Optimizing Patient Access During an Emergency While Using Intraoperative Computed Tomography

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■ BACKGROUND: **As minimally invasive spine surgery evolves, spine surgeons increasingly rely on advanced intraoperative computed tomography (iCT). iCT provides rapid acquisition of high-resolution images, reduces radiation exposure, improves surgical accuracy, and decreases operative time. However, all iCT systems currently available pose a patient safety risk as their physical space requirements limit patient access in the event of an emergency, particularly when patients are in the prone position. After a near-cardiac arrest at our institution during posterior cervical spine surgery, it was apparent that the presence of the iCT complicated the ability to rapidly reposition the patient in order to provide appropriate resuscitation.**

■ METHODS: **To ensure our ability to provide timely care during an emergency, we determined that a process which included all members of the operating room (OR) team was required. We held an initial planning meeting where a detailed plan-of-action was created, reviewed, and revised in response to feedback from all stakeholders. We then simulated a cardiac arrest to test our resuscitation plan with all members of the neurosurgery team. A mannequin was positioned prone on an OR table within the iCT, and a resuscitation plan was created.**

■ RESULTS: **The team orchestrated the mock resuscitation, and the time of cardiac arrest in the prone position to supine repositioning required 110 seconds. The simulation was recorded for post-"code" performance review. Application of the protocol during an actual cardiac arrest was associated with successful restoration of spontaneous circulation and full recovery.**

■ CONCLUSIONS: **The development and rehearsal of an emergency plan of action greatly facilitated the timely responsiveness of the neurosurgical OR team during a simulated cardiac arrest and was an effective way to identify and address key logistical issues regarding the use of an iCT system.**

INTRODUCTION

As minimally invasive spine surgery evolves, spine surgeons increasingly rely on advanced intraoperative image-guided navigation. Recent studies suggest that intraoperative computed tomography (iCT) can reduce radiation exposure, improve surgical accuracy, and decrease operative time, thereby improving workflow.[1-5] iCT is a compact, mobile, computed tomography (CT) scanner that can be stationed in the operating room and which permits real-time imaging while a patient is anesthetized. Although multiple navigation systems are commercially available, they all present a safety risk to the patient as their physical space requirements limit access to the patient in the event of an emergency. As the use of iCT imaging becomes more

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- Education
- Intraoperative imaging
- Operating room safety
- Patient safety
- Quality improvement
- Resuscitation
- Spine

Abbreviations and Acronyms
ACLS: Advanced cardiovascular life support
CPR: Cardiopulmonary resuscitation
iCT: Intraoperative computed tomography
OR: Operating room

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commonplace, operating room (OR) teams need to proactively develop, implement, and rehearse appropriate workflow strategies to facilitate timely access to the patient and expeditiously reposition the patient during an emergency when such imaging is used.

USE OF iCT AND LOGISTICAL CONSIDERATIONS

The Airo is a mobile iCT system that can be used for cranial and spine procedures and is designed to function inside the OR; it consists of a CT x-ray tube and scanner, radiolucent table, and table base that is connected to the scanner (Figure 1A). The scanner component is positioned at the patient's head when not in use (Figure 1B). When an image is required, the scanner moves along the longitudinal axis of the patient and the bed during image acquisition (Figure 2).

For prone cervical spine procedures, the patient's head is fixed in place using a 3-pronged skull clamp device (e.g., a Mayfield head clamp), which is secured to the table so that the head is immobile. Release of the head clamp from the table is typically performed by the neurosurgeon and must be done before the patient can be turned supine onto another bed; as the fixation system uses threaded screws to attach the frame to the table, it cannot be released immediately in the event of an emergency.

In addition to the standard noninvasive physiology monitors (blood pressure, electrocardiogram, pulse oximetry) used during all surgical procedures, the majority of the spine cases performed using iCT require intraoperative neurophysiologic monitoring (IOM) including motor evoked potentials, somatosensory evoked potentials, electromyography (EMG), and electroencephalography. To maximize the sensitivity of evoked potential monitoring, we avoid the use of volatile anesthetics. General anesthesia is maintained using an intravenous anesthetic regimen (i.e., total intravenous anesthesia). The use of total intravenous anesthesia frequently requires the presence of 2 intravenous access lines; in addition, invasive blood pressure monitoring (arterial line) is routinely used. Given all the equipment and personnel in the room, floor space in close proximity to the patient is limited (Figure 3); consequently, all fluid lines, monitoring cables, suction tubing, electrocautery leads, and the forced hot-air warming hose pass through the scanner gantry to reach the patient so as to allow unencumbered movement of the scanner along the longitudinal axis of the bed (Figure 3). At the conclusion of the procedure, or in the event of an emergency, all of these items and devices must be easily and quickly repositioned to facilitate the rapid transfer of the patient from the OR table to a stretcher.

