Can J Anesth/J Can Anesth (2015) 62:918–926
DOI 10.1007/s12630-015-0393-0

SPECIAL ARTICLE

# Salvaging catastrophe in transcatheter aortic valve implantation: rehearsal, preassigned roles, and emergency preparedness

# Le rattrapage d'une catastrophe lors d'une implantation transcathéter de valve aortique: importance des répétitions, des rôles prédéterminés et du degré de préparation à l'urgence

**Derrick Y. Tam, MD · Philip M. Jones, MD · Bob Kiaii, MD · Pantelis Diamantouros, MD · Patrick Teefy, MD · Daniel Bainbridge, MD · Andrew Cleland, CCP, CPC · Philip Fernandes, CCP, CPC · Michael W. A. Chu, MD**

Received: 18 November 2014 / Accepted: 9 April 2015 / Published online: 29 April 2015


## Abstract

**Purpose** *Emergency rescue plans for acute complications during transcatheter aortic valve implantation (TAVI) commonly include cardiopulmonary resuscitation, femoro-femoral cardiopulmonary bypass (CPB), and hemodynamic stabilization before definitive intervention is achieved. Nevertheless, most cases of emergency resuscitation remain chaotic and disorganized and often take longer than necessary, even in experienced centres. We sought to determine which factors and procedures may be associated with improved patient outcomes when emergencies arise during TAVI.*

**Sources** *MEDLINE® and EMBASE™ were searched with the following key words: "TAVI" or "TAVR" or "transcatheter valve implantation" or "transcatheter valve replacement" and "emergency cardiac surgery" or "conversion". Two hundred seventeen articles met the criteria and were reviewed.*

**Principal findings** *Utilization of a formal emergency checklist by a multidisciplinary TAVI team may reduce procedural errors, smooth the transition to CPB, and ultimately speed the delivery of corrective measures including emergency cardiac surgery.*

**Conclusion** *A well-organized regularly-rehearsed emergency rescue plan that preassigns resuscitative roles may shorten the duration of patient instability and*

**Author contributions** *Derrick Y. Tam*, *Philip M. Jones*, *Bob Kiaii*, *Pantelis Diamantouros*, *Patrick Teefy*, *Daniel Bainbridge*, *Andrew Cleland*, *Philip Fernandes,* and *Michael W. A. Chu* made substantial contributions to the conception and design of the study. *Derrick Y. Tam*, *Philip M. Jones*, *Bob Kiaii*, *Pantelis Diamantouros*, *Patrick Teefy*, *Daniel Bainbridge*, *Andrew Cleland*, and *Philip Fernandes* made substantial contributions to drafting and revising the manuscript. *Michael W. A. Chu* made substantial contributions to the acquisition of data and analysis and played a critical role in drafting and revising the manuscript.

D. Y. Tam, MD
Division of Cardiac Surgery, Department of Surgery, University of Toronto, Toronto, ON, Canada

P. M. Jones, MD · D. Bainbridge, MD
Department of Anesthesia & Perioperative Medicine, Western University, Toronto, ON, Canada

P. M. Jones, MD
Department of Epidemiology & Biostatistics, Western University, London, ON, Canada

B. Kiaii, MD · M. W. A. Chu, MD (✉)
Division of Cardiac Surgery, Department of Surgery, Western University, B6 – 106 University Hospital, LHSC, 339 Windermere Road, London, ON N6A 5A5, Canada
e-mail: michael.chu@lhsc.on.ca

P. Diamantouros, MD · P. Teefy, MD
Division of Cardiology, Department of Medicine, Western University, London, ON, Canada

A. Cleland, CCP, CPC · P. Fernandes, CCP, CPC
Clinical Perfusion Services, London Health Sciences Centre, London, ON, Canada

*resuscitation and improve patient outcomes when catastrophe occurs in TAVI. The anesthesia team plays a central role in preventing, detecting, and treating intraprocedural complications during TAVI.*

**Résumé**

**Objectif** *Les plans de sauvetage d'urgence en cas de complications aiguës pendant l'implantation transcathéter d'une valve aortique (ITVA) comprennent souvent la réanimation cardiorespiratoire, la circulation extracorporelle fémoro-fémorale (CEC) et la stabilisation hémodynamique avant de réussir l'intervention définitive. Toutefois, la plupart des cas de réanimation d'urgence demeurent chaotiques et désorganisés et prennent bien souvent plus longtemps que nécessaire – même dans les centres d'expérience. Nous avons cherché à identifier les facteurs et interventions qui pourraient être associés à de meilleurs pronostics pour les patients lors d'urgences pendant une ITVA.*

