Supplementary

Figure S1 *In-situ* thoracic robotic simulation photo. All *in-situ* simulations were performed in a fully functional operating room where the robotic-assisted thoracic surgery cases are performed regularly at our institution.

Figure S2 KindHeart Thoracic Surgical Simulator manikin (Intuitive Surgical, Inc., Chapel Hill, NC). The porcine KindHeart thoracic model included a fully perfused beating heart and lungs. Injury to the great vessels led to significant simulated bleeding. During the simulations, OR teams prepped and draped this manikin's thoracic region, gained intravenous access in the manikin arm, and intubated the manikin airway.

https://dx.doi.org/10.21037/jtd-24-291

Pre-Operative Checklist			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Be prepared for an emergency. ☑ Be prepared for a seamless transition to open.	☑ Loupes in room. ☑ Headlights in room. ☑ Mark potential thoracotomy incision.	☑ Place 2 PIV prior to robot docking. ☑ High risk cardiac patients: Consider placing defib pad on pre-operatively.	☑ Ensure overhead lights are configured in a way that allows for quick removal of the robot. ☑ Check for the "Bleed Bag." ☑ Have extra gowns and gloves available on the sterile table for the surgical team.
*To be completed prior to start of simulation			

Scenario 1: Massive hemorrhage due to PA injury			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Identify bleeding vessel. ☑ Apply manual pressure to bleeding vessel robotically in a reasonable amount of time (within 30 seconds). ☑ Continue applying manual pressure for 7 minutes. ☑ Call for help in a reasonable amount of time (within 5 minutes). ☑ Have all necessary hemostatic agents in the room in a reasonable amount of time (within 7 minutes). ☑ Call for and receive all blood products in a reasonable amount of time (within 5 minutes, if needed). ☑ Identify need for conversion in a reasonable amount of time (within 8 minutes).	☑ Identify bleeding source/ suction to see bleed (30 seconds). ☑ Apply manual pressure with robot and hold for 7 minutes (1 minute). ☑ Call for hemostatic agents and "Bleed Bag"/Hemostatic agents (within 3 minutes). ☑ Call for help (within 5 minutes). ☑ Discuss possible need for transfusion (within 5 minutes). ☑ Determine need for conversion (within 8 minutes). ☑ Discuss undocking plan for robot with OR team (within 8 minutes).	☑ Communicate with surgeon (1 minute) Give IV fluid bolus (1 minute). ☑ Call for Anesthesia Attending and for Anesthesia help (within 1 minute). ☑ Consider ordering and call for 2-4 units of pRBC and FFP (within 2 minutes). ☑ Determine the need for additional peripheral IV access (Within 3 minutes). ☑ Delegate responsibilities. (Within 3 minutes). ☑ Communicate with the surgeon about patient's hemodynamics, plan for control of hemorrhage and blood products given. (3 minutes). ☑ Call anesthesia techs for ISTAT, Hemocue, and Belmont rapid infuser (within 5 minutes). ☑ Get baseline labs, ABG with ISTAT and Hemocue (within 7 minutes). ☑ Start vasopressors if needed (5 minutes).	☑ Discuss need for overhead call for help/call front desk for other Thoracic attendings/Call other Thoracic attendings (30 minutes). ☑ Start wall timer/clock for manual pressure (1 min). ☑ Get "Bleed Bag" and hemostatic agents per surgeon request (within 5 minutes). ☑ Discuss getting open tray/Get Open tray (5 minutes). ☑ Discuss undocking plan with Surgeon (7 minutes).
Anticipated Time: 30 seconds to ID bleeding source, 7 minutes of manual compression, 1 minute to determine conversion, given continued bleeding. Total (give or take): 10 minutes			

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Scenario 2: Decision to convert to open (10 minutes into simulation)			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Adequately determine need for conversion to open (5 minutes). ☑ Call for help in a reasonable amount of time. ☑ Have all necessary equipment in the room in a reasonable amount of time (5 minutes). ☑ Maintain manual pressure robotically while converting to open. ☑ Obtain open, manual pressure prior to undocking robot. ☑ Correctly undock robot in a reasonable amount of time (3 minutes). ☑ Attending surgeon is at bedside within 8 minutes. ☑ Discuss possible need for transfusion (within 5 minutes), if needed administer blood within 10 minutes.	☑ Continue applying manual pressure to the bleeding vessel while bedside assistant begins thoracotomy (immediately). ☑ Ask for lights on/Headlights (1 min) State that you are making the thoracotomy incision (within 2 minutes). ☑ Ask for and call for additional surgical help (within 5 minutes). ☑ Apply manual pressure to bleeding vessel when chest is open (within 5 minutes). ☑ Attending surgeon to bedside (within 8 minutes). ☑ Remove all robotic instruments (Within 11 minutes). ☑ Undock robot (within 14 minutes). ☑ Attending attempts primary repair (within 16 minutes).	☑ Give blood based on EBL and hemodynamics. (3 minutes). ☑ Discuss vasopressors as needed to maintain hemodynamics (3 minutes). ☑ Reevaluate need for additional IV access/Belmont rapid infuser (4 minutes). ☑ Check iStat labs, ABG and hemocue (6 minutes).	☑ Ensure “Bleed Bag” and additional sponges are on sterile field (within 1 minutes). ☑ Open thoracotomy tray (within 2 minutes). ☑ Confirm undocking plan with surgeon with closed loop communication (1 minute). ☑ Overhead call/call front desk for additional surgical help or on-call vascular attending (x4111) (within 5 minutes). ☑ Get an extra table and cover (3 min). ☑ Set up suction (5 min). ☑ Get extra scrub to clean up robot set up (7 minutes). ☑ Get extra OR nurse to be a runner (7 minutes).
Anticipated time: <30 sec to continue robotic pressure, 1 minute for addition trays to be opened/supplies given, 5 minutes to open chest, 3 minutes for attending to scrub and be at bedside, 3 minutes for robotic instruments to be removed, and attending in chest, 3 minutes to undock the robot. Total (Give or take): 16 minutes ***PA IS APPROPRIATELY REPAIRED***			

