Incidence and results of reoperations following the Senning operation: 27 years of follow-up in 314 patients at a single center

Jürgen Hörer a,*, Elisabeth Karl a, Georgia Theodoratou a, Christian Schreiber a, Julie Cleuziou a, Zsolt Prodan a, Manfred Vogt b, Rüdiger Lange a

a Department of Cardiovascular Surgery, German Heart Center Munich at the Technical University, Lazarettstr. 36, D-80636 Munich, Germany
b Department of Pediatric Cardiology and Congenital Heart Disease, German Heart Center Munich at the Technical University, Munich, Germany

Received 24 July 2007; received in revised form 13 November 2007; accepted 20 November 2007; Available online 4 March 2008

Abstract

Objectives: Atrial switch procedures for transposition of the great arteries are associated with reoperations mainly for systemic ventricular dysfunction and baffle complications. This study aims at identifying the results of reoperations following the Senning operation. Methods: Records of 314 hospital survivors who had undergone the Senning operation were reviewed for details concerning cardiac reoperations. Results: Reoperations were required in 32 patients (systemic ventricular failure n = 12, baffle complications n = 11, left ventricular outflow tract obstruction n = 7, aortic coarctation n = 2) during a mean follow-up time of 18.2 ± 5.7 years. Freedom from reoperation and survival at 25 years was 88.0 ± 2.1% and 90.9 ± 2.3%, respectively. Among patients who underwent reoperation for systemic ventricular failure (arterial switch and Senning take-down without prior pulmonary artery banding n = 2, with prior banding n = 3, banding without conversion n = 4, tricuspid valve repair n = 3), two patients died at the time of arterial switch and Senning take-down, and two patients died 4 and 16 months after tricuspid valve repair, respectively. Mean follow-up time after the first reoperation was 7.7 ± 5.9 years. Survival after reoperation for systemic ventricular failure at 30 days, 1 year, and 10 years, was 91.7 ± 8.0%, 83.3 ± 10.8%, and 64.8 ± 14.3%, respectively. Survival after reoperation for baffle complications and left ventricular outflow tract obstruction at 10 years was 85.7 ± 13.2% and 83.3 ± 15.2%, respectively. Conclusions: Reoperations following the Senning operation are rare. Reoperations for baffle complications or left ventricular outflow tract obstruction can be performed with good results in the mid-term. However, reoperations for systemic ventricular failure are demanding, and are associated with a high operative and mid-term mortality.

© 2007 European Association for Cardio-Thoracic Surgery. Published by Elsevier B.V. All rights reserved.

Keywords: Congenital heart disease; Transposition of great arteries; Adults

1. Introduction

The surgical technique of an atrial switch for patients presenting with transposition of the great arteries (TGA) was first described by Senning in 1958 [1]. In 1963, Mustard presented a similar approach by using synthetic material instead of autologous tissue to create the intra-atrial baffles [2]. Since then, atrial switch operations have been successfully applied to numerous patients during 3 decades from the early 1960s to the late 1980s [3,4]. Then, this treatment was abandoned in favor of the arterial switch operation (ASO) [5].

Survival was reported to range between 75% and 90% 25 years after the Mustard operation [3] and 25 years after the Senning operation [4], respectively. However, atrial switch procedures are associated with reoperations mainly for systemic ventricular dysfunction and baffle complications.

Besides heart transplantation and tricuspid valve surgery, the conversion to ASO was considered to handle those patients with failing right ventricles. In most cases, these procedures are performed once the right ventricular function has already deteriorated, and left ventricular training may no longer be possible, with the consequence of a high operative mortality [6–9]. A mortality rate of up to 42% has also been reported with respect to baffle reoperations [10]. Hence, reoperations are a challenge in this adult patient population with complex anatomy and account for a significant number of late deaths.

The aim of the present study was to identify the incidence, indication, and the outcome of reoperations in a population of 314 hospital survivors after the Senning operation.

