Tracking workflow during high-stakes resuscitation: the application of a novel clinician movement tracing tool during in situ trauma simulation

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ABSTRACT

Introduction Clinician movement and workflow analysis provides an opportunity to identify inefficiencies during trauma resuscitation care. Inefficient workflows may represent latent safety threats (LSTs), defined as unrecognised system-based elements that can negatively impact patients. In situ simulation (ISS) can be used to model resuscitation workflows without direct impact on patients. We report the pilot application of a novel, tracing tool to track clinician movement during high-fidelity ISS trauma sessions.

Methods Twelve unannounced ISSs were conducted. An open source, Windows-based video overlay tracing tool was developed to generate a visual representation of participant movement during ISS. This tracing tool used a manual mouse tracking algorithm to produce point-by-point location information of a selected participant in a video. The tracing tool was applied to video recordings of clinicians performing a cricothyroidotomy during ISS trauma scenarios. A comparative workflow and movement analysis was completed, which included distance travelled and space utilisation. This data was visually represented with time-lapsed movement videos and heat maps.

Results A fourfold difference in the relative distance travelled was observed between participants who performed a cricothyroidotomy during an ISS trauma resuscitation. Variation in each participant's movement was attributable to three factors: (1) team role assignment and task allocation; (2) knowledge of clinical space: equipment location and path to equipment retrieval; and (3) equipment bundling. This tool facilitated LST identification related to cricothyroidotomy performance.

Conclusion This novel tracing tool effectively generated a visual representation of participants' workflows and quantified movement during ISS video review. An improved understanding of human movement during ISS trauma resuscitations provides a unique opportunity to augment simulation debriefing, conduct human factor analysis of system elements (eg, tools/technology, physical environment/layout) and foster change management towards efficient workflows.

INTRODUCTION

Clinician workflow and movement analysis is an important tool to identify latent safety threats (LSTs), defined as previously unrecognised system-based elements that can negatively impact patient safety.[1] Understanding clinician workflow, especially during trauma resuscitations, can be difficult as clinical environments are often dynamic and complex.

In situ simulation (ISS) provides a valuable opportunity to recreate clinical scenarios for focused analysis of workflows and patient care within the actual clinical environment.[2] Using ISS, high-risk or rarely performed scenarios can be replicated to better understand a complex system and improve on system-based inefficiencies.[3 4] ISS is also an effective technique to identify and remedy LSTs (eg, team performance, physical layout and equipment issues).[5–7] The implementation of resuscitation-based ISS enables a systematic evaluation of team-based and system-based processes without risks to patients.[8]

We describe the application of an open source, Windows-based video overlay tracing tool for a comparative analysis of trauma team member movement during ISS video review. This application was piloted as part of a larger ISS study investigating LSTs during trauma resuscitation.[9] Although this study focuses on the application of the tool during a high-stakes and rare procedure, we envision this technique will be applicable for studying movement of individuals and teams in any environment. The purpose of this pilot study was to explore the use of a tracing tool as a means for quantifying movement, evaluating individual clinicians' workflow and identifying LSTs related to ergonomics during a simulated trauma resuscitation.

METHODS

Simulation design

A series of 12 multidisciplinary ISS trauma scenarios was performed at a level 1 trauma centre in Toronto, Ontario, Canada as part of the Trauma Resuscitation Using in Situ simulation for Team training (TRUST) Study.[9] Each ISS session was video recorded using four video cameras placed throughout the trauma room (two GoPro Hero4 2015, one GoPro Hero and one Sony Handycam Exmor R). The purpose of the TRUST Study was to identify LSTs using a human factor perspective that included analyses of workflow and equipment location within the clinical workspace. During the study, four distinct simulation cases were conducted monthly over a year (ie, each case was performed two to four times). One case (ie, a cricothyroidotomy scenario) was selected as a pilot study to evaluate variability in clinician workflow and movement. Cricothyroidotomy was selected for the following reasons: (1) it is a rare, high-stakes and time-sensitive procedure; (2) it is typically performed by a single clinician with a well-defined start and finish time, as such, an optimal focus for workflow evaluation; (3) at our institution, several different techniques can be undertaken to complete this procedure, further increasing the possibility of variation in workflow and clinician performance; and (4) it is a low-opportunity, high-acuity event which makes it an ideal candidate for integration within simulation scenarios given the lack of real clinical opportunities.[10]

