The modified Senning operation – surgical aspects

Krishna Subramony Iyer
Department of Pediatric & Congenital Heart Surgery, Fortis Escorts Heart Institute, New Delhi, India

ABSTRACT

The advent of the arterial switch operation for the treatment of transposition of great arteries (TGA) made the atrial switch operation largely redundant and its use in the developed world is now confined to the atrial component of the double-switch operation for congenitally corrected TGA. In resource-limited countries, however, it remains relevant as a treatment option for patients presenting late with transposition and a regressed left ventricle. The operation is intricate with many potential pitfalls, and this "how I do it" article describes the operative steps in detail to enable surgeons to learn this procedure and make it a part of their surgical armamentarium.

Keywords: Senning operation, atrial switch, Transposition of Great Arteries

INTRODUCTION

In 1959, Ake Senning from Sweden first published an ingenious technique for physiologic correction of transposition of great arteries (TGA), utilizing flaps of atrial wall to interchange the venous inflows into the two ventricles.[1] The procedure which takes his name became the first viable intracardiac surgery for the relief of cyanosis in patients with TGA. It was soon to be overshadowed, albeit temporarily, by another atrial switch procedure described by Mustard *et al.* from Toronto in 1964.[2] However, both these procedures were almost relegated to history with the advent of an anatomical correction in the form of the arterial switch procedure (ASO) first described by Jatene *et al.*[3] in 1975 and later adapted for neonates by Castaneda *et al.*[4] in 1984. Today, the ASO remains the mainstay for the surgical management of patients with TGA. The atrial switch procedures witnessed some revival with the evolution of the double-switch procedure for the anatomical correction of congenitally corrected transposition where the atrioventricular discordance is corrected with the use of an atrial switch.[5] For the rare entity known as isolated ventricular inversion (atrioventricular discordance with ventriculoarterial concordance), the Senning operation becomes an anatomic correction.

The atrial switch for TGA can be performed at any age since the right ventricle (RV) remains the systemic ventricle and the outcome is not affected by the time-bound regression of the left ventricle that occurs in TGA with intact ventricular septum (IVS). In many resource-limited countries, patients with TGA often present at an age where the left ventricle has regressed and an ASO becomes risky. The atrial switch procedure is appealing, given its low-risk and favorable intermediate-term outcomes, and so remains an alternate treatment modality in such situations.[6] It is essential therefore for surgeons in resource-limited countries to know well the technique of performing a good Senning operation. The following article describes the way the author performs the Senning operation and is presented stepwise as a series of short video clips. An attempt has been made to highlight the numerous finer technicalities that pave the way for a repair that is effective as well

Videos Available on: www.annalspc.com

Access this article online

Quick Response Code:

Website: www.annalspc.com

DOI: 10.4103/apc.apc_154_21

How to cite this article: Iyer KS. The modified Senning operation – surgical aspects. Ann Pediatr Card 2021;14:382-7.

Address for correspondence: Dr. Krishna Subramony Iyer, Fortis Escorts Heart Institute, Okhla Road, New Delhi - 110 025, India.
E-mail: iyerks@hotmail.com

Submitted: 30-Jul-2021 **Accepted:** 10-Aug-2021 **Published:** 26-Aug-2021

as long lasting. Permission has been obtained from patient's parents for recording and publication of the surgical video.

Preoperative considerations

In general, the operation is performed in patients with TGA, IVS who are beyond the age of 6 months and are not considered suitable for a primary ASO or an ASO after left ventricular (LV) retraining.[7] A normally functioning morphologic RV without tricuspid regurgitation is a prerequisite. There should be no pulmonary hypertension, although the procedure can be performed as a palliative operation in patients with TGA and ventricular septal defect having elevated pulmonary vascular resistance. Echocardiographic evaluation suffices for most patients, however, when indicated, cardiac catheterization is done for measurement of pulmonary artery pressure.

These patients are generally polycythemic, and detailed hematological evaluation is performed to detect coagulation abnormalities and take appropriate measures to counteract them at the time of surgery. In the presence of severe polycythemia, neuroimaging of the brain is recommended preoperatively to exclude occult intracranial bleeds that may expand with heparinization during cardiopulmonary bypass.

