The "excluding" suture technique for surgical closure of ventricular septal defects: A retrospective study comparing the standard technique

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ABSTRACT

Background : **Conventional methods of closure of ventricular septal defects involve placement of sutures 4-5 mm from the posterior inferior margin. This study compares the conventional method with an alternative technique wherein sutures are placed along the edge of the defect thereby "excluding" the conduction system and the tensor apparatus of the tricuspid valve from the suture line.**

Materials and Methods : **Between January 2013 and January 2016, 409 consecutive patients were retrospectively reviewed and divided into two matched groups. Group A (n = 174) underwent closure using the alternative technique and Group B (n = 235) with the conventional technique. Patients with isolated ventricular septal defects (VSDs) (n = 136) were separately analyzed as were infants within this subset.**

Results : **Immediate postoperative results were similar with no statistically significant differences in either group in terms of incidence of residual defects or postoperative tricuspid regurgitation. There was however a significantly increased incidence of post operative complete heart block (CHB) among patients in the conventional group (P = 0.02). Incidence of temporary heart block that reverted to sinus rhythm was also more in the conventional method group (Group B) (P = 0.03) as was right bundle branch block ($P \leq 0.05$) in all the subsets of patients analyzed.**

Conclusion : **Surgical closure of VSDs can be accomplished by placing sutures along the margins or away with comparable results. The incidence of CHB, however, seems to be less when the "excluding" technique is employed.**

Keywords : Congenital heart disease, ventricular septal defect, ventricular septal defect closure

INTRODUCTION

Ventricular septal defects (VSDs) constitute one of the most common congenital cardiac anomalies that require surgical closure early in life. Almost all VSD closures are accomplished with a patch of synthetic material or pericardium using the interrupted or the continuous suture technique. These sutures are usually inserted 4-5 mm away at the posterior inferior margin to avoid the specialized conduction tissue. Standard textbooks of surgery describe this technique in detail and therefore constitute the conventional technique.

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This study aims to popularize an alternative continuous suture technique wherein the sutures bites are taken on the posterior inferior rim of the VSD thereby "excluding" the conduction system and the tensor apparatus of the tricuspid valve outside the area occupied by the suture and the VSD patch. It also aims to compare the results of the conventional with the "excluding" technique within the same institution performed during a similar time period with the purpose of demonstrating similar if not superior results over the conventional technique.

MATERIALS AND METHODS

Approval of the hospital ethics committee was obtained for the study prior to the collection of data. The details of 409 patients operated on between January 2013 and January 2016 for closure of ventricular septal defect were retrospectively reviewed. They were divided into two groups based on the technique of VSD closure employed. Both groups were operated during the same time period by three surgeons. Categorization into either of the groups was based on individual techniques preferred by the three surgeons. All patients in Group A were operated by a single surgeon whereas the patients in Group B were operated by either of the other two surgeons. Group A consisted of 174 patients operated using the "excluding" technique whereas Group B consisted of 235 patients operated using the conventional technique. All patients underwent expanded polytetrafluoroethylene (ePTFE) patch closure using the continuous suture technique through the right atrial approach.

The preoperative patient characteristics and anatomical diagnoses are summarized in Tables 1 and 2, respectively.

Patients with isolated VSDs were analyzed separately. Of 136 patients who had isolated VSDs, 63 were from Group A and 73 from Group B. Within this group, infants were analyzed as a separate subgroup as the majority of isolated VSD closures were performed in this age group [Table 3].

Perimembranous (infracristal) VSDs and VSDs with inlet extension were included in the study as also were the subaortic VSDs associated with Tetralogy of Fallot and other conotruncal anomalies in which the conduction system is closely related to the posterior inferior margin of the defect. Muscular VSDs and those purely in the outlet septum (supracristal) were excluded because of their remote location from the His bundle. Complete atrioventricular canal defects were also excluded from the study because of the course of the bundle of His traversing the crest of the interventricular septum in these patients.

Data collection

Clinical records, operative notes, and echocardiographic and electrocardiographic reports of all patients from the medical records department were retrospectively analyzed. Preoperative and postoperative findings were collected. Follow-up data were also reviewed from the medical records available in the clinical files.