2. Patients and methods

2.1. Patient selection

The study group comprised all patients with transposition of the great arteries who had undergone a Senning procedure...
at the German Heart Center, Munich, and who survived until hospital discharge. Twenty-eight patients who had come from foreign countries were excluded because follow-up data could not be generated. This study has been approved by the ethics committee of the Technical University Munich. Individual consent for the study was obtained from each patient.

2.2. Study group

The cohort included 219 male and 95 female patients who had undergone the Senning operation between 1977 and 2001. A simple TGA was diagnosed in 217 patients (69.1%), a TGA + VSD (ventricular septal defect) in 63 patients (20.1%), a TGA + LVOTO (left ventricular outflow tract obstruction) in 15 patients (4.8%), and a TGA + VSD + LVOTO in 19 patients (6.1%).

2.3. Surgical technique

The operation was performed as described by Senning [1]. VSD-closure was performed in 55 patients. The VSD was closed via a right atrial approach in all but one patient, in which it was closed through the ascending aorta. VSD-closure was performed with a patch in 32 patients, and by direct suture in 23 patients. Details concerning the operative technique are reported elsewhere [4].

2.4. Data collection and follow-up

Preoperative, perioperative, and follow-up data were retrospectively reviewed for details concerning cardiac reoperations. The prospective arm of the study consisted of a written questionnaire that was sent to all patients between May 2003 and July 2004. Fifteen patients were lost to follow-up at a mean time of 11.3 ± 7.6 years after the Senning operation (follow-up 94.8% complete). Mean follow-up time was 18.2 ± 5.7 years (maximum 27 years). The functional status was determined according to the New York Heart Association (NYHA) functional class, and the ability index, as described by Warnes and Somerville [11]. In case of death, the relatives and the general physicians of the patients were contacted to determine the cause of death.

2.5. Data analysis

Descriptive data for continuous variables are presented as means ± standard deviation; categorical variables are presented as relative frequencies. The outcome parameters were defined as time from the Senning operation to death, and time to reoperation for baffle complications, right ventricular dysfunction, or left ventricular outflow tract obstruction. Reoperation for baffle complications was defined as operation including enlargement of the venous pathways, and/or closure of baffle leaks, excluding any other concomitant procedure. Reoperation for systemic ventricular failure was defined as any operation including one or more of the following procedures: tricuspid valve repair or replacement, pulmonary artery banding (PAB), and ASO including Senning take-down. Reoperation for left ventricular outflow tract obstruction was defined as any operation including conduit placement from the left ventricle to the pulmonary artery or enlargement of the left ventricular outflow tract, including any other procedures except procedures performed for right ventricular dysfunction. The probability of freedom from events was estimated according to the Kaplan–Meier method. Freedom-from-event curves were compared using the log-rank test. P values <0.05 were considered as significant. Analyses were performed with SPSS 14.0.2 for Windows (SPSS Inc., Chicago, IL).

3. Results

3.1. Incidence of reoperations

Cardiac reoperations were performed in 32 patients. In 27 patients only one reoperation was necessary. In five patients, two reoperations were performed. The first reoperation was performed at a median time interval of 8.3 years (range 1–21 years) after the Senning operation. Median patient age at the time of the first reoperation was 8.5 years (range 2–22 years). Freedom from reoperation at 10 and 20 years was 93.1 ± 1.5% and 89.0 ± 12%, respectively (Fig. 1).

3.2. Indication of reoperations

There were three main indications for reoperations. The most frequent indication was baffle complication in 17 patients. Systemic ventricular failure was the indication for reoperations in 12 patients. Upon reoperation for systemic ventricular failure, five patients (patients 2, 3, 4, 23, and 24, Table 1) underwent tricuspid valve repair, either as single procedure or in combination with pulmonary artery banding and/or enlargement of the venous pathways. Freedom from reoperation for tricuspid valve repair was not significantly different between patients who had undergone transtricuspid VSD-closure at the time of the Senning operation, compared to patients who had not (p = 0.092). Ten patients underwent reoperations for left ventricular outflow tract obstructions. Frequently, more than one indication was present, hence in most of the patients more than one procedure had to be performed during reoperation (Table 1). For analysis of freedom from reoperation and survival,