Description of Sentinel Event

At the New York-Presbyterian Hospital—Weill Cornell Medical Center, we routinely use mobile intraoperative iCT (Airo, Brainlab AG, Feldkirchen, Germany; described later) during spine surgery. The precipitating event that led to this project involved a patient with cervical stenosis who underwent elective posterior laminectomy and fusion using Airo iCT and Brainlab imaging-guidance. The patient was positioned prone inside the Airo system with the head immobilized in a Mayfield head clamp attached to the Airo table. The appropriate American Society of Anesthesiology standard monitoring was in place (as well as intraoperative neurophysiologic monitoring). Midway through the surgical procedure, the patient became hypotensive without initial response to peripherally administered vasopressors. After calling for assistance, multiple clinical staff arrived to provide additional support, and subsequent pharmacologic efforts were sufficient to stabilize the patient's hemodynamics without the initiation of advanced cardiovascular life support (ACLS). It was apparent to all present, however, that a predetermined, organized, and logical plan was needed for removing the patient from the Airo in an emergency situation.

METHODS—PLAN

Overview

In response to this event, we hypothesized that a well-defined plan of action was needed in order to safely and efficiently provide

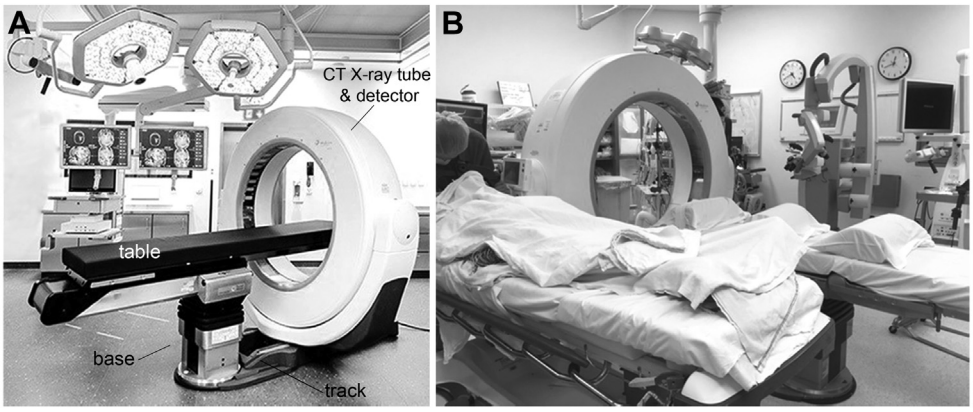

Figure 1. Airo system components and positioning in the operating room. (**A**) The Airo mobile intraoperative imaging system consists of a computed tomography x-ray tube and detector, an x-ray compatible table, and a table base. Note the presence of a track attached to the base, which allows the x-ray tube to move along a fixed path parallel to the long axis of the table. (**B**) The patient stretcher is positioned on the side of the Airo table closest to the anesthesia machine before positioning the patient on the Airo table.