Table 1: Preoperative patient characteristics

	All			Isolated VSDs		
	Group A	Group B	Total	Group A	Group B	Total
Total no (*n*)	174	235	409	63	73	136
Median age (months)	22	24		5	12	
Age range (months)	1-372	1-455		1-287	1-431	
Median weight (kg)	12	12		5.1	8	
Median BSA (m^2)	0.5	0.6		0.4	0.5	

BSA: Body surface area, VSD: Ventricular septal defect

Table 2: Anatomical diagnoses

	Group A	Group B
Tetralogy of Fallot	92	125
Isolated VSD	63	73
Double outlet ventricles	13	19
Double chambered ventricles	2	6
D TGA	3	4
CoA/IAA	1	5
Pulmonary atresia	0	1
Aortic regurgitation	0	2
Total	174	235

CoA: coarctation of aorta, IAA: interrupted aortic arch, TGA: transposition of great arteries, VSD: ventricular septal defect

Statistical analysis

The Student's *t* test was used for the statistical analysis. Other variables were expressed as mean, median, and standard deviation. A "*P* value" less than 0.05 was considered significant.

Operative techniques

Conventional method

Cardiopulmonary bypass was accomplished by aortic and bicaval cannulation [Figure 1]. The temperature of the perfusate was maintained at moderate hypothermia (28°C) for isolated VSDs whereas lower temperatures were sometimes chosen for cases that required hypothermic perfusion. Cold blood cardioplegic arrest was achieved and the VSD was closed through the tricuspid valve (trans atrial approach). All closures were achieved using the continuous suture technique and a patch of ePTFE. Polypropylene of 5.0′ or 6.0′ gauge was the suture material used depending on the size of the child. The first suture was taken as a double-armed pledget-reinforced mattress suture at the anterior and inferior margin of the defect. The needles were then passed through the lower margin of an appropriately configured patch. The patch was lowered into the defect, pushed into the VSD, and tied to three knots to stabilize the patch and the suture. One arm of the suture was then continued along the anterior margin of the defect

taking bites on the septal muscle and then the patch till the annulus of the tricuspid valve at the anterior and superior margin was reached. Here the suture makes a turn by taking a mattress suture bite on the patch and then through the annulus of the tricuspid valve thereby coming out on the right atrial side. This arm of the suture is tagged in a rubber-shod mosquito clamp and laid aside. The other arm of the suture is next continued toward the inferior and posterior margins of the defect. These suture bites are taken approximately 4-5 mm distant to the margin until the posterior margin is reached when these bites are made shallower than the previous bites to avoid the conduction system close to the annulus of the tricuspid valve. On reaching close to the annulus of the tricuspid valve on the posterior margin, this suture is also turned similar to that at the anterior margin by taking a mattress bite on to the patch and then through the base of the septal leaflet at the posterior margin. The suture thereby comes out on to the right atrial side similar to the one at the anterior margin. This suture is then woven in an alternate manner through a strip of pericardium, the base of the septal leaflet as a mattress suture, thereby strengthening the suture line at the base of the septal leaflet and the ePTFE patch to prevent its dehiscence [Figure 2]. The tagged suture at the anterior margin is also similarly woven through pericardium, leaflet tissue, and patch, until the two meets. The sutures are then tied down. Any chordae of the tricuspid valve encountered along the suture line is dealt with by weaving the suture around the structure thereby seating the patch in such a manner as to leave the chord on the right ventricular aspect of the patch. A bunch of chordae close to the posterior margin may be more difficult to deal with by weaving around them; in these instances, the patch would be slit at the site of the chordal attachment. The patch would thus be seated firmly around the chordae, and if necessary, interrupted sutures are taken at the site of the slit in the patch. Following the closure of the interventricular septal defect, any associated anomalies were dealt with. If no other anomaly required surgical attention, the child was rewarmed and weaned off cardiopulmonary bypass.

