Original Article

A comparative study of three-dimensional high-definition and two-dimensional high-definition video systems in totally endoscopic mitral valve replacement

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Background: Three-dimensional vision with improved depth perception and spatial orientation has already proved its superiority to the two-dimensional vision in endoscopic surgery. However, those benefits remain unidentified in cardiac surgery. For the first time, we compare performance of a three-dimensional high-definition video system with a two-dimensional high-definition video system in patients undergoing totally endoscopic mitral valve replacement.

Methods: We enrolled 90 patients with mitral valve disease in a single institution, from June 2013 to June 2016. Totally endoscopic mitral valve replacement was performed by the same surgeon using either a three-dimensional high-definition (n=43) or a two-dimensional high-definition (n=47) video system with the same surgical technique. Short-term outcomes were compared between the two groups. All medical records were retrieved from a prospectively maintained database of minimally invasive cardiac surgery.

Results: All surgeries were successfully completed under totally endoscopic guidance. There were no intraoperative complications in either group. The use of three-dimensional video system reduced aortic cross-clamp time by approximately 10% (3D *vs.* 2D: 65.74±14.32 *vs.* 72.67±14.67 min, P=0.027). No significant differences were observed in cardiopulmonary bypass time, postoperative ventilation duration, length of surgical intensive care unit stay, length of hospital stay, and major complications between the two groups. There were no perioperative deaths in either group.

Conclusions: Compared with the two-dimensional video system, the three-dimensional high-definition video system provided a better surgical experience with the same operative safety for totally endoscopic mitral valve replacement.

Keywords: Imagine; three-dimensional (3D); minimally invasive surgery; surgery, thoracoscopic; mitral valve

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Introduction

It has been widely accepted that the development of endoscopy was a milestone in the history of cardiovascular surgery. Over the past two decades, Endoscopic surgery has been increasingly adopted by cardiovascular surgeons in the management of valvular, congenital, and coronary heart disease. Initially, endoscopic cardiac surgery was based on two-dimensional (2D) imaging. However, the development of three-dimensional high-definition (3D-HD) video system with improved depth perception may

Figure 1 Operating room set-up for 3D TEMVR. (A) 3D screen for the operator and assistant (on the left side of the patient); (B) 2D screen for the assistant (on the head side of the patient); (C) the operator and assistant wearing polarized glasses. TEMVR, totally endoscopic mitral valve replacement.

prove to be superior to the 2D system. At our institution, we began performing 2D endoscopic cardiac surgery in 2010. In June 2013, the 3D-HD image system was installed. To date, over 350 surgeries have been performed under 3D image guidance.

In the literature, 3D image system has proved its superiority to the 2D system in gastrointestinal resections, hysterectomies, and urologic procedures (1). However, to the best of our knowledge, there have been no comparative reports for cardiovascular procedures. This study aims to compare the performance and benefits of the 3D-HD image system with those of 2D-HD imaging in patients undergoing totally endoscopic mitral valve replacement (TEMVR).

Methods

Study design and patient selection

This study was a single-center comparative trial. Clinical data was recorded in a prospective database for minimally invasive cardiac surgery.

Inclusion criteria was symptomatic congestive heart failure due to rheumatic or non-rheumatic mitral valve disease. All patients underwent preoperative examinations, including: chest X-ray, pulmonary function test, arterial blood-gas analysis, electrocardiogram, echocardiography and coronary angiography (for patients aged over 50). All the patients were operated on by the same surgeon using either 2D or 3D image guidance. Exclusion criteria were as follows: previous cardiac surgery; moderate or severe aortic valve insufficiency; compromised lung function with intolerance to single lung ventilation; peripheral vascular lesions not suitable for cannulation or procedures other than single MVR, including concomitant tricuspid valvuloplasty or concomitant ablation for atrial fibrillation. This study was approved by our Institutional Ethics Review Board (no ID number). Informed consent forms were obtained from all patients enrolled.

The primary outcome measures were aortic cross-clamp time and cardiopulmonary bypass time. Secondary outcome measures included postoperative mechanical ventilation time, length of surgical intensive care unit (SICU) stay, length of hospital stay, major complications, and mortality.

3D-HD and 2D-HD image systems

Surgical procedures in the 3D group were performed using the TIPCAM1 Karl Storz 3D system with a 30-degree binary camera head. Surgeons wore polarized glasses to view 3D images on the monitor during the procedure (*Figure 1*). Surgeries in the 2D group were performed using the Karl Storz Tuttlingen system. Image resolution in each system was identical.