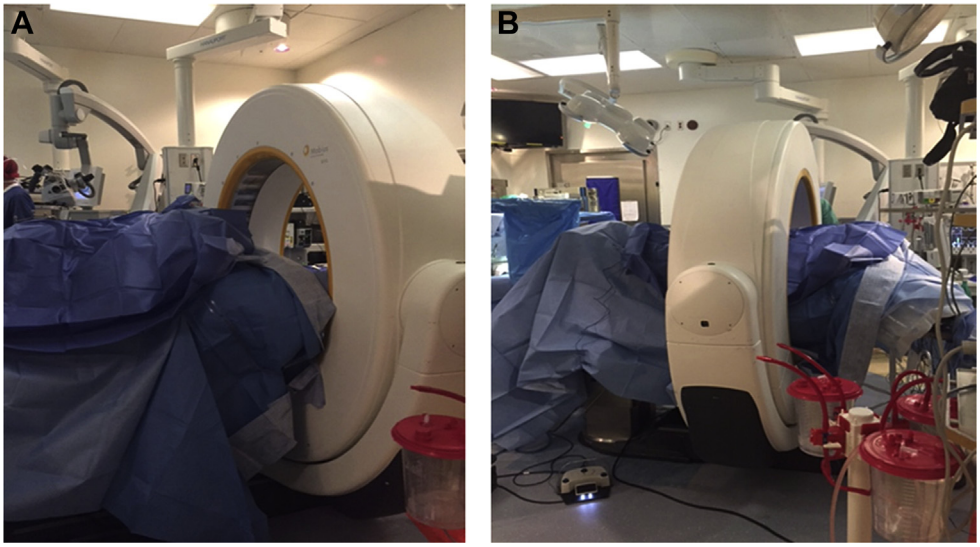

Figure 2. Movement of the gantry during image acquisition. (**A**) When not actively scanning, the x-ray tube is positioned at the patient's head. (**B**) During image acquisition, the x-ray scanner moves along the track at the bottom of the base (as seen in Figure 1A) along the longitudinal axis of the patient, moving from head to foot.

appropriate emergency care (here cardiopulmonary resuscitation) to patients when iCT is used. The *design* of an effective plan would require active input from all members of the neurosurgical operating room team (nursing, technical, and physician [including residents and attendings from both neurological surgery and neuroanesthesia] staff) while effective *implementation* of the plan would require active rehearsal before an actual critical event. We predicted that the development and rehearsal of an emergency

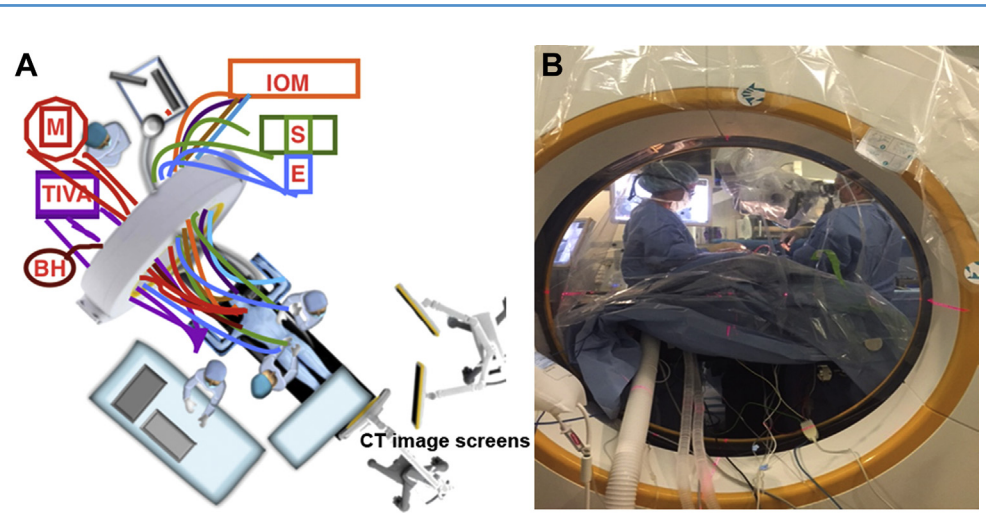

Figure 3. Patient and room configuration when using intraoperative computed tomography imaging. (**A**) Cartoon image demonstrating the overall room configuration when the Airo is used. Note that all intravenous lines, cables, and warming devices pass through the scanner gantry. (**B**) The view of the operative field from the perspective of the anesthesia care team. The use of clear plastic drapes facilitates situational awareness among all operating room personnel. BH, Bair Hugger (or similar forced hot-air warming device); E, electrocautery cables; IOM, neurophysiology monitoring cables; M, standard physiology monitoring (blood pressure—both invasive and noninvasive, electrocardiogram, pulse oximetry) cables; S, suction tubing; TIVA, total intravenous anesthesia infusion lines.

plan of action would facilitate the timely responsiveness of the neurosurgical OR team during an intraoperative emergency requiring rapid repositioning of a patient.

PLAN DEVELOPMENT—DO

After a departmental and institutional review of the preceding case report, we developed a clear process to provide appropriate resuscitation while using iCT, *which included all members of the OR team*. We held an initial planning meeting consisting of OR personnel routinely involved in neurosurgical procedures requiring the use of the Airo including neuroanesthesiologists, neurosurgeons, neurosurgical OR nurses, neurophysiology and radiology technicians, as well as a technical representative from the Airo manufacturer. After feedback from all participants and stakeholders, a plan of action was created and distributed to everyone who attended the planning session, as well as to other team members who were not present. The drafted plan of action was reviewed over the next 2 weeks and revised in response to feedback from all stakeholders. The group met again in the OR 2 months later to test the revised plan of action (**Appendix A**) in a simulated cardiac arrest scenario.

