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Optimization of anesthesia strategies for transapical beating-heart septal myectomy in hypertrophic obstructive cardiomyopathy: a retrospective cohort study of 119 patients

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Research Article

Keywords: Hypertrophic obstructive cardiomyopathy, TA-BSM, Anesthetic management, Septal myectomy, Cardiopulmonary bypass

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10335238/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Our institution recently reported transapical beating-heart septal myectomy (TA-BSM) as a novel surgical procedure for patients diagnosed hypertrophic cardiomyopathy (HCM), which avoided cardiopulmonary bypass (CPB) procedure. Herein, we identified the details of the anesthesia strategy in TA-BSM via retrospective analysis to guide perioperative anesthetic management.

Methods

119 patients undergoing TA-BSM were retrospectively evaluated, and comprehensive perioperative data were collected including endotracheal intubation type about single or double lumen tube, anesthetic protocols, surgical team cooperation, hemodynamic fluctuations, and perioperative complications. According the endotracheal intubation type, the recruited patients were divided into the single-lumen tube (SLT) group and the double-lumen tube (DLT) group.

Results

Baseline characteristics showed that 17 patients (14.29%) were aged ≥ 65 years and 71 patients (59.66%) were basal-mid septal myocardial hypertrophy. Isoproterenol provocation was performed in 68 patients, and hypotensive episodes requiring intervention was decreased from 32 patients before resection to 15 patients after resection during provocation period. With precise anesthetic management, perioperative vital signs were remained stable on the basis of autologous blood transfusion in 88 patients (mean ± SD, 448 ± 250 mL). Postoperatively, no significant differences were showed between SLT group and DLT group in the residual left ventricular outflow tract obstruction (LVOTO) or postoperative complications (risk ratio, 0.679; 95% CI, 0.328 to 1.405; P = 0.296).

Conclusion

There was little impact for the endotracheal tube choice on the surgical outcomes of TA-BSM. Anesthetic management should prioritize the precise regulation of circulatory fluctuation during isoproterenol provocation, meticulous volume status maintenance, and emergency treatment for acute complications.

Introduction

Symptomatic hypertrophic cardiomyopathy (HCM) was hallmarked by left ventricular outflow tract obstruction (LVOTO), and might be accompanied by systolic anterior motion (SAM) of the anterior mitral valve leaflet [1, 2]. This pathological condition could be exacerbated during strenuous physical activities

or emotional stress, and it might precipitate ventricular arrhythmias and represent a prevalent cause of sudden cardiac death in the young population [3–5]. Septal myectomy was considered as the definitive therapeutic modality for symptomatic patients, including open-heart surgery with the support of cardiopulmonary bypass (CPB), or percutaneous minimally invasive septal ablation for select patients [6, 7].

No matter which surgical method was accomplished, there were distinctive challenges in anesthesia management for obstructive HCM patients. During the anesthetic induction period, the low blood pressure was caused by the inhibitory effect of anesthetics, and the increased heart rate was irritated due to endotracheal intubation [8]. Both of these issues leaded to severe circulatory fluctuations, and exacerbated the symptoms of the disease [8]. Additionally, the establishment and withdrawal of CPB in open-heart surgeries increased the complexity of anesthesia management and the probability of CPB-related complications. In these two periods, it could be influenced by many factors, such as changes in blood flow patterns, volume status, variations in body temperature, release of vasoactive substances, and the functional status of the heart [6]. And the aggravation of SAM sign and LVOTO by insufficient preload or afterload volume, the insufficient ventricular ejection, or excessive myocardial load due to rapid heart rate were also high anesthesia risks during the whole perioperative period [6, 8]. And for the minimally invasive surgery, there was no even less guarantee at the situation without CPB [9, 10]. All of these posed significant challenges and difficulties for perioperative anesthesia management in surgeries for HCM patients [10, 11]. And the thorough understanding of the pathophysiology was the foundation to insure circulatory stability.

The classical open-heart Morrow procedure was associated with considerable technical complexity and a high incidence of complication [12, 13]. Meanwhile, the process of learning and growth was long and arduous for these cardiothoracic surgeons, which underscored the importance of institutional expertise and case volume on clinical outcomes [14–16]. Currently, transapical beating-heart septal myectomy (TA-BSM), the innovative and minimal invasive strategy, had provided a novel insight and achieved a significant advancement in the surgical therapy of HCM [17]. This surgical procedure simplified the procedure of the traditional open-heart Morrow surgery. And it was involved a transapical septal myectomy procedure using an original beating-heart myectomy device, which was inserted into the left ventricular outflow tract through the cardiac apex [18]. Under the guidance of transesophageal echocardiography (TEE), the basal anteroseptal myocardium underlying the right aortic cusp was identified, resected, and collected by the device [18, 19]. The feasibility, safety, and efficacy of TA-BSM had been substantiated in both preclinical animal models and human subjects [17, 18].

For the anesthesia management for the new surgical procedure, it was still necessary to follow the pathological and physiological mechanism, cooperate closely with the surgeon to complete each step, and precisely prepared for the potential risks, with the aim to maintain stable hemodynamics and reduce the occurrence of adverse events [20, 21]. The absence of CPB demanded more precise physiologically expertise, and it was important to integrate comprehensive information to provide anesthetic strategies in real time, as we previously reported in the cases serial [10]. However, it was still lack of systematic

retrospective analysis of the anesthetic strategies, and any publication about multidisciplinary team (MDT) collaboration details for this novel surgical procedure.

At the initial stage of clinical implementation, because of the surgical preference for wide exposure field and minimized impact of respiration on septal myectomy during this beating-heart surgery, the choice between single-lumen tube (SLT) and double-lumen tube (DLT) endotracheal intubation was a key consideration during the formulation of this surgical protocol. And in our institution, DLT endotracheal intubation was preferentially utilized to establish one-lung collapse and the other one-lung ventilation, to provide an optimal surgical field [22]. However, with the technical expertise accumulation of the surgeons, we observed that SLT ventilation combined with a low tidal volume strategy was sufficient to meet the technical demands for the experienced surgeons.