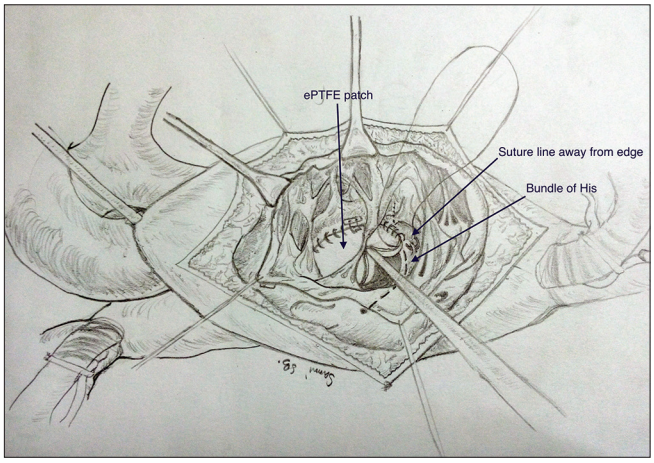

Figure 1: Sketch showing conventional technique of ventricular septal defect closure with suture line outside the course of the bundle of His

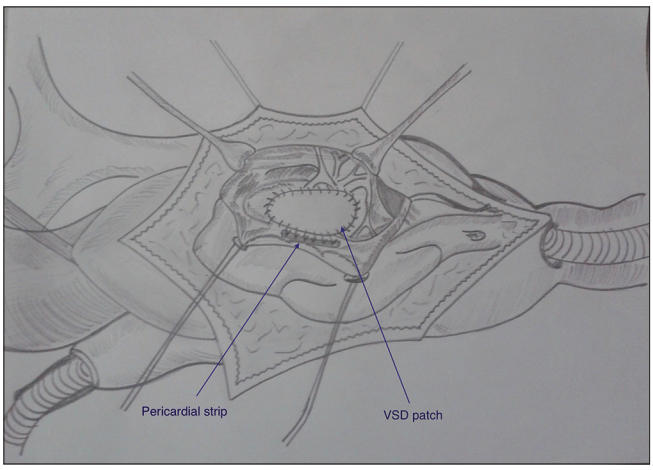

Figure 2: Completed ventricular septal defect closure showing the strip of pericardium at the septal leaflet of tricuspid valve

Table 3: Results for isolated VSDs

	All				Infants			
	Group A	Group B	Total	*P*	Group A	Group B	Total	*P*
No of patients (*n*)	63	73	136		43	45	88	
Mean AXC time (min)	108.2±65.5	89.46±47.6		0.291	86.95±24.3	85.47±37.6		0.49
Ventriculotomy	0	1 (1.7%)	1 (0.9%)	0.236	0	1 (2.6%)	1 (1.4%)	0.45
CHB	0	0	0	–	0	0	0	–
RBBB	3 (4.7%)	9 (12.3%)	12 (8.8%)	0.054	3 (14%)	7 (15.5%)	10 (11%)	0.02
Residual VSD	0	0	0	–	0	0	0	–
Tricuspid regurgitation	0	0	0	–	0	0	0	–
Temporary CHB	0	1 (1.7%)	1 (0.9%)	0.237	0	0	0	–
JET	1 (2.0%)	0	1 (0.9%)	0.025	1 (3.1%)	0	1 (1.4%)	0.31
Followup (FU)	37 (74%)	42 (70%)	79 (71.8%)	0.642	28 (84.8%)	28 (73.7%)	56 (78.8%)	0.25
FU duration (months)	6.6±5.0	6.06±5.8	6.2 (M)	0.023	6.92±5.1	5.98±5.61	6.4 (M)	0.57
Mortality	0	0	0	–	0	0	0	–

AXC: Aortic cross clamp, CHB: Complete heart block, JET: Junctional ectopic tachycardia, RBBB: Right bundle branch block, VSD: Ventricular septal defect