Surgical techniques

All patients were placed in supine position with the right side slightly elevated. General anesthesia and double-lumen endobronchial intubation were performed. Four skin incisions were made (*Figure 2*). After systemic heparinization, peripheral cardiopulmonary bypass was established with cannulation of the right femoral artery and vein. The right jugular vein was also cannulated by the anesthesiologist to enhance drainage of the superior vena cava. The patient was cooled to 32 ℃ before the ascending aorta was cross-clamped. Cold blood cardioplegia was delivered through the aortic root. After cardiac arrest, a direct left atriotomy was performed. Exposure of the mitral valve was facilitated with a self-retaining retractor system. The mitral valve was then resected and replaced with an artificial prosthesis. The internal orifice of the left atrium auricle was closed with running sutures when preoperative atrial fibrillation was present. All procedures were completely endoscopic, performed under the guidance of images displayed on the monitor. At the conclusion of each procedure, transesophageal echocardiography was used to exclude prosthesis malfunction, to verify that there

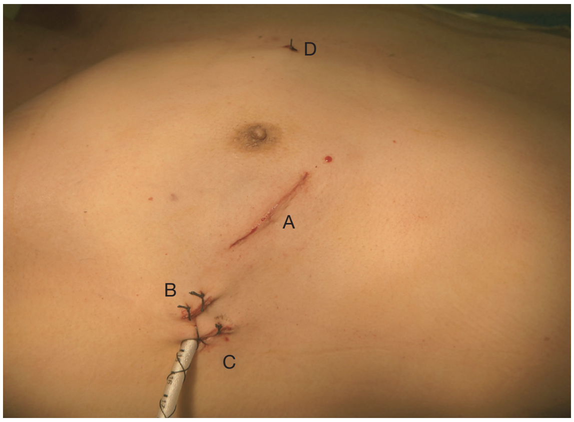

Figure 2 Skin incisions for TEMVR. (A) 4 cm in length, anterolateral thoracotomy at the fourth intercostal space, for the surgical instruments, cardioplegic cannula, and mitral valve prosthesis; (B) 1 cm in length, on the anteroaxillary line at the fourth intercostal space, for the endoscope; (C) 1 cm in length, on the midaxillary line at the fifth intercostal space, for the chi-wood aortic cross-clamp and left atrium vent; (D) 1 cm in length, on the parasternal line at the third or fourth intercostal space, for the self-retaining left atrium retractor. TEMVR, totally endoscopic mitral valve replacement.

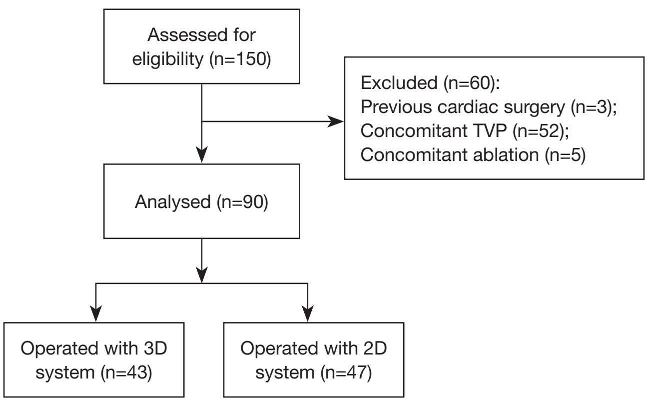

Figure 3 Patient selection and allocation of the 3D and 2D group. TVP, tricuspid valve repair.

was no perivalvular leak and to confirm air removal.

Statistical analysis

Comparisons between the 2D and 3D group were made using Student's *t*-test for continuous variables. Pearson χ^2 test was used for comparisons of categorical variables. A P value less than 0.05 was considered statistically significant. All analyses were performed using the SPSS version 19.0 (SPSS Inc., United States).

Results

Between June 2013 to June 2016, 150 consecutive patients who underwent TEMVR were included. The analysis excluded 60 patients who failed to meet the exclusion criteria: 52 with concomitant tricuspid valve repair, 5 with concomitant ablation for atrial fibrillation, and 3 with previous cardiac surgery. For the remaining 90 patients, the 3D system was used in 43 while the 2D system was used in 47 (*Figure 3*).

