Time Cost of Provider Skill: A Pilot Study of Medical Officer Occupied Time By Knowledge, Skill, and Ability Level

Dana R. Levin; Margaret Siu; Kristina Kramer; Edward Kelly; Reginald Alouidor; Gladys Fernandez; Tovy Kamine

INTRODUCTION: On space missions one must consider the operating cost of the medical system on crew time. Medical Officer Occupied Time (MOOT) may vary significantly depending on provider skill. This pilot study assessed the MOOT Skill Effect (MOOTSkE).

METHODS: An expert surgeon (ES), fifth year surgical resident (PGY5), second year surgical resident (PGY2), and an expert Emergency Physician (EP) with only 4 mo direct surgical training each performed two simulated appendectomies. The completion times for endotracheal intubation, appendectomy, and two subprocedures (multilayer tissue repair and single layer tissue repair) were recorded.

RESULTS: The ES performed the appendectomy in 410 s, the PGY-5 in 498 s, the PGY-2 in 645 s, and the EP in 973 s on average. The PGY-2 and EP time difference was significant compared to the expert. The PGY-5 was not. The EP's time was significantly longer for the appendectomy and the multilayer repair than either surgical resident. For the single layer repair, only the EP-ES difference was significant. A single intubation attempt by the PGY-2 took 73 s while the EP averaged 27 s. The average recorded MOOTSkE between novice and expert was 2.5 (SD 0.34).

DISCUSSION: This pilot study demonstrates MOOTSkE can be captured using simulated procedures. It showed the magnitude of the MOOTSkE is likely substantial, suggesting that a more highly trained provider may save substantial crew time. Limitations included small sample size, limited number of procedures, a simulation that may not reflect real world conditions, and suboptimal camera angles.

KEYWORDS: knowledge, skills, and abilities, crew medical officer, procedure skills, training, space.

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This pilot study was designed to assess the time to completion required by providers of different knowledge, skills, and abilities (KSA) performing the same procedure. Since medicine aims to reduce patient risk and improve quality of life, expedition medical kits and space medical systems are designed to minimize risks such as death, need for evacuation, and disability.[3,9] Similarly, provider KSA is evaluated through expected skills obtained at various points in standardized training curricula and assessed through testing, simulation, or educator written skills evaluations. These baseline skills are readily available through publications such as national guidelines for Emergency Medical Technicians and ACGME milestones for physicians.[1,12] However, on missions with small crews, limited resources, and tight timelines, one must also consider the operating cost of the medical system on aspects of the mission itself, such as crew time.[3,13] Patient downtime is often accounted for since time for recovery is expected and, by rendering care, the unavoidable time cost of injury or illness is minimized.[13] Medical Officer Occupied Time (MOOT), however, is not typically considered and may

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vary significantly depending on provider KSAs. This MOOT skill effect (MOOTSkE) can be combined with estimations of medical event frequency to better understand how much crew time is spent on unplanned medical events and if/how the onboard KSA can mitigate the cost.

The purpose of this study was to evaluate: 1) if there is a difference in time taken to perform medical tasks as a function of skill level; and 2) if simulation can detect and quantify the potential time difference. The methods used in this study were meant to be applied to any medical procedure. For the purposes of this trial, simulated open appendectomy was chosen due to the easily marked starting and ending points, the commonality of the illness, and the ability to capture time for multiple procedures (e.g., intubation, appendectomy, multilayer tissue repair, and single layer tissue repair) in a single testing session.[2,8,11] Additionally, while laparoscopic surgery is certainly possible in microgravity, laparoscopic equipment requires much more mass and volume and is more challenging for a novice to perform.[5]

The authors acknowledge that this and other surgical emergencies are not likely to occur or be managed in spaceflight, but with the exponential increase in crew time spent in orbit over the last 5 yr (**Fig. 1**) and increased focus on long duration exploration missions, the risk of a mission critical surgical problem occurring in flight is significant and it is worth considering how such events would be managed.[4,6,7]

METHODS

Subjects

An expert Surgeon board certified in General Surgery and Surgical Critical Care (ES), a Surgical Chief Resident (PGY-5), a second year Surgical Resident (PGY-2), and an Emergency Medicine Physician board certified in Emergency Medicine and Aerospace Medicine (EP) were tasked to perform an open appendectomy on a simulator. The EP served as the "novice." Participants were chosen from a convenience sample for their training level, interest, and availability for the pilot study.