"Excluding" suture technique

Cardiopulmonary bypass and myocardial protection strategies were similar to the conventional method as was the approach to the VSD (trans atrial) [Figure 3]; 6.0′ polypropylene was used for all the patients irrespective of the age of the child. The initial double-armed pledgetted mattress suture was placed as previously described and passed through a similar patch of ePTFE. The suture line along the anterior margin of the defect was also similar to the conventional method, and at the annulus of the tricuspid valve, this suture was also tagged in a similar manner. With the other arm of the suture, bites are then taken along the inferior and posterior margin staying flush with the edge of the defect keeping to the right ventricular side. The assistant takes particular care while following the suture to ensure adequate tension is maintained and at the same time ensuring that the suture does not cut through the septum by using overzealous force. Should the surgeon get the impression that a particular suture bite was too shallow, this would be repeated to prevent the suture from cutting out. The suture line continues all along the posterior margin up to the annulus of the tricuspid valve at the base of the septal leaflet. Here also, similar suture bites are taken with the same precautions. On reaching the annulus at the septal leaflet, the suture is turned as in the conventional method to gain the right atrial aspect at the base of this leaflet. The remainder of the suturing and weaning off bypass are similar to that of the conventional method.

Detachment of the anteroseptal commissure or the septal leaflet of the tricuspid valve was performed whenever necessary in either group to access the corresponding margins of the defect. The detached leaflet was reattached at the completion of the procedure using 6.0′ polypropylene interrupted sutures or incorporated into the suture line at the superior aspect reinforcing the same in the pericardial strip. All repairs were verified by intraoperative transesophageal echocardiography immediately on weaning off bypass during the period of modified ultrafiltration.

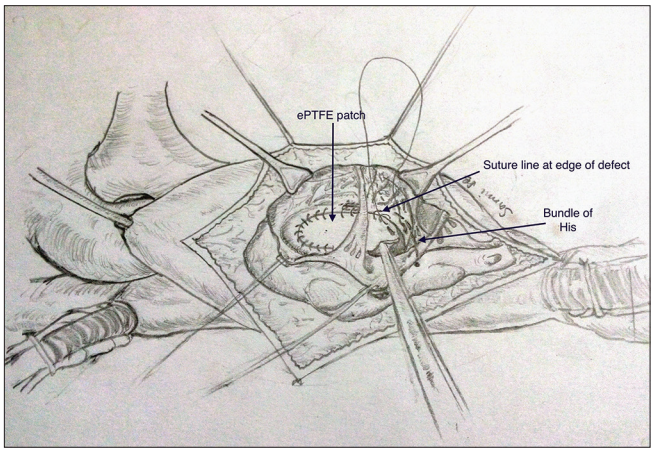

Figure 3: "Excluding" technique of ventricular septal defect closure with suture line on the edge of the defect

RESULTS

Mean aortic cross-clamp (ACC) time was 144.5 ± 74.07 min in Group A and 144.4 ± 83.38 min in Group B (*P* value = 0.034) [Tables 3 and 4].

There were five patients (2.1%) from Group B who developed surgically induced complete heart block (CHB) that required insertion of permanent pacemaker whereas none of those from Group A developed CHB (*P* = 0.02). The incidence of temporary CHB that reverted to sinus rhythm was nil in Group A and eight (3.4%) in Group B (*P* value 0.03). The mean duration of heart block in these patients was 36 h.

Temporary junctional ectopic tachycardia (JET) was observed in one patient in Group A (0.65%) whereas six patients (2.5%) developed this event in Group B.

Fifty-nine patients (25.1%) from Group B developed right bundle branch block (RBBB) whereas only 13 (7.47%) developed this from Group A in the immediate postoperative period. This showed statistical significance (*P* value = 0.0005).

In-hospital mortality was three (1.7%) in Group A and 16 (6.8%) in Group B (*P* = 0.04). These were not related to the ventricular septal defect or the technique used to close them. They were related rather to the associated cardiac anomaly these patients had. The causes of death for these patients are listed in Table 5.