Therefore, we retrospectively analyzed 119 patients who underwent TA-BSM in our institution, to summarize the anesthesia management experiences, including the association between endotracheal tube selection and the operative outcome, intraoperative provocative testing for HCM patients in this beating-heart surgery, vasoactive agent requirement, volume status optimization, and circulatory assessment. These points strengthened intraoperative MDT collaboration in TA-BSM, and contributed to more stable perioperative hemodynamics guidance and improved prognosis.

Materials and methods

Study design and patients

All enrolled patients diagnosed with HCM were received professional evaluations by surgeon, and underwent the new TA-BSM surgery procedure after obtaining informed consent. This retrospective cohort study was conducted on these patients. Institutional Review Board (IRB) approval for our retrospective study was obtained from the Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (approval number, TJ-IRB20230910). And then this study was retrospectively registered at ClinicalTrials.gov (identifier, NCT06397092). Per IRB regulations, the requirement for informed consent from participants on this retrospective analysis was waived.

Patients underwent TA-BSM surgery between April 2022 and February 2023. A total of 122 patients were included, who had refractory HCM symptoms or intolerance to medical therapy, with American Society of Anesthesiologists (ASA) physical status classifications from II to IV. Key exclusion criteria were as follows: patients who were converted to hypertrophic ventricular septal resection with CPB assistance, or those deemed unsuitable or ineligible to include by the attending medical team and researchers. All patients were received a 30-day postoperative follow-up.

Perioperative data and outcome collection

Demographic variables were collected, including age, sex, height, weight, comorbid conditions and ASA physical status classification. Intraoperative parameters were recorded including heart rate, pulse oxygen saturation, arterial pressure, central venous pressure, endotracheal tube type, end-tidal carbon dioxide tension, infusion volume, blood loss, urine output, blood product transfusion volume, the number of emergency thoracotomy, isoproterenol provocation with the triggered hemodynamic changes, and perioperative biochemical indicators. Severe intraoperative complications included massive hemorrhage, malignant arrhythmias, hemodynamic instability, complete atrioventricular block, ventricular structure rupture and postoperative mortality. For patients were admitted to the intensive care unit (ICU) postoperatively, continuous monitoring of electrocardiography (ECG), intra-arterial pressure and pulse oxygen saturation was performed, and the data were collected. Postoperative 30-day outcomes, such as the reoperation rate, mortality rate and complications, were documented.

Outcome variables including preoperative versus postoperative parameter comparisons, differences in pathophysiological features and complications between the SLT and DLT groups, perioperative hemodynamic data, and vasoactive agent usage were collected. The primary outcomes were defined as the association between the selection of SLT or DLT and postoperative residual of LVOTO as well as postoperative complications. Secondary outcomes encompassed hemodynamic changes during provocative testing and perioperative alterations in hemodynamic and biochemical parameters.

Key anesthetic cooperation of TA-BSM

HCM patients were managed by the institutional clinical pathway. Upon admission, all necessary laboratory data were collected. Following surgical assessment, an isoproterenol stimulation test was administered as clinically indicated, based on HCM related symptoms. As ventricular tachycardia (VT) or ventricular fibrillation (VF) might occur due to aggravated LVOTO and secondary low cardiac output during anesthetic induction and surgical resection, automated external defibrillator pads were still routinely placed before anesthetic induction.

Premedication, including anticholinergics, sedatives and dexmedetomidine, was prohibited on the day of surgery. All procedures were performed under general anesthesia. Patients were placed in the supine position in preparation for TA-BSM. Routine intraoperative monitoring included anesthesia standard parameter, bispectral index (BIS), and urine output. Prior to anesthetic induction, invasive arterial pressure monitoring was established, and optimization of preload volume was performed. An additional dedicated catheter via the left ventricular (LV) apical approach was prepared for left ventricular pressure monitoring. In accordance with routine preoperative preparation protocols for cardiovascular surgery, the CPB circuit was maintained in a standby status to address potential intraoperative emergencies. A cell saver was utilized for blood conservation and autologous blood transfusion.

Anesthetic induction was achieved via slow incremental administration of etomidate (0.3 mg/kg), cisatracurium besylate (0.2 mg/kg), and sufentanil (0.5 μg/kg). Intermittent doses of α-receptor agonists (e.g., metaraminol, phenylephrine) were administered to maintain hemodynamic stability. Following

induction, endotracheal intubation was performed. The selection of SLT versus DLT was at the discretion of the surgeon's preference, based on the anatomical feature of hypertrophic myocardium which related to the surgical procedure. A TEE probe was then inserted carefully for intraoperative assessment and surgical guidance.

Anesthesia maintenance was accomplished with sevoflurane at 1.0 minimum alveolar concentration (MAC), supplemented by continuous infusions of cisatracurium besylate (0.1 mg/kg/h), sufentanil (0.4 μg/kg/h), and dexmedetomidine (1 μg/kg/h). Subsequently, central venous pressure was monitored by another manometric catheter, followed by the establishment of LV apical pressure via a pre-prepared manometric catheter. It was imperative to ensure that the LV apical pressure measurement catheter remained sterile and was appropriately positioned within the sterile surgical field when connected. And then the degree of obstruction could be evaluated via pre-prepared TEE.

Prior to septal myectomy, isoproterenol provocation was performed according to the surgeon judgment and the clinical symptoms. Verification of the presence of SAM via isoproterenol provocation was conducted under TEE monitoring, and anesthesiologists needed to ensure the restoration of hemodynamic stability during this critical stage. Vasoactive agents were administered to counteract hypotension. Subsequent resections were performed based on preprocedural planning and real-time assessments. The three-dimensional resection window was identified under the guidance of TEE images in both long-axis and short-axis views. During the resection, norepinephrine could be selected to administer or with intermittent α-receptor agonists (e.g., metaraminol, phenylephrine) to maintain hemodynamic stability. Crystalloids, colloids, or blood products were supplemented according to the volume and severity of bleeding. After the ventricular septum resection procedure was completed, repeat isoproterenol provocation could be performed to confirm the resolution of obstruction.

Postoperatively all patients were transferred to the cardiovascular ICU with endotracheal intubation, and the patients in the DLT group needed to be converted to SLT. Postoperative re-evaluation via transthoracic echocardiography (TTE) and ECG was performed to assess the residual of the LVOTO, mitral regurgitation (MR), and LV morphology changes, as well as the impact on cardiac conduction. Perioperative blood pressure management was optimized, and close monitoring for iatrogenic ventricular septal defect (VSD) was implemented.

