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SYSTEMS-LEVEL QUALITY IMPROVEMENT

The Effect of an Electronic Dynamic Cognitive Aid Versus a Static Cognitive Aid on the Management of a Simulated Crisis: A Randomized Controlled Trial

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Abstract

The aim of this study was to assess the effect of a dynamic electronic cognitive aid with embedded clinical decision support (dCA) versus a static cognitive aid (sCA) tool. Anesthesia residents in clinical anesthesia years 2 and 3 were recruited to participate. Each subject was randomized to one of two groups and performed an identical simulated clinical scenario. The primary outcome was task checklist performance with a secondary outcome of performance using the Anesthesia Non-technical skills (ANTS) scoring system. 34 residents were recruited to participate in the study. 19 residents were randomized to the sCA group and 15 to the dCA group. Overall inter-rater agreement for total checklist, malignant hyperthermia, hyperkalemia and ventricular fibrillation was 98.9%, 97.8%, 99.5% and 99.5% respectively with similar Kappa coefficient. Inter-rater agreement for ANTS partial ratings, however, was only 53.5% with a similar Kappa of 0.15. Mean performance was statistically higher in the dCA group versus the sCA group for total check list performance (15.70 ± 1.93 vs 12.95 ± 2.16, $p < 0.0001$). The difference in performance between dCA and sCA is most notable in dose-dependent related checklist items (4.60 ± 1.3 vs 1.89 ± 1.23, $p < 0.0001$), while the performance score for dose-independent checklist items was similar between the two groups ($p = 0.8908$). ANTS ratings did not differ between groups. In conclusion, we evaluated the use of a sCA versus a dCA with embedded decision support in a simulated environment. The dCA group was found to perform more checklist items correctly.

Clinical Trial Registration: Clinicaltrials.gov study #: NCT02440607.

Keywords Simulation · Cognitive aid · Crisis management

Introduction

The use of cognitive aids (CA) to improve care was first described in aviation as early as the 1930s [1]. Gaba defined it as a term that "encompasses a host of physical (or now virtual) items aimed to assist professionals in executing the complex decision making of diagnosis and therapy." [2] Although medicine has been slower to adopt these tools, the use of cognitive aids is becoming widespread. The mass dissemination of advanced cardiac life support (ACLS) algorithm 'cards' by organizations such as the American College of Cardiologists (ACC) is one such example. Emergency management tools have spread into the operating room as well, following a multitude of studies demonstrating improved crisis management in simulated medical scenarios when cognitive aids are used [1, 3, 4]. To date, studies evaluating cognitive aids have focused on static physical tools such as the emergency manual created at Stanford [4]. These studies show impressive strides

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towards improved quality with the utilization of a simple treatment tool.

Because the provision of medical care is increasingly complex, tools used to aid clinicians and drive quality are continually sought. Clinical decision support (CDS) tools are elements often embedded in the electronic medical record (EMR) that act to alert clinicians of to perform certain tasks in real time [5]. CDS tools are designed to harness the power of technology to streamline, simplify and improve care processes throughout medicine.

To date, cognitive aid studies have focused on static aids such as laminated cards or electronic aids used to prompt and drive the algorithmic management of crises in the operating room [6]. The aim of this study was to assess the effect of a dynamic electronic cognitive aid with embedded CDS (dCA) versus a static cognitive aid (sCA) tool. We hypothesized that dCA would result in better performance in a simulated emergency scenario than sCA.

Methods

This study was approved by the NorthShore University HealthSystem Institutional Review Board and took place in the Grainger Center for Simulation and Innovation and registered with Clinical Trials.Gov (NCT02440607). Anesthesia resident physicians in clinical anesthesia years 2 and 3 (CA 2 and CA3) were recruited to participate. A standard letter of recruitment was sent to all CA2 and CA3 residents in two training programs. Those choosing to participate signed an informed consent to perform a clinical scenario which was recorded for grading purposes. Each subject was randomized to one of two groups and asked to perform an identical simulated clinical scenario. The sCA group was given a static cognitive aid identical to that used in the operating rooms at NorthShore University HealthSystem and given standard instructions on its location in the simulated OR. (Fig. 1) The dCA group was presented with an electronic large screen display that contained a CA tool with dynamic clinical decision support embedded within a simulated electronic medical record (Fig. 2).

