic venous atrium increases considerably during systole, giving room for blood to enter the atrium and allowing better filling of the ventricle during diastole. Thus our measurements also indicate that the function of the venous atrium is better after the Senning repair for transposition of the great arteries.

Additionally, in our study similar changes could be demonstrated for the posterior part of the pulmonary venous atrium, where the same differences were noted as for the systemic venous atrium, though to a lesser degree. The pulmonary venous atrium after Senning's operation was significantly
smaller than after the Mustard procedure. The difference in shortening fraction was not significant, although the four highest fractions were all in patients who had had Senning operations.

It has been suggested that the main merit of the Senning over the Mustard procedure is the potential for atrial growth and normalisation of atrial function, due to avoidance of atrial septalisation by foreign material. The present study supports these assumptions by showing that the newly created atrial walls after Senning repair were moving more vigorously with heart action. In particular, the wall dividing the systemic and pulmonary venous atri showed cyclic movements synchronous with the heart beat that were much greater after Senning repair than after the Mustard procedure. The interior atrial wall after Mustard repair seemed to follow the overall movements of the heart, whereas the walls after Senning repair showed vigorous movements anteriorly and posteriorly within the heart itself. These movements suggest sequential atrial filling and emptying. Coinciding with the time of rapid early diastolic filling of the left ventricle, there was a rapid reduction in diameter of the systemic venous atrium, after a gradual increase of diameter throughout systole. A second reduction of diameter took place after the P wave of the electrocardiogram, where atrial contraction would be expected to have taken place. No movements like these were recorded after Mustard repair.

Our findings indicate that the modified Senning operation with diversion of atrial inflow through living atrial flaps provided a degree of variability of atrial diameter that was far superior to the findings after Mustard correction. Although the observation time after Senning repair has been shorter than in the other group, later follow up of these patients does not suggest that the difference between the Senning and the Mustard group might be a time related phenomenon. It does seem reasonable to assume that continued normalisation of atrial function will persist with the growth of the patients because of the avoidance of foreign material in atrial reconstruction.

References

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