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ORIGINAL ARTICLE

# Three-port totally endoscopic repair vs conventional median sternotomy for atrial septal defect

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## Abstract

**Purposes** We assessed the validity of three-port totally endoscopic repair (3PTER) for atrial septal defect (ASD).

**Methods** Between February, 2000 and November, 2017, 151 patients underwent surgery for ASD. Forty-seven patients underwent 3PTER as minimally invasive cardiac surgery (MICS) and 104 patients underwent conventional median sternotomy (CMS). Propensity matching yielded 94 matched patients (47 vs 47). We compared the early results between the groups. The 3PTER technique was performed with the patient in the partial left lateral position, under cardio-pulmonary bypass (CPB) established through a groin incision. The three ports consisted of a main incision (3 cm), a trocar for the left-handed instrument, and a camera port in right antero-lateral chest.

**Results** MICS needed longer cross clamp and CPB times (57, 48–86 vs 24, 16–30 min, $p < 0.01$ and 115, 106–131 vs 53, 43–80 min, $p < 0.01$, respectively)*, although the operation time and hospital stay were significantly shorter (180, 159–203 vs 190, 161–225 min, $p = 0.024$ and 6.0, 6–8 vs 15, 13–19 days, $p < 0.01$, respectively)*. The intra-operative and postoperative bleeding were significantly less in MICS than CMS (20, 5–40 vs 225, 130–287.5 $p < 0.01$ and 200, 145–290 vs 340, 250–535 ml, $p < 0.01$, respectively)*. *: median, 25th–75th percentile.

**Conclusion** Irrespective of the longer CPB and cross-clamp time than for CMS, MICS had a shorter operation time, less bleeding, and resulted in quicker recovery. The 3PTER was safe and cosmetically excellent.

**Keywords** Minimally invasive cardiac surgery · Atrial septal defect · Endoscopic surgery

## Introduction

There are considerable differences in the cosmetic outcome and invasiveness between surgery using the standard median sternotomy and Amplatzer septal occlusion (ASO) to repair an atrial septal defect (ASD) [1, 2]. However, open surgery is still needed for some patients who are not suitable candidates for ASD occlusion with catheter devices or who need concomitant surgery, such as tricuspid valve annuloplasty. Recently, minimally invasive cardiac surgery (MICS) or robotic surgery using the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) has become popular and is associated with almost 0% mortality and morbidity rates for ASD repair, allowing early return to normal daily activities, less pain, and better cosmetic results [3–12].

Regarding the cosmetic outcome and postoperative pain, video-assisted direct vision MICS for ASD reportedly needs a 5–8 cm skin incision with a metal rib spreader, whereas the da Vinci system needs smaller incisions and no rib spreader. However, four-to-five stab wounds are necessary for the robotic arms and aortic clamp, in addition to a service port for the surgeon on the patient side [9–11]. We previously reported a three-port totally endoscopic surgical system without robotic assistance for mitral valve surgery [13] and applied this system to ASD surgery. We assessed the validity and safety of three-port totally endoscopic repair (3PTER) for ASD.

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## Patients and methods

Between February, 2000 and November, 2017, 151 patients (48 female and 103 male patients; median age, 37.7 years; range 0–80 years) underwent surgery for ASD at our institution. Data were collected retrospectively. Forty-seven patients underwent MICS with 3PTER and 104 patients underwent a conventional median sternotomy (CMS). For MICS, the minimum body height was set at 140 cm for peripheral cannulation and space of the thoracic cavity that is necessary for endoscopic work. Because of the different indications, the unadjusted backgrounds between the two groups were significantly different. Therefore, propensity matching was performed using age, height, and type of ASD as matching factors, and 47 matched pairs (94 patients) were yielded. Early results were compared between the two matched groups. Chronological change of the procedural time in the 3PTER group was plotted as a learning curve. Our Institutional Review Board approved endoscopic cardiac surgery including 3PTER (number 2015-038), and consent by the individual patients was waived because of the retrospective nature of this study.