Simulation design

The simulation scenario, hemodynamic variables, cardiac rhythms and lab work were carefully scripted so that event timing and confederate actions remained consistent throughout the study. The SimMan simulation mannequin (Laerdal Medical, Gatesville, Texas) was used for all simulations. The confederates' roles were carefully scripted and remained the same for all subjects. The case scenario involved malignant hyperthermia complicated by hyperkalemia and ventricular fibrillation.

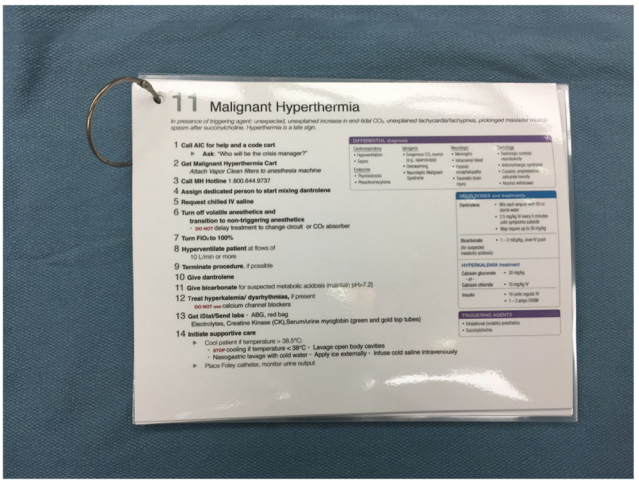

Fig. 1 Static cognitive aid. Image of the actual laminated card used by study participants

Data collection

All simulation scenarios were recorded using standard software (B-Line Medical, Washington D.C) and fixed cameras. Subjects were subsequently evaluated by two independent raters using identical grading systems. Raters were blinded to the assigned variable. Technical performance was assessed using the MH performance task checklist as seen in Fig. 3. These checklists were developed directly from accepted cognitive aids published by the Malignant Hyperthermia Association of the United States (MHAUS) and the American Heart Association [7, 8]. Subjects were awarded 1 point for each check point item. For dose-dependent items (e.g. medications, defibrillation (J)), a correct score was counted only if the dose was within 10% of the correct weight based dose. In addition, the two raters scored subjects using the previously validated Anesthesia Non-Technical Skills (ANTS) grading rubric [7]. (Fig. 4).

Statistics

Sample size calculation was based on effect sizes described in two prior simulation studies by Bruppacher and Neal [3, 10]. An effect size greater than 1 was assumed clinically significant. We calculated that 34 subjects would yield a minimum power of 80% to detect one standard unit mean difference in performance scores between sCA and dCA using a two-sided alpha of 0.05.

The primary outcome was the subject checklist performance score in each group. The secondary outcome was subject non-technical skill performance as measured by the Anesthesia Non-technical (ANTS) score. Additional, checklist performance in the subcategories of Malignant Hyperthermia (MH), Hyperkalemia (HK) and ventricular fibrillation (VF) management was also analyzed.