Fig. 1. Freedom from reoperation after the Senning operation.
patients were assigned to three groups of reoperations (systemic ventricular failure \( n = 12 \), baffle complications \( n = 11 \), left ventricular outflow tract obstruction \( n = 7 \)) as defined above. Freedom from reoperation for systemic ventricular failure at 25 years was 95.7 \( \pm \) 1.2%. Freedom from reoperation for baffle complications at 25 years was 95.5 \( \pm \) 1.2%. Freedom from reoperation for left ventricular outflow tract obstruction 25 years was 97.6 \( \pm \) 0.9% (Fig. 2).

### 3.3. Outcome of patients undergoing reoperations

Three patients died during hospital stay at the time of reoperation. Early mortality rate of reoperations was 9.4% (3 early deaths in 32 reoperations). One 13-year-old patient died from myocardial ischemia at the first reoperation for ASO and Senning take-down on the day of surgery. One 15-year-old patient died from left heart failure at the second reoperation for ASO and Senning take-down 4 days after surgery. This patient had undergone prior PAB at the age of 12 years. One 14-year-old patient died from left heart failure at the first reoperation for enlargement of the left ventricular outflow tract and mitral valve replacement 1 day after surgery. There was no hospital mortality in patients operated exclusively for baffle complications.

Of the 30 patients who survived the first reoperation, 4 patients died during a mean follow-up time of 7.7 \( \pm \) 5.9 years after the first reoperation. Three patients died after reoperation for systemic ventricular failure. One 2-year-old patient died from an unknown cause 4 months after reoperation for tricuspid valve repair. One 17-year-old patient died from right heart failure 16 months after reoperation for tricuspid valve repair, PAB and enlargement of the venous pathways. As mentioned above, one patient died 23 months after PAB, enlargement of the left ventricular outflow tract and the venous pathways during the second reoperation for ASO and Senning take-down. There was one death after reoperation for baffle leak. This patient died 9 years after the reoperation from right heart failure and pulmonary hyperten-

### 3.4. Functional status related to reoperations

Information concerning the functional status at the time of final follow-up could be obtained from 269 patients (ability index) and 267 patients (NYHA functional class), 92.8% and 91.4% of the long-term survivors, respectively. Accordingly, 86.6% of the patients led a normal life with full-time work (ability index class I), 11.9% were able to work part-time (class II), and 1.5% experienced noticeable limitations on activities (class III). With regard to NYHA functional class, the same proportion of patients (47.9%) could be assigned to NYHA functional class I and II, and 4.1% of the patients could be assigned to class III.

Data concerning the functional status of patients who underwent reoperations could be obtained from 6 patients after a mean time interval of 6.5 \( \pm \) 2.5 years after reoperation for systemic ventricular dysfunction, from 10 patients after a mean time interval of 11.4 \( \pm \) 6.9 years after reoperation for baffle complications, and from 6 patients after a mean time interval of 10.7 \( \pm \) 2.7 years after reoperation for LVOTO. The proportion of patients assigned to NYHA functional class I was lower in patients following reoperations compared to patients, who did not undergo reoperations (Fig. 3).

### 3.5. Rhythm disturbances

Electrocardiography at final follow-up could be obtained from 85% of the long-term survivors. Accordingly, 78.3% of
them were in sinus rhythm, 12.5% presented with atrial or junctional rhythm with good chronotropic response, and 7.7% presented with poor chronotropic response, significant enough to require permanent pacemaker implantation. After hospital discharge after the Senning operation, pacemaker implantation was required in 22 patients. Indications for pacemaker implantation were sick sinus syndrome ($n = 9$), complete AV-block ($n = 3$), atrial fibrillation with marked bradycardia ($n = 3$), long-QT-syndrome ($n = 1$), and unspecified conduction disturbances ($n = 6$). Estimated freedom from pacemaker implantation for all hospital survivors at 25 years was $81.3 \pm 5.9$.