As part of the larger TRUST Study, the scenario was conducted three times and each was subject to analysis using the tracing tool. In this case, the patient suffered significant facial injuries resulting in a 'can't intubate, can't ventilate' situation. On arrival in the trauma room, there was a predictable and timed decrease in the patient's oxygen saturation in this scenario such that the only successful airway intervention was an emergency cricothyroidotomy, whereby ventilation and oxygenation is achieved through an incision in the patient's neck.

At our institution, clinicians are free to decide what equipment and technique they will use for a cricothyroidotomy. Two sets of equipment are available to perform the following: a traditional open surgical technique and a percutaneous Seldinger technique using a prepackaged kit.[11] No alterations to equipment or packaging were made during the study period to best represent a current state analysis. To maintain realism and consistency between sessions, clinicians (nurses, physicians and respiratory therapists) participating during each ISS were also members of the trauma team who would attend any actual trauma resuscitation. As per usual practice, in each case, the team selected which clinician would perform the cricothyroidotomy during the simulation rather than a priori by our research team.

Tracing tool design

An open source, Windows-based video overlay tracing tool was developed using Microsoft Visual Studio (Redmond, Washington) to generate visual representations and to quantify participant movement during ISS video review. (Tool available at https://github.com/rmaalmeida/CATT and instructions at https://github.com/rmaalmeida/CATT/wiki). The tool used a manual mouse tracking algorithm to produce point-by-point location information of the selected participant or object in a video.

The cumulative distance travelled was calculated for distance comparison. Heat maps demonstrating high-volume and low-volume locations occupied by the participants as well as time-lapsed movement videos, were generated. The heat maps and time-lapsed movement videos were exported into an XML file with the raw data and then exported into a Microsoft Excel (Redmond, Washington) file for further analysis. To remove extraneous data, the heat maps and time-lapsed movement diagrams were exported and placed on top of a still image of the clinical environment. All images of individuals and their identifying information were removed from the tool's final visual representation maintaining participant anonymity.

Video review

Two independent trained operators (MF and RA) reviewed the videos and used the tracing tool to track the activities of the clinician performing the cricothyroidotomy. Sample video tracing data were used to ensure accuracy and intercoder reliability. During video review, the operator started tracing when the team had voiced their decision to perform a cricothyroidotomy (ie, before procedure), continued tracing during the procedure, and terminated the tracing at the end of the ISS session (ie, after the procedure). Multiple individuals theoretically can be tracked within one video, however, only the participant performing the cricothyroidotomy procedure in each video was tracked for this study. Only one of four video angles was used for consistency to capture the relative distance travelled. The original ISS video footage was also reviewed to provide context (eg, location travelled to, equipment used) to the variability of movement observed with the tool.