**Source** *Nous avons effectué une recherche dans les bases de données MEDLINE® et EMBASE™ afin de retrouver les mots clés suivants : « TAVI » ou « TAVR » ou « transcatheter valve implantation » ou « transcatheter valve replacement » et « emergency cardiac surgery » ou « conversion ». Deux cent dix-sept articles répondaient à nos critères et ont été passés en revue.*

**Constatations principales** *L'utilisation d'une liste de contrôle d'urgence formelle par une équipe pluridisciplinaire d'ITVA pourrait réduire les erreurs d'intervention, faciliter la transition vers la CEC et, en fin de compte, accélérer la mise en place de mesures correctives, notamment d'une chirurgie cardiaque d'urgence.*

**Conclusion** *Un plan de sauvetage d'urgence bien organisé et souvent répété qui prédétermine les rôles lors de la réanimation pourrait réduire la durée de l'instabilité du patient et de la réanimation et améliorer les pronostics des patients en cas de catastrophe pendant une ITVA. L'équipe d'anesthésie joue un rôle central dans la prévention, le dépistage et le traitement des complications liées à l'intervention pendant une ITVA.*

## Introduction

Although significant experience with transcatheter aortic valve implantation (TAVI) has accrued, major intraprocedural complications still occur and are associated with a ninefold increase risk of mortality.[1] In a recent meta-analysis, catastrophic intraoperative complications during TAVI requiring emergency cardiac surgery (ECS) were reported to occur in 1.0-7.7% of cases and were associated with 67% mortality.[1] Emergency rescue plans commonly include cardiopulmonary resuscitation (CPR), femoro-femoral cardiopulmonary bypass (CPB), and attempts at hemodynamic stabilization before definitive intervention can be achieved. Nevertheless, most cases of emergent resuscitation remain chaotic and disorganized and often take longer than necessary, even in experienced centres.

Current TAVI guidelines recommend a "heart-team" approach with the presence of cardiac surgery, interventional cardiology, and cardiac anesthesia in a hybrid operating room (OR).[2-4] When catastrophic complications occur during TAVI in the cardiac catheterization laboratory, there is evidence to suggest that the increased time required for patient transfer to the OR is associated with increased mortality. For example, in a retrospective analysis of the German TAVI registry, 24 (1.2%) of 1,975 patients required emergency conversion to open heart surgery. Three patients suffered from aortic annulus rupture—clearly a serious life-threatening complication.[5] Of the two patients who survived, both had their TAVI performed in a hybrid operating room (combining a regular OR and a cardiac catheterization laboratory), allowing for quick conversion to ECS.

The purpose of this narrative review is to highlight the incidence and mortality associated with intraprocedural TAVI complications, to identify key preventive measures, and to reinforce the importance of developing and rehearsing a rescue protocol.

In order to identify key publications in this area, a literature search using MEDLINE® and EMBASE™ was conducted with the following key words: "TAVI" or "TAVR" or "transcatheter valve implantation" or "transcatheter valve replacement" and "emergency cardiac surgery" or "conversion". Two hundred seventeen articles met the criteria and were subsequently reviewed.

## Incidence and mortality of catastrophic intraprocedural complications in TAVI

A meta-analysis of 46 studies including 9,251 patients showed a 1.0-7.7% incidence of intraprocedural complications during TAVI requiring conversion to ECS [1] These complications included acute cardiac failure, coronary obstruction, annular rupture, left/right ventricular perforation, severe paravalvular leak, and aortic dissection.[1,5] The 30-day mortality for these patients was 67%—ninefold higher than for uneventful TAVI procedures.[1] Nevertheless, the mortality in one institution was found to be 35%—almost 50% lower than the incidence described in the meta-analysis—by utilizing a heart-team approach along with preparation of both the patient and the hybrid OR for emergency open heart surgery in every TAVI case.[6] In this single-centre study of 411 patients undergoing TAVI via the transfemoral or the

transapical route, 20 (4.9%) patients required ECS during their TAVI procedure. The authors credited their improved mortality outcomes to having optimal surgical back-up, specifically, by performing all TAVI cases in a hybrid OR with the patient draped and the room immediately ready for open heart surgery. Although the incidence of these catastrophic complications is relatively uncommon, the high associated mortality reinforces the importance of a well-planned rescue strategy by the multidisciplinary TAVI team.[7]

## Minimizing complications during conversion to ECS

A smooth transition to cardiopulmonary bypass (CPB) and/or conversion to ECS/definitive treatment will provide the best outcome for the patient. Nevertheless, there are many barriers to an optimal conversion to ECS. These barriers are outlined in Table 1 along with possible solutions to overcome these issues. Key barriers described in this Table include delays in transfer to an OR and in initiating CPB. The solutions to these barriers include performing the procedure in a hybrid OR and having the CPB circuit primed with appropriate pre-selected arterial and venous cannulae at hand in the room.

