

Review

Innovations and Developments in Totally Thoracoscopic Cardiac Procedures

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Abstract

New technology is increasing being introduced to minimizing the invasiveness of cardiac surgery. In addition to catheter based interventions and robotic-assisted procedures, totally thoracoscopic cardiac surgery (TTCS) has emerged as a new minimally invasive technique in the cardiac surgeons' armamentarium to treat cardiovascular disease. This review summarizes the existing literature on TTCS and provides updates on the exploration and management of TTCS in various cardiac diseases including mitral and tricuspid valve dysfunction, congenital heart defects, tumors, and hypertrophic obstructive cardiomyopathy. Due to small port incisions and high cost-effectiveness, TTCS has been increasingly embraced by both patients and surgeons. This review summarizes the literature on TTCS and how it may minimize the morbidity associated with open cardiac surgical procedures and result in faster recovery and earlier discharge from the hospital.

Keywords

cardiac surgical procedure; totally thoracoscopic cardiac surgery; innovations

Background

Minimally invasive cardiac surgery (MICS) is being increasing employed to treat cardiac disease world-wide. A wide range of MICS has been embraced by cardiac surgeons in the management of a wide variety of cardiac structural diseases. Along with robotic-assisted cardiac surgery (RACS), and partial sternotomy to preserve the integrity of the thoracic wall [1], totally thoracoscopic cardiac surgery (TTCS, Fig. 1) has been increasingly used in the last decade.

This surgical approach is growing in popularity not merely because of its minimal invasive approach standards as seen with video-assisted thoracoscopic cardiac surgery (Fig. 2), but because it does not require sophisticated operational systems or expensive disposable materials, which is a major advantage in low and middle-income countries. The thoracoscopic approach depends heavily on the surgeons' manual techniques due to a lack of many advanced controlling programs such as speech recognition, position control and simulation operation such as seen in the RACS system. The surgeons using TTCS should be experienced in conventional cardiac surgery techniques and also good at handling the endoscopic system. We reviewed the literature in PubMed with the words "totally thoracoscopic cardiac procedure" or "totally thoracoscopic cardiac surgery" and excluded "robotic assistance" and "atrial fibrillation ablation". The majority of the eligible studies on TTCS were from China and were mostly characterized by observational reports with a small sample size, or by comparative studies with cardiac surgery performed via median sternotomy. Young (<2 years old) or older (>80 years old) patients were not conventionally included. Recognizing the advantages and the challenges of TTCS, we have reviewed the innovative achievements and practical experiences that promise to improve the procedure's technique.

Technology Innovations

The Shortened or Simplified Incisions

MICS shares the advantage of preservation of the sternal integrity and stability, and/or without traditional cardiopulmonary bypass (CPB), which differs from a median sternotomy. Unlike many kinds of MICS, the surgeons performing TTCS fail to obtain touch feedback through direct vision, but only depend on video signals from optical reflection of the thoracoscopy system [2]. The incision has

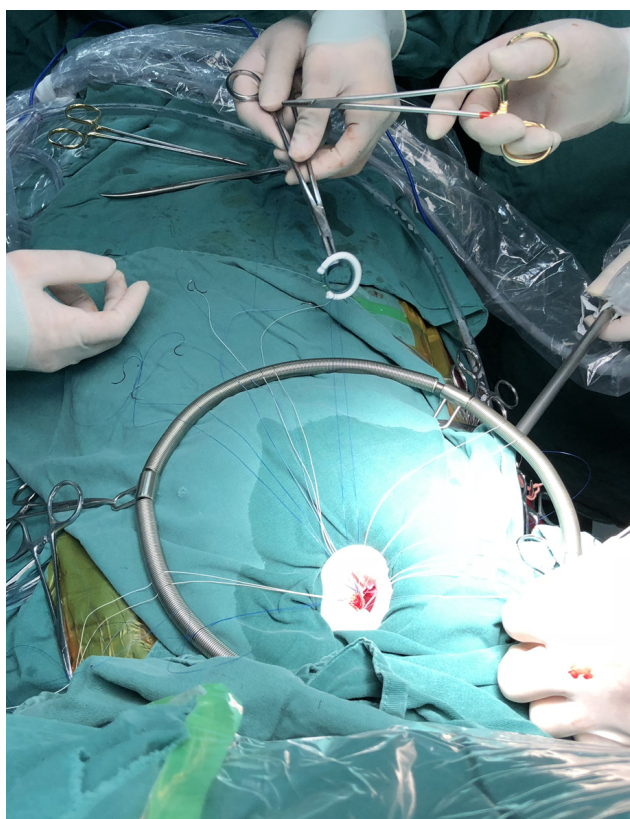


Fig. 1. The totally video-assisted thoracoscopic procedure for partial endocardial cushion defect. The thoracoscope was inserted from the port at fifth intercostal space in the totally thoracoscopic cardiac surgery. The main incision is about 3-cm length.