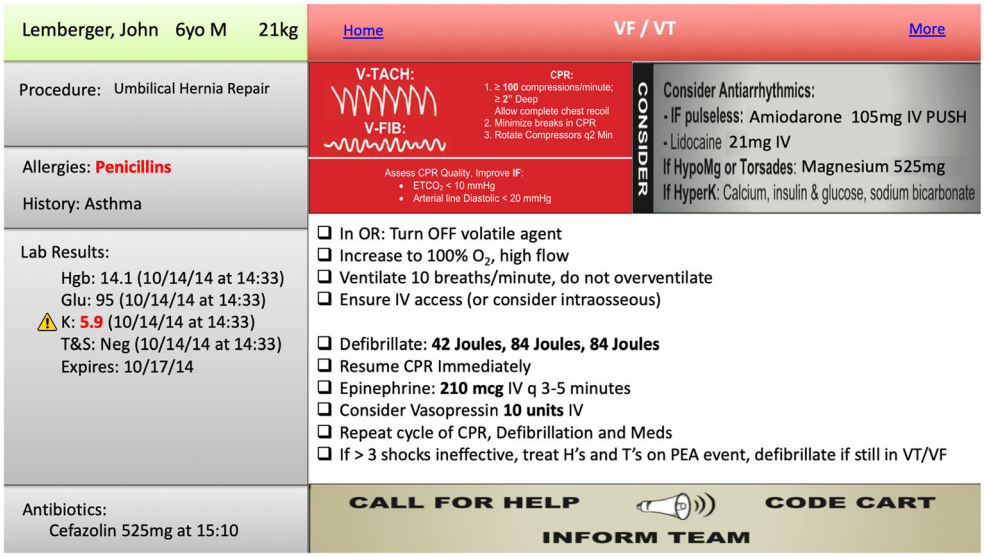

Fig. 2 Dynamic electronic cognitive aid. Interactive cognitive aid with embedded emergency algorithms shown in lower right corner

Interrater reliability was assessed using Kappa coefficient. In addition, we calculated the percent of agreement between the two raters within each subcategory. Total checklist scores from each rater as well as overall mean scores from the two

Fig. 3 Technical Skills Performance Checklist used by raters to evaluate performance of tasks during the simulated crisis

Yes	No	**MH performance task checklist**
		Discontinue volatile agents and succinylcholine. If surgery must be continued, maintain general anesthesia with IV nontriggering anesthetics (eg, propofol).
		Notify surgeon to halt procedure ASAP.
		Get dantrolene/MH cart. (Call 911 if surgicenter.)
		Call for help within your institution
		Call the MHAUS Hotline
		100% oxygen at flows of 10L/min to flush volatile anesthetics
		Increase Ventilation
		IV dantrolene 2.5 mg/kg rapidly through large-bore IV
		Proper dilution (20mg in at least 60 ml sterile water)
		Obtain blood gas
		Treat Acidosis with Bicarb 1-2 mEq/kg dose, for base excess greater than -8 (maximum dose 50 mEq).
		Cool the patient (core temperature is >39°C or less if rapidly rising. Stop cooling when the temperature has decreased to <38°C)
		Hyperkalemia
		Recognzed?
		Insulin: For pediatric patients: 0.1 units regular insulin/kg IV and 0.5 Grams/kg dextrose (% in formulation not important).
		Calcium: Calcium chloride 10 mg/kg (maximum dose 2,000 mg) or calcium gluconate 30 mg/kg
		Sodium bicarbonate 1-2 mEq/kg IV (maximum dose 50 mEq)
		Furosemide 0.5-1 mg/kg once (maximum dose 20 mg)
		Appropriate Temp monitoring: core temp or bladder
		Appropriate hemodynamic monitors: arterial line
		Diurese to >1ml/kg/hr urine output. If CK or K+ rise, assume myoglobinuria and give bicarbonate infusion of 1 mEq/kg/hr, to alkalinize urine.
		Dysrythmia treatment
		Recognizes VF
		Start chest compressions
		Defibrillate with appropriate J
		Epinephrine 1 mg
		No break in chest compressions

25 POINT TOTAL (items with italic font are dose-dependent tasks)

Anesthesiologist's Nontechnical Skills (ANTS) Global Rating Scale

Subtopics	Elements	Partial Rating (1-4)	Global Category Rating (1-4)
Task Management			
	Planning and preparing		
	Prioritizing		
	Providing and maintaining standards		
	Identifying and utilizing resources		
Team Working			
	Coordinating activities with team		
	Exchanging information		
	Using authority and assertiveness		
	Assessing capabilities		
	Supporting others		
Situation Awareness			
	Gathering information		
	Recognizing and understanding		
	Anticipating		
Decision-making			
	Identifying options		
	Balancing risks and selecting options		
	Reevaluating		
		TOTAL POINTS (total of global ratings)	