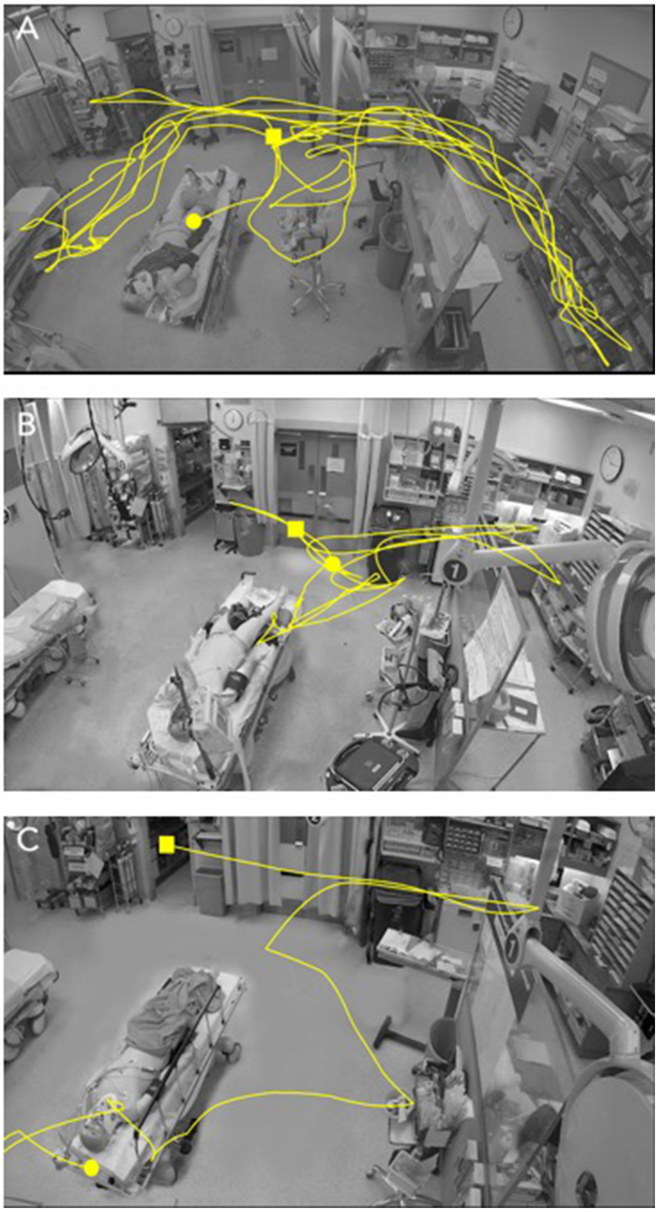

Figure 1 Movement tracing of the cricothyroidotomy-performing clinician. The yellow line represents the movement of the clinician leading up to, and during the performance of the cricothyroidotomy for session 1(A), session 2 (B) and session 3 (C). The start and finish are denoted by square and triangle icons, respectively.

RESULTS

A different clinician performed the cricothyroidotomy in each of the sessions, including: a senior general surgery resident (session 1, figure 1A), a staff general surgeon (session 2, figure 1B) and a senior anaesthesia resident (session 3, figure 1C). In all three

Table 1 Time to procedure and distance travelled during three in situ simulations among clinicians performing a cricothyroidotomy

	Session 1	Session 2	Session 3
Participant	Senior general surgery resident	Staff general surgeon	Senior anaesthesiology resident
Distance travelled as percentage relative to scenario 3	459%	206%	100%
Time to cricothyroidotomy (from decision to procedure performance) Min:sec	6:29	5:50	2:00

sessions, the individual performing the cricothyroidotomy had never performed the procedure earlier in either clinical practice or simulation. Two clinicians performed the traditional open surgical technique (sessions 1 and 2) while one used a percutaneous Seldinger technique (session 3). In each session, the selected technique was based on personnel and team preferences as equipment for both techniques is routinely available within our trauma room. In all cases, the clinician performing the cricothyroidotomy was selected by the team leader, as defined by our institution's airway management protocol.

A comparative analysis of cricothyroidotomy performance demonstrated differences across sessions in both distance travelled (table 1) and workflow (table 2). The tool generated a visual representation of the movement of each cricothyroidotomy-performing participant (figure 1) while the 'heat-map' demonstrated participant position based on time spent in each location (ie, greater opacity represents more time spent, figure 2). The cumulative distance travelled differed between sessions. Table 1 provides the cumulative relative distance travelled by the cricothyroidotomy-performing participant in each session, using session 3 as the reference. Figure 3 provides a graphical representation of the cumulative relative distance travelled over time before, during and after the cricothyroidotomy.

The complete simulation videos were reviewed to provide additional context to each study participant's movement (table 2). Observations that may account for the variation in movement among the three clinicians included: (1) role within the trauma team and task allocation; (2) knowledge of clinical space: equipment location and path to equipment retrieval; and (3) equipment bundling. Each of these factors represent potential LSTs related to cricothyroidotomy performance.

Team role assignment and task allocation

The participant in session 1 travelled more than twice as far as the participants in sessions 2 and 3 (table 1). In sessions 2 and 3, both travelled a similar distance before the procedure was performed (figure 3). However, in session 3, the participant remained nearly stationary at the head of the bed following the cricothyroidotomy (figure 3). The participant in session 3 delegated the tasks of gathering equipment to other team members more so than participants in sessions 1 and 2, thereby resulting in less travel time.