### Surgery

#### 3PTER

After the induction of general anesthesia, the patient was placed in a partial left lateral position, raising the right elbow over the face, and cardio-pulmonary bypass (CPB) was established through a groin incision. We measured the diameter of the femoral artery preoperatively, using plain computed tomography (CT) in young patients, or enhanced CT in elderly patients. A mixture of 5 ml of 1% milrinone and 15 ml of 1% lidocaine was injected locally into the vascular sheaths of the right iliac and femoral arteries via the groin incision to prevent arterial spasm, using a small dilator for the Seldinger technique. The inflow cannula was inserted by only 4–5 cm, to preserve distal perfusion through the side holes of the cannula. Oxygen saturation of the lower leg muscles was monitored continuously using a near infra-red wave monitoring system. The three ports consisted of a 3 cm main incision in the 4th intercostal space, a 5 mm trocar incision in the 3rd intercostal space for the left-handed instruments, and a 5 mm or 11 mm camera port incision in the 4th or 5th intercostal space (Fig. 1). A wound protector (Alexis wound protector XS, Applied Medical, Rancho Santa Margarita, CA, USA) was used to open the intercostal space, but a metal rib spreader was not used. An aortic clamp, cardioplegic cannula, suction, vent, $CO_2$ insufflation tube, and atrial retractor were

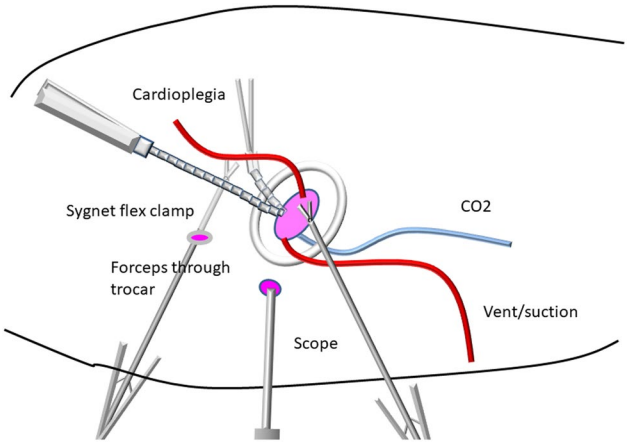


**Fig. 1** Schema of three-port repair of atrial septal defect. Main window is created in the 4th intercostal space. 5 mm trocar as left-handed working port is placed in the 3rd intercostal space. Endoscopic port is placed posterior to these working ports. All cannulae, and aortic clamp are inserted through the main window

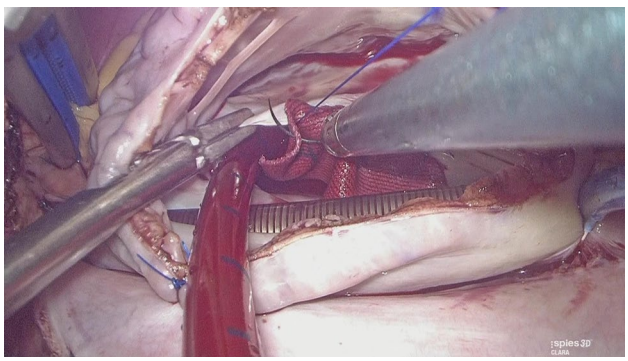

**Fig. 2** Intra-operative endoscopic view. Atrial septal defect was closed with a Dacron patch. The forceps and the needle holder keep appropriate angle owing to independent working ports

all inserted through the main window in the 4th inter-costal space. In early cases, an additional venous cannula was inserted directly into the superior vena cava through the main window. In recent cases, we used a two-stage venous cannula (Next Gen, Biomedicus, Medtronic, Minneapolis, MN, USA) without an additional venous cannula. When there was a persistent left superior vena cava, a suction tube was placed directly into the coronary sinus to draw the venous return. The body temperature was cooled to 32° centigrade. The ASD was closed under cardioplegic arrest, or low body-temperature ventricular fibrillation. We used a 2D high-definition endoscope, or a 3D high-definition endoscope (IMAGE1 S™ 3D, Karl Storz, Tuttlingen, Germany). The endoscope was controlled manually by an assistant surgeon throughout the procedure, so that the target site could be seen in the middle of the monitor, between right- and left-handed instruments (Fig. 2).

## Statistical analysis

Quantitative variables are expressed as means ± the standard deviation if normally distributed; otherwise, as the median and 25–75 percentile. Categorical variables are expressed as numbers. Statistical significance was evaluated using the Student's *t* test or non-parametric equivalent (the Mann–Whitney *U* test) for continuous variables. $\chi^2$ analysis or Fisher's exact tests were used for categorical variables. All statistical tests were two-sided, with significance set at $p < 0.05$. SPSS version 22.0 software (IBM, Chicago, IL, USA) was used for statistical analysis.