SURGICAL PROCEDURE

Anesthesia and monitoring

The procedure is performed under general anesthesia and cardiopulmonary bypass (CPB). The patient is positioned supine with a small roll under the shoulders to open up the neck. In severely polycythemic patients, nasotracheal intubation is avoided and oral intubation is preferred to avoid troublesome bleeding from adenoidal injury. Invasive radial arterial pressure monitoring is routine, and a short right internal jugular catheter is placed for central venous pressure monitoring. The line is positioned in the proximal superior vena cava (SVC) so as not to interfere with the intracardiac repair. Surgery is performed under cardiopulmonary bypass using aorto-bicaval cannulation and mild hypothermia. The author preferentially uses the del Nido cardioplegia, however, any cardioplegia may be used as per the surgeon's preference.

A standard median sternotomy is performed and the thymus gland is dissected away. The pericardium is opened a little to the right of the midline and the pericardial cavity marsupialized. The diagnosis of TGA is confirmed on inspection of the heart. It is an advantage if the right atrium appears roomy, as is shown in Figure 1.

The SVC is dissected extrapericardially and looped below the origin of the azygos vein so as to permit high

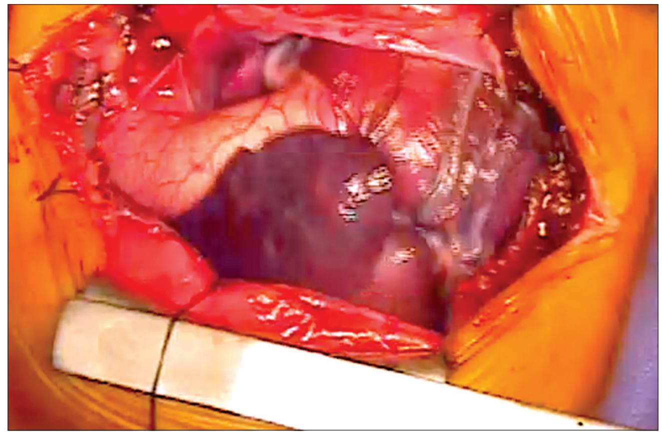

Figure 1: External appearance of the heart with transposition of great arteries showing the anterior aorta arising from the right ventricle and prominent right atrium

cannulation and at the same time prevent troublesome return from the azygos vein into the operative field [Video 1]. Care is taken to maintain the integrity of the pericardial recess between the cavoatrial junction and the right pulmonary artery as this area will be incorporated into the pulmonary venous chamber later in the repair. A purse-string suture is placed on the anterior wall of the bared extrapericardial SVC to allow for placement of an angled venous cannula. The inferior vena cava (IVC) is similarly dissected and looped extrapericardially again preserving the pericardial fold at the inferior cavoatrial junction. The IVC is dissected away from the diaphragm as much as is feasible. A purse-string suture is placed in this portion of the dissected IVC to allow for low cannulation with an angled venous cannula [Video 2].

CPB is established with an angled aortic cannula placed in the aorta as usual and angled venous cannulas in the vena cavae as described above. Once the heart is collapsed on full CPB, the SVC and IVC are looped extrapericardially and snuggers are placed. The right atrium is retracted and spread out by the first assistant, and the two important landmarks are identified – (a) the Waterston's groove at the junction of the right pulmonary veins and the right atrium [Figure 2, green arrow] and (b) the sulcus terminalis which externally marks the level of the crista terminalis [Figure 2, black arrow].

The Waterston's groove is dissected with sharp scissors to create a plane in the interatrial septum taking care not to enter the left atrial cavity [Video 3]. This helps create a wider left atrial opening for pulmonary venous egress. The aortic cross-clamp is then applied and cardioplegia is administered. The heart is immersed in ice-cold saline while the cardioplegia is flowing. The caval snuggers are then tightened and a stab incision is made into the left atrium at the base of the dissected Waterston's groove to vent the heart. The first incision in the right atrium is made parallel to the sulcus terminalis at a distance from it that is equal to the distance between the Waterston's groove and the sulcus terminalis. This width of posterior atrial flap is necessary to create a wide enough systemic venous channel. The incision is extended superiorly up to the superior margin of the right atrium and inferiorly just short of the inferior cavoatrial junction [Video 4]. Two stay sutures are placed on the anterior lip of the atriotomy such as to approximately divide this edge into three equal parts [Figure 3]. A single stay suture is placed at the center of the posterior lip of the right atrial incision. The interatrial septum is carefully examined for the size of the atrial septal defect (ASD) and extent of the remaining atrial septum available for creation of the atrial septal flap.