4. Discussion

Atrial switch operations have proven to be a successful surgical approach for small children presenting with TGA. The Senning and the Mustard operation have allowed most patients not only to survive early childhood, but also to reach adulthood. Survival 20 years after the Senning operation was $92.6 \pm 1.5\%$ in the present cohort of 314 hospital survivors,
with a mean patient age of $20.3 \pm 3.9$ years at final follow-up. The long-term outcome in terms of functional status and quality of life was reported to be reasonably good in the majority of the patients [4,12,13]. However, there is significant morbidity and mortality associated with specific complications following atrial switch operations, such as systemic ventricular dysfunction [3,14], and baffle complications [3,10]. Reoperations for those late sequelae are demanding, and mortality rate of up to 37% associated to reoperations have been reported [10].

Baffle stenoses or baffle leaks account for most of the reoperations in previously reported series. In the Toronto Mustard group, 5% of 478 hospital survivors underwent reoperations of baffle complications during a mean follow-up period of $11.6 \pm 7.2$ years [10]. A lower rate of baffle reoperations was reported by Oechslin and Jenni from the Zurich Senning group. During a mean follow-up period of 13.4 years, 3% of hospital survivors underwent baffle reoperations [3]. A lower rate of baffle reoperations in Senning patients compared to Mustard patients was also reported by Sarkar et al. [15]. In their study, the reoperation rate for baffle complications was 12% in 226 hospital survivors after the Mustard operation, and 2% in 132 hospital survivors after the Senning operation, with mean follow-up intervals of 11.7 ± 6.1 years and 13.4 ± 6.5 years, respectively. In the present Senning group, we observed a reoperation rate for baffle complications of 5.4% during a mean follow-up period of 18.2 ± 5.7 years, which was also significantly lower compared to the Mustard series of our institution [4]. Interestingly, freedom from baffle reoperation curves suggests that there is an ongoing risk for baffle complications in adulthood.

The relief of stenoses of the venous pathways is of major importance because due to impaired filling of the ventricle, baffle stenoses may contribute to severe low cardiac output and to sudden death in case of ventricular tachycardia. Sudden death was reported to be higher in patients who had undergone a Mustard operation compared to patients who had undergone a Senning operation [3,4]. This may be due to the lack of flexibility of the synthetic material that is used to create the venous pathways in the Mustard procedure. In contrast, the Senning procedure uses autologous tissue for baffle construction. Surgical relief of baffle stenoses has proven to be efficacious in the present study population. There was no second reoperation for baffle stenoses necessary during a mean follow-up time of 11.2 ± 6.6 years after the first reoperation for baffle complications. Relief of venous pathway obstructions by gradual angioplasty and placement of stents was reported to be an alternative approach for the treatment of baffle obstructions [16,17]. However, careful long-term follow-up of transcatheter treatment of channel obstructions is mandatory.

A mortality rate of up to 42% has been reported to be associated with reoperations for baffle complications [10]. In contrast, there was no death during reoperations for exclusively baffle revision in the present study population. Survival after the Senning operation for patients who underwent exclusively baffle reoperations was similar compared to patients who did not undergo reoperations. This indicates that reoperations for baffle revision can be performed with low operative mortality and good results in the long-term, at least in patients with preserved systemic ventricular function and competent tricuspid valve.

Reoperations for systemic ventricular dysfunction account for the second most frequent indication for reoperations in the present study population. In the literature, the incidences of reoperations for systemic ventricular failure were reported to range between 1% and 2% [3,15,18]. In the present cohort with the longest reported follow-up interval to date, 3.8% of the patients underwent reoperations for systemic ventricular failure. The surgical strategies applied to those patients need to take the function of the ventricles, the function of the valves, the presence of associated lesions such as LVOTO, the cardiac rhythm, and finally the age of the patient into account.