## Results

There were no significant differences in preoperative patient characteristics after matching (Table 1). As concomitant surgeries, tricuspid valve annuloplasty was more frequently performed in the MICS group than in the CMS group (14 vs 5 cases, respectively). Combined malformations included persistent left superior vena cava in two MICS patients and a partial anomalous pulmonary venous connection in three CVS patients. Most of the patients had an ostium secundum ASD; however, one patient each in the MICS group had ostium primum and coronary sinus ASD.

There were no hospital deaths.

**Table 1** Preoperative clinical characteristics

| Characteristics | MICS ($n = 47$) | CMS ($n = 47$) | $p$ value |
|---|---|---|---|
| Age (years)[a] | 44 (14–63) | 47 (16.61) | 0.724 |
| Sex (female)[b] | 13 (27.6) | 23 (49.0) | 0.055 |
| Body height (cm)[a] | 154 (148–162) | 157 (150.5–164) | 0.293 |
| Body weight (kg)[a] | 52.5 (148–157) | 52.5 (44–60) | 0.374 |
| $Q_p/Q_s$[a] | 2.3 (1.9–3.15) | 2.7 (2.0–3.35) | 0.365 |
| PAP (mmHg)[a] | 36 (28.75–40.0) | 33 (25.0–37.5) | 0.319 |
| Combined malformation ($n$)[b] | 2 (4.2) | 3 (6.3) | 0.889 |
| Concomitant surgeries ($n$)[b] | 15 (31.9) | 8 (17.0) | 0.093 |
| Tricuspid valve repair[b] | 14 (29.8) | 5 (10.6) | 0.038 |
| Mitral valve repair[b] | 5 (10.5) | 1 (2.1) | 0.2 |
| Maze[b] | 1 (2.1) | 5 (10.5) | 0.2 |
| Type of defect | | | |
| Ostium secundum[b] | 45 (95.8) | 44 (93.7) | |
| Ostium primum[b] | 1 (2.1) | 0 | |
| Sinus venosus[b] | 0 | 3 (6.3) | |
| Coronary sinus[b] | 1 (2.1) | 0 | |

*MICS* minimally invasive cardiac surgery, *CVS* conventional median sternotomy, *PAP* pulmonary artery pressure

[a]Data are expressed as the median (25th–75th percentile)

[b]Data are expressed as *n* (%)

There were no major adverse cardiac events in the MICS group, but two events (4.2%) in the CMS group ($p = 0.557$; Table 2). Minor adverse events included pericardial effusion in the MICS group and misplacement of a piece of gauze in the CMS group. Postoperative blood loss was significantly less in the MICS group. No patient in the MICS group showed undue elevation of the CPB circuit pressure of the inflow side as a sign of iliac artery spasm, and no additional cannulation was needed. Oxygen saturation of the lower extremities dropped in some patients, but additional distal perfusion was not performed, because the CPB time was anticipated to be short enough. Almost all patients needed only an overnight stay in ICU, although the postoperative hospital stay was significantly shorter in the MICS group.

Table 3 summarizes the operative data. MICS needed a longer cross-clamp time and a longer CPB time, but the mean operation time was significantly shorter. Intraoperative bleeding was also less in the MICS group than in the CMS group. Patch closure was done for almost all of the MICS patients, but for only about 50% of the CMS patients.

Figure 3 shows a representative postoperative cosmetic outcome of MICS. Figure 4 shows the chronological change in the total operative time in the MICS group. This learning curve improved gradually throughout the study period. The total operation time has now been reduced to approximately 2 h.

**Table 2** Postoperative results

| Variables | MICS ($n = 47$) | CMS ($n = 47$) | $p$ value |
|---|---|---|---|
| Major adverse events[a] | 0 | 2 (2.4) | 0.495 |
| Conversion | 0 | NA | |
| Hospital mortality | 0 | 0 | |
| Stroke | 0 | 0 | |
| Aortic dissection[a] | 0 | 1 (2.1) | |
| Re-exploration for bleeding[a] | 0 | 1 (2.1) | |
| Minor adverse events[a] | 1 (2.1) | 3 (6.3) | 0.617 |
| Paroxysmal atrial fibrillation[a] | 0 | 2 (4.2) | |
| Others[a] | 1 (2.1) | 1 (2.1) | |
| Total complications[a] | 1 (2.1) | 5 (10.5) | 0.091 |
| Ventilation time (hours)[b] | 5 (3–6) | 4 (2.5–8) | 0.698 |
| ICU stay (hours)[b] | 23.0 (22–24) | 21.0 (20–23) | 0.480 |
| Hospital stay (days)[b] | 6.0 (6–8) | 15 (13–19) | < 0.01 |
| BTF ($n$)[a] | 7 (14.7) | 5 (10.5) | 0.759 |
| Bleeding in 24 h[a] | 200 (130–287) | 340 (250–535) | < 0.01 |

