The modified Senning procedure continues to be indicated for complex cases of transposition of the great arteries (TGA) that are not suitable to the anatomical correction (arterial switch operation). Some modifications of the Senning procedure were proposed to augment both the atrial septal flab and/or pulmonary veins. In our study, autologous pericardium treated by saline and heparin was used to augment the right atrium (pulmonary venous) pathway. The aim was to avoid pulmonary venous pathway stenosis (PVPS) complications.

Patients and methods: 74 patients who underwent a modified Senning procedure in Geneva University Hospital between 1989 and 2013 were analyzed retrospectively as well as prospectively during the time of the study. The follow up period extended up to 24 years, and any patient with follow up period less than 1 year was excluded.

Results: 67 patients (90%) were discharged with sinus rhythm, and in the latest follow up, 34 patients (45%) maintained their sinus rhythm. 26 patients (35%) experienced at least a single episode of arrhythmia in the early post-operative period. This episode was either nodal rhythm (n = 10), complete AV block (n = 8), supraventricular tachycardia (SVT) (n = 6) and bradycardia (n = 2). Permanent pacemaker (PM) implanted in 7 patients (9.5%) before discharge. During the follow-up period, 22 patients (29.7%), presented with SVT (all referred for ablation), 1 presented with nodal rhythm and 1 presented in AV block (both had a PM implantation). These two cases raised the total of patients who had PM implantation at the latest follow-up to 9 patients (12%). We had 3 patients (4.1%) who had experienced pulmonary venous pathway stenosis (PVPS). One patient had early presentation on the 3rd day post-operatively requiring surgical revision and patch augmentation. 2 patients had the presentation during the follow-up period, 3 and 5 years respectively after surgery. Both had reoperation with smooth post-operative course. We assessed the survival of patients along the follow-up period, using Kaplan Mayer showing 86.1% survival at 24 years. At the latest follow-up, 9 patients out of 74 patients included in our study (12.2%) died during the follow-up period; 6 patients due to heart failure, 2 patients due to fatal arrhythmias, and one post tricuspid valve implantation.

Conclusion: The modified Senning procedure using autologous pericardial patch augmentation, showed less incidence of late PVPS, and higher incidence of restoration of sinus rhythm at the time of discharge in comparison to the published results of the standard technique in the literature. It had a low mortality and comparatively better survival.
1. Introduction

The Senning procedure continues to be indicated for complex cases of transposition of the great arteries (TGA) who are not suitable to the anatomical correction (arterial switch operation) [1].

Some modifications of the Senning procedure were proposed to augment both the atrial septal flab [2] and/or pulmonary veins' pathway [3].

In our study, the autologous pericardium treated by saline and heparin was used to augment the right atrium (pulmonary venous) pathway. The aim was to avoid PVPS complications which is not uncommon with Senning procedure and can occur up to 15% according to the literature [4]. PVPS may cause a decrease in left ventricular filling volume and may contribute to low cardiac output and even sudden death in the presence of ventricular tachycardia [5].

2. Patients and methods

2.1. Study population

Approval of the study was granted by the institutional Ethics Committee. 74 patients who underwent a modified Senning procedure in Geneva University Hospital between 1989 and 2013 were analyzed retrospectively as well as prospectively during the time of the study.

Demographic and preoperative data are summarized in Tables 1 and 2.

2.2. Surgical technique

The Senning procedures were performed by two cardiac surgeons. Standard techniques of cannulation and cardiopulmonary bypass were used. All cases underwent surgery in moderate hypothermia (28 °C–32 °C) with cold crystalloid cardioplegia. The atrial switch followed the principles of Senning's original technique (Fig. 1) except harvesting a patch of autologous pericardium, preparing it with saline and heparin and suturing it to the pulmonary venous atrial wall to augment it (Fig. 2).

Table 1
The demographic data of the studied group.

<table>
<thead>
<tr>
<th>Study group (n = 74)</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>56</td>
<td>75.7</td>
</tr>
<tr>
<td>Female</td>
<td>18</td>
<td>24.3</td>
</tr>
<tr>
<td>Age (in month)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. – Max.</td>
<td>1.25–132.0</td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>18.65 ± 25.14</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Weight (in kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. – Max.</td>
<td>3.40–32.0</td>
<td></td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>7.65 ± 4.49</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>6.50</td>
<td></td>
</tr>
</tbody>
</table>
2.3. Data collection and follow-up

All data were retrieved from medical records. Patients were seen once a year for follow-up visits in Geneva University Hospital or in their original hospitals. All patients were assessed by transthoracic echocardiography (TTE) and 12-lead resting electrocardiography (ECG). To detect asymptomatic arrhythmia, cardiac rhythm was systematically evaluated by 24-h ambulatory ECG.