There was no incidence of significant tricuspid regurgitation in either group. One hundred and seventy nine (43.8%) patients underwent right ventriculotomy as part of the repair. These were for the insertion of the transannular or infundibular patches in patients with Tetralogy of Fallot physiology. None of the patients in

Table 4: Overall results

	Group A	Group B	Total	*P*
No of patients (*n*)	174	235	409	
Mean AXC time (min)	144.5±74.07	144.4±83.38		0.034
Ventriculotomy	74 (42.5%)	107 (45.5%)	181 (44.2%)	0.521
CHB	0 (0%)	5 (2.1%)	5 (1.2%)	0.02*
RBBB	13 (7.5%)	59 (25.1%)	72 (17.6%)	0.0005*
Residual VSD	0 (0%)	1 (0.6%)	1 (0.29%)	0.361
Tricuspid regurgitation	0 (0%)	1 (0.6%)	1 (0.29%)	0.361
Temporary CHB	0 (0%)	8 (3.4%)	8 (1.95%)	0.03*
JET	1 (0.65%)	6 (2.5%)	7 (1.71%)	0.32
Followup (FU)	127 (72.9%)	162 (69%)	289 (70.6%)	0.04*
FU duration (months)	6.1±4.8	6.15±5.62	5.02	0.817
Mortality	3 (1.7%)	16 (6.8%)	19 (4.64%)	0.04*

AXC: Aortic cross clamp, CHB: Complete heart block, JET: Junctional ectopic tachycardia, RBBB: Right bundle branch block, VSD: Ventricular septal defect *Significant values

the isolated VSD group underwent right ventriculotomy to access the VSD.

Postoperative followup was 70% complete with a mean duration of 5 months. There were no late deaths or reinterventions during the follow-up period in either group (surgical or catheter based) for residual VSDs. Electrocardiograms on follow-up showed no cases of late-onset heart block or incidence of new arrhythmias in either group. The results are summarized in Table 4.

The patients with isolated VSDs were separately analyzed for similar variables as in the previous subset. Mean ACC times were 108.28 ± 65.59 min and 89.46 ± 47.62 min in Group A and Group B, respectively ($P = 0.291$). There were no incidence of CHB or residual defects in either group in this subset of patients, neither was there any incidence of temporary heart block in either group. The incidence of postoperative RBBB was, however, lower in Group A (4.76%) than in Group B (12.32%) although this failed to show statistical significance (P value = 0.054). Temporary JET was seen in one (2.0%) patient in Group A and none in Group B. There was no hospital mortality in either group. Followup was 72% complete with a mean duration of 6.2 months for both the groups; similar to the earlier subset, there were no incidence of late-onset arrhythmias or late-onset heart block.

When the results in infants were analyzed, it was found that the outcomes were similar in both the groups. The duration of VSD closure (ACC times) were not significantly different as were the incidence of surgically induced heart block, residual VSDs, or tricuspid regurgitation. The incidence of RBBB was significantly higher in Group B ($P = 0.02$) [Table 3].

DISCUSSION

Surgical closure of ventricular septal defects is one of the safest procedures in modern pediatric cardiac surgical practice. Most centers now have mortality rates less than 1% for isolated single VSDs.[1,2] The risks may be marginally higher when associated anomalies are present and these are due, in large part, to the coexistent anomaly than the VSD itself. The techniques of VSD closure have evolved to the extent that complications are also minimal in most units worldwide. The incidence of CHB is approximately 1%.[3,4] The incidence of RBBB is 6-20% in different series.[5] Of crucial importance to the procedure are the measures taken to avoid damage to adjacent structures ensuring complete closure of the defect leaving no residual shunts. The structures most likely to be at risk during the operation are the tricuspid valve apparatus, the aortic valve, and the conduction system.

Evolution of the surgical techniques for VSD closure has brought about two main methods: The interrupted and the continuous suture techniques. The interrupted suture technique utilizes multiple pledget-reinforced monofilament or multifilament sutures whereas the continuous suture technique uses a single suture of monofilament material to achieve the closure. The advantages of one over the other seem negligible. There are significant number of surgeons that employ a combination of the interrupted and continuous suture techniques.