## Inadequate resuscitation effort

There may be many factors that contribute to inadequate resuscitation of the patient. First, there may be a delay in locating all the appropriate personnel (perfusionist, surgeon, anesthesiologist, and scrub nurses) to attend the procedure room. Second, there may be delays in transferring patients to the appropriate setting (from the catheterization lab to the OR). Finally, CPR may be of poor quality due to frequent interruptions (e.g., trying simultaneously to use fluoroscopy for "last-ditch maneuvers"), uncoordinated efforts, or inadequate blood volume for effective CPR (due to massive hemorrhage).

## Complications related to cardiopulmonary bypass

There may be delays in instituting CPB due to inadequate equipment, e.g., the proper cannulae not being readily available in the room or the CPB pump not being primed for immediate use. There may also be difficulty in finding vascular access for cannulation as the most commonly used arterial and venous sites may already be cannulated for the TAVI procedure itself (or they may be diseased). Further issues with initiating CPB include injury to vascular access and bleeding, which have been well documented in the literature.[7] Once on-pump, further related complications include inadequate pump flow due to poor cannulae placement or accidental decannulation during preparation for transport to the OR.

## Other potential complications

If the TAVI procedure is performed in the cardiac catheterization laboratory, there may be delays in obtaining blood products, further slowing the resuscitative efforts. This is especially relevant in patients with aortic root rupture or ventricular perforation. Another potential, albeit delayed, postoperative complication is infection due to breaches in sterility, which can easily occur during chaotic resuscitations.

These complications during conversion to ECS can be minimized with a well-prepared and rehearsed emergency plan. Although descriptions are lacking in the literature, we strongly advocate for a team-based approach with preassigned roles and duties for each team member along with regular practice of the rescue plan to ensure a smooth transition to ECS in the event of a complication.

## A team-based approach

Both the European Society of Cardiology and the American Association for Thoracic Surgery guidelines indicate that the standard of care during TAVI involves a multidisciplinary heart team consisting of an actively involved cardiologist, cardiac surgeon, anesthesiologist, and perfusionist in the procedure room.[2,4] Given the time-sensitive nature of complications associated with TAVI, a hybrid cardiac catheterization laboratory/OR setting has also been recommended as the setting for TAVI procedures.[2,3] Particular complications such as annular rupture and aortic dissection require immediate CPB and conversion to ECS, and these patients stand to benefit significantly from being in a hybrid OR where more timely interventions can occur.[5]

A few interesting trends were observed in one study despite the low number of patients suffering a life-threatening complication.[5] Patients with life-threatening complications (aortic annular rupture, aortic perforation, and aortic dissection) generally survived their procedure when their TAVI was performed in a hybrid OR in contrast with those whose TAVI was performed in a cardiac catheterization laboratory. These findings suggest that a short conversion time to surgery improves survival of the "bail-out" procedure, and having a procedure in a hybrid OR (or regular OR) provides the optimal environment for surgical conversion.

**Table 1** Barriers to optimal conversion to emergency cardiac surgery in TAVI catastrophes

| Barriers | Possible solutions |
|---|---|
| Inadequate preparation | |
| Delay in locating key personnel (perfusionist, nurses, surgeons, anesthesiologist) | Team huddle before the patient is brought into the room; introducing all members of the team and pre-assign roles. |
| Delay in transfer to operating room after catastrophe occurs | Perform procedure in a hybrid operating room with cardiopulmonary bypass circuit primed. |
| Delay in volume resuscitation | Have a rapid fluid infuser available. |
| | Have typed and cross-matched blood in the room. |
| Heart-lung machine related complications | |
| Delay in initiating cardiopulmonary bypass | Have cardiopulmonary bypass machine primed and in the room. |
| | Have appropriate cannulae in the room. |
| Vascular access delay | Preoperatively map access sites to ensure vessels are free of disease or have an alternate access site. |
| | Mark out access sites and have appropriate cannula insertion tools in the room. |
| Inadequate pump flow once on bypass | Team should have a general understanding of cardiopulmonary bypass and be aware of accidental decannulation during transfer to the operating room. |
| | Surgical assistant should be responsible for securing access sites during transfer. |
| Other potential complications | |
| Inadequate cardiopulmonary resuscitation. | Assign the role for CPR to two alternating individuals to ensure uninterrupted CPR. |
| | Avoid last-ditch maneuvers (use of fluoroscopy) which will delay going onto the heart-lung machine. |
| Postoperative infection due to break in sterility. | Have patient draped for open heart surgery with the groins exposed for cannulation. |

CPR = cardiopulmonary resuscitation; TAVI = transcatheter aortic valve implantation