Patients in the permanent sinus rhythm group included those in sinus rhythm without bradycardia and with a good chronotropic response. Patients in intermittent junctional rhythm with a good chronotropic response were excluded from the permanent sinus rhythm group, as were patients in permanent junctional rhythm with or without bradycardia.

Table 2
The distribution of the studied group according to the diagnosis.

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGA + BAS</td>
<td>15</td>
<td>20.3</td>
</tr>
<tr>
<td>TGA + ASD</td>
<td>14</td>
<td>18.9</td>
</tr>
<tr>
<td>TGA + VSD</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>TGA + PS</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>TGA + PFO</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>TGA + PDA + VSD</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>TGA + ASD + PS</td>
<td>10</td>
<td>13.5</td>
</tr>
<tr>
<td>TGA + PDA + PS</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>TGA + ASD + PDA</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>TGA + PDA + BAS</td>
<td>7</td>
<td>9.5</td>
</tr>
<tr>
<td>TGA + VSD + PS + BAS</td>
<td>9</td>
<td>12.2</td>
</tr>
<tr>
<td>TGA + VSD + BAS</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>TGA + CoA</td>
<td>3</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Fig. 1. Creation of atrial septal flab like the standard technique of Senning procedure.

2.3. Data collection and follow-up

All data were retrieved from medical records. Patients were seen once a year for follow-up visits in Geneva University Hospital or in their original hospitals. All patients were assessed by transthoracic echocardiography (TTE) and 12-lead resting electrocardiography (ECG). To detect asymptomatic arrhythmia, cardiac rhythm was systematically evaluated by 24-h ambulatory ECG.

Patients in the permanent sinus rhythm group included those in sinus rhythm without bradycardia and with a good chronotropic response. Patients in intermittent junctional rhythm with a good chronotropic response were excluded from the permanent sinus rhythm group, as were patients in permanent junctional rhythm with or without bradycardia,
and patients with complete atrioventricular block with or without a pacemaker. Patients in the active arrhythmia group included those with at least one episode of SVT, atrial fibrillation (AF) or atrial flutter.

Demographic, clinical and hemodynamic data were collected retrospectively as well as prospectively from hospital records between 2009 and 2013; data from the last visits were considered.

No patients were lost during follow-up. The duration of follow-up was defined as the period between the operation and the last clinic visit. Mean follow-up time was 11.6 ± 5.9 years.

2.4. Statistical analysis

Statistical analysis was carried out using IBM SPSS software package version 20.0. Descriptive data for continuous variables were reported as median, range, and mean ± standard deviation (SD); categorical variables were presented as relative frequencies.

Categorical variables were analyzed using Chi-square test or Fisher's exact 2-tailed test if one of the numerators of the population was ≤5 events. P values <0.05 were considered significant. The probability of survival was estimated by the Kaplan Mayer method.

3. Results

3.1. Rhythm disturbances

67 patients (90%), discharged with sinus rhythm, and in the latest follow up, 34 patients (45%) maintained their sinus rhythm.

26 patients (35%) experienced at least a single episode of arrhythmia, in the early post-operative period in the form of nodal rhythm (n = 10), complete AV block (n = 8), SVT (n = 6) and bradycardia (n = 2). PM was implanted in 7 patients (9.5%) before discharge.

During the follow-up period, 22 patients (29.7%), presented with SVT (all referred for ablation). 1 presented with nodal rhythm and 1 presented with AV block (both had a PM implantation). These two cases raised the total of patients who had PM implantation at the latest follow-up to 9 patients (12%).
3.2. Pathway stenosis

We had 3 patients (4.1%) who had experienced pathway stenosis. 1 patient had early presentation on the 3rd day post-operatively, with later surgical revision and patch augmentation. 2 patients had the presentation during the follow-up period, 3 and 5 years respectively after surgery. Both had reoperation with smooth post-operative course.

3.3. Survival

We assessed the survival of patients along the follow-up period, using Kaplan Mayer method showing 86.1% survival at 24 years (Fig. 3).

At the latest follow-up, 9 patients out of 74 patients included in our study (12.2%) died during the follow-up period. 6 patients due to heart failure, 2 patients due to fatal arrhythmias, and one post tricuspid valve implantation.

4. Discussion

The arterial switch operation is today, the treatment of choice for patients born with transposition of great arteries. Late referral of patients with TGA is common in Egypt [6]. The left ventricle ability to sustain a systemic function is slowly decreasing after 1 month of age in TGA. There is ongoing controversy around the optimal surgery to perform in these patients [7].

Standard Senning procedure is one of the surgical options for this group of patients, which offer them a solution with an excellent survival even with long follow-up [5]. However, standard Senning procedure shows also some common complications like arrhythmias and/or pulmonary pathway complications [4].

The proposed modified Senning procedure, might simplify the original concept, and provide adequate capacity of the pulmonary venous atrium, to preserve optimal geometry of the mitral valve and to minimize the damage to SA node [3].