Rating Options		Descriptor
Good	4	Performance was of a consistently high standard, enhancing patient safety; it could be used as a positive example for others
Acceptable	3	Performance was of a satisfactory standard but could be improved
Marginal	2	Performance indicated cause for concern, considerable improvement is needed
Poor	1	Performance endangered or potentially endangered patient safety, serious remediation is required

- Subject Number _____ Date _____

Fig. 4 Anesthesia Non-Technical Skills (ANTS) score card used by raters to evaluate performance [9]

raters were compared between sCA and dCA groups using Student t-test. Finally, we analyze each checklist separately by calculating percentage of correctly answered graded by each rater within sCA and dCA group, and compared them using Chi-square test. All data were analyzed using SAS 9.3 (SAS Inc., Cary, NC) and a p value <0.05 was considered statistically significance.

Results

Between June and August, 2015, 34 residents were recruited to participate in the study. 19 residents were randomized to the sCA group and 15 to the dCA group. All subjects were in the CA2 or CA3 training year. Inter-rater reliability is reported in Kappa values and shown in Table 1. Overall inter-rater agreement for total checklist, MH, HK and VF was 98.9%, 97.8%, 99.5% and 99.5% respectively with similar Kappa coefficient. Inter-rater agreement for ANTS partial ratings, however, was only 53.5% with a similar Kappa of 0.15. Global ratings subcategories for the areas of task management, team work, situation awareness, decision making are also shown in

Table 1 Inter-rater reliability

Instrument	Total (n = 34)		
	Kappa	95% CI	% Rater agreement
Total Checklist	0.978	(0.97, 1.00)	98.9%
MH	0.950	(0.87, 1.00)	97.8%
H K	0.991	(0.97, 1.00)	99.5%
Vfib	0.988	(0.98, 1.00)	99.5%
ANTS Partial Ratings	0.150	(0.05, 0.35)	53.3%
ANTS subcategory			
Task Management	0.393	(0.13, 0.66)	64.7%
Team Work	0.212	(0.00, 0.43)	38.2%
Situation Awareness	0.340	(0.11, 0.57)	55.9%
Decision Making	0.346	(0.08, 0.61)	64.7%

(MH = Malignant Hyperthermia, HK = hyperkalemia, Vfib = ventricular fibrillation, ANTS = Anesthesia Non-Technical Skills)

Table 1, ranging from 0.21 to 0.39 for Kappa and 38.2% to 64.7% for percent rater agreement.

Checklist performance score in both static aid and dynamic aid groups is listed in Table 2. Mean performance was statistically higher in the dCA group versus the sCA group for HK (2.67 ± 1.21 vs 1.18 ± 1.09, $p < 0.0001$), VF (3.27 ± 0.58 vs 2.03 ± 0.79, $p < 0.0001$) and total check list performance (15.70 ± 1.93 vs 12.95 ± 2.16, $p < 0.0001$). No difference was observed in checklist performance of MH in dCA vs sCA groups (9.77 ± 0.86 vs 9.74 ± 1.33, $p = 0.9113$). The difference in performance between dCA and sCA is most notable in dose-dependent related checklist items (4.60 ± 1.3 vs 1.89 ± 1.23, $p < 0.0001$), while the performance score for dose-independent checklist items was similar between the two groups ($p = 0.8908$). ANTS ratings did not differ for partial or global categories between groups.

Performance of individual tasks is reported in Table 3. The correct administration of dantrolene and calling the MH hotline were performed more often in the dCA group. In the management of hyperkalemia, insulin, dextrose and calcium were performed more often in the dCA group. Defibrillation and epinephrine were performed correctly more often in the dCA group.