## The critical role of the anesthesiology team

Transcatheter aortic valve procedures have been traditionally performed in the catheterization laboratory and with the anesthesiology team having a somewhat limited role. Nevertheless, the anesthesiology team clearly has a central role in the prevention, detection, and treatment of life-threatening complications that can occur during TAVI procedures. As in other cardiac operations, the anesthesiology team conveys important concerns about patient comorbidities in the preoperative briefing (i.e., "team huddle"), which allows for preparation of preventive measures. Given that TAVI patients are often frail and decompensated, early signs of hemodynamic instability during anesthetic induction may be predictive of subsequent problems and allow for additional preventive measures to be initiated, such as an earlier decision to commence inotrope and/or vasopressor infusions. The anesthesia team is well situated within the "cockpit" of the hybrid OR for the best assessment of all patient monitoring and recognition of early hemodynamic instability that may portend a subsequent catastrophe. It is also important for the anesthesiology team to have clear visualization of the fluoroscopy monitor, as this allows the anesthesiologist to anticipate complications specific to a particular stage of the TAVI procedure (e.g., aortic annular rupture after post-implant balloon valvuloplasty). Anesthesia principles of optimal situational awareness enable the anesthesiology team to integrate evolving information from several sources, to make rapid clinical assessments, and to transmit these findings to the cardiologist and surgeon. Finally, from a practical standpoint, the anesthesiology team is required to implement vasoactive medications and rapid fluid transfusion appropriately as well as maintain an appropriate depth of anesthesia while the rest of the TAVI team manages the technical aspects of the procedure, especially during emergency resuscitation.

## The importance of general anesthesia in TAVI

Recently, some physicians have advocated performing TAVI in awake patients using moderate sedation.[8] Nevertheless, we consider general anesthesia to be superior to sedation. As the patient's trachea is already intubated, general anesthesia allows for better control of

oxygenation, ventilation, and hemodynamics, facilitates optimal imaging with intraoperative transesophageal echocardiography (TEE), and simplifies conversion to ECS if required.[9,10] Under ordinary circumstances, tracheal extubation can be performed immediately following completion of the TAVI procedure with little added consequence. Even if some TAVI programs are promoting early patient discharge (within 48-72 hr), evidence is lacking that general anesthesia is inferior to moderate sedation when considering these discharge targets, though this is an understudied area.

## Transesophageal echocardiography is critical to TAVI success

Transesophageal echocardiography plays a critical role in assessing valvular and ventricular function and also provides crucial image guidance during valve implantation, particularly when fluoroscopic landmarks are difficult to appreciate. Additionally, TEE is important for early detection of complications, such as coronary obstruction and paravalvular leaks, as well as for rapid detection of cardiac tamponade. Thus, TEE plays an important role in the prevention and early detection of complications after TAVI, and we strongly recommend its routine use in these cases. Furthermore, the Canadian Cardiovascular Society, American Society of Echocardiography, and the European Association of Echocardiography have recommended intraoperative TEE as the gold standard for any valve surgery.[11,12]