Provocative test

General anesthesia might mask LVOTO due to reduction of preload and alterations in cardiac contractility. So, the patient needed provocative test to verify obstruction in the case of resting left ventricular outflow tract gradient (LVOTG) less than 50 mmHg, the age less than 75 years old, and no severe arrhythmias. The LVOTG was confirmed via the pressure gradient between the left ventricle and radial artery, and intraoperative provocation could be performed to unmask obstruction and optimize assessment of post-procedural outcomes [23, 24]. Isoproterenol provocative test permitted evaluation of multiple cardiac cycles. However, escalating doses of isoproterenol induced non-physiological status,

leading to overestimation of gradients and a consequent risk. And then it might precipitate severe hemodynamic instability.

In our retrospective analysis, isoproterenol provocation was clearly detected induced by an elevation in heart rate. Isoproterenol provocation was typically administered at a dosage of 0.01–0.1 μg/kg/min. As the patient's heart rate increased incrementally, the LVOTG rose progressively until the heart rate reached a peak within the acceptable range. At this point, prompt and effective administration of vasoactive agents was required to rapidly restore hemodynamic status to baseline. If the adverse events happened, it needed more time to open the chest for CPB in TA-BSM procedures compared to conventional surgery.

SAM, MR and LVOTO were key metrics for evaluating the obstruction. To better assess surgical resection efficacy and improvement, repeat provocative testing could be performed after ventricular septum resection, to determine the adequacy of the resection for resolving SAM, MR and LVOTO. Hypertension and subsequent secondary bleeding were major concerns during provocation.

Echocardiography

For all patients scheduled to undergo TA-BSM, preoperative TTE was mandatory. And parameters were monitored intraoperatively in real time and re-evaluated by TEE postoperatively [25]. Meanwhile, intraoperative guidance via TEE was also required to ensure accurate device positioning for resection. Subsequent to each resection, the need for further surgery manipulations and the functional assessments were determined under TEE guidance.

Statistical analysis

Normal distributions of continuous variables were assessed by Kolmogorov–Smirnov test. Continuous variables were presented as means ± standard deviation (SD). Categorical variables were summarized as counts (and percentages, where applicable). Missing data was not replaced. Between-group differences were evaluated using the independent t test or Mann-Whitney U test for continuous variables and the $\chi 2$ test or Fisher exact test for categorical variables, as appropriate. Statistical significance was defined as $P < 0.05$ with 2-sided testing. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 22.0 statistical software package (SPSS Inc).

Result

A total of 122 patients were included in the retrospective study. And 1 patient required conversion to the CPB-assisted procedure with intra-aortic balloon pump (IABP) assistance due to impaired myocardial contractility, so 121 patients met the inclusion criteria. Then 2 patients were excluded due to deviations from the standard TA-BSM surgical strategy, who underwent mitral valve repair or replacement with CPB assistance following septal resection. Ultimately, 119 patients were included in the final analysis, and 58 patients in the SLT group and 61 patients in DLT group respectively (Fig. 1).

Demographic data

The baseline clinical characteristics of these 119 patients were summarized in Table 1. Demographically, 17 patients (14.29%) were aged ≥ 65 years, with an age range from 11 to 78 years. Regarding the anatomical distribution of hypertrophic myocardium, the majority patients was the basal to mid ventricular septum hypertrophy, accounting for 71 patients (59.66%), followed by 16 patients resulted from the mid to apical ventricular septum hypertrophy (13.45%), and 13 patients resulted from in the basal ventricular septum hypertrophy (10.92%). With respect to comorbidities, 35 patients (29.41%) had a history of hypertension, and 57 patients (47.90%) had a history of coronary artery disease. For ASA physical status classification, 109 patients (91.60%) were classified as ASA grade III, 9 patients (7.56%) as ASA grade IV, and only 1 patient (0.84%) as ASA grade II. The patient characteristics and pathophysiology in the SLT and DLT groups were compared as well, and no difference in these two groups.

Table 1
The clinical characteristics and pathophysiological features.

Item	Total (n = 119)	SLT (n = 61)	DLT (n = 58)	*P* Value
Gender (n)				0.070
Male	83	38	45	
Female	36	23	13	
Age (n)	48.4 ± 14.8	48.3 ± 15.4	48.5 ± 14.1	0.950
11–18 years	5	3	2	
19–40 years	31	17	14	
41–64 years	66	31	35	
65–78 years	17	10	7	
Height (cm)	166.8 ± 8.2	165.8 ± 8.1	167.7 ± 8.3	0.212
Body weight (kg)	70.5 ± 14.0	69.6 ± 15.6	71.5 ± 12.0	0.445
BMI (kg/m^2)	25.2 ± 3.8	25.1 ± 4.0	25.4 ± 3.5	0.653
BMI ≥ 25 (n)	66	32	33	0.131
Anatomical feature of hypertrophic myocardium (n)				0.084
Base	13	8	5	
Base - Mid	71	40	31	
Mid	2	1	1	
LV apex	2	0	2	
Mid - LV apex	16	2	14	
Base – Mid - LV apex	15	10	5	
Comorbidities (n)				0.252
Hypertension	35	19	16	
Diabetes	4	3	1	
Coronary disease	57	32	25	
PCI	4	3	1	

ASA American Standards Association, DLT double-lumen tube, LV left ventricle, SLT single-lumen tube, PCI percutaneous coronary intervention

Item	Total (n = 119)	SLT (n = 61)	DLT (n = 58)	*P* Value
Renal dysfunction	4	4	0	
Ventricular septal surgery	3	1	2	
Preoperative cardiac pacemaker	3 (Temporary 2 / Permanent 1)	1	2	
Atrial fibrillation	2	0	2	
ASA classification (n)				0.593
II	1	1	0	
III	109	55	54	
IV	9	5	4	

ASA American Standards Association, DLT double-lumen tube, LV left ventricle, SLT single-lumen tube, PCI percutaneous coronary intervention

Anesthetic and surgical profiles

Based on the classification of obstruction in HCM patients, as well as clinical factors including patient manifestations and age, intraoperative isoproterenol provocation was deemed necessary for some subtypes, and this procedure was performed in 68 patients. During isoproterenol provocation and the septal resection, the intraoperative vasoactive agents were administered to maintain hemodynamic stability. The selection and utilization of these vasoactive agents were summarized in Table 2, with norepinephrine administered via continuous infusion in 87 patients, while α-receptor agonists (e.g., phenylephrine, metaraminol) were used in 22 patients.