PLAN TESTING AND REFINEMENT

For the simulation, *all* members of the neurosurgery OR team met in an OR where a mannequin was positioned in the prone position on the Airo table. The OR was staffed with the full complement of personnel: 2 nurses (scrub technician and circulating nurse), 2 anesthesiologists (attending and resident physicians), 2 neurosurgeons (attending and resident physicians), and 2 technicians (1 each from radiology and BRAINLAB) and neurophysiology personnel. The OR was fully configured (comparable with the image in **Figure 3B**), with all monitors, cables, drapes, and devices positioned and applied as they would be during an actual surgical procedure.

With the collaboration of the simulation team from the institutional Skills Acquisition and Innovation Laboratory, we conducted a full cardiac arrest simulation in the neurosurgical OR. The neuroanesthesiologist ran the mock code, and roles were identified for all personnel and rehearsed. The neurosurgeons were instructed to immediately pack the wound and cover the incision, begin chest compressions, and prepare to move the "patient" off the Airo table. After the incision was packed and covered, while one neurosurgeon performed chest compressions,[6-8] the second neurosurgeon readied the mannequin to be returned to the supine position on a stretcher by releasing the Mayfield clamp from the table. The nursing staff assisted in moving equipment away from the Airo table. The attending anesthesiologist guided the medical and physiologic management, while helping the anesthesiology resident remove extraneous cables and connections from the "patient" and simultaneously reposition critical monitors (invasive blood pressure, pulse oximetry, electrocardiogram); concurrently, the neurophysiology team disconnected their cables. An OR assistant brought the stretcher to the side of the Airo table closest to the anesthesia machine (this side being the most efficient to continue resuscitative efforts as well as to permit rapid removal of other equipment (e.g., monitors, x-ray equipment, operating microscope) obstructing access to the "patient," and the OR scrub nurse brought the "code cart" to the anesthesia team. The mannequin was turned supine and "cardiopulmonary resuscitation" (CPR) continued.

The time from "cardiac arrest" to returning the mannequin to a supine position was 110 seconds (no additional "CPR" was performed once the mannequin was supine as the point was not to rehearse our CPR skills per se). During the debriefing and review of the simulation video, key logistical issues were identified including the need for a detachable, portable vital signs monitor, extension tubing for the anesthesia circuit, and additional capped IV access. Among members of the anesthesia care team, the universal opinion was that use of a detachable, portable, vital signs monitor would significantly enhance the expeditious repositioning of the "patient" as critical monitors would not need to be disconnected during repositioning.

On review, the consensus opinion was that the development *and rehearsal* of an emergency plan of action greatly facilitated the timely responsiveness of the neurosurgical OR team during the simulated cardiac arrest scenario. The use of a detailed plan removed the typical uncertainties surrounding a given individual's role commonly seen during an emergency.

RESULTS—STUDY

Implementation of Action Plan

Shortly after completing the first Airo crisis simulation, a 79-year-old male with a medical history notable for obesity, hypertension, and multiple previous spine fusions underwent a posterior laminectomy and fusion for suspected osteomyelitis in the prone position. Intraoperatively, the patient experienced a cardiac arrest due to acute mitral regurgitation from undiagnosed endocarditis. Resuscitation commenced while the neurosurgeons packed the wound, the patient was rapidly removed from the Airo, he was turned supine, and CPR continued, with return of spontaneous circulation within 5 minutes of the initial arrest. An intraaortic balloon pump was inserted for hemodynamic stabilization. The patient returned to the OR several days later with the intraaortic balloon pump still in situ for removal of the packing and completion of the originally planned spine surgery. Two weeks after the initial event, the patient underwent mitral valve replacement surgery and was ultimately discharged from the hospital without neurologic deficits.

DISCUSSION—ACT

A simulated cardiac arrest scenario is an excellent means of identifying key logistical issues surrounding the use of an iCT-imaging system during spine surgery. The information gathered during the simulation was used to develop and test a plan of action that could be used during any emergency requiring a patient to be safely and expeditiously moved from an iCT-imaging table to a stretcher. The ability to rapidly reposition a patient from a table such as the Airo is not merely academic: for patients who experience an in-hospital cardiac arrest, a time to defibrillation greater than 2 minutes was associated with a significantly lower rate of survival to hospital discharge, and there was a graded association between each minute of delay to defibrillation and lower rates of

survival to hospital discharge.[9] Thus time is of the essence, and our response time of 110 seconds is in the time range associated with the greatest likelihood of survival to hospital discharge following prompt defibrillation for witnessed cardiac arrest. It is worth emphasizing that while repositioning from the prone to the supine position is strongly encouraged so as to provide effective chest compressions, chest compressions in the prone position should be initiated when possible[8] with hands properly positioned just below (~1-2 vertebral segments) the line crossing both the inferior angles of the scapula).[6,7] Furthermore, 3-point head fixation (if used) should be released as soon as possible if chest compression is required so as to minimize the risk of injuring the cervical spinal cord, but CPR, if required, should not be delayed.