Knowledge of clinical space: equipment location and path to equipment retrieval

In session 1, the participant independently retrieved all of the required equipment without aid from other team members (table 2). The heat map in figure 2A indicates that this participant spent the majority of his/her time in the supply area, personally retrieving a scalpel (top left circle seen in figure 2A) and at the patient's head performing the procedure. In session 2, the participant personally gathered some equipment while additional equipment was brought by another team member (figure 1B). The heat map for this individual (figure 2B) indicates that time was spent at the foot of the bed overseeing the resuscitation, gathering equipment and performing the procedure at the patient's neck. In several instances, in sessions 1 and 2, participants had difficulty locating equipment prior to the procedure resulting in a greater distance travelled (figure 3). In session 3, this participant remained nearly stationary at the head of the bed (figure 2C) and all the supplies were brought to the bedside by another team member.

Equipment bundling

Participants in sessions 1 and 2 chose to perform the traditional open surgical cricothyroidotomy which does not have a prepacked kit containing the necessary supplies at our institution. The participants had to retrieve individual supplies unlike the participant in session 3 who elected to perform the percutaneous Seldinger technique, which are available in a prepackaged kit at our institution.

DISCUSSION

In this study, we describe the pilot application of a novel, open source video overlay tracing tool for clinician workflow and movement analysis during trauma resuscitation ISS. The tool was piloted to analyse human movement of three clinicians

Table 2 Latent safety threats (LSTs) identified using movement tracking

	Comparative impact of LSTs between sessions	LST
Role within the trauma team and task allocation	Participant 1 retrieved all equipment without help from team members while participants 2 and 3 delegated equipment retrieval to a variable extent	Delegation of equipment retrieval to the individual tasked with performing a cricothyroidotomy
Knowledge of clinical space: trauma room layout and equipment location	Participant 1 had minimal familiarity with the equipment location resulting in inefficient movement while participant 2 was more familiar with the workspace resulting in a direct path to retrieve sterile gloves Participant 3 waited at the head of the bed while team members brought equipment to the bedside The equipment for the open surgical technique was located far from the bedside while the bundled Seldinger kit was near the head of the bed	Knowledge gaps related to the location of essential equipment Location of cricothyroidotomy equipment and supplies far from the bedside
Equipment bundling	The traditional open surgical cricothyroidotomy equipment used in sessions 1 and 2 was not bundled; the equipment was spread throughout the trauma room The percutaneous Seldinger technique used in session 3 was bundled (ie, kept in a prepackaged kit)	Cricothyroidotomy equipment spread throughout the trauma room

Participant 1=study participant session 1, senior general surgery resident; Participant 2=study participant in session 2, staff general surgeon; Participant 3=study participant in session 3, senior anaesthesia resident.

Figure 2 Heat maps. Visual representation of high frequency and low frequency of clinician location during session 1 (A), session 2 (B) and session 3 (C). High-frequency location is denoted by greater white colour opacity while lower-frequency locations are nearly transparent.

each performing a cricothyroidotomy. Qualitative and quantitative analysis demonstrated differences in workflow, movement and space used between each clinician. Human movement and ergonomic analysis are important human factors during resuscitations and inefficiencies in these elements may negatively impact patient outcomes particularly when critical, life-saving interventions are delayed. While traditional video review may be sufficient to appreciate overall team performance and generalised team movement, there are considerable distractions and competing activities when observing 8–10 individuals work within a busy resuscitation environment. A tracing tool that specifically isolates the movement of selected individuals mitigates distractions for the viewer and provides both visual and quantitative metrics that can be considered in conjunction with the sequence of significant events captured during a simulated resuscitation.

To our knowledge however, there are no free, readily available tools to objectively analyse clinician movement within the confines of a resuscitation room. As a result, the development of this video overlay tool offers a unique application for workflow analysis. Application of this tool for ISS is useful to comparatively analyse human movement during clinical care for several reasons: (1) scenarios are reproducible and actions/procedures are predictable; (2) rare procedures may be preferentially selected for analysis and; (3) risk to actual patients is minimised.