## Checklists and practice may improve outcomes

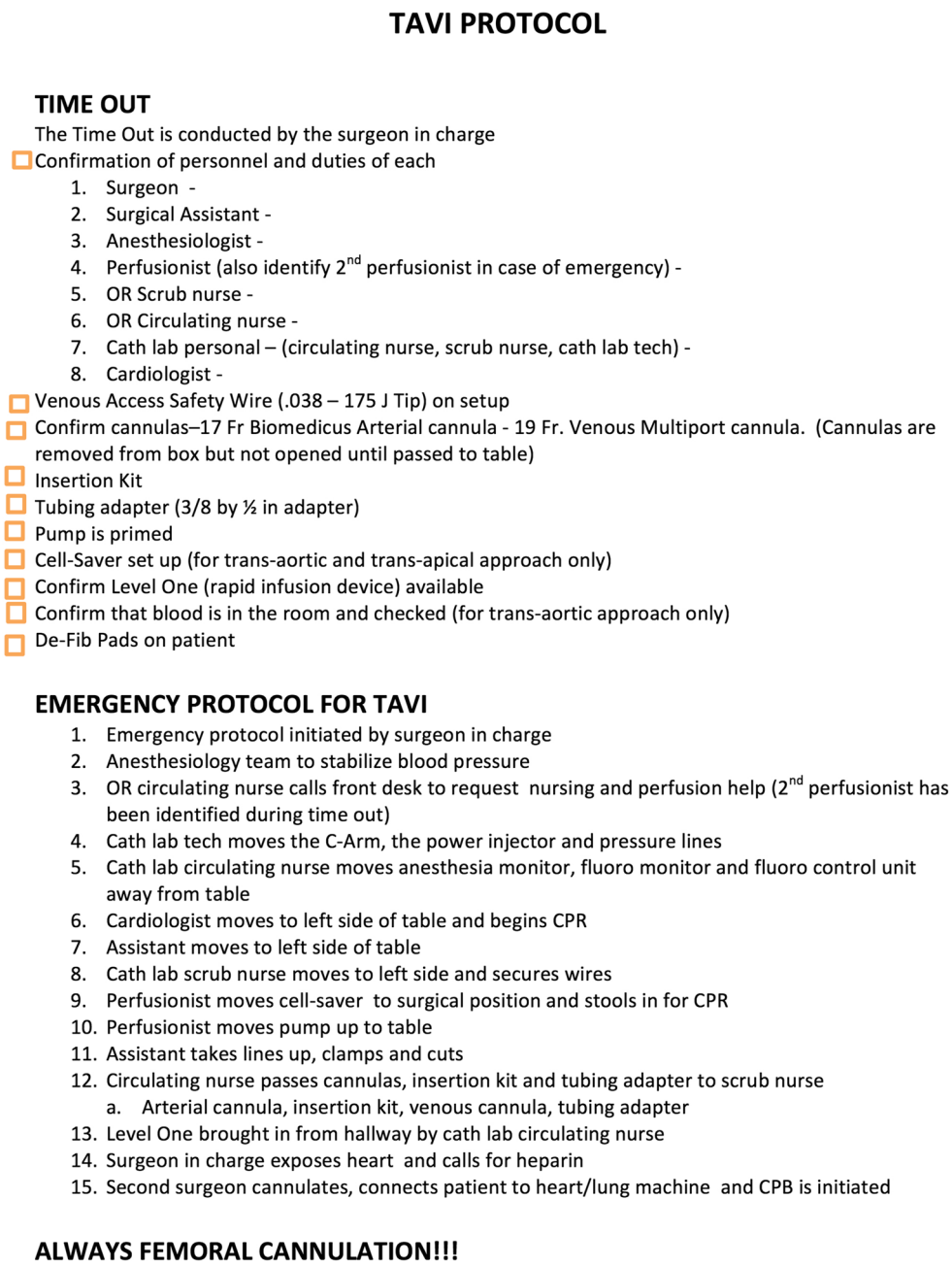
In the literature search undertaken, there were no specific studies detailing a protocol for the implementation of emergent CPB in TAVI. Nevertheless, in a study of 303 patients undergoing TAVI, 12 patients required "salvage" CPB, and the rate of survival to discharge was 83% for complications such as annular rupture, aortic insufficiency, tamponade, and valve embolization.[13] In that report, all TAVI procedures were performed in a hybrid OR utilizing a heart-team approach that included a "time-out" at the beginning of the case to discuss emergency plans. In addition, the CPB pump was primed and appropriate cannulae were in the OR. Once again, this suggests that key factors in patient survival are reduction in time to CPB and preparation.

In our view, however, these factors alone may be inadequate; therefore, we recommend introducing preparation protocols that include simulation training along with the use of a pre-TAVI checklist. The introduction of the surgical checklist by the World Health Organization has revolutionized safety in the OR.[14] Adopting a TAVI protocol checklist that includes emergency resuscitative protocols to be conducted before every procedure may help to improve patient safety with TAVI (Fig. 1). In particular, a TAVI protocol should include identification of all personnel involved in the procedure along with their preassigned roles should a catastrophe occur (Table 2). Personnel should be identified by name and clearly noted in the emergency protocol with their preassigned roles. Preassigning roles reduces confusion, ensures uninterrupted CPR, improves efficiency, and ultimately reduces time to CPB, thus likely improving survival outcomes. The checklist should also ensure that all proper equipment is available in the room to facilitate emergency resuscitation. For example, we advocate using a checklist that confirms the presence of the appropriate cannulae for peripheral cannulation, a primed CPB circuit, a rapid infusion device, and checked packed red blood cells (for direct aortic and transapical cases only). Having blood in the room along with a rapid fluid infusion device allows the anesthesiology team to fluid resuscitate patients quickly in the event of life-threatening hemorrhage or cardiac tamponade while the rest of the team prepares for CPB.

## Simulation training may enhance the implementation of checklists

While studies evaluating the effects of simulation in TAVI emergencies are lacking, simulation and team-building training in trauma surgery—where time plays a critical role in patient outcomes—has itself shown improvement in the clinical care of trauma patients.[15] In a pre/post-training intervention study,[15] all surgical residents and trauma attending physicians participated in a didactic course. The didactic teaching focused on communication skills and a leadership tool called "the briefing" where team members are identified, roles are explained, and preliminary care plans are made before the patient arrives. Learning was consolidated with simulation training to re-enact common trauma scenarios. Compared with pre-intervention, there was significant improvement in the qualitative outcomes of leadership and communication and in the quantitative outcomes of time to imaging and endotracheal intubation. In our view, this study can be extrapolated to highlight the importance of simulation training to improve outcomes in TAVI emergencies.