We now practice the cardiac arrest scenario using the Airo twice a year. Repeat simulations prevent degradation in proficiency, may improve overall efficiency, and allow refinement of the protocol as new observations are made.[10,11] With the help of the Skills Acquisition and Innovation Laboratory (SAIL), our institutional simulation center, an instructional video was created for residents and faculty to view before they provide anesthesia for patients when use of the Airo is planned. The video provides a description of the anesthesia setup when the Airo is used and the steps necessary to reposition the patient during an emergency. The use of the video ensures that all OR personnel who participate in surgical cases in which the Airo is employed are familiar with the logistics surrounding its use even if they did not attend 1 of the rehearsal sessions. We encourage all users of iCT-imaging systems, including the Airo, to adopt and regularly practice a plan-of-action protocol that anticipates the need to rapidly reposition a patient in the event of an emergency; such efforts are concordant with national and hospital-wide goals of improving patient safety.

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APPENDIX A

ANESTHESIA SETUP AND MANAGEMENT OF PATIENTS HAVING SURGERY USING AIRO COMPUTED TOMOGRAPHY IMAGING SYSTEM

1. Considerations for anesthesia setup:
   - The anesthesia breathing circuit is configured with extralong tubing and, if necessary, additional extensions.
   - A detachable, portable, vital signs monitor (such as the IntelliVue X2 multimeasurement module and transport monitor; Phillips North America Corp., Andover, Massachusetts) is used.
   - A second intravenous (IV) catheter is inserted into a peripheral vein; this may be capped (i.e., "hep-locked") if significant bleeding is not expected. A second IV pole with an extra (unused) IV setup is positioned near the anesthesia machine.
   - All IV lines have extension tubing attached, and all IV lines (including infusion lines) are clearly labeled (site, maintenance fluid, infusion medication).
   - Following positioning on the computed tomography (CT)-compatible imaging table, all monitoring cables, intravenous lines, tubing, etc. are cleanly separated from each other so that if repositioning is necessary, time will not be spent untangling them.
2. In the event that the patient needs to be emergently turned supine:
   - If required, initiate advanced cardiovascular life support (ACLS, including chest compressions in prone position) immediately and continue necessary resuscitation efforts until the patient can be turned supine. The attending anesthesiologist should ideally direct all efforts at resuscitation/rescue including the management of cardiopulmonary resuscitation in the event of cardiac arrest.
   - The circulating nurse will notify the operating room (OR) and anesthesia control desks of the emergency situation and the need for additional assistance.
   - The surgeon(s) will expeditiously pack and cover the surgical site (there may not be sufficient time to fully close the surgical site depending on the nature of the emergency).
   - Once the surgical site is appropriately secured, the surgeon or surgical resident will start chest compressions while the other releases the skull clamp from the bed frame and prepares to assist in turning the patient supine.
   - If already initiated, CONTINUE ACLS while readying the patient for repositioning.
   - Nursing staff brings the cardiopulmonary resuscitation cart and airway cart (if the airway has been compromised) into the room.
   - The Anesthesia Attending will instruct the Anesthesia Resident in disconnecting all nonessential lines, monitors, and devices.
   - An OR Perioperative Patient Assistant will bring a stretcher into the room and position it on the side of the OR table nearest the anesthesia machine.
   - Without disconnecting the requisite cables (electrocardiogram, pulse oximetry, blood pressure), the detachable monitor is unplugged from its primary connection, passed through the imaging gantry, and then reconnected to the main monitors (thereby insuring uninterrupted monitoring of critical vital signs).
   - A member of the anesthesia team now disconnects the patient's endotracheal tube from the anesthesia breathing circuit.
   - The patient is moved from the OR table to the stretcher and into the supine position; the breathing circuit is immediately reconnected to the endotracheal tube and ventilation resumed and ACLS continued if necessary.
   - Once supine, the previously capped IV can be connected to the spare IV setup. The patient can now be removed from the OR or, if further resuscitation is required, the CT imaging system can now be moved to allow improved access to the patient.