Demographic characteristics and preoperative examination results are displayed in *Table 1*. No significant differences were observed between the two groups. Surgical results are displayed in *Table 2*. There were no perioperative deaths in each group. All the procedures were performed endoscopically without conversion to middle sternotomy. Intraoperative complications including mitral prosthesis obstruction, perivalvular leak or left ventricular rupture did not occurred in both groups. No significant differences were observed between the 3D and 2D image systems with respect to type of procedure (P=0.637), year of procedure (P=0.501), postoperative duration of ventilation (P=0.466), length of SICU stay (P=0.742), or length of hospital stay (P=0.619). Major postoperative complications occurred in 10 patients (3D *vs.* 2D, 5 *vs.* 5, P=0.881, *Table 2*). Bleeding requiring revision occurred in 2 patients, both were well-controlled endoscopically. Postoperative low cardiac output syndrome (cardiac output index <2 $L/min/m^2$) occurred in 2 patients, for whom intra-aortic balloon pump was used for circulatory assist.

The aortic cross clamp time in the 3D group (65.74±14.32 min) was significantly shorter than that of the 2D group (72.67±14.67 min; P=0.027). The cardiopulmonary bypass time was also shorter in the 3D group, but not significantly (110.00±26.23 *vs.* 116.60±23.93 min; P=0.219).

Discussion

Currently, endoscopic cardiac surgery is mainly based on 2D, 3D, and robotic image systems. The 2D image system was invented and implemented first. After over 30 years of modification and improvement, 2D is now widely used in minimally invasive cardiac surgery with excellent results. However, the lack of depth perception and spatial orientation with the 2D image system is now recognized as a major drawback (2). The robotic system

Table 1 Demographic characteristics of the 3D and 2D TEMVR groups

Demographic data	3D TEMVR (n=43)	2D TEMVR (n=47)	P value
Age, mean ± SD (years)	51.04±14.14	50.62±14.07	0.888
Gender, n (%)			0.818
Male	12 (27.9)	15 (31.9)	
Female	31 (72.1)	32 (68.1)	
BMI, mean ± SD (kg/m^2)	21.76±3.65	22.20±3.46	0.622
Hypertension, n (%)	6 (14.0)	4 (8.5)	0.412
Diabetes Mellitus, n (%)	2 (4.7)	4 (8.5)	0.463
NYHA classification, n (%)			0.965
I	7 (16.3)	6 (12.7)	
II	31 (72.0)	36 (76.6)	
III	3 (7.0)	3 (6.4)	
IV	2 (4.7)	2 (4.3)	
Mitral valve pathology, n (%)			0.598
Rheumatic	27 (62.8)	32 (68.1)	
Non-rheumatic	16 (37.2)	15 (31.9)	
Endocarditis	13 (30.2)	11 (23.4)	
Degeneration	3 (7.0)	4 (8.5)	
Mitral valve physiology, n (%)			0.942
Stenosis	15 (34.9)	18 (38.3)	
regurgitation	21 (48.8)	22 (46.8)	
Stenosis and regurgitation	7 (16.3)	7 (14.9)	
LVEF, mean ± SD (%)	64.34±6.56	64.67±5.97	0.832
LVED, mean ± SD (mm)	45.61±8.50	49.27±9.11	0.095

TEMVR, totally endoscopic mitral valve replacement; BMI, body mass index; NYHA, New York Heart Association; LVEF, left ventricle ejection fraction; LVED, left ventricle end-diastolic diameter.

provides both high-definition stereovision and precise surgical performance. The robots are competent in challenging procedures such as total endoscopic coronary artery bypass surgery (3). Nevertheless, the robotic system requires specific instruments that takes a much longer time to prepare and a prolonged learning curve for surgeons to adopt the technique (4). Most importantly, the expansion of the robotic system is substantially limited due to its extraordinary high cost, especially in developing countries (5). In comparison with the 2D system, the 3D image system provides a natural sense of depth and better hand-eye coordination. In addition, the costs for 3D and 2D surgery are similar, both of which are much lower than those of robotic surgery. Furthermore, tactile feedback is perfectly preserved in 3D surgery, another advantage over robotic surgery.