Tricuspid insufficiency may be the result of annular dilatation as a consequence of right ventricular dysfunction or the consequence of iatrogenic damage of the tricuspid valve during transtricuspid VSD-closure at the time of the initial operation. In the present study group, the incidence of reoperations for tricuspid valve repair was not significantly higher in patients who had undergone transtricuspid VSD-closure indicating that right ventricular dilatation may be the main cause for the development of an insufficiency of the systemic atrioventricular valve. In addition, three of the five patients who underwent tricuspid valve repair in the present study group did not present with a VSD at the time of the Senning operation. Hence, the outcome after tricuspid valve repair in patients with right ventricular dysfunction is poor, since the ventricular dysfunction remains untreated. Wells and Blackstone reported on a Mustard patient presenting with right ventricular failure who did not survive reoperation for tricuspid valve replacement [10]. In the present cohort, tricuspid valve repair failed in two patients presenting with severe right ventricular dysfunction. One patient died 4 months after surgery, the other patient exhibited severe tricuspid insufficiency and right ventricular dysfunction 4 years after reoperation. In contrast, one patient with tricuspid insufficiency and preserved right ventricular dysfunction presented with mild tricuspid insufficiency and mildly impaired right ventricular function at final follow-up. From their experiences with patients presenting with congenitally corrected transposition of the great arteries and tricuspid insufficiency, Acar et al. reported that tricuspid valve repair always failed when the right ventricle is left in the systemic position [19]. This might also be the case in patients who had undergone an atrial switch operation suggesting that a strategy of conversion to ASO may be beneficial in patients presenting with tricuspid insufficiency.

Poirier and Mee [20] reported an improvement of tricuspid regurgitation and functional status after PAB in patients with systemic right ventricle. This finding was confirmed by Winlaw et al. [21] who also found improvement in functional status after PAB. However, in contrast to Poirier and colleagues, this was not mirrored by an improvement in tricuspid regurgitation. In our cohort, of four patients who received PAB, and who did not undergo ASO, three are in ability index class I after a mean time of $7.2 \pm 1.0$ years after the PAB. One patient died 1.4 years after PAB from heart failure. Like Winlaw et al. [21] we could observe functional improvement without improvement in tricuspid regurgitation. However, these findings suggest that PAB as definitive
palliation may be a valid option for these patients if one takes into account the high operative mortality of a conversion by an ASO.

The hospital mortality of an ASO and atrial switch take-down ranges from 13% to 33% in the literature [6–8]. In addition, there is a significant interim mortality between PAB and conversion. In the present cohort, overall mortality of this approach was 33% with one patient dying after PAB and two patients dying at the time of conversion. The response to PAB is very fast in children [22], and the likelihood of successful conversion to ASO after PAB is higher in patients younger than 16 years of age [21]. However, since most of the patients of the present cohort are now grown-up and PAB for left ventricular reconditioning may lead to rapid left ventricular failure in adult patients [9], this strategy will no longer be a therapeutic option for these patients. In this study, PAB or ASO without prior banding was exclusively performed in patients below the age of 16 years. Finally, the fate of the systemic left ventricle and the neoaortic valve in patients who underwent successful conversion by an ASO is unknown [15]. In the present cohort, two patients had undergone aortic valve replacement following ASO. Presumably, heart transplantation will be the only surgical option for these patients with failing right ventricle. Fortunately, among adults with congenital heart disease who undergo cardiac transplantation, those who had undergone an atrial switch operation seem to do well [23].

Surprisingly, the third main cause for reoperations in the present population was left ventricular outflow tract obstruction, which has not been reported previously in other patient groups who had undergone an atrial switch operation. Presumably, the Senning operation was preferred to the Rastelli operation in patients with TGA, VSD, and mild pulmonary stenosis to avoid conduit implantation prior to the era of ASO. The long-term outcome of these patients seems to justify this approach. Survival of 34 hospital survivors presenting with TGA, VSD, and pulmonary stenosis 20 years after the Senning operation was 90.2 ± 4.5%, compared to 57.5 ± 15.1% of 39 hospital survivors 20 years after the Rastelli operation at our institution [24].