Mortality is high when catastrophic events take place during a TAVI procedure because of the time-sensitive nature of the opportunity to rescue the patient, i.e., minutes count. The evidence of checklists and simulation training in other surgical specialties not only supports the development of a rescue protocol but also encourages rehearsing the protocol with the entire TAVI team. We recommend simulating various TAVI crash resuscitation



# TAVI PROTOCOL

## TIME OUT

The Time Out is conducted by the surgeon in charge

- ☐ Confirmation of personnel and duties of each
  1. Surgeon -
  2. Surgical Assistant -
  3. Anesthesiologist -
  4. Perfusionist (also identify 2nd perfusionist in case of emergency) -
  5. OR Scrub nurse -
  6. OR Circulating nurse -
  7. Cath lab personal – (circulating nurse, scrub nurse, cath lab tech) -
  8. Cardiologist -
- ☐ Venous Access Safety Wire (.038 – 175 J Tip) on setup
- ☐ Confirm cannulas–17 Fr Biomedicus Arterial cannula - 19 Fr. Venous Multiport cannula. (Cannulas are removed from box but not opened until passed to table)
- ☐ Insertion Kit
- ☐ Tubing adapter (3/8 by ½ in adapter)
- ☐ Pump is primed
- ☐ Cell-Saver set up (for trans-aortic and trans-apical approach only)
- ☐ Confirm Level One (rapid infusion device) available
- ☐ Confirm that blood is in the room and checked (for trans-aortic approach only)
- ☐ De-Fib Pads on patient

## EMERGENCY PROTOCOL FOR TAVI

1. Emergency protocol initiated by surgeon in charge
2. Anesthesiology team to stabilize blood pressure
3. OR circulating nurse calls front desk to request nursing and perfusion help (2nd perfusionist has been identified during time out)
4. Cath lab tech moves the C-Arm, the power injector and pressure lines
5. Cath lab circulating nurse moves anesthesia monitor, fluoro monitor and fluoro control unit away from table
6. Cardiologist moves to left side of table and begins CPR
7. Assistant moves to left side of table
8. Cath lab scrub nurse moves to left side and secures wires
9. Perfusionist moves cell-saver to surgical position and stools in for CPR
10. Perfusionist moves pump up to table
11. Assistant takes lines up, clamps and cuts
12. Circulating nurse passes cannulas, insertion kit and tubing adapter to scrub nurse
    a. Arterial cannula, insertion kit, venous cannula, tubing adapter
13. Level One brought in from hallway by cath lab circulating nurse
14. Surgeon in charge exposes heart and calls for heparin
15. Second surgeon cannulates, connects patient to heart/lung machine and CPB is initiated

## ALWAYS FEMORAL CANNULATION!!!

**Fig. 1** The London Health Sciences Centre transcatheter aortic valve implantation protocol. Pre-assignment of clearly defined emergency resuscitative roles to each team member takes place during the "time out". The cardiopulmonary bypass machine is in the room, primed, and ready for use in case of emergency

scenarios (coronary obstruction, valve malposition, valve embolization, aortic root and left ventricular rupture) with the entire TAVI team. Ideally, but not necessarily, this would take place in a simulation lab (ideally every six months) with a resuscitation mannequin and the appropriate equipment. During the simulation, we recommend identifying a resuscitation leader and defining all personnel roles and responsibilities in a manner similar to the Advanced Cardiac Life Support and Advanced Trauma Life Support algorithms.[16,17] Furthermore, a dedicated person should be responsible for recording each step of the resuscitative effort so that the entire scenario can be reviewed in a post-simulation debriefing. Additionally, we also routinely discuss crash resuscitative plans as part of our checklist before each TAVI case in the hybrid OR. Finally, in order to keep order and clarity amongst team members during crash resuscitation, a TAVI protocol needs to emphasize and prioritize early patient stabilization, commonly with cardiopulmonary bypass, before determining the next steps.