Discussion

Use of checklists for the management of clinical emergencies is growing throughout medicine and in particular in the operating room [11]. This change has been prompted by an increasing recognition that best practice paradigms are often not followed during clinical crises [12]. For years cognitive aids have taken the form of laminated cards or booklets outlining care algorithms for given medical emergencies. The most well-known may be the ACLS cards widely dispersed by the ACC/AHA for the management of many cardiac emergencies. As typical of static aids, these sCAs represent information to the provider in an algorithmic or checklist format. Positively, these cards provide an information source to care givers that improves the delivery of care. Neal et al described the use of a checklist cognitive aid in the management of simulated care of local anesthetic toxicity [3]. Simulated performance and retention of information was improved with trainees who used the cognitive aid. This and many other studies led to editorial views urging a more widespread use of CAs in clinical care [13]. While these static aids are a necessary conduit to better care, certain limitations exist. Broadly based algorithms are not patient specific, leaving room for error when more information is needed to make the correct intervention (medication dose, defibrillation energy). Additionally, clinical crises often involve more than one type of emergency.

In this present study, a 'parent' scenario of MH, with subcrises that included HK and VF, was used. A sCA requires clinicians actively search out the proper checklist for each malady. A dCA tied to the electronic medical record or patient monitor could trigger new checklists automatically and provide real time decision support. We postulated that this dynamic cognitive aid would improve care over the traditional cognitive aid in current use in our operating room (laminated cards).

Favorable interrater reliability was noted for the primary outcome of checklist performance. The results of this study demonstrate increased adherence to best care in the dCA

Table 2 Checklist performance in dynamic and static aid groups

Score, mean ± sd	Static Aid (sCA) ($n = 19$)			Dynamic Aid (dCA) ($n = 15$)			P value (comparing dCA vs. sCA)		
	Rater 1	Rater 2	Overall Mean	Rater 1	Rater 2	Overall Mean	Rater 1	Rater 2	Overall
MH	9.74 ± 1.37	9.74 ± 1.33	9.74 ± 1.33	9.73 ± 0.96	9.80 ± 0.77	9.77 ± 0.86	0.9933	0.8635	0.9113
HyperK+	1.16 ± 1.12	1.21 ± 1.08	1.18 ± 1.09	2.67 ± 1.23	2.67 ± 1.23	2.67 ± 1.21	**0.0007**	**0.0009**	**<.0001**
Vfib	2.00 ± 0.82	2.05 ± 0.78	2.03 ± 0.79	3.27 ± 0.59	3.27 ± 0.59	3.27 ± 0.58	**<.0001**	**<.0001**	**<.0001**
Total checklist	12.89 ± 2.33	13.00 ± 2.03	12.95 ± 2.16	15.67 ± 2.06	15.73 ± 1.87	15.70 ± 1.93	**0.001**	**0.0003**	**<.0001**
Dose-dependent	1.89 ± 1.24	1.89 ± 1.24	1.89 ± 1.23	4.60 ± 1.35	4.60 ± 1.35	4.60 ± 1.33	**<.0001**	**<.0001**	**<.0001**
Dose-independent	11.00 ± 1.56	11.11 ± 1.37	11.05 ± 1.45	11.07 ± 1.44	11.13 ± 1.30	11.10 ± 1.35	0.8981	0.952	0.8908
ANTS Partial Ratings	42.79 ± 9.11	44.00 ± 6.14	43.39 ± 7.69	41.73 ± 8.45	43.27 ± 6.64	42.50 ± 7.51	0.7314	0.7409	0.6319
ANTS subcategory									
Task Management	3.00 ± 0.58	2.89 ± 0.46	2.95 ± 0.52	3.00 ± 0.65	2.87 ± 0.74	2.93 ± 0.69	1.0000	0.8931	0.9240
Team Work	2.84 ± 0.96	3.16 ± 0.69	3.00 ± 0.84	2.53 ± 0.83	3.00 ± 0.76	2.77 ± 0.82	0.3311	0.5292	0.2533
Sit. Aware	2.89 ± 0.81	2.63 ± 0.68	2.76 ± 0.75	2.87 ± 0.64	2.93 ± 0.59	2.90 ± 0.61	0.9132	0.1857	0.4208
Decision-Making	2.68 ± 0.58	2.95 ± 0.40	2.82 ± 0.51	3.00 ± 0.76	2.80 ± 0.56	2.90 ± 0.66	0.1780	0.3799	0.5561