Table 2
Perioperative parameters and clinical events related to anesthetic and surgical profiles.

Perioperative index	Total (n = 119)
Isoproterenol provocation (n)	68 (57.1%)
Intraoperative application of vasoactive drug (n)	
Norepinephrine (pump)	87 (73.1%)
Phenylephrine	18 (15.1%)
Metaraminol	4 (3.4%)
Esmolol	37 (31.1%)
Nicardipine	56 (47.1%)
Allogeneic blood transfusion (n)	1 (0.8%)
Autologous blood transfusion (n)	88 (73.9%)
Autologous blood volume (ml)	448 ± 250
Crystalloid infusion volume (n)	
≤ 1000 mL	69 (58.0%)
1000–2000 mL	42 (35.3%)
>2000 mL	4 (3.4%)
Colloid infusion volume (n)	
0 mL	46 (38.7%)
500 mL	58 (48.7%)
1000 mL	10 (8.4%)
1500 mL	1 (0.8%)
Resection times	9.4 ± 4.7
Duration of surgery (min)	185 ± 50
Duration of anesthesia (min)	245 ± 58
Extubation time after surgery (h)	5.3 ± 3.9

Additionally, blood transfusion was administered to patients who underwent multiple resection times, as these procedures were associated with increased blood loss. 1 patient received allogeneic blood transfusion due to preexisting anemia, while 88 patients underwent autologous blood transfusion, with a mean autologous blood transfusion volume of 448 ± 250 mL. Crystalloid and colloid infusions were

administered as needed, and the volume grades of these parts were summarized in Table 2. The key perioperative parameters were summarized in Table 2. The mean number of resections times was 9.4 ± 4.7, the mean surgical duration was 185 ± 50 minutes, the mean anesthetic duration was 245 ± 58 minutes, and the mean postoperative extubation time was 5.3 ± 3.9 hours.

Hemodynamic parameter changes in provocative test

For the 68 patients who underwent isoproterenol provocation, heart rates recorded before and during provocation, as well as the number of hypotensive episodes requiring intervention after provocation, were presented in Fig. 2. Before resection, the mean heart rate was 62 ± 9 bpm, which increased to 92 ± 21 bpm during isoproterenol provocation. After resection, the mean heart rate was 64 ± 10 bpm, and rose to 93 ± 16 bpm during isoproterenol provocation. Intraoperative isoproterenol provocation was performed in these 68 patients. Among them, hypotension was occurred in 32 patients that required intervention during pre-resection provocation, whereas only 15 patients experienced such hypotension during post-resection provocation.

Changes in perioperative parameters

The perioperative hemodynamic changes at different time points were recorded and presented in Fig. 3. The time points included the baseline before surgery, after endotracheal intubation, before resection, during resection, the end of surgery, and back to the ward. The data demonstrated that vital signs were remained stable throughout the perioperative period which were attributed to precise anesthetic management. Particularly, enhanced stability of vital signs was observed both after septal resection and during the transfer to the ward.

Hemoglobin (Hb) was the marker reflecting surgical blood loss and clinical prognosis, and creatinine (Cr) was the indicator of postoperative renal function. Both of these two indicators were collected, and the data were summarized in Table 3. When comparing preoperative and postoperative parameters, no statistically significant difference was observed in Cr levels between the two time points (Table 3).

Table 3
Perioperative parameters changes and comparisons between preoperative and postoperative periods.

Parameters	Preoperative	Postoperative	*P* Value
Hb (g/L)	142.6 ± 20.6	119.8 ± 17.0	<0.001
Cr (μmol/L)	81.3 ± 14.6	87.4 ± 26.8	0.947
LVOTG measured by TTE (mean ± SD)	65.5 ± 39.2	14.4 ± 9.3	<0.001
LVOTG measured by TTE (n)			<0.001
< 30 mmHg	25	116	
30–50 mmHg	20	1	
50–100 mmHg	50	2	
> 100 mmHg	24	0	
MR (n)			<0.001
None	0	4	
Mild	32	101	
Mild - Moderate	22	8	
Moderate	25	5	
Moderate - Severe	26	1	
Severe	14	0	
Cr creatinine, Hb Hemoglobin, MR mitral regurgitation			

We further stratified and analyzed the degree of LVOTG alleviation based on the preoperative condition. Preoperatively, the LVOTG less than 30 mm Hg were 25 patients, the LVOTG in 30–50 mm Hg were 20 patients, the LVOTG in50–100 mm Hg were 50 patients, and the LVOTG over 100 mm Hg were 24 patients, with the maximum of 204 mm Hg. Prominently, the preoperative high LVOTG were predominantly in 50–100 mm Hg range. Postoperatively, the LVOTG less than 30 mm Hg were increased to 116 patients (97.48%), whereas only 1 patient with the LVOTG of 30–50 mm Hg, 2 patients with the LVOTG of 50–100 mm Hg, and no patients with the LVOTG > 100 mm Hg (Table 3).

As for MR, there were different degrees of MR in all 119 patients preoperatively. Regarding MR severity classification, 32 patients were categorized as mild, 22 patients were categorized as mild to moderate, 25 patients were categorized as moderate, 26 patients were categorized as moderate to severe, and 14 patients were categorized as severe. Postoperatively, there were no evidence of MR in 4 patients. The MR of 101 patients (84.87%) were alleviated to mild after ventricular septal resection. And only 8 patients MR were mild to moderate, 5 patients MR were moderate, and 1 patients MR was moderate to

severe. It was very good that there were no patients of severe MR after the surgery. Overall, MR severity was significantly alleviated in all 119 patients (Table 3).