The anatomy of the cardiac conduction system has been demonstrated in normal hearts and in heart with ventricular septal defects.[6,7] Using gross anatomical dissection as well as microscopy with histochemical studies, the atrioventricular node has been localized in the apex of the triangle of Koch and opposite the anteroseptal commissure of the tricuspid valve [Figure 4]. The bundle of His penetrates the central fibrous body and descends closely related to the posterior inferior margin of the VSD on the left ventricular side of the septum. Of surgical significance vis-à-vis, the "excluding" technique is the feature that closely related to the annulus of the tricuspid valve at the posterior margin of the VSD also this anatomical arrangement is preserved. The bundle descends till the level of the septal papillary muscle where it then divides into the right and left Purkinje fibers. The right bundle branch courses toward the moderator band. This anatomical arrangement is preserved in all

Table 5: Causes of death

	Group A	Group B
LCOS	1	5
MODS, DIC	1	1
Persistent LCOS + ARF	1	2
Refractory JET + LCOS + ARF	0	2
Recurrent tonic Seizures	0	3
Respiratory Failure Rt lung collapse	0	1
Sepsis	0	1
Total	3	16

ARF: Acute renal failure, JET: Junctional ectopic tachycardia, LCOS: Low cardiac output state, MODS: Multiple organ dysfunction syndrome

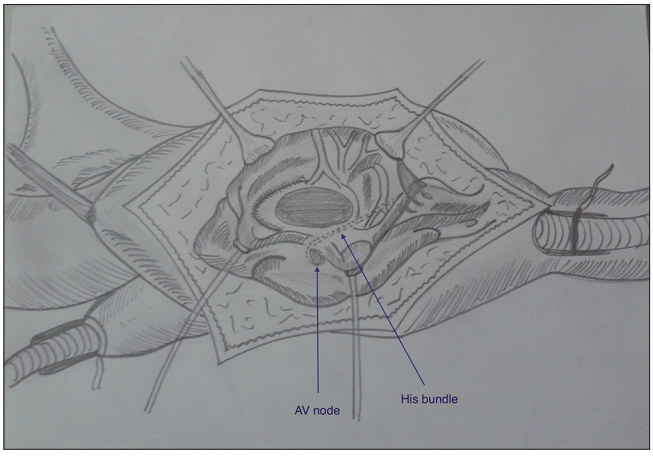

Figure 4: Course of the specialized atrioventricular conduction pathway

interventricular septal defects that are situated inferior to the crista supraventricularis (infracristal VSDs) and adjacent to the annulus of the tricuspid valve.

Most surgeons place sutures about 4-5 mm from the margin at the posterior inferior aspect of the defect to avoid injury to the conduction system. Although this is the time-honored method with good results, we aim to popularize the alternative technique wherein the sutures at the posterior and inferior margin are also along the edge of the defect. This technique takes advantage of the anatomical arrangement wherein the penetrating bundle of His lies on the left ventricular side of the defect and not on the right. Although this alternative technique has many proponents and is quite popular, there is scarcity of data in the literature comparing the two methods. Fukuda *et al*.[5] demonstrated a significantly lower incidence of complete RBBB when the sutures are taken closer to the rim of the defect along the posterior and inferior margin of the VSD.[5] Their technique, however, involves placing these sutures within 4 mm from the edge of the defect. Our technique differs from theirs in that these sutures are in fact taken right on the edge of the defect, within 1 mm. Our study shows the incidence of RBBB to be significantly lower in the "excluding" technique group. This is particularly evident in the subset wherein infants were analyzed separately. Age as a variable was not a factor in the development of CHB or RBBB in our study; both groups were evenly matched for age. Infants were separately analyzed in this study to exclude bias. Right ventriculotomy was also not a variable for the incidence of RBBB as mentioned by Van Lier *et al*.[8,9] Incidence of CHB in our study compares favorably with the published literature.[3,4] However, there is a significantly increased incidence of CHB in the conventional method group when all patients were analyzed together. This significance did not show up in the isolated VSD subset or when infants were separately analyzed. Probably, this was a statistical aberrance and not a true-positive result. The incidence of temporary CHB that reverted to sinus rhythm was, however, significantly more in the conventional technique group. This does imply that the suture bites were probably placed rather close to the specialized conduction tissues in this group of patients than in the "excluding" technique group.