The 3D-HD video system has already been shown to be superior to the 2D-HD system in terms of shorter operative time in endoscopic surgeries, including pulmonary lobectomies (6-9) and esophagectomies (10). In the 2D images, monocular cues were used to compensate for the lack of depth perception, including motion parallax through movement of the scope, relative position, size of instruments, anatomic structures, shading of light and dark, and texture grading (11,12). The surgeons were actually performing the procedure with one eye closed,

Table 2 Surgical results of the 3D and 2D TEMVR groups

Surgical results	3D TEMVR (n=43)	2D TEMVR (n=47)	P value
Type of procedures, n (%)			0.637
MVR	25 (58.1)	25 (53.2)	
MVR+LAA closure	18 (41.9)	22 (46.8)	
Year of procedures, n (%)			0.501
2013	5 (11.6)	7 (14.9)	
2014	12 (27.9)	18 (38.3)	
2015	16 (37.2)	16 (34.0)	
2016	10 (23.3)	6 (12.8)	
Type of prosthesis, n (%)			0.661
Mechanical	29 (67.4)	29 (61.7)	
Tissue	14 (32.6)	18 (38.3)	
Size of prosthesis	25.65±0.95	25.77±0.98	0.575
CPB time (min)	110.00±26.23	116.60±23.93	0.219
ACC time (min)	65.74±14.32	72.67±14.67	0.027
Ventilation duration (h)	12.31±8.72	13.67±8.58	0.466
SICU duration (h)	42.93±33.55	40.72±29.42	0.742
Hospital stay (days)	8.90±7.84	8.11±7.26	0.619
Complications, n (%)	5 (11.6)	5 (10.6)	0.881
Bleeding	1	1	
Incision infection	2	2	
III° AV block	1	0	
Pneumothorax	0	1	
Low cardiac output syndrome	1	1	
Death	0	0	

CPB, cardiopulmonary bypass; ACC, aortic cross-clamp; SICU, surgical intensive care unit; TEMVR, totally endoscopic mitral valve replacement.

which is a clear handicap during the initial learning phase. In the 3D images, the separate input from two viewpoints allows for summation on a cortical level (13). Visual acuity improves by 10% using binocular vision (14). The use of 3D devices has already been shown in randomized studies to shorten the learning curve and to shorten task performance time for laparoscopic surgery, both for novice trainees (15) and experienced surgeons (16).

TEMVR as a single and fixed procedure was compared between two homogenous group of patients in our study: all patients were relatively young, with similar mitral valve disease etiology, operated by the same surgeon using identical surgical techniques. Even though, we still observed approximately 10% of reduction in the aortic cross-clamp time. We believed this significant improvement was mainly attributed to the change of the image system. When performing TEMVR, 3D images provided valuable depth information regarding the left atrium and left ventricle, as well providing structural details regarding the mitral valve leaflets, chordae tendineae, and papillary muscles. We felt much more confident when resecting the diseased valvular leaflets and placing sutures around the annulus under 3D image guidance. Less time was wasted with repetitive and correctional moves compare to the 2D TEMVR. In addition, the anti-fog feature of the 3D camera head definitely reduced the time for lens cleaning during surgery.

There was no significant difference between the 3D and 2D group in terms of postoperative mechanical ventilation time, length of SICU stay, length of hospital stay, or incidence of major complications. Our data suggested that 2D and 3D TEMVR are both safe procedures in the surgical treatment of mitral valvular diseases.

In spite of so many advantages, there are still much room for improvement for the current version of the 3D-HD imaging system. To some extent, the depth perception of the surgical field may be exaggerated and distorted by the 3D-HD image system. As a result, unpleasant feelings including nausea, vertigo, and visual fatigue occur occasionally. The camera head of 2D endoscope can rotate separately from the hand shank, so a 360-degree view is available. However, the camera head for the 3D endoscope has to rotated with the hand shank together. As a result, the entire image is rotated as well. It is very challenging for a surgeon to operate under a rotated view.

Study limitations

Our study is based on a single surgeon's experience, since each surgeon has different perception and adaptability of the 3D images, individual discrepancy has to be considered. The study design is non-randomized therefore it is difficult to eliminate selection bias in the allocation of the 2D and 3D groups. Seven minutes difference in aortic cross-clamp time may not be convincing enough in favour of the 3D system. In addition, the sample size was relatively small, larger randomized control trials are necessary for further confirmation of the benefits of the 3D-HD video system.

Conclusions

The 3D-HD video system appears to be superior to the 2D system for TEMVR, with better surgical performance and similar operative safety. The 3D vision is a promising technology that is worth wide promotion in the field of cardiac surgery.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was approved by our Institutional Ethics Review Board. Informed consent forms were obtained from all patients enrolled.

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