evolved to several intercostal ports in the chest wall like RACS, which differs from a longer and curved one in many other MICS procedures. The incision is further simplified into two ports with the longest incision being 3 cm which has been shown to be both feasible and safe [3]. For patients with secondary tricuspid insufficiency after previous left-sided valve surgery, tricuspid valvuloplasty can be successfully performed by TTCS with one port since it is not necessary for aortic cross clamping and to deliver cardioplegia [4]. Additionally, the total number of incisions in TTCS is also less than that in RACS, which usually needs four auxiliary ports and a working port in the right chest wall [5]. Consequently, surgical incisions of the TTCS provide improved cosmesis according to scar cosmesis assessment and rating scales, especially in those susceptible patients with a high risk of developing keloid and hypertrophic scars [6].

The Incision Layout

The operative position for TTCS is supine with the right hemithorax elevated to 20–30° and the right arm suspended onto the anesthesia rack. The incisions of the TTCS are mainly classified into two kinds depending on the procedure: (1) atrial septum defect (ASD) repair, tricuspid valve surgery, and anomalous pulmonary venous drainage correc-

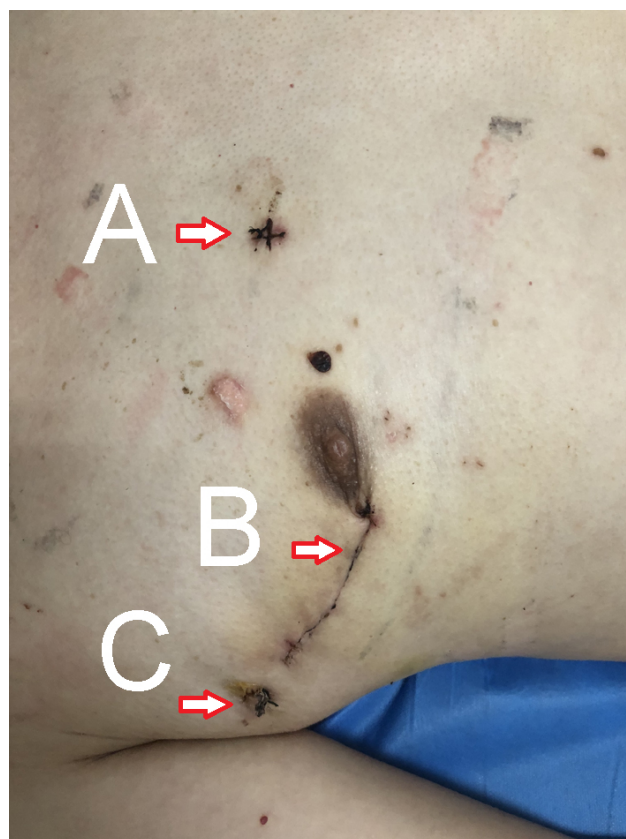


Fig. 2. The incision layout of minimally invasive cardiac surgery with assistance of the thoracoscope. The thoracoscope is placed from the upper port adjacent to the axillary region (port C). Port A is for inserting the instrument to lift up the left atrium. Port B is the main incision of 7–10 cm length.

tion such as the Warden procedure; (2) mitral valve procedures (MVP), partial endocardial cushion defects, excision of atrial myxomas [7], and modified Morrow procedures [8]. Alternatively, the mitral valve replacement could also be achieved by Ma's tri-port thoracoscopic system whose layout is distributed as an inverted triangle [9]. The cardiotomy is made through the right atrium in the former and via the interatrial sulcus in the latter. The layout of the incisions for right-sided procedures is distributed in a triangle around the periphery of the breast. The main working port is oriented near the sternum in the third intercostal space for the passage of surgical instruments such as scissors and needle holders, medical wastes or artificial materials. This port is shifted nearer to the midclavicular line in the fourth intercostal space for left sided surgery to oversee the working field in the left atrium. To expose the mitral valve, the roof of the left atrium is retracted by a blade retractor, which could be transferred easily in and out of the pleural cavity and fastened on the operating table. This mechanical component is usually customized into a spherical surface to prevent a stretch injury, and attached onto one shaft which penetrates through the chest wall and which is fixed on the operation platform with the aid of a set of hinges. The oper-

ative complexities, risks and complication rates of the right-sided operation are less than those of the left-sided mitral valve procedure. Therefore, the annual surgical volume is higher in the former than those of the latter. Many institutions that had launched the TTCS often began and continue with ASD repairs [10–12]. At present, although performing MVP using TTCS techniques has been increasing utilized in many centers, only a small number of dedicated centers use TTCS to do MVP.