The next step is to extend the stab incision in the Waterston's groove superiorly to the point where the upper limit of the right superior pulmonary vein merges with the left atrium. Likewise, the incision is extended inferiorly till the floor of the left atrium is reached. This forms the opening through which the pulmonary venous flow will exit from the left atrium and therefore needs to be as large as possible. This is usually possible by using a cutback incision into the right upper pulmonary vein up to the pericardial reflection. Overhanging edges of atrial muscle are excised in order to have a smooth-walled opening [Video 5].

Creation of the atrial septal flap requires care and ingenuity. It is usually possible to get enough atrial tissue to create an adequately sized flap required to septate the left atrium. The atrial septum is put on stretch with an eyelid retractor at the anterior margin of the ASD and another at the base of the right atrial appendage. An inverted L-shaped incision is made in the superior limb of the ASD. The transverse limb is a short incision in the septum which starts at the anterior extent of the ASD and is directed superiorly till it is felt that one may be coming out of the heart. The longer limb of the L starts at this point and is directed toward the superior extent of the opening in the Waterston's groove. This incision has to be a bold cut with one blade of the scissors in the left atrium and the other in the right atrium [Video 6]. There is always a fear that one may come out of the heart superiorly. This is never a problem even if this happens since it can be fixed with a few interrupted sutures. In any event, the raw surface of the atrium thus created has to be re-endothelialized with multiple interrupted sutures. The flap, thus cut out, serves to flatten the pathway from the superior caval orifice toward the roof of the left atrium. If there is a residual ledge of tissue here, then that may result in obstruction to the SVC pathway. The inferior flap is created from whatever is left of the atrial septum between the ASD and the tricuspid valve. The superior flap is opened out like a book by cutting into its thick muscular belly [Video 7]. The two flaps are sutured to each other in the region where the original ASD was to create a single flap that is hinged laterally at the medial margin of the left atriotomy. The creation of the atrial septal flap results in a large ASD which will form the pathway for the systemic venous flow into the left atrium and mitral valve.

The next part of the surgery is the suturing of this flap to the walls of the left atrium to create a posterior chamber that receives the left pulmonary veins and opens into the pericardial cavity through the opening created in the Waterston's groove and an anterior chamber that opens into the mitral valve. The suturing starts at the far end of the left atrium on the ledge of muscle that separates the opening of the left atrial appendage and the opening of the left pulmonary veins. A double-ended suture is used to approximate the midpoint of the atrial septal flap to the midpoint of this ledge of muscle. The two ends of this suture are then used to continue the suture line superiorly and inferiorly. Superiorly, the upper margin of the flap is sutured to the roof of the left atrium [Video 8].

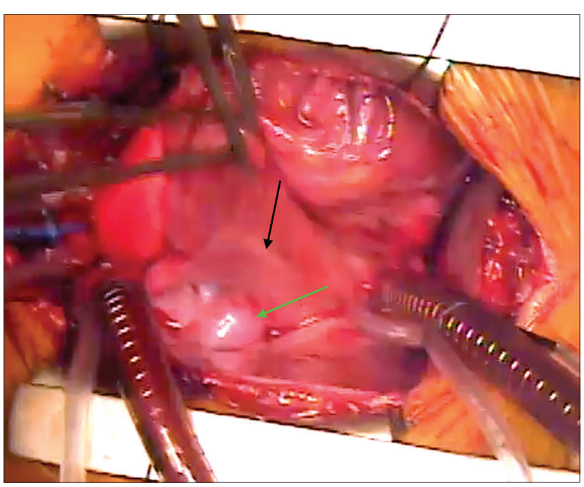

Figure 2: Lateral view of the right atrium showing the sulcus terminalis (black arrow) and Waterston's groove (green arrow)

Figure 3: Placement of stay sutures along the anterior cut margin of the right atrium