(Sit Aware = situational awareness)

Table 3 Individual task performance

Items	Static Aid (sCA) (n = 19)			Dynamic Aid (dCA) (n = 15)			P value comparing sCA vs. dCA		
	Rater 1	Rater 2	Overall	Rater 1	Rater 2	Overall	Rater 1	Rater 2	Overall
MH									
Turn off agents	100.0	100.0	100.0	100.0	100.0	100.0	1.0000	1.0000	1.0000
Stop surgery	94.7	84.2	89.5	80.0	80.0	80.0	0.2994	0.7491	0.3175
MH cart	100.0	94.7	97.4	100.0	100.0	100.0	1.0000	0.3671	0.3707
Call for help	89.5	89.5	89.5	86.7	86.7	86.7	0.8009	0.8009	0.7213
Call hotline	57.9	57.9	57.9	26.7	26.7	26.7	0.0686	0.0686	**0.0100**
100% O2	100.0	100.0	100.0	93.3	100.0	96.7	0.2533	1.0000	0.2569
Increase vent	73.7	89.5	81.6	93.3	93.3	93.3	0.1356	0.6936	0.1555
Dantrolene	63.2	63.2	63.2	100.0	100.0	100.0	**0.0083**	**0.0083**	**0.0002**
Blood gas	89.5	89.5	89.5	100.0	100.0	100.0	0.1962	0.1962	0.0670
Bicarbonate	52.6	52.6	52.6	73.3	73.3	73.3	0.2174	0.2174	0.0811
Dose (mEq)									
Cool patient	100.0	100.0	100.0	93.3	100.0	96.7	0.2533	1.0000	0.2569
Temp monitor	100.0	100.0	100.0	100.0	100.0	100.0	1.0000	1.0000	1.0000
Arterial line	47.4	47.4	47.4	26.7	20.0	23.3	0.2174	0.0973	**0.0412**
Diurese	5.3	5.3	5.3	0.0	0.0	0.0	0.3671	0.3671	0.2021
HK									
Recognition	31.6	36.8	34.2	53.3	53.3	53.3	0.2006	0.3363	0.1134
Insulin	15.8	15.8	15.8	53.3	53.3	53.3	**0.0202**	**0.0202**	**0.0010**
Dextrose	10.5	10.5	10.5	46.7	46.7	46.7	**0.0177**	**0.0177**	**0.0008**
Calcium	36.8	36.8	36.8	93.3	93.3	93.3	**0.0008**	**0.0008**	**<.0001**
Bicarbonate	21.1	21.1	21.1	20.0	20.0	20.0	0.9399	0.9399	0.9151
Furosemide	100.0	100.0	100.0	100.0	100.0	100.0	1.0000	1.0000	1.0000
Vfib									
Recognition	68.4	73.7	71.1	80.0	80.0	80.0	0.4473	0.6664	0.3975
Chest compress	89.5	89.5	89.5	100.0	100.0	100.0	0.1952	0.1952	0.0670
Defibrillate	5.3	5.3	5.3	86.7	86.7	86.7	**<.0001**	**<.0001**	**<.0001**
Epinephrine	31.6	31.6	31.6	60.0	60.0	60.0	0.0975	0.0975	**0.0191**
No break in comp	5.3	5.3	5.3	0.0	0.0	0.0	0.3834	0.3834	0.2177

Percentage of each item correctly answered by residents within each group

(MH = Malignant Hyperthermia, mEq = milliequivalents, HK = Hyperkalemia, Vfib = ventricular fibrillation)

group when compared to the sCA group. In particular, checklist items with dose specificity were significantly more likely to be performed correctly in the dCA group. Several factors may account for an improved performance seen in the dCA group.

The dCA offered real time dose calculations and prompts to the provider. The results indicate, not surprisingly, that providers are more likely to administer the medication correctly, if given the actual dose needed, not just a prompt to give the medication without further detail. We postulate that this phenomenon is due to both provider errors in calculating medication doses in crises, as well as knowledge gaps that may exist for rarely administered therapies (i.e. correct dose of dantrolene, correct energy for defibrillation).