The Thoracoscope Placement

When performing MICS with a thoracoscope, most surgeons are accustomed to placing the thoracoscope from the upper port adjacent to the axillary region. However, the upper port for the thoracoscope is replaced by the lower auxiliary port on the anterior axillary line at the fifth intercostal space in TTCS. This transposition allows the surgeon to operate comfortably without sacrificing adequate lighting. The assistant who manipulates the thoracoscope can comfortably stand next to surgeon [13].

The Streamlined Superior Vena Cava Drainage

Isolated tricuspid valve procedures can be performed with a cell saver collecting the blood return from the superior vena cava (SVC) and inferior vena cava drainage via femoral vein cannulation [14]. On the most occasions, SVC drainage should be manipulated after the right atrium is opened for better drainage. The great majority of MICS procedures use percutaneous right internal jugular vein (IJV) cannulation. However, the leakage from the IJV around the puncture site can result in subcutaneous congestion, and ultimately scars around the neck. The anesthesiologists have switched to bilateral IJV sheaths with appropriate sizes to puncture the vessels to overcome these leakage effects [15]. Transferring the puncture site from the neck to the subclavian region has resulted in better SVC drainage [16], and provides better cosmesis, but can still result in subclavian vein and brachial plexus injury and pneumothorax. Furthermore, the difficulty or failure from venipuncture manipulation could delay the initiation of the operation. Overcoming the obstacles with SVC drainage is still a key element for MICS. One simple solution to the problem is for surgeon to use longer surgical instruments to insert the rectangular head of the cannula into the SVC through a stab incision in the center of the purse string suture after the pericardiotomy [13]. This technique through the existing chest ports in the TTCS is similar to those used in a median sternotomy. There is no need for an additional skin incision or further manipulation from the anesthesiologist. This approach saves procedure time and the need for extra supplies.

Temporary Pacing Wire (TPW) Implantation

To prevent postoperative bradycardia or even cardiac arrest, TPW is conventionally sewed on the surface of the right ventricular free wall. A clear area is preferably selected to accommodate the entrance and exit of the electric wire head. Conventionally, this routine fixing and hemostasis procedure is using a knot of running suture around the two ends, which is easy to insert via a median sternotomy. However, the visual angle of the surgeon is in parallel with the surface of the right ventricle during TTCS because the manipulating posture is in alignment with the patient position of a left tilt of 20–30 degrees. This may be difficult to visualize, particularly when the heart is filled with blood. On occasion, the bleeding at the site of TPW is difficult to control and a second CPB and another mini-thoracotomy may be necessary to control the bleeding site [13]. A solution to this problem is fixing the TPW with a teflon cushion which is pressed by a titanium clip at both ends as a prophylactic measure to achieve hemostasis [17]. In this technique, the TPW is sewed into the center of a Teflon cushion and fixed with a titanium clip on a bare electrode head at its tail end, and then implanted into epicardium, being penetrated through another Teflon cushion and fastened using another titanium clip on the head end. The slight tension must be maintained by modulating the distance between the head and the tail ends without affecting the expansion after heart after it is filled with blood. For redo surgery involving a tricuspid valve prosthesis replacement or annuloplasty, the “bare” zone on the surface of right ventricular is unlikely to be accessible due to tissue adhesions and inflammatory hyperplasia. Another creative strategy is implanting the endocardial temporary pacing catheter into the right ventricle instead of the epicardial TPW [18].

Simultaneous Procedures and Emergency Salvage Surgery

Some concomitant diseases other than intracardiac lesions could be simultaneously treated by TTCS using the primary incisions or additional tiny incisions, such as a primary adenocarcinoma of the right upper lobe and severe mitral regurgitation [19]. Another case is a lacerated anterior mitral valve leaflet after percutaneous balloon valvuloplasty during an elective cardiac catheterization intervention which required urgent TTCS for mitral valve replacement [20]. Another case is a failed mitral valve clip implantation emergently transferred for TTCS redo mitral valve replacement [21]. All of the patients were successfully treated and discharged from the hospital uneventfully.

Practical Studies

TTCS requires close teamwork involving dedicated anesthesiologists, experienced perfusionists, proficient ultrasonographers, and skilled nurses. The disease spectrum

that can be treated with TTCS includes congenital heart defects, cardiac tumors, mitral valve procedures and hypertrophic obstructive cardiomyopathies. Atrial myxomas and atrial septum defects can be repaired with similar surgical incisions [7]. The hypertrophic obstructive myocardium is similar to lesions treated with TTCS for the left ventricle [22]. Aortic valve procedures with TTCS have been mainly reported at a few centers in Europe [23,24], and recently in China [25]. Minimally invasive coronary artery bypass grafting via thoracoscopy has also been successfully performed under CPB [26] but not via off-pump [27].