Comparison of pathophysiological features and complications between SLT and DLT groups

Comparisons of pathophysiological characteristics and complications between the SLT and DLT groups were summarized in Table 4. No significant difference was found between the two groups in the degree of LVOTG alleviation (95% CI, -8.44 to 17.80; *P* = 0.406) and the total complications (risk ratio, 0.679; 95% CI, 0.328 to 1.405; *P* = 0.296). As to the incidence of perioperative complications and intergroup comparisons, 2 patients required conversion to CPB support due to iatrogenic cardiac injury, with 1 patient in each group (risk ratio, 0.950; 95% CI, 0.058 to 15.551; *P* = 0.971). Additionally, 2 patients underwent surgery with femoral-femoral bypass support due to hemodynamic instability, also with 1 patient distributed equally in each group (risk ratio, 0.950; 95% CI, 0.058 to 15.551; *P* = 0.971). No VF was observed during the induction phase in each group. However, 1 patient of VT and 1 patient of VF occurred in the SLT group during the resection procedure (risk ratio, 0.984; 95% CI, 0.952 to 1.006; *P* = 0.327). There were 1 patient of postoperative ventricular tachycardia, 1 patient of VSD developed after extubation and required repair via CPB, and 1 patient of death on the 10th day postoperatively in the SLT group (risk ratio, 0.984; 95% CI, 0.952 to 1.006; *P* = 0.327).

Table 4
Comparison of cardiac parameters and complications between the SLT and DLT groups.

Cardiac parameters and complications	**Total (n = 119)**	**SLT (n = 61)**	**DLT (n = 58)**	***P* Value**
LVOTG alleviation (mean ± SD)	76.6 ± 36.0	74.2 ± 32.5	78.9 ± 39.2	0.406
Perioperative complication (n)				0.296
Conversion to CPB as massive hemorrhage	2	1	1	0.971
Intraoperative bypass assistant	2	1	1	0.971
Intraoperative VF	1	1	0	0.327
Postoperative VT	1	1	0	0.327
Postoperative VSD	1	1	0	0.327
Postoperative mortality	1	1	0	0.327
Postoperative complete LBBB	55	24	31	0.123
Postoperative PPM implantation	3	1	2	0.529

CPB cardiopulmonary bypass, DLT double-lumen tube, LBBB left bundle branch block, LVOTG Left ventricular outflow tract gradient, SLT single-lumen tube, PPM, permanent pacemaker, VSD ventricular septal defect, VF ventricular fibrillation, VT ventricular tachycardia

The most common postoperative complication was complete left bundle branch block (LBBB), with a total of 55 patients. There were 24 patients in the SLT group and 33 patients in the DLT group (risk ratio, 0.565; 95% CI, 0.273 to 1.170; *P* = 0.123). Complete LBBB typically manifested immediately after resection of the hypertrophic myocardium, though it did not impair circulatory stability in most patients. For patients with severe conduction block, postoperative permanent pacemaker (PPM) implantation was performed to maintain heart rate and circulatory stability. Among the 119 patients, 1 patient was received PPM implantation in the SLT group and 2 patients in the DLT group (risk ratio, 0.467; 95% CI, 0.041 to 5.290; *P* = 0.529).

Although certain complications were uniquely observed in the SLT group and absent in the DLT group, generally there was no statistically significant difference in the overall incidence of complications between the two groups (Table 4).

Discussion

Refuting “DLT dogma” in airway management in TA-BSM

In the early stages of TA-BSM clinical practice, the DLT was preferentially adopted, because it facilitated lung isolation, collapse and ensured an unobstructed surgical field, which thought to be critical for optimizing the surgical view during transapical resection procedures. However, for the anesthesiologists, the SLT airway management simplified intraoperative ventilation management, which minimized mechanical trauma to the airway mucosa, attenuated the hemodynamic stress response triggered by endotracheal intubation, and eliminated the need for postoperative conversion from a DLT to a SLT for the patients to the ICU [26]. These advantages were the key considerations for reducing the incidence of perioperative airway complications [18, 27, 28].

As the surgical experience with TA-BSM and the implementation of optimized tidal volume, there was the potential for the SLT airway management in this specific surgical procedure. An additional analysis of body mass index (BMI) values in the study also revealed that a substantial proportion of HCM patients exhibited super standard BMI. It was independently associated with an increased risk of difficult airway [29, 30]. Therefore, the relative ease of the SLT endotracheal intubation enabled the anesthesiologists to achieve secure airway control more rapidly and lower risk of failed endotracheal intubation [31, 32]. This efficiency in airway management, in turn, allowed the anesthesia team to focus on other clinically significant aspects of intraoperative care for TA-BSM.

Therefore, contrary to the initial expectations of the surgical team, no statistically significant difference in the feasibility of transapical surgical access was observed between patients managed with a SLT or a DLT in our retrospective analysis. Although certain complications only happened in the SLT group might imply a potential advantage associated with the DLT approach, data presented in Table 4 confirmed that the type of tracheal tube (SLT vs. DLT) had little impact on the residual LVOTO and overall perioperative complication ratio. These data also underscored the alignment of SLT application with enhanced

recovery after surgery (ERAS) principles, as simplified airway management of the key goals in ERAS protocols [33].

TA-BSM anesthesia management as a “Paradigm Shift” from conventional Morrow myectomy

TA-BSM was fundamentally distinct from conventional Morrow septal myectomy, with its defining feature being minimal reliance on CPB [10]. However, TA-BSM did not entirely eliminate the need of CPB for emergency interventions. In the context of severe complications (e.g., massive hemorrhage, VSD), CPB remained the vital standby measure for rescue. It was suggested from Table 4 that 2 patients were required conversion to CPB because of iatrogenic cardiac injury, while an additional 2 patients received femoral-femoral bypass support as hemodynamic instability. This balance between minimal CPB utilization and preparedness for emergent events underscored the wisdom to handle these critical points in anesthesia strategy, and negotiation with surgeons [10].

For patients with mitral valve structural abnormalities or requiring extensive surgical intervention, conventional Morrow myectomy remained the preferred approach [34, 35]. However, a subset of patients with stable circulation and mild mitral valve abnormalities could undergo mitral valve correction immediately following TA-BSM to minimize CPB exposure [36]. As showed in Table 1, geriatric patients and those with ASA IV were benefited from the minimally invasion of TA-BSM, which facilitated early tracheal extubation, enhanced postoperative recovery, and reduced perioperative stress. The advantages were aligned with enhanced MDT management strategies for high-risk subgroups.