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Scenario 3: Hemodynamic instability (26 minutes into simulation)			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Continue to apply manual pressure. ☑ Determine need for additional blood products (within 3 minutes). ☑ Call blood bank and initiate massive transfusion protocol if needed (within 5 minutes to call, 10 minutes to receive blood). ☑ Determine need for pressor support (within 6 minutes). ☑ Call for additional help if not already done (5 minutes). ☑ Retrieve internal paddles (8 minutes). ☑ Discuss other possible reasons for hemodynamic instability. ☑ Ensure bleeding has been controlled/there are no other areas of bleeding.	☑ Ensure bleeding has been controlled/there are no other areas of bleeding (within 2 minutes). ☑ Discuss other possible reasons for hemodynamic instability (within 3 minutes). ☑ Discuss amount of blood loss (4 minutes).	☑ Continue giving IV fluids or blood using fluid warmer if available (within 1 minute). ☑ Consider TXA (within 1 minute). ☑ Call for Belmont rapid infuser (within 2 minutes). ☑ Maintain normothermia (within 3 minutes). ☑ Consider additional blood products (3 minutes). ☑ Increase pressor support (within 4 minutes). ☑ Consider other causes of hemodynamic instability in addition to bleeding (e.g., air embolus, tamponade) (within 5 minutes).	☑ Get cell-saver set up (within 10 minutes).
Anticipated time: <30 sec to replace manual pressure, 1 minutes to discuss need for additional blood products, 2 minutes to discuss other causes of hemodynamic instability, 5 minutes to retrieve internal paddles, 2 minutes to retrieve code cart. Total (give or take): 11 minutes			

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Scenario 4: PEA/Asystole (37 minutes into simulation)			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Identify Asystole/PEA on rhythm strip (1 min). ☑ Determine if the rhythm is shockable (1 min). ☑ Call for help in a reasonable amount of time (1 min). ☑ Begin adequate intra-thoracic cardiac massage (<2 min). ☑ Maintain manual pressure on bleeding vessel throughout internal cardiac massage. ☑ Pulse and rhythm check (4 min). ☑ Give epinephrine (5 min). ☑ Continue cardiac massage.	☑ Discuss intra-thoracic cardiac massage with Anesthesia (1 minute). ☑ Begin adequate intra-thoracic cardiac massage (<2 min). ☑ Continue cardiac massage.	☑ Identify a rhythm change on the monitor (Within 1 minute). ☑ Correctly identify Asystole or PEA (Within 1 min). ☑ Designate code leader and instruct someone to start a code clock (within 1 minute). ☑ Determine if the rhythm is shockable (within a minute). ☑ Instruct surgical team to begin intra-thoracic cardiac massage at a rate of 100 BPM (within 1 minute). ☑ Give Epinephrine 1 mg IV every 3-5 mins (within 1 minute). ☑ After 2 mins of cardiac massage, perform a pulse and rhythm check (within 3 minutes). ☑ Continue cycling through cardiac massage, pulse checks and administrating epinephrine (within 3 minutes). ☑ For completeness, review H's and T's and treat cause (within 5 minutes). ☑ Once ROSC is achieved, discuss MAP goals, vasopressor infusion (Epinephrine, Norepinephrine, Vasopressin) (within 6 minutes).	☑ Get the Code Cart (1 min). ☑ Call Code over intercom (1 min). ☑ Start Code clock (within 1 minute). ☑ Put internal paddles on sterile field (2 min). ☑ Remove people who are not assigned a role from the OR (3 min).
Anticipated Time: 1 minute to identify rhythm strip/determine if it is shockable, 1 minute to begin cardiac massage, 8 minutes of internal cardiac massage. Total: 10 minutes			