It is important to keep the suture line as far back into the left atrium as possible so as not to compromise the SVC pathway into the left atrium [Figure 4]. It is also important to keep the lengths of the flap and atrial wall equal so as not to have excessive tension on the suture line since the roof of the left atrium is relatively immobile. In the rare event of a left superior vena cava draining into the left atrium, the suture line must run below the point of entry of the anomalous vein so that the left caval vein drains into the systemic venous compartment. The inferior margin of the flap is sutured to the floor of the left atrium keeping a safe distance from the posterior mitral annulus. This portion of the left atrium can be plicated without any consequence if the inferior margin of the atrial flap is shorter. This suture line ends at the floor of the right atrium close to the opening of the coronary sinus [Video 9].

The adequacy of the space behind the atrial septal flap is checked at this point to ensure that the left pulmonary veins have unhindered egress. The systemic venous pathway is next constructed by suturing the posterior flap of the right atrial wall to the atrial septum anterior to the septal defect so that the caval return is channeled to the mitral valve. The suture line starts at the upper end of the right atriotomy incision and proceeds in a straight line along the base of the right atrial appendage and then onto the atrial septum till the anterior tip of the septal defect is reached. Care is taken to obliterate all the muscular trabeculations in the upper part of this suture line to prevent a baffle leak [Video 10].

We next move onto the IVC end of the systemic venous pathway. The low cannulation of the IVC allows for a clear visualization of the inferior cavoatrial junction which is often roomy in patients with TGA. The coronary sinus ostium is identified as also the presence of a prominent Eustachian valve. The right atrial incision is extended

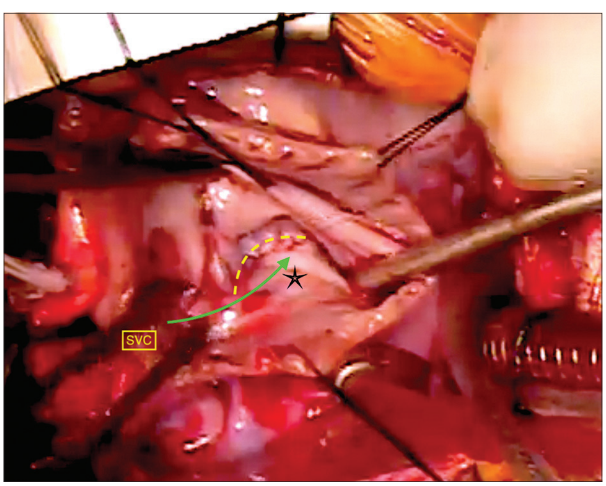

Figure 4: The unhindered pathway from the superior caval orifice toward the mitral valve through the atrial septal defect (green arrow) anterior to the atrial septal flap (black star). The yellow dotted line marks the superior suture line of the atrial septal flap

appropriately toward the cavoatrial junction to a point where the atrial wall can be comfortably folded to meet the medial wall of the cavoatrial junction. The suture line starts with a semicircular purse-string suture at this point and then continues in a straight line posterior to the orifice of the coronary sinus to meet the suture line of the SVC end of the systemic venous channel [Video 11]. If the Eustachian valve is prominent, then the flap can be sutured to its edge and continued posterior to the coronary sinus. A visual check is made during suturing to ensure that the channel so created is adequate enough to provide free flow from the IVC into the ASD. In patients with a left SVC draining into the coronary sinus, the suture line has to pass along the anterior lip of the coronary sinus orifice so as to direct coronary sinus flow into the systemic venous channel. Superficial bites are taken in the region of the coronary sinus to prevent injury to the atrioventricular node which lies at the apex of the triangle of Koch. After completion of the systemic venous channel, the caval snares are released and the venous line is partially clamped. This allows the systemic venous pathway to distend and reveals any leak along the suture line. The billowing of the systemic venous channel also gives a visual guide as to how roomy the pulmonary venous chamber would have to be since it would have to curve around the systemic venous channel to meet the tricuspid valve.