*MICS* minimally invasive cardiac surgery, *CMS* conventional median sternotomy, *ICU* intensive care unit, *BTF* blood transfusion

[a]Data are expressed as *n* (%)

[b]Data are expressed as the median (25th–75th percentile)

**Table 3** Operative data

| Variables | MICS ($n = 47$) | CMS ($n = 47$) | $p$ value |
|---|---|---|---|
| Operation time (min)[a] | 180 (159–203) | 190 (161–225) | 0.024 |
| CPB time (min)[a] | 115 (106–131) | 53 (43–80) | < 0.01 |
| Ao XC time(min)[a] | 57 (48–86) | 24 (16–30) | < 0.01 |
| Patch/direct closure ($n$) | 42/5 | 25/22 | < 0.01 |
| Operative bleeding (ml)[a] | 20 (5–40) | 225 (130–287) | < 0.01 |

*MICS* minimally invasive cardiac surgery, *CMS* conventional median sternotomy, *CPB* cardio pulmonary bypass, *Ao XC* aorta cross clamp

[a]Data are expressed as the median (25th–75th percentile)

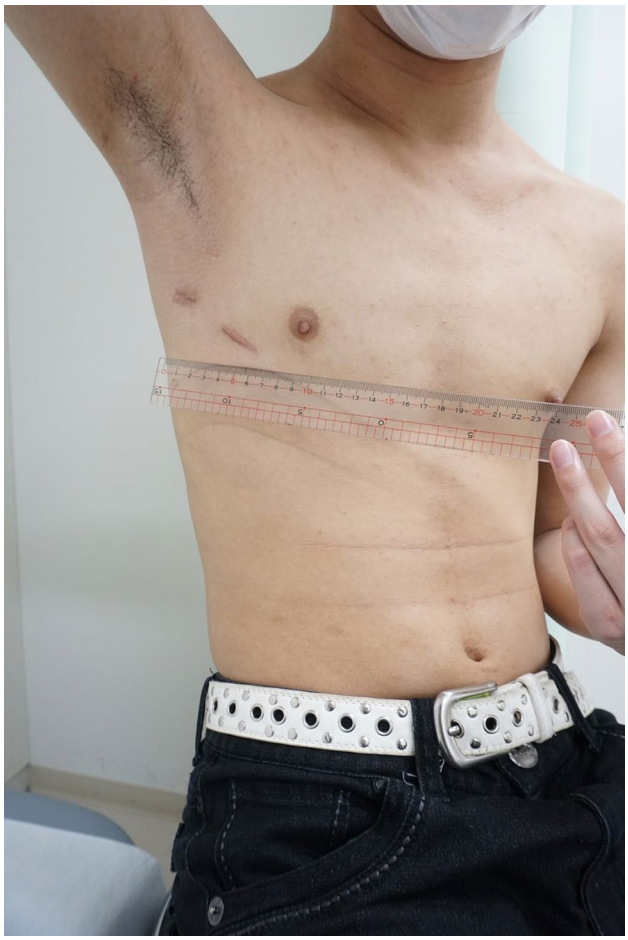

**Fig. 3** Postoperative wound after three-port endoscopic repair of ASD. There are only three small scars located in right antero-lateral chest. Wound for aortic clamp, or atrial retractor is not necessary. These are inserted through the small main window

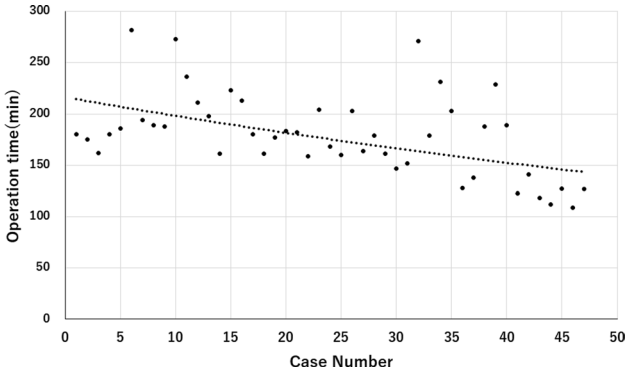


**Fig. 4** Change in operation time in three-port endoscopic repair of ASD. Operation time showed gradual decrease, and did not reach plateau during this study period. Operation time of last several cases was about 2 h