This study represents a pilot of a novel tracing and human movement tool applied to a rare, high-risk procedure. Despite the small sample size, considerable variation in workflow and movement between clinicians was observed and we characterised system elements that contribute to inefficiencies during trauma resuscitation requiring improvement. Our study shows the value of small samples to characterise local gaps in care that require improvement. We recommend supporting improvement through rapid-cycle improvement initiatives that could then be validated with larger sample study designs.[12]

Output formats from our tool

This tool has several output formats that facilitate movement analyses that can be tailored to the design and human factor objectives of the ISS session. The output formats used in this study are outlined below.

Heat maps

The heat maps removed extraneous information to highlight locations where clinicians concentrated their time. With this data, it is possible to identify space requirements for clinicians preparing and performing a cricothyroidotomy (ie, all clinicians required a space to place their equipment and ready access to the patient's neck). In our institution, this data helped guide a reorganisation of our supplies to facilitate easy access for high-stakes procedures and bedside trays for procedural equipment.

Time-lapsed video diagram

The time-lapsed video diagrams provide an enhanced understanding of clinician movement throughout the clinical environment over time. Opportunities to increase clinician efficiency, particularly during time-sensitive situations (eg, cricothyroidotomy) may positively impact patient outcome. For example, in session 1, using the time-lapsed video diagram we identified inefficient clinician movement when the participant searched the supply area for over 4 min before the procedure. Ideally, the team member preparing to perform a high-stakes procedure can focus on the set-up, ergonomics and nuances of the skill instead of searching for the necessary equipment. This highlights an opportunity for task allocation optimisation within a team where equipment gathering can be offloaded to another member.

Relative cumulative distance comparison

By calculating the relative cumulative distance travelled by each participant, we comparably quantified movement between participants. The differences found in our study led to detailed task analysis for each participant and several factors were found to contribute to observed variation in distance travelled including (1) team role assignment and task allocation; (2) knowledge of clinical space: equipment location and path to equipment retrieval and; (3) equipment bundling.