We avoided the use of bovine pericardium which is known to have a higher incidence of calcification in comparison to the autologous pericardium [15]. Augmentation of the atrial wall (Fig. 2) was done to offer more capacity and less tension on the suture lines in comparison to the standard technique. We studied the incidence of arrhythmias, pathway complications as well as the survival of the patients along the follow-up period which extended up to 24 years and to be considered in our knowledge, this study shows one of the longest follow-up periods available for Senning procedure in the literature [8,12].

![Fig. 3. The survival of patients at 24 years using Kaplan Mayer.](image-url)
4.1. Arrhythmia

Early and late development of both atrial bradyarrhythmias and tachyarrhythmia are common after Senning procedure and is more likely to occur with longer follow-up [8]. The cause is probably the damage to the sinus node and atrial conduction tissue or interruption of sinus node blood flow at the time of operation [8], or progressive fibrosis of the sinus node due to surgical scars in this region [9]. Atrial arrhythmias can precipitate a significant deterioration in systemic ventricular function and in general, sinus rhythm should be restored whenever possible [10].

Using a pericardial patch for augmenting the pulmonary venous pathway and to avoid tension on suture lines, showed a relatively high incidence of restoration of sinus rhythm at the time of discharge (90%). In comparison to Roubertie et al. [8] who published in 2011 the results of 132 patients after standard Senning procedure; they showed an incidence of (80%) of restoration of sinus rhythm at the time of discharge. Comparing to our group which didn’t show any benefit of the modified technique over the standard in the later follow up, 45% showed sinus rhythm in comparison to 44% in Roubertie [8] group. In the later follow-up, comparing our group with Roubertie [8] group, the modified technique used in this study did not show any benefit over the standard one, 45% showed sinus rhythm in comparison with 44% in Roubertie [8] group. In comparison to the other studies, Williams et al. [12], reported a freedom from a permanent pacing 15 years after repair of 89%, which is comparable to our study. Moon et al. [13], reported a PM implantation in 5.5%, Roubertie et al. [8], reported 12 patients (9%) of his hospital survivors required pacemaker implantation and reported a freedom from a PM implantation at 25 years of 85%.

The early relative superiority of the modified technique over the standard technique regarding the restoration of sinus rhythm, mostly was attributed to tension free sutures which preserved blood flow to sinus node but failed to offer a benefit regarding fibrosis on long term outcome.

4.2. Pathway stenosis

PVPS is seen more often after the Senning procedure than after the Mustard repair [11]. The site of obstruction is typically between the inferior vena cava baffle limb and the lateral atrial wall. Physiologically, this type of stenosis is similar to mitral stenosis in the normal heart [11]. Its incidence after standard Senning procedure ranges from 5 to 15% [3].

In our study, we had 3 patients (4.1%) presented with pathway stenosis. One patient presented early by symptoms of pulmonary oedema, and has a surgical revision in form of patch augmentation, on the 3rd day post-operatively with a smooth recovery. 2 patients (2.7%) presented with marked lower limb oedema and ascites. 3 and 5 years respectively after the initial repair with an elective re-intervention and a smooth post-operative course.

Roubertie et al. [8], reported in their group 4 patients out of 132 patients (3%) with late pathway stenosis with mean time after surgery, 2.1 ± 3 years. Khairy et al. [14], reported an incidence of PVPS after the modified Senning of 7.6% in his series. Horer et al. [5] reported the pathway complications in 11 patients out of 314 patients with Senning procedure. Roubertie et al. [8] reported 4 patients out of 132 patients were reoperated after Senning operation for PVPS with mean time after surgery, 2.1 ± 3 years. Moons et al. [13], reported only 2 cases (1.4%) of pathway obstruction in his Senning group of patients.

The lower incidence of the PVPS in our group, was expected and planned to be avoided by using the pericardial patch of a suitable size for augmenting the atrial wall.

4.3. Survival

Our group of patients after the Modified Senning procedure showed a survival of 86.1% at 24 years’ follow-up which is was comparable with the other studies. In comparison to the other studies, Williams et al. [12], reported a survival of 74% at 17 years of his group of Senning. Moons et al. [13], reported a survival of 78.6% in his Senning group. Roubertie et al. [8], reported 7 (5.3%) early deaths out of 132 patients included in their study and 12 late deaths (9.6% of 125 hospital survivors): 5 sudden deaths and 3 heart failures. They showed an overall survival of 88% at 20 years which is comparable to our results.
This study had several limitations inherent to any retrospective study, limiting data collection to variables available in medical records. Changes in pre-operative, operative, and post-operative management may have affected the outcome parameters in a way may not covered by our analysis.

5. Conclusion

In conclusion, the modified Senning procedure, showed a less incidence of late PVPS and a higher incidence of restoration of sinus rhythm at the time of discharge in comparison to the standard technique. In addition, it had a lower mortality and comparable survival rates.

Conflict of interest

No conflict of interest.

References