## Discussion

### Safety endpoints and invasiveness

Surgery for ASD is considered safe, with a mortality rate of 0–0.3% according to the annual report of Japanese Association for Thoracic Surgery [14]. Because surgery for ASD is relatively simple, both a minimally invasive technique via a small right thoracotomy and a totally endoscopic technique using the da Vinci surgical system have been attempted, with mortality rates of almost 0% [3–12]. We proposed the three-port totally endoscopic system for mitral valve surgery to improve the video image and handling of instruments by keeping an appropriate angle between the instruments inserted through independent ports. Fewer ports are necessary for our system than for the da Vinci surgical system, and the cost is lower [9–11].

In this study, 3PTER was as safe as median sternotomy, although the CPB and aortic clamp time was longer. In the MICS group, most of the patients required patch closure. Some recent patients were referred for surgery because closure with catheter devices would not work, and consequently, they have large or complicated defects. The higher ratio of patch closure and tricuspid valve annuloplasty in the MICS group may have extended the aortic clamp and CPB times. Irrespective of the longer CPB time, 3PTER reduced the postoperative hospital stay and bleeding significantly, implying less invasiveness.

Young patients tend to have arterial spasms during CPB through a groin incision. We used the topical application of a mixture of milrinone and lidocaine, both potent vascular dilators, to prevent arterial spasms. Although we could not show the effectiveness of this maneuver statistically in this study without a control group, there was no case of undue elevation of CPB circuit pressure.

### Learning curve

The initial cases required an operation time of more than 3 h. Several years of experience have reduced the operation to within 2 h when performed by an experienced surgeon,

equivalent to the operation time when the procedure is done through a median sternotomy. The learning curve did not show a typical learning phase and plateau phase, but rather linear improvement throughout the study period. We performed more than 300 cases of three-port endoscopic mitral valve surgeries during the period of this study, which may have contributed to our familiarization with endoscopic surgery. Moreover, the 3D endoscope was introduced in 2015 and the two-stage venous cannula also became available. Our experience and the new devices may have contributed to the improvement of the learning curve. Therefore, it was difficult to define the case number necessary to become accustomed to the endoscopic ASD closure, according only to data in this study. We estimate that experience of up to 100 endoscopic cardiac surgeries is necessary to achieve competence [13], although the 3D endoscope may reduce the learning period.

### Indications for MICS and timing of surgery for ASD

As our data and previous reports have shown, MICS for ASD can be performed safely with excellent cosmetic results. However, small children are not suitable candidates for this surgery, because endoscopic MICS usually needs the establishment of CPB through peripheral cannulation. Our youngest patient was 10 years. Surgery for ASD is often performed before school age via partial or full sternotomy, or right thoracotomy. However, a small scar in childhood becomes larger in time and sternotomy or thoracotomy in childhood can lead to deformity of the thorax. On the other hand, symptoms and complications of untreated ASD usually develop in adulthood. We suggest the necessity of early surgery for ASD be considered if MICS becomes popular.

### Limitations

This study has several limitations. First, it was a single institution, retrospective study with a limited number of patients. Although propensity score matching was applied, the operation periods differed between the MICS and CMS groups. CMS was performed predominantly in the first half of the study period and MICS was started in 2012. The surgeon in charge of congenital heart disease also changed during the study period. Second, in the CMS group, the mean operation time appeared to be longer than expected. Most of the CMS cases were assigned to trainees, whereas the MICS cases were performed by consultant surgeons (TI and AM). However, no transection of bones and limited incisions in size and number in 3PTER enabled quick opening of the chest, and easy confirmation of hemostasis before closure of the chest. This benefit of 3PTER may have shortened the total operation time and decreased bleeding irrespective of the expertise of the surgeon. Third, the policy within the health insurance system changed during the study period, in that early discharge was not supported previously, but now it is encouraged to reduce insurance costs.

## Conclusion

Irrespective of the longer CPB and cross-clamp times than required for CMS, MICS needed a shorter procedure time and resulted in significantly less bleeding and quicker recovery. The 3PTER for ASD was safe and cosmetically excellent.

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### Compliance with ethical standards

**Conflict of interest** We have no conflicts of interest to declare.

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