It is not uncommon to have the tensor apparatus of the tricuspid valve lying across the margins of the defect on both the anterior and the posterior aspects. The presence of these chordae tendinae necessitates careful placement and weaving of the sutures to work around them so as to seat the patch beneath these structures. Failure to do so would restrict these chords and lead to tricuspid insufficiency postoperatively. Improper placement of sutures around these chords may also lead to significant residual defects. The threshold for detaching the septal leaflet of the tricuspid valve to gain access to the margins of the defect was low in either group. There was no incidence of significant tricuspid regurgitation because of leaflet restriction using either technique.

With these concerns in mind, the "excluding" suture technique was chosen as an alternative method to close these infracristal VSDs. The technique is similar in all aspects to the conventional continuous method with the exception that the bites along the posterior and inferior margins of the septum are placed superficially and along the edge of the defect on the right ventricular side of the septum. While placing these sutures and, therefore, the patch "within" the area occupied by the bundle of His, the bundle is "excluded" from the patch and damage to the bundle is avoided in the same manner as placing the sutures outside the area of the bundle thereby seating the patch over the penetrating bundle of His. Apart from avoiding injury to the bundle of His and the right bundle branch, this "excluding" suture technique seems easier to avoid all the tensor apparatus of the tricuspid valve because the suture bites are on the edge of the defect "thereby "excluding" the chords of the tricuspid valve as well the chordae of the tricuspid valve.

The "excluding" suture technique, however, requires that the bites along the posterior inferior margin are shallow bites; care must therefore be taken that they are strong enough to prevent the sutures from avulsing through the muscle while the assistant follows the same. This technique by necessity uses a patch of smaller dimension than the regular suture technique; it is therefore important to ensure that the patch is not unduly small as to get avulsed during the period when cardiac activity resumes. These are, however, theoretical considerations and the authors have not experienced any instance of the patch getting avulsed in the postoperative period or on followup. There was no significant difference in the incidence of residual VSD in either group. There was also no incidence of patch dehiscence early or late on followup in either group.

The ACC times when analyzed for isolated VSDs were similar in either group suggesting that the procedure is easily performed irrespective of the technique used.

Another situation arises when a bunch of chordae lie across the posterior margin of the VSD close to the tricuspid annulus with gaps between them and the defect further posteriorly extends for a short distance. The conventional technique may be difficult to perform in this situation and care needs to be taken while weaving around the chordae. Some surgeons make a small slit in the patch to accommodate this bunch of chords whereas others suture over these chords immobilizing them thereby leading to some degree of tricuspid regurgitation. The "excluding" technique avoids this problem by staying exactly on the margin of the defect

thereby leaving the chords of the tricuspid valve untethered by the VSD patch. The septal leaflet of the tricuspid valve may be detached to facilitate this step of the operation. It also avoids having to make slits in the patch to accommodate the chordae, which may lead to residual shunts through the slit.

Although it is usual practice for surgeons to call their own preferred techniques as "conventional," the term is employed in this article to specifically denote the technique of VSD closure described in standard textbooks of congenital cardiac surgery.[4]

Limitations of the study

The main limitation of this study is probably the higher age in both the groups leading to skewed mean values for age and weight. Median values were therefore chosen to represent these variables. In addition, infants in the study were separately analyzed to emphasize the feasibility of employing the "excluding" technique irrespective of age and weight (Table 2 shows the experience in neonates with transposition of great arteries and interrupted aortic arch).

CONCLUSION

Surgical closure of VSDs can be accomplished with comparable results irrespective of the technique employed, whether the suture bites are taken along the margin of the defect or distant from the margin as in the conventional method. The long-term consequences of RBBB need to be assessed. A larger multicenter study may be required to confirm the significance of these findings. The "excluding" technique may be technically easier to perform when the tensor apparatus of the tricuspid valve lies across the posterior inferior margin of the defect.

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Conflicts of interest

There are no conflicts of interest.

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