The last step of the surgery is the completion of the pulmonary venous pathway with the use of *in situ* pericardium. A purse-string suture is placed at the tip of the right atrial appendage, and the tip is amputated to create a small opening large enough to allow a pediatric sucker tip to be inserted. The interior of the appendage is visualized and all trabeculae are divided to provide more mobility to the atrial flap [Video 12]. The superior suture line for the pulmonary venous chamber starts at the upper end of the right atrial incision. From this point, the atrial flap is sutured along the crest of the right atrium and then onto the anterior wall of the SVC till the pericardial reflection on the lateral wall of the SVC is reached. Superficial interlocking sutures are placed on the SVC to prevent purse stringing and narrowing of the SVC [Video 13]. The suture line then runs onto the pericardium and runs obliquely downward in the direction of the IVC [Figure 5]. If the right pleura has not been entered, it helps to open the pleura at this stage and allow the right lung to collapse and free the pericardium. The suture line thus remains well away from the sinoatrial node, thereby reducing the potential for atrial arrhythmias. The inferior suture line starts at the lower end of the right atrial incision. The atrial flap is sutured initially obliquely to the lateral wall of the inferior cavoatrial junction till the lower end of the left atrial opening is reached [Video 14]. The suture line then jumps onto the pericardium and proceeds

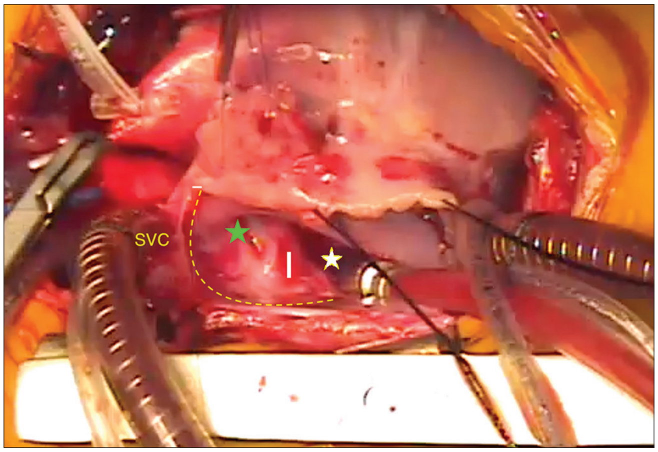

Figure 5: Surgical view showing the proposed suture line (yellow dotted line) where the upper end of the right atrial flap would be sutured traversing from the superior vena cava to the pericardium. The white star is the left atrial opening. The green star locates the pericardial cul-de-sac posterior to the superior cavoatrial junction that has to be preserved intact

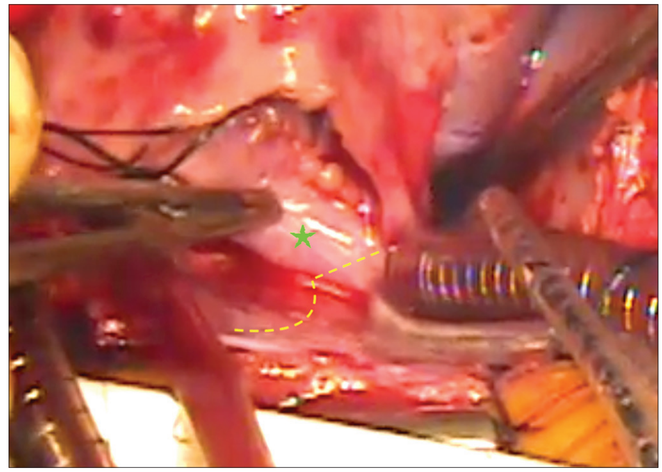

Figure 6: Surgical view showing the proposed suture line (yellow dotted line) where the lower end of the right atrial flap would be sutured traversing from the inferior vena cava to the pericardium. The green star denotes the lateral wall of the systemic venous channel

to meet the suture line from the upper end [Figure 6]. If the angulation from the lateral wall of the IVC to the pericardium is too acute, then this angle can be obliterated with a few interrupted sutures between the lateral cavoatrial junction and the adjacent pericardium. A sucker passed through the tip of the right atrial appendage allows for the left atrial return to be sucked and improves visualization for the final stages of this suture line [Video 15]. The division of the atrial flap into three equal parts with the stay sutures as shown in Figure 3 is helpful in aligning this suture line. The upper third is used for the SVC component, the lower third for the IVC component, and the middle third for the body of the pulmonary venous atrium. The bites on the pericardium should be just deep enough so as to not exit on its parietal surface. This averts any chance of injury to the phrenic nerve at the lower end of the suture line. There is no need to dissect the phrenic nerve off the pericardium. It should be apparent by now that the left atriotomy opens freely into a pericardial chamber that is partitioned off from the remaining pericardial cavity by the right atrial flap. The suture line is far away from the left atriotomy, and this reduces the chances of late narrowing of the pulmonary venous channel. It also highlights the importance of maintaining the integrity of the pericardial reflections off the lateral surfaces of the SVC and IVC, since these recesses are now part of the pulmonary venous chamber.