Personalized provocation testing: indications, timing, and risks

Isoproterenol provocation testing was a critical intraoperative challenging in the management of patients undergoing TA-BSM, and the implementation required careful consideration of both clinical indications and potential risks [37, 38]. Ongoing refinements aimed to strike an optimal balance between procedural safety and diagnostic efficacy. This testing strategy was not applied uniformly but instead individualized based on two key factors, which were the baseline LVOTG and patient-specific characteristics, such as age, degree of myocardial hypertrophy, and presence of comorbidities. For patients with severe, extreme myocardial hypertrophy or symptomatic geriatric individuals, pre-resection isoproterenol provocation was generally omitted [10].

The requirement for vasoactive agents was aimed at strict control of heart rate and blood pressure, and minimized the hemodynamic perturbations induced by isoproterenol. Specific agents were selected based on their pharmacodynamic profiles. In Table 2, it showed that intravenous infusion norepinephrine administered at a low dose (0.01–0.05 μg/kg/min) was the mostly used, for its dominant α_1-adrenergic vasoconstrictive effect [39, 40]. Single-dose phenylephrine or metaraminol were also used, as their ability to induce reflex bradycardia during the stimulatory phase of isoproterenol administration [41, 42]. In some more serious tachycardia, esmolol, a short-acting β_1-adrenergic antagonist with a rapid onset and

short half-life, was used to achieve precise control of stress-induced tachycardia. And TEE was employed continuously to monitor for early signs of hemodynamic instability or worsening LVOTO [38]. The anesthesiologists should choose suitable vasoactive drugs to restore the appropriate hemodynamic status.

Even with meticulous TEE guidance, residual LVOTO might still persist in some patients, often in a subclinical form that was not readily apparent during routine intraoperative assessment [43]. For this reason, post-resection provocation testing was routinely carried out to unmask such residual obstruction, ensuring that any unresolved LVOTO was identified before the procedure concluded. Our data were statistically analyzed the alleviation of LVOTO, aligned closely with the results of post-resection isoproterenol provocation testing. Among the patients received isoproterenol provocation test, the number of hypotension intervention in post-resection provocation was obvious reduced, implied the resection effect and relief of obstruction.

Diagnosis and monitoring of cardiac function

LBBB was identified as the most frequent perioperative complication in TA-BSM [44]. Real-time monitoring by TEE was essential for the diagnosis and functional evaluation of LBBB [45–47]. Importantly, our data suggested that LBBB had not been linked to adverse outcomes, and no significant differences between the SLT and DLT groups. Additionally, another more serious cardiac-related complication was VF and VT. There was each of one case in the complication of VF and VT in the SLT group, however, no significant difference was found in the incidence rates between the SLT and DLT groups. Automated external defibrillator pads were placed prior to anesthetic induction to mitigate the risk of VT or VF.

Strengths and limitations

Our study demonstrated that protocolized anesthesia management provided a feasible and secure protocol for TA-BSM, such as low CPB conversion rate and zero provocation-related severe complications, from 119 patients including geriatric and ASA III or IV classification individuals. As the first cohort analysis for TA-BSM anesthesia management, it confirmed that SLT was non-inferior to DLT in air management, and verified that personalized provocation testing guided by LVOTG and patient comorbidities balanced diagnostic accuracy with safety.

This study had several limitations primarily related to its retrospective single-center design, limited the applicability of results to multi-center settings. The retrospective nature prevented intervention in exposure factors such as SLT or DLT selection, might increasing the risk of selection bias. Randomized comparisons of anesthesia-related outcomes were also needed further investigation, such as cognitive function complications, or comparation between TA-BSM and conventional Morrow myectomy [48, 49]. The follow-up period was only 30 days, which was insufficient to observe the long-term prognosis, such as the impact of intraoperative hypotension on renal and cerebrovascular health in geriatric patients, the re-obstruction and the cardiac function status, and the pacemaker installed in the long term or not, etc.

These gaps highlighted the need for future multi-center prospective studies to supplement the anesthetic strategy for TA-BSM [50].

Conclusion

Our findings provided original contributions to TA-BSM anesthesia literature by addressing critical knowledge gaps, and advanced the systematic implementation of evidence-based care for HCM patients undergoing this minimally invasive procedure. With the development and promotion, it was also clinically relevant guidelines that empowered more anesthesia and surgical teams to accomplish and refine this approach routinely.

Abbreviations

ASA American Society of Anesthesiologists

BIS Bispectral index

BMI Body mass index

Bpm Beats per minute

CPB Cardiopulmonary bypass

Cr Creatinine

DLT Double-lumen tube

ECG Electrocardiography

ERAS Enhanced recovery after surgery

Hb Hemoglobin

HCM Hypertrophic cardiomyopathy

IABP Intra-aortic balloon pump

ICU Intensive care unit

IRB Institutional Review Board

LV Left ventricle

LBBB Left bundle branch block

LVOTG Left ventricular outflow tract gradient

LVOTO Left ventricular outflow tract obstruction

MAC Minimum alveolar concentration

MDT Multidisciplinary team

MR Mitral regurgitation

PPM Permanent pacemaker

PVCs Premature ventricular contractions

SAM Systolic anterior motion

SIRS Systemic inflammatory response syndrome

SLT Single-lumen endotracheal tube

TA-BSM Transapical beating-heart septal myectomy

TEE Transesophageal echocardiography

TTE Transthoracic echocardiography

VF Ventricular fibrillation

VSD Ventricular septal defect

VT Ventricular tachycardia

Declarations

Ethics approval and consent to participate

This retrospectively study was received the IRB approval from the Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (approval number, TJ-IRB20230910) on Sep 18, 2023. And then the study was registered at ClinicalTrials.gov (identifier, NCT06397092) on May 1, 2024.

Consent for publication

Per IRB regulations, the requirement for informed consent from participants on this retrospective analysis was waived.

Competing interests

The authors declare no conflict of interest.

Funding

There was no funding for this case report.