Congenital Heart Defect

TTCS for treating intracardiac diseases is feasible without robotic assistance for simple ASD and ventricular septum defects [28–30]. There are studies reporting the technical details for performing these procedures [31,32]. The initial study in the patients undergoing TTCS for ASD was on postoperative quality of life and cardiac function [33]. The evaluation of the therapeutic effects on the closure for ASD was made by comparing TTCS with its counterparts such as conventional median sternotomy and right anterolateral thoracotomy [34,35]. Immediate extubation in the operating room can also be performed in most patients undergoing TTCS for congenital heart defects [36]. Postoperative levels of inflammatory cytokines and myocardial enzymes are lower in patients undergoing surgical repair of ASDs using TTCS compared with conventional surgery [37].

Mitral Valve Procedure

There are many techniques available for totally thoracoscopic mitral valve repair using all of the Carpentier techniques, including leaflet folding, cleft suture, commissuroplasty, commissurotomy, edge to edge, and artificial chordae implantation [38]. For mitral valve replacement due to rheumatic stenosis, one point needs to be emphasized is that a small size prosthetic valve should be considered to prevent the difficulty of “site-down” onto the annulus. In the thoracoscopic procedures, both the prosthetic valve and ring are suggested to be sutured with double-armed sutures with pledgets using an interrupted mattress suture technique. A propensity-score matching study comparing a median sternotomy with TTCS for mitral valve replacement showed fewer transfusions, less wound infections, faster recovery, faster return to work, and greater satisfaction with the incision compared with a median sternotomy [39]. Likewise, mitral valvuloplasty via TTCS is superior to those via median sternotomy in terms of the rate of blood transfusion, and the incidence of sternal and wound complications [40]. Although there was no survival difference at 7-year follow-up, it has been demonstrated that the perioperative outcomes including tracheal intubation, chest tube drainage, and transfusion in the patients who underwent re-

operative mitral valve replacement via TTCS is improved [41]. A re-do mitral valve procedure following TTCS is safer since there are less retrosternal adhesions [42]. Three-dimensional video systems in which the operator and the assistant wear polarized glasses appears to provide more comfort and improved fields of vision than that with the two-dimensional video system, and resulted in a 10% reduction of aortic cross-clamp time [43]. Patients undergoing MVP using TTCS have had lower post-procedural systemic inflammatory reaction indexes [44] but similar neurologic complications [45], similar to the effects of remote ischemic conditioning [46], high-altitude hypobaric hypoxia adaptation [47], and high socioeconomic status [48]. Dexmedetomidine has a protective effect on pulmonary function in patients undergoing TTCS, which is also associated with a reduction in the concentration of inflammatory cytokines [49]. Therefore, TTCS provides benefits in both cosmetic appearance and clinical effects.

Hypertrophic Obstructive Myocardium

Although it provides superior high-definition surgical view, the TTCS approach for removing hypertrophic obstructive myocardium has only been adopted by a couple of centers [8]. This approach provides excellent relief of left ventricular outflow tract obstruction and eliminates mitral regurgitation [50].

The Advantages and Challenges

The advantages of TTCS mainly lie in its high cost-effectiveness and similar or even less invasiveness compared to RACS and MICS. Although there are significant advantages for TTCS, there are considerable challenges, such as technical complexity, learning curve, and patient selection criteria. The required instrumentation includes highly integrated operational devices consisting of a visible video-assisted thoracoscope, minimally invasive cannula, and incision exposure devices. The learning curve varies amongst cardiac surgeons despite the fact that they had mastered the skilled and talents needed during conventional cardiac surgical procedures. Regardless, at least 40 cases were regarded as the watershed for most practitioners performing TTCS for mitral valve replacement procedures [51]. An important selection criteria is that the operative chest cavity be free of any adhesions. Complex or composite cardiac procedures, severe heart failure, or pulmonary hypertension are considered to be contraindications for TTCS.

Conclusion

TTCS is increasingly being performed at experienced centers due to successful experiences with this technique

[52]. Improved surgical instruments for TTCS are currently being developed [53,54]. More experimental observation and clinical trials are expected to define the role of TTCS compared with traditional MS cardiac surgery. It is generally accepted that the approach is a safe, curative and a viable alternative to traditional thoracotomy once the operative skills are learned and mastered by surgeons [55]. Aortic cross-clamp and CPB times are shortened once the TTCS techniques are mastered. TTCS procedures are optimized by a multi-disciplinary working group included surgeons, anesthesiologists, perfusionists, echocardiographers and nurses. Currently, there is a paucity of international consensus guidelines on TTCS, and standardized techniques and operative protocols will need to be developed based on data from centers who have successfully adopted this technique. This will allow more patients in low and middle-income countries to safely enjoy the advantages of TTCS.

Author Contributions

QJ and KH were main contributing authors of context conception and writing this review article. XM and SH conceived article layout and assisted literature collection. DZ and YX contributed to interpretation and the critical revision of the manuscript. All authors read and approved the final manuscript. All authors contributed to editorial changes in the manuscript. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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