**Table 2** General concepts of the TAVI protocol categorized by preoperative preparation and intraoperative management

| | |
|---|---|
| Preoperative preparation | |
| Introduction of personnel and duties of each. | Surgeon |
| | Anesthesiologist |
| | Assistant |
| | Perfusionist |
| | Scrub nurse |
| | Circulating Nurse |
| | Cath lab personnel |
| | Cardiologist |
| Cardiopulmonary bypass circuit | Appropriate cannulae for venous and arterial cannulation |
| | Insertion instruments available |
| | Pump is primed |
| Severe hemorrhage management | Cell saver set-up. |
| | Rapid fluid infusion device available. |
| | Cross-matched blood available in room. |
| Intraoperative management | |
| Initiation of protocol | Protocol initiated by surgeon in charge. |
| | OR circulating nurse calls for additional nurses and perfusionists. |
| Room set-up | Cath lab tech moves C-arm out. |
| | Cath lab circulating nurse moves monitors and pressure lines away from table. |
| | Cath lab scrub nurse secures wires and moves to assistant side of the table. |
| Resuscitation | Cardiologist moves to the assistant side of table and begins CPR (alternating with assistant). |
| | Anesthesiologist calls for second anesthesiologist and additional personnel as necessary. |
| | Anesthesiologist to secure airway if procedure performed under sedation. |
| | Anesthesiologist begins resuscitation effort with the administration of necessary fluids and pharmacologic support. |
| | Rapid fluid infuser hooked up to patient. |
| Perfusion | Perfusionist moves cell saver to surgical position. |
| | Perfusionist moves pump up to table. |
| | Assistant takes lines up, clamps and divides. |
| | Circulating nurse passes cannulae and insertion tools to scrub nurse. |
| Diagnosis and Monitoring | Anesthesiology team continuously monitors the patient's hemodynamics and communicates vitals to the team. |
| | Consider adjuncts of TEE for monitoring and diagnosis with sufficient personnel in the OR and with resuscitative efforts underway. |
| Cannulation | Surgeon in charge exposes the heart and calls for heparin. |
| | Anesthesiologist ensures that the patient receives sufficient heparin. |
| | Second surgeon cannulates femorally, connects patient to the cardiopulmonary bypass machine, and initiates cardiopulmonary bypass. |

Cath = catheterization; CPR = cardiopulmonary resuscitation; OR = operating room; TAVI = transcatheter aortic valve implantation. TEE = transesophageal echocardiography

## The London Health Science Centre experience and outcomes

In a retrospective analysis of our first 80 consecutive TAVI patients (transfemoral, transapical, and direct aortic approaches), we experienced five (6%) intraprocedural complications requiring emergency CPB. These complications included ascending aorta rupture ($n$ = 1), refractory hypotension despite inotropic support ($n$ = 2), valve embolization ($n$ = 1), and severe aortic insufficiency ($n$ = 1). Fig. 2 shows the time required to institute CPB for each patient and their initial serum lactate after institution of CPB. We initiated our routine checklist and use of the emergency TAVI protocol after the first two patients. In our view, the use of our rehearsed emergency protocol contributed to the shorter times to CPB and the lower initial lactate levels.

Given the baseline cardiac dysfunction and poor cardiac reserve in this patient population, metabolic acidosis may

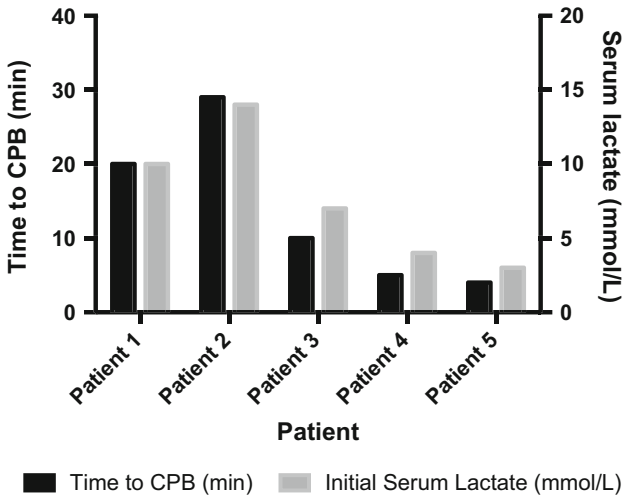



**Fig. 2** Time (min) from onset of "crash" emergency to cardiopulmonary bypass (CPB) and initial "post-crash" serum lactate after initiation of CPB support ($n$ = 5)

be difficult to correct despite hemodynamic stabilization. As such, decreasing the time to CPB and avoiding deleterious metabolic debt (as signalled by an increase in lactate concentration) may be key factors in improving patient outcomes in salvage situations. Of the five patients undergoing emergency CPB, there were no intraoperative deaths; however, there were two in-hospital deaths (40%) and three living patients discharged (60%) from hospital. We acknowledge that this is only a very limited experience, and we cannot attribute these improved outcomes solely to the implementation of our checklist and resuscitation protocol as our overall experience has similarly improved as well. Further study is required to confirm the success of this protocol.

## Conclusions

Although TAVI outcomes have improved with experience, the high mortality associated with complications that require ECS highlights an area for improvement in this evolving field. Following is a summary of the several recommendations made in this review:

(1) TAVI should be performed in a hybrid OR under the care of a dedicated cardiac anesthesiology team.
(2) All personnel on the multidisciplinary TAVI team should be identified by name, and their specific roles and responsibilities (including in emergency situations) should be pre-defined during the team briefing at the beginning of the case.
(3) The CPB circuit should always be in the room, primed and with the appropriate cannulae immediately available, in order to avoid unnecessary delays in initiating emergency CPB when needed.
(4) When a catastrophe occurs, the first priority is to resuscitate and stabilize the patient.
(5) Each institution performing TAVI should develop an individualized emergency TAVI protocol/checklist for procedural complications. The protocol should be regularly practiced by the entire TAVI team in a simulation setting.