Author Contribution

WLY and QQX were involved in the design, data acquisition, writing the first draft of the manuscript, and critical revision. YL, RL, YNL, and YC provided critical analysis and interpretation of data, and participated in critical revisions of the draft. JJY were involved in the design and data collection. CI and XW were involved in the critical revision of the final draft. All authors read and approved the final manuscript.

Acknowledgement

The authors would like to thank the patients and their families for helping shed a light into this relevant clinical issue.

Availability of data and materials

All data analyzed during this study were included in this published article.

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Figures

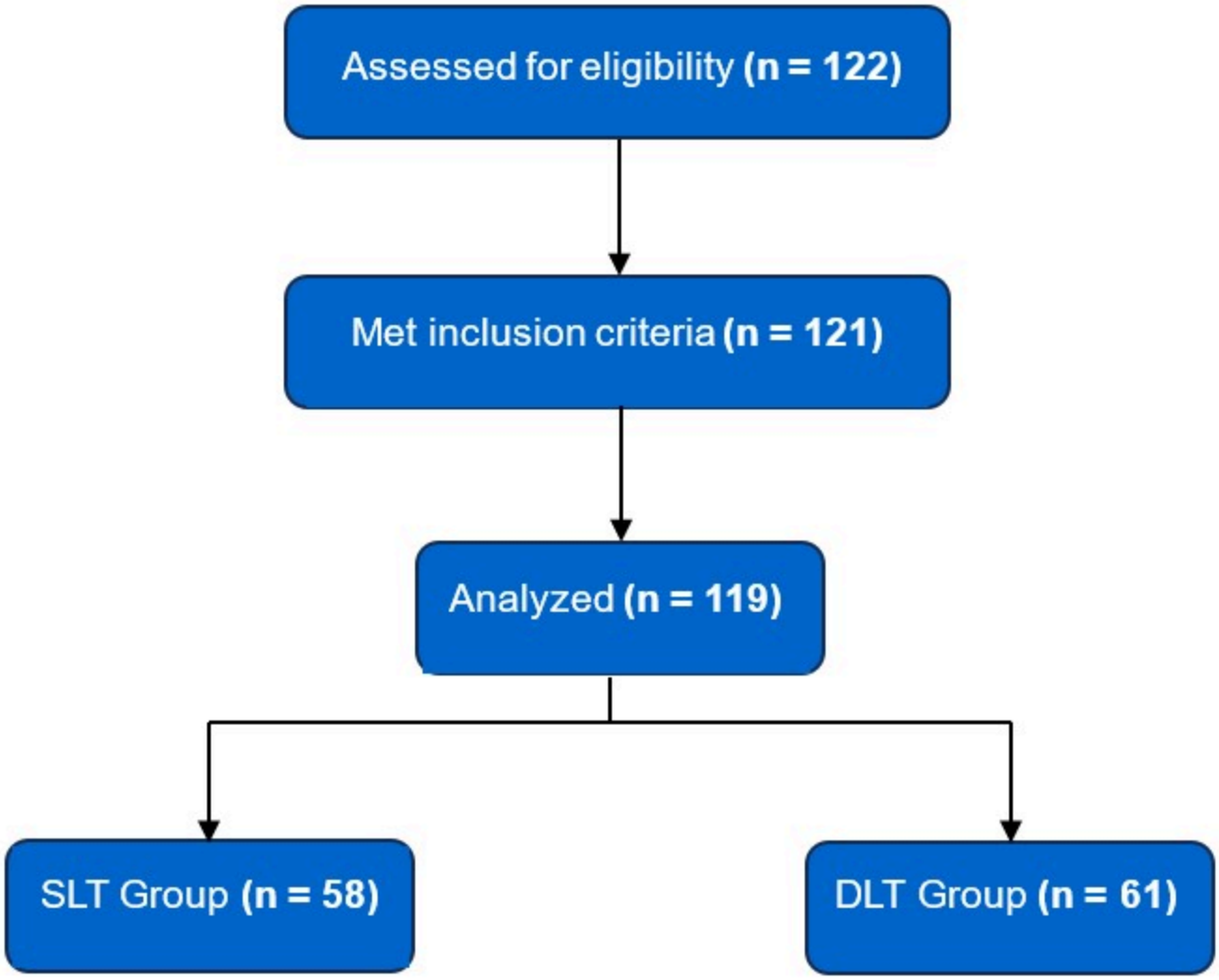


Figure 1

Flow diagram of study selection. DLT, double-lumen tube; SLT, single-lumen tube.