The heart can now be deaired and the aortic cross-clamp released. The opening in the right atrial appendage is kept open and allowed to bleed and keep the RV decompressed till vigorous cardiac activity returns. The author prefers to place a left atrial pressure monitoring line through the tip of the right atrial appendage (which is now in the functional left atrium). Pacing wires are placed and the patient is weaned from cardiopulmonary bypass after adequate rewarming. Low-dose dobutamine infusion is used as a standard postoperative inotrope. After the venous cannulas are removed [Video 16], an epicardial echo is done to assess the repair, and if that is judged satisfactory, then protamine is administered and the aortic cannula is removed. Video 17 shows an unrestricted flow in the pulmonary venous channel on an epicardial echocardiogram while Video 18 demonstrates the unobstructed SVC channel.

The sternotomy is closed in usual fashion, and the patient is transferred to the intensive care unit on the ventilator. Weaning from the ventilator and endotracheal extubation is possible within a few hours after hemodynamic stability has been assured. The left atrial line is usually removed on the fourth postoperative day, and discharge from hospital is possible by the sixth or seventh postoperative day.

ADDITIONAL PULMONARY ARTERY BANDING

Of late, the author prefers to place a loose pulmonary artery band prophylactically, at the end of the procedure, tight enough to produce a gradient of 25–30 mm Hg. The reasons for this are as follows:

1. As the patient grows into the band, the LV pressure would increase and minimize the shift of the interventricular septum into the left ventricle that usually occurs with a systemic RV. This helps to reduce the chances of late-onset tricuspid regurgitation which is a precursor of RV dysfunction
2. A slow preparation of the left ventricle may allow conversion to an arterial switch electively or in the

event of RV failure. This would eliminate the need for a later surgery for LV retraining in the event of systemic RV failure.

CONCLUSIONS

The Senning procedure can appear to be technically challenging but is in reality fairly easy to learn and reproduce if the proper steps are followed. Modifications to the original description of the procedure have helped reduce the incidence of early and late complications.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Turina MI, Siebenmann R, von Segesser L, Schönbeck M, Senning A. Late functional deterioration after atrial correction for transposition of the great arteries. Circulation 1989;80:I162-7.
2. Mustard WT, Keith JD, Trusler GA, Fowler R, Kidd L. The surgical management of transposition of the great vessels. J Thorac Cadiovasc Surg 1964;48:953-8.
3. Jatene AD, Fontes VF, Paulista PP, Souza LC, Neger F, Galantier M. *et al*. Anatomic correction of transposition of the great vessels. J Thorac Cardiovasc Surg. 1976; 72: 364-70.
4. Castaneda AR, Norwood WI, Jonas RA, Colan SD, Sanders SP, Lang P. Transposition of the great arteries and intact ventricular septum: Anatomical repair in the neonate. Ann Thorac Surg 1984;38:438-43.
5. Hraska V, Murin P, Arenz C, Photiadis J, Asfour B. The modified senning procedure as an integral part of an anatomical correction of congenitally corrected transposition of the great arteries. Multimed Man Cardiothorac Surg 2011;2011(224):mmcts.2009.004234.
6. Sarris GE, Balmer C, Bonou P, Comas JV, da Cruz E, Di chiara L, *et al*. Clinical guidelines for the management of patients with transposition of the great arteries with intact ventricular septum. Eur J Cardiothorac Surg 2017;51:e1-32.
7. Iyer KS, Sharma R, Kumar K, Bhan A, Kothari SS, Saxena A, *et al*. Serial echocardiography for decision making in rapid two-stage arterial switch operation. Ann Thorac Surg 1995;60:658-64.