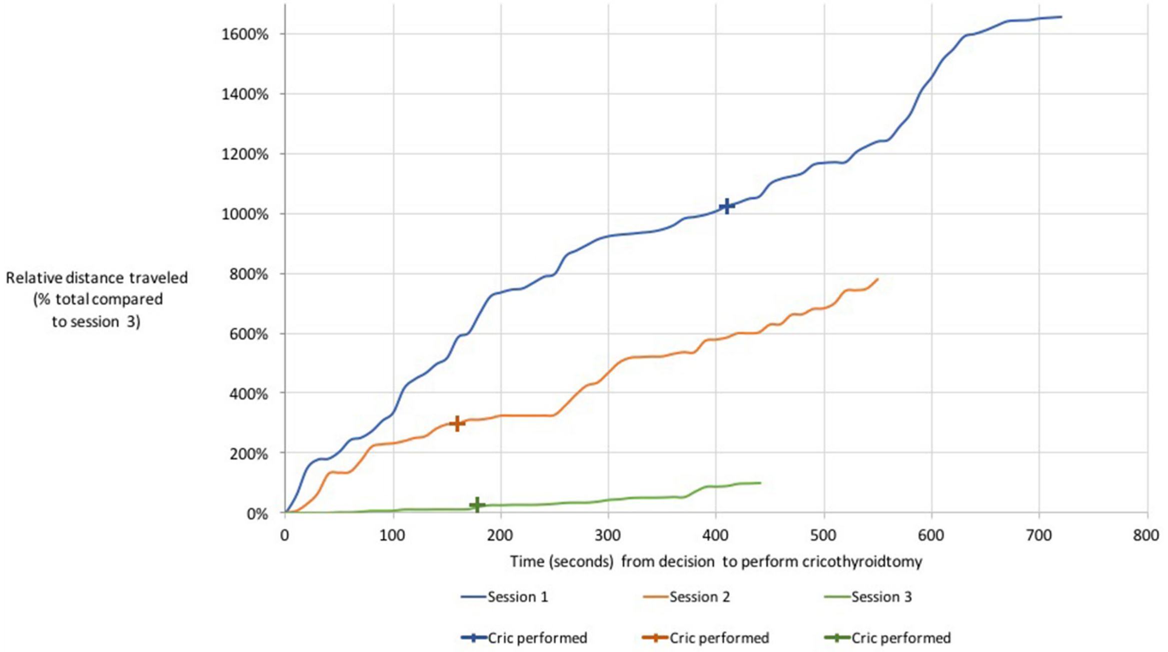

Figure 3 Relative distance travelled by three clinicians performing a cricothyroidotomy during simulated trauma resuscitations. Cric, cricothyroidotomy.

Overview of current tracking methods

The importance of understanding individual and team movement within the trauma bay is underscored by the potential LSTs resulting from clinical inefficiencies during complex trauma resuscitations. When combined with ISS, whereby the scenario is preplanned, ergonomics and clinician movement can be specifically evaluated in a predictable manner. Tools to identify LSTs related to clinician movement and efficiency are needed, yet lacking. Interviews and surveys provide detailed information requiring individual recall or stand-out events, however, they do not allow for real-time data collection.[1 13 14] Direct observation has been used in the trauma room to capture continuous and real-time qualitative data, yet observers may disrupt clinician workflows while spatially distributed or simultaneous activities may not be captured.[1 13 15] Radio frequency identification (RFID) technology has been used in emergency departments (EDs) and/or trauma rooms to gather positional data on patients and objects, however, it cannot precisely detect positional data within small environments or capture contextual details about the interactions between RFID tagged elements.[1 13] Tracking clinician's movement in the ED with smartphones is a simple-to-use, cost-effective and non-intrusive qualitative method, however, further advancements are needed to precisely track movement and changes in direction in a resuscitation room.[14 16] Optical tracking is yet another localisation technology that has been used in healthcare to precisely track movement of instruments during procedures and guide procedures, however, application to simulation-based activities is lacking.[17 18] The tool used in this study overcomes several of the challenges that exist among other technologies by providing a precise visual representation of clinician movement within the actual resuscitation environment.

Proposed ISS applications of a human tracing tool

The application of this human tracing tool during ISS represents a novel method of simulation-based analysis. While this tool could be applied during video review of actual resuscitations, there are benefits linked to using ISS. In situ simulation allows for prospective, reproducible and predictable analyses of predefined objectives. Simulation facilitators, clinicians and human factors experts, through ISS, can apply this tracing tool for at least three main functions based on our experience: (1) appraisal of team role assignment and task allocation, (2) knowledge of clinical space: trauma room layout and equipment location and (3) equipment bundling.

Appraisals of team role assignment and task allocation

High-performing teams create shared mental models resulting in implicit coordination, efficient team movement and designated role assignments.[19 20] In situ simulation, where cases are predictable and reproducible, provides an ideal venue to observe teams and their ability to achieve these characteristics. The complexity of high-stakes resuscitations, however, can be overwhelming to even the trained observer as they watch video recorded ISSs for each interaction and overall movement within the clinical environment. Augmenting ISS with this human tracing tool removes extraneous information for the observer. When used as part of a debriefing, ISS participants can be shown the time-lapsed video diagram as a means to initiate conversations about clinician workflow. For example, tracing the movement of the clinician performing a cricothyroidotomy provides an opportunity for a team to reflect on their ability to support a high-risk procedure. A question may arise such as, '*could other members of the team have been designated to retrieve equipment instead of the clinician also tasked with performing the skill*?' An understanding of clinician movement without other distractions from the entire simulation may offer an opportunity to probe team role assignments and task allocation.