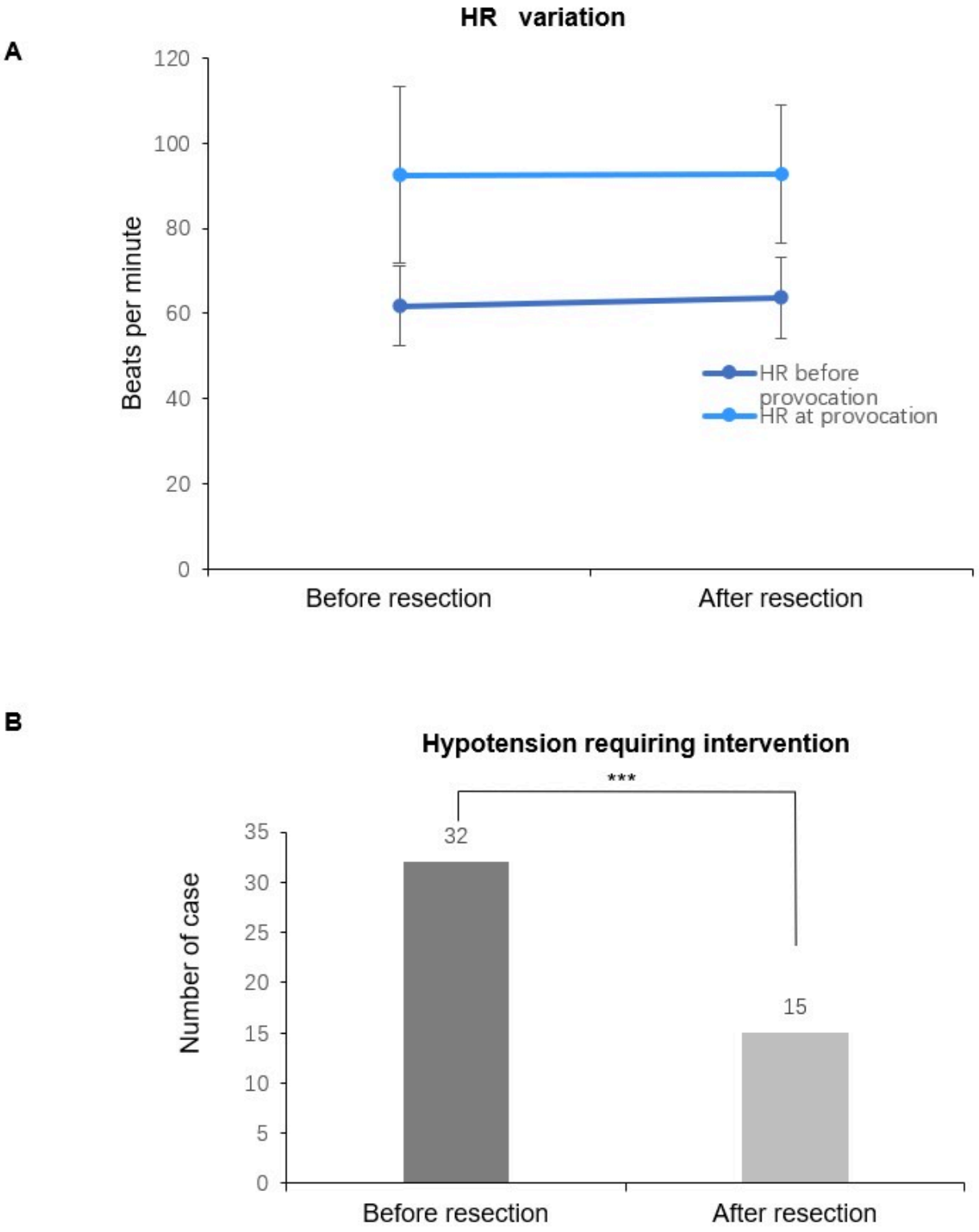


Figure 2

Hemodynamic changes during provocative testing. **a.** 68 patients underwent isoproterenol provocation both before and after hypertrophic myocardium resection. **b.**Among these 68 patients, hypotension requiring clinical intervention occurred in 32 patients during pre-resection provocation, whereas only 15 patients developed hypotension necessitating intervention during post-resection provocation. HR, heart rate.

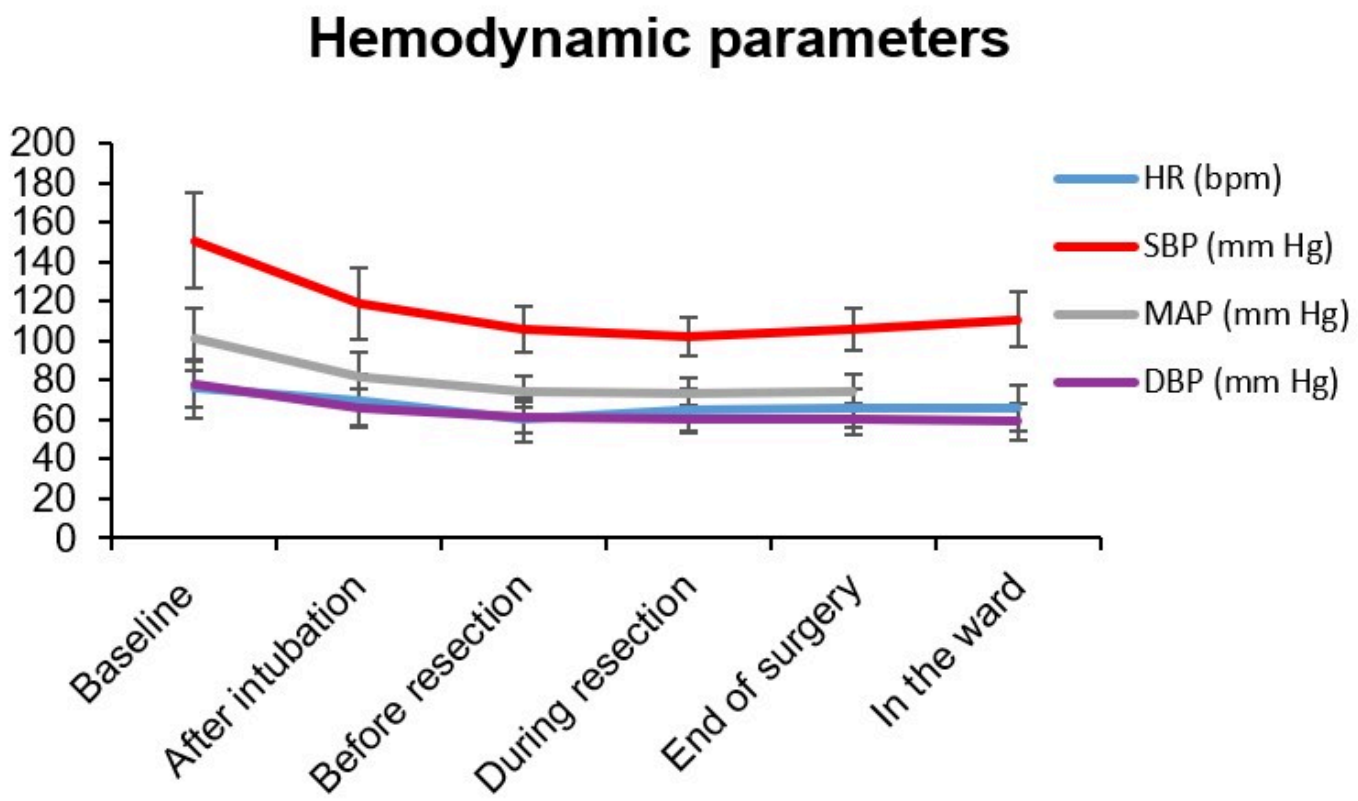


Figure 3

The perioperative hemodynamic changes of patients undergoing TA-BSM at different time points were presented. DBP, diastolic blood pressure; HR, heart rate; MAP, mean arterial pressure; SBP, systolic blood pressure.