Loss of sinus rhythm at long-term has been described in patients after atrial baffle procedures [18,25]. Freedom from pacemaker insertion in the present Senning group was 98.7% at 10 years, and thus compares favorably to the findings by Wells and Blackstone [10] (91% at 10 years). At 20 years, freedom from pacemaker insertion was still 94.4%. However, at 25 years, freedom from pacemaker insertion decreased to 81.3%, indicating that loss of sinus rhythm might become a serious problem in this special entity of patients in the near future.

In conclusion, reoperations following the Senning operation are rare. Reoperations for baffle complications or left ventricular outflow tract obstruction can be performed with low operative mortality and good results in the mid-term in patients with preserved systemic ventricular function. However, the results of tricuspid valve repair are not encouraging in patients presenting with systemic ventricular dysfunction. Conversion by an ASO and restoring the left ventricle into the systemic position will no longer be an option since most of the patients will not respond to PAB because of advanced age. Hence, PAB without the intention to achieve systemic pressure for conversion as definitive palliation or as bridge to transplant may be the way for those patients.

References


Appendix A. Conference discussion

Dr J. Stark (London, United Kingdom): In the options for the right ventricular failure, you didn’t include transplantation in your original slide. Is it because you have not performed any transplantations, or in view of the last slide, you would consider it as an option now?

Dr Hörer: Yes, that is correct, there was no heart transplantation in this group. We did one cardiac transplantation in a group of 88 Mustard patients, but in the Senning group there was no transplantation.

Dr Stark: Until what age would you consider conversion to arterial switch?

Dr Hörer: This is a difficult question. I don’t think that it’s just a matter of age. We consider the conversion under the age of 16, but all of our patients now are older than 16. The mean age of the Senning patients now is 20. That’s why I concluded that this will probably no longer be an option for those patients.

Dr Stark: Because it is also in the literature, certainly from Dr Mee, that the results over 16 are poor, so probably transplantation would be a better option.

Dr Hörer: Yes. It would be the same cut-off point as for patients with congenitally corrected transposition who are scheduled for a double switch procedure.

Dr R. Pretre (Zurich, Switzerland): You also had some patients in your cohort with LVOT obstruction who might have a trained left ventricle without any banding. Would you consider an anatomical correction then?

Dr Hörer: In principle, yes, they are ideal candidates if they have systemic pressure in the left ventricle and at the same time low pressure in the pulmonary artery.

Editorial comment

Dr Lange’s group [1] from the German Heart Centre in Munich has provided further evidence of the long-term reliability of Senning’s operation, and has demonstrated a low incidence of late complications, when the procedure was performed properly, respecting the anatomy of the systemic and pulmonary venous inflow. Their results complement our previously published experience [2] with this operation, with similar extended outlook for atrial correction of the TGA. Furthermore, their analysis lends strong support to the notion of using patient’s own tissue in correction of cardiac anomalies, especially when performed early in life, because the natural growth of the tissue provides superb anatomical results into adulthood. The reported long-term survival is excellent, although it must be mentioned that the paper analyses only the survivors of the initial operation, i.e. those who went home after the total correction of TGA. One regrets the lack of some crucial information:

1. There is no indication of the age at the initial total correction of the patients with complications when compared with those surviving without reoperation, especially those presenting later with the failure of systemic ventricle. Does the long-term exposure to systemic hypoxia in patients submitted to total correction at the higher age (beyond first year of life) represent a risk factor for development of systemic ventricle failure? Does the very early operation (in the first weeks of life) predispose the patient to more baffle and inflow complications later in life?
2. The authors do not provide information about the cardiac rhythm at the last follow-up. The incidence of atrial dysrhythmias, the stability of sinus rhythm, the incidence of significant arrhythmias and of pacemaker implanta-