Implementation of a checklist and rehearsal (ideally simulation-based) of a rescue protocol offer an effective solution for improving outcomes in ECS. In our view, both of these practices should be used to reduce mortality in this high-risk population. The role of the cardiac anesthesiologist in the heart team is vital for the prevention, detection, and treatment of serious intraprocedural complications during TAVI.

**Conflicts of interest** None declared.

**Disclosures** Both Bob Kiaii and Michael Chu are consultants for Medtronic Canada and Edwards Lifesciences.

## References

1. *Eggebrecht H*, *Schmermund A*, *Kahlert P*, *Erbel R*, *Voigtlander T*, *Mehta RH*. Emergent cardiac surgery during transcatheter aortic valve implantation (TAVI): a weighted meta-analysis of 9,251 patients from 46 studies. EuroIntervention 2013; 8: 1072-80.
2. *Holmes DR Jr*, *Mack MJ*, *Kaul S*, *et al*. 2012 ACCF/AATS/SCAI/STS expert consensus document on transcatheter aortic valve replacement: developed in collabration with the American Heart Association, American Society of Echocardiography, European Association for Cardio-Thoracic Surgery, Heart Failure Society of America, Mended Hearts, Society of Cardiovascular Anesthesiologists, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance. J Thorac Cardiovasc Surg 2012; 144: e29-84.
3. *Vahanian A*, *Alfieri O*, *Al-Attar N*, *et al*. Transcatheter valve implantation for patients with aortic stenosis: a position statement from the European Association of Cardio-Thoracic surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). EuroIntervention 2008; 4: 193-9.
4. *Vahanian A*, *Alfieri O*, *Andreotti F*, *et al*. Guidelines on the management of valvular heart disease (version 2012): the Joint Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Eur J Cardiothorac Surg 2012; 42: S1-44.
5. *Hein R*, *Abdel-Wahab M*, *Sievert H*, *et al*. Outcome of patients after emergency conversion from transcatheter aortic valve implantation to surgery. EuroIntervention 2013; 9: 446-51.
6. *Griese DP*, *Reents W*, *Kerber S*, *Diegeler A*, *Babin-Ebell J*. Emergency cardiac surgery during transfemoral and transapical transcatheter aortic valve implantation: incidence, reasons,

management, and outcome of 411 patients from a single center. Catheter Cardiovasc Interv 2013; 82: E726-33.
7. *Seiffert M, Conradi L, Baldus S, et al.* Severe intraprocedural complications after transcatheter aortic valve implantation: calling for a heart team approach. Eur J Cardiothorac Surg 2013; 44: 478-84; discussion 484.
8. *Hutchinson N*. Sedation vs general anaesthesia for the 'high-risk' patient—what can TAVI teach us? Anaesthesia 2011; 66: 965-8.
9. *Rex S*. Anesthesia for transcatheter aortic valve implantation: an update. Curr Opin Anaesthesiol 2013; 26: 456-66.
10. *Fassl J*. Pro: transcatheter aortic valve implantation should be performed with general anesthesia. J Cardiothorac Vasc Anesth 2012; 26: 733-5.
11. *Zoghbi WA, Chambers JB, Dumesnil JG, et al.* Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report From the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves, developed in conjunction with the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. J Am Soc Echocardiogr 2009; 22: 975-1014; quiz 1082-4.
12. *Jamieson WR*, *Cartier PC*, *Allard M*, *et al*. Surgical management of valvular heart disease. Can J Cardiol 2004; 20(Suppl E): 7E-120E.
13. *Roselli EE*, *Idrees J*, *Mick S*, *et al*. Emergency use of cardiopulmonary bypass in complicated transcatheter aortic valve replacement: importance of a heart team approach. J Thorac Cardiovasc Surg 2014; 148: 1413-6.
14. *Haynes AB*, *Weiser TG*, *Berry WR*, *et al*. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med 2009; 360: 491-9.
15. *Capella J*, *Smith S*, *Philp A*, *et al*. Teamwork training improves the clinical care of trauma patients. J Surg Educ 2010; 67: 439-43.
16. *American College of Surgeons Committee on Trauma.* Advanced Trauma Life Support for Doctors - ATLS Student Course Manual 2008.
17. *American Heart Association; Sinz E, Navarro K, Soderberg ES.* Advanced Cardiovascular Life Support. Laerdal Medical Corporation; 2011.