Treatment algorithms for HK were presented when laboratory evidence of HK was shown to the clinician. This provided real time decision support with minimal clinician effort. The availability of information in a rapid, patient specific fashion, likely accounted for improved checklist performance. Indeed, clinical decision support tools have been found useful in previous studies [5]. Our findings are consistent with prior findings in the literature.

Relative differences in ease of use may also account for improved performance with a large screen display based dCA. Clinicians were presented with the dCA on a 50-in. monitor mounted on the wall of the simulated operating room. The sCA consisted of laminated 8 × 11 in. cards held together by a ring binder. Each card represented unique algorithms. A

large screen display may provide a visual advantage over smaller laminated cards and offer the advantage of not having to turn pages between algorithms while managing multiple issues such as HK and VF. The integration of these algorithms into a single screen with pertinent patient data provides a single platform for clinical decision making.

While this study evaluated one provider, large screen display based dCAs may offer even more advantage to the healthcare team. By creating a central screen where all team members can view the checklist, a shared mental model is created. This gives each member more understanding and engagement in the process. This has been noted in previous studies with regard to the preoperative surgical safety checklist. Shear et al noted improved procedural timeout compliance with the use of an electronic large screen display compared to a paper form [14]. This study evaluated teams performing surgical timeouts in the operating room.

ANTS ratings were not different among groups. While inter-rater reliability was not high for this outcome measure, both raters found no difference between groups. Poor rater agreement appears to be at an individual subject level with overall ANTS rating similarly for both groups. This suggests dCA may have less of an impact on non-technical skills in the operating room. This finding differs from a previous study by Marshall which found improved ANTS scores with CA use [15]. It is possible that CAs in general improve non-technical skills such as communication and leadership. Enhancing CAs with decision support may not cause incremental improvement in ANTS.

Several limitations to the current study exist. First, this study was conducted in a simulated environment and the application of its findings to the real clinical arena are unknown. Second, individual performance only was evaluated and the effect of a dCA on team-based care is not clear. It is possible, however, that teams may see even more benefit from a shared dCA presented on a large screen. Finally, subjects were familiar with the sCA as these were in use at the study institution. This may have influenced the results as clinician familiarity may be a key factor in the successful use of CAs [11]. Clinicians were not familiar with the dCA. Despite a lack of familiarity, the dCA, improved performance. This study may actually underestimate the positive impact of a dCAs as increased familiarity should only serve to improve CA adherence. Finally, this study evaluated a pediatric scenario where dose calculations are imperative. In adult scenarios providers may use more generic dosing regimens (i.e. 1 mg epinephrine). This may decrease the advantage seen with dCAs that present patient specific data.

In conclusion, we evaluated the use of a sCA versus a dCA with embedded decision support in a simulated environment. Resident physicians were found to perform more checklist items correctly when randomized to the dCA group. The use of CAs in clinical care improves clinician performance and is here to stay. Future studies should focus on ways to enhance and improve the decision support that CAs provide. Leveraging human factors data and technology in the design of CAs will be paramount to improving care and offering clinicians greater opportunity to do the right thing.

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Compliance with Ethical Standards

Summary Statement n/a

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Conflict of Interest The authors declare no competing interests.

Appendix 1: Scenario

A 6 year old male is scheduled for an umbilical hernia repair under general anesthesia. The subject is called to the operating room by a colleague for relief. Upon entering the room the patient is under general anesthesia with sevoflurane administered via an endotracheal tube. Subsequently, hypercarbia is noted on end-tidal capnography simultaneous to surgical insufflation of the abdomen. As the case progresses, tachycardia, hypertension and hyperthermia follow. Hyperkalemia induced tachyarrythmias soon develop. When prompted by the subject, a confederate operating room nurse will offer the designated cognitive aid. If no cognitive aid is sought after 4 min, the confederate nurse, prompts its use. Management of the patient by the subject then determines the clinical course.

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