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Scenario 5: Unstable Ventricular Tachycardia/Fibrillation (45 minutes into simulation)			
Protocol Objectives	Surgery Checklist	Anesthesia Checklist	Nursing/Scrub Checklist
☑ Determine if the rhythm strip is displaying a shockable rhythm (1 min). ☑ Check pulse to determine if there is a pulse present/stable or unstable VT (1 min). ☑ Begin cardiac massage (two hand technique, rate >100bpm) (1 min). ☑ Retrieve internal paddles in a reasonable time frame (1 min). ☑ Call for additional help (5 min). ☑ Defibrillate/shock at max joules (3 min). ☑ Continue with internal cardiac massage for 2 minutes following shock (two hand technique, rate >100 bpm). ☑ Rhythm check and possible defibrillation/shock.	☑ Discuss situation with Anesthesia (1 minute). ☑ Start intra-cardiac massage while getting internal defibrillators (1 minute). ☑ Retrieve internal paddles in a reasonable time frame (1 min). ☑ Defibrillate at max joules with internal paddles (3 min) (10J and then go up by 5J).	☑ Determine if the rhythm strip is displaying a shockable rhythm (1 min). ☑ Check pulse/waveform to determine if there is a pulse present (1 min). ☑ Discuss situation with Surgery (1 minute). ☑ Instruct Surgeon to start intra-cardiac massage while getting internal defibrillators (1 minute). ☑ Charge defibrillator depending on rhythm strip at 10-20J (increase by 5J as needed) (within 2 minutes). ☑ Consider amiodarone and anti-arrhythmic medications (within 4 min). ☑ Rhythm check and possible defibrillation.	☑ Continue being Code clock/ recorder. ☑ Call front desk to alert eICU.
Anticipated Time: 1 minute discuss with Anesthesia/Surgery, 1 minute to shock/start cardiac massage, 5 minutes of cardiac massage until ROSC achieved. Total: 7 minutes			

[1]Abbreviations: PIV, peripheral intravenous catheter; PA, pulmonary artery; pRBC, packed red blood cells; FFP, fresh frozen plasma; ABG, arterial blood gas; TXA, tranexamic acid; PEA, pulseless electrical activity; BPM, beats per minute; ROSC, return of spontaneous circulation; MAP, mean arterial pressure; VT, ventricular tachycardia; J, joules.

Figure S3 Emergency checklist protocols for all five scenarios. All five emergency scenarios (massive hemorrhage due to PA injury, decision to convert to open, hemodynamic instability, PEA/Asystole, unstable ventricular tachycardia/fibrillation) had accompanying checklists. Additionally, a pre-operative checklist was created. Each of these checklists were further subdivided into team member role (surgery, anesthesia, nursing/scrub).

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Appendix 1 Pre-OR simulation survey

Pre-OR Simulation Survey:

1. What is your role in the OR?
   a. Anesthesia (Attending/Resident)
   b. Circulating nurse
   c. Scrub nurse/Tech
   d. Surgery (Attending/Resident)
   e. Other _____
2. How long have you worked at UMASS?
3. What percentage of your time is devoted to Thoracic patients/procedures?
4. I am confident that I know my role during an intra-operative emergency.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
5. I know how to undock the da Vinci robot.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
   f. Other: Anesthesia
6. I believe emergency checklists are helpful and would use them during an intra-operative emergency.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
7. I believe simulations are an important part of continuing education and are helpful in learning skills that are infrequently used.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
8. What are you specifically looking to learn from this session:
9. Other comments:

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Appendix 2 Post-simulation survey

Post-Simulation Survey:

1. What is your role in the OR?
   a. Anesthesia (Attending/Resident)
   b. Circulating nurse
   c. Scrub nurse/Tech
   d. Surgery (Attending/Resident)
   e. Other _____
2. How long have you worked at UMASS?

3. What percentage of your time is devoted to Thoracic patients/procedures?

4. I am confident that I know my role during an intra-operative emergency.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
5. I know how to undock the da Vinci robot.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
   f. Other: Anesthesia
6. I believe emergency checklists are helpful and would use them during an intra-operative emergency.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
7. I believe simulations are an important part of continuing education and are helpful in learning skills that are infrequently used.
   a. Strongly agree
   b. Agree
   c. Neutral
   d. Disagree
   e. Strongly disagree
8. The emergency protocols are easy to use and functional.
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree
9. The scenarios were realistic and true to a real clinical scenarios.
   a. Strongly disagree
   b. Disagree

https://dx.doi.org/10.21037/jtd-24-291

c. Neutral
d. Agree
e. Strongly agree

10. The checklists made me feel better prepared for intra-operative emergencies.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
11. The checklists were easy to use.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
12. If you were presented with these emergencies in real life, you would want to use the checklist during the emergency.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
13. If you were a patient experiencing an intra-operative crisis you would want practitioners to use one of the emergency checklists.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
14. I would rate the overall quality of the emergency checklists as:
    a. Excellent
    b. Above average
    c. Average
    d. Below average
    e. Terrible
15. I believe high fidelity simulation of intra-operative emergency situations are helpful and provide an opportunity to train for a high-stakes, low frequency event. (For pre-iCELS simulations)
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree
16. After this simulation session I feel comfortable using the intra-operative emergency protocols and checklists.
    a. Strongly disagree
    b. Disagree
    c. Neutral
    d. Agree
    e. Strongly agree

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17. Did you feel the simulation met your needs?
    a. Yes
        i. Explain:
    b. No
        i. Explain:
18. Were there any specific areas in the protocols or checklists that you believe can be improved upon?

19. Possible improvements to the simulation:

20. Other comments:

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