Knowledge of clinical space: equipment location and path to equipment retrieval

Human factors and ergonomics encompass the study of human-human and human-system interactions with a goal to optimise design and performance.[21] This tool offers a unique opportunity to deliberately analyse clinician movement within the confines of the resuscitation room, an exercise in ergonomic evaluation. Our results demonstrate that procedural performance time is impacted by time to locate and retrieve necessary equipment. Data from this tool can inform the layout and design of clinical environments and aid in the evaluation of visual management strategies (eg, labels, spacing, location). In existing clinical environments, ISS scenarios can be developed to study areas of high personnel movement and low personnel movement ultimately leading to optimisation of equipment placement throughout the clinical space. This user-based approach is critical to the application of design thinking and human-centred designs, where clinician needs are identified followed by ergonomically optimised solutions.[22]

ISS has been well described as an important tool for LST identification such as missing equipment and team communication issues.[6 23 24] Clinical ergonomics remains an underinvestigated source of LSTs that may be better understood through clinician movement tracings. Equipment located far from the patient may represent an LST when a time-sensitive procedure is indicated. This represents a distinct reality especially for rarely performed procedures where equipment placement is often not considered given the relative infrequency until an actual clinical situation arises. Prospective evaluations using ISS is a prophylactic measure that can help mitigate unforeseen delays to procedural completion.

Bundling

This tracing tool provides a simple but effective visual representation whereby the 'urgency' of inefficient clinician movement can be highlighted and opportunities for ergonomic optimisation can be identified. In reviewing workflows, clinicians, educators and administrators quickly observe inefficiencies that serve to launch process and system changes. Once implemented, changes can be evaluated objectively for improvements in efficiency. For example, human movement before and after the bundling of procedure kits can be objectively quantified. We observed this exact phenomenon with increased participant movement to gather necessary items when equipment was scattered, in contrast to bundled. Without this tool however, the urgency to drive change by bundling equipment may not have been established and greater efforts would have been needed.

Additional considerations: fostering change

We identified an unanticipated application especially during the early stages of our ISS programme. A strength of this tool lies in its simplicity to depict movement while removing extraneous information. Kotter's first step in change management is to, 'create a sense of urgency'.[25] We embedded images and videos created with this tool in presentations to highlight opportunities for ergonomic and process improvement within our existing workflows. These issues quickly became apparent to our institution's administration as we sought stakeholder engagement for ISS. Not only did it help garner institutional support but it also aided with end-user support for a newly implemented ISS programme.

LIMITATIONS

This study and this tool have several limitations. This tool only compared surgical performances by three clinicians, yet despite this, there was still substantial variation observed. The objective of this study was to identify LSTs and gaps in care related to surgical airway performance which only required a small sample size, although, three times more than our institution's once/year volume of cricothyroidotomies. For such local quality improvement initiatives, small sample sizes may be sufficient to trigger a more detailed review and guide the closure of performance gaps.[12] This study only evaluated a single procedure and a single clinician from each scenario for movement analysis. This allowed for a more comparable and focused analysis related exclusively to the clinician performing the surgical airway. Further studies should seek to evaluate how clinician variability affects patient-centred outcomes. Also, the absolute distance travelled by each participant was not used, instead the relative distance between each session was presented. Our tool requires calibration specific to each location to calculate absolute distances. The utility of absolute differences may be useful to clinicians when distances are short (eg,<1 m), however, during a resuscitation where distance travelled can be several hundred metres, relative distances represent an efficient method of conveying a difference, particularly during a simulation debriefing. For example, a difference of 50 m is less meaningful, while a fourfold variability in distance travelled to prepare for a cricothyroidotomy between two clinicians may make the comparison more personal and relevant to the clinician. Further studies can be sought to evaluate the utility of relative versus absolute comparisons. A logistical limitation of the tool is a required line of sight to the participant of interest. In individual trauma rooms, the location where we perceive the greatest value for this tool, this is less of an issue. The utility of this tool for movement throughout a department or institution is considerably limited. Finally, the tracing is overlaid on a static image which fails to account for dynamic changes in the clinical environment (eg, a cart is moved into the usual workflow path). While the tracing can still be created, it requires corroboration with the simulation video to fully understand workflows.

CONCLUSION

This study describes the application of a novel,open source video overlay tracing tool to high-fidelity, trauma ISS sessions where a cricothyroidotomy was performed. This tool provides an opportunity to capture, compare and understand the complex workflow of clinicians within a confined space and team-based environment. Future work will focus on the integration of this tool into ISS debriefings as a means to stimulate discussion related to clinician workflows. In addition, this tool may prove useful when applied during actual trauma resuscitations to better understand real clinical workflows.

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