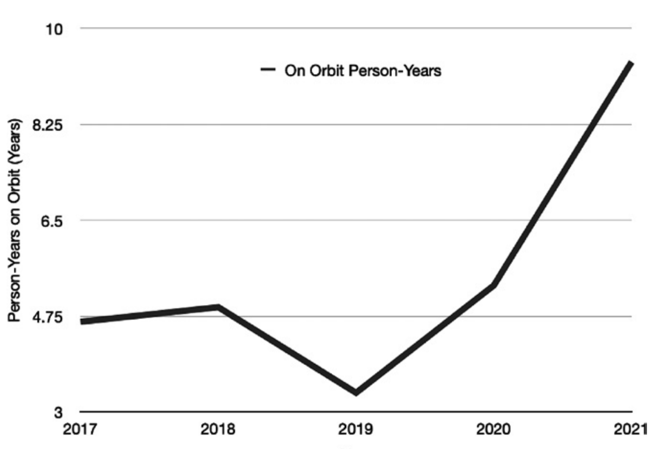

Fig. 1. On orbit person-years by mission launch year.

Equipment

The Baystate Simulation Center and Goldberg Surgical Skills Laboratory (Springfield, MA, USA) were used to simulate a spacecraft. Operating room (OR) table and arm board dimensions were measured in centimeters from an OR approved by The Joint Commission. The operating room table measured 194 cm × 58 cm, and 194 cm ×124 cm with one arm extended. Standard hospital tables were used to represent an operating table. A trauma back board was used to stabilize the simulated patient when performing appendectomies in kneeling fashion. A standard intubation training head-and-lungs mannequin was secured at the head of the backboard and a surgical trainer abdominal cavity was secured in the appropriate position on the backboard. The Ambu bag, face mask, endotracheal tube, and a laryngoscope with a MAC 3 blade were placed on a tray near the head of the bed.

A set of surgical instruments considered essential in performing an open appendectomy was gathered. Instruments included a disposable 10-blade scalpel, a Jacobson mosquito forceps, a standard Kelly clamp, sutures, a needle driver, a set of pick-ups, a pair of scissors, and appropriate 3-0 and 4-0 sutures. A simulated inflamed appendix was forged using a tubular-shaped foam, measuring 2″ long and 1 cm wide, adhered to soft rubber tubing that mimicked the cecum. The simulated appendix was placed deep into a hollow mannequin to represent appendicitis.

Procedure

Internal review board (IRB) approval was obtained from the Baystate Health IRB. This pilot study used a simulated open appendectomy to assess the MOOTSkE for selected components of the procedure, estimate its magnitude for various training levels, and identify areas for study design improvement. Times were captured by defining the beginning and ending as follows.

1) Endotracheal intubation begins: laryngoscope picked up. Endotracheal intubation ends: delivery of first breath via Bag Valve Mask.
2) Appendectomy begins: scalpel picked up. Appendectomy ends: needle driver placed on surgical tray after skin closure.
3) Multilayer Repair of a 12-cm abdominal cavity incision begins: suture material picked up from tray at start of fascial repair. Multilayer Repair ends: scissors replaced on tray after final deep suture placed.
4) Single Layer Repair of a 12-cm abdominal cavity incision begins: suture material picked up from tray at start of skin closure. Single Layer Repair ends: needle driver replaced on tray after final skin suture placed.

Since the novice (EP) had only 4 mo of direct surgical training, their initial appendectomy was performed under in-room guidance from the ES. The EP's second appendectomy was done with telemedical guidance from the ES using a camera placed over the surgical field.

Video cameras were used to record the procedure. The video was then analyzed to capture time data using the start/stop points in **Table I** and **Table II**. Data from the EP's second procedure was not captured due to technical difficulties.

Statistical Analysis

The small sample size limited statistical analysis. The reported results were obtained by averaging the two procedure attempts of each participant and comparing the results with a two-tailed, two-sample homoscedastic Student's *t*-Test. Significance was set at $P < 0.05$. No analysis was possible for the intubation procedure in this pilot study as only a single data point from the initial attempt by the PGY-2 was available for comparison to the expert EP.

RESULTS

The average time to perform an appendectomy by KSA level fits a logarithmic curve with a correlation coefficient of 0.99. Similar curves can be seen for the multilayer repair and the single layer repair (**Fig. 2**), both with a correlation coefficient of 0.91.

Table I and Table II present the average time each KSA provider took to complete each procedure and the statistical significance of their time compared to the expert reference. The difference between the PGY-5 and the ES was not significant for any procedure. The PGY-2 was only significantly different for overall appendectomy time while the EP took significantly longer than the ES for the appendectomy, the multilayer repair, and the single layer repair. The magnitude of this difference was 2.4 times greater for the appendectomy, 2.6 times greater for the multilayer tissue repair, and 2.8 times greater for the single layer repair.

A significant difference between surgeon and nonsurgeon was also present with both the PGY-5 and the PGY-2 compared to the EP for the appendectomy and the multilayer repair. However, the magnitude of this difference decreased by 19% for the appendectomy, 16% for the multilayer repair, and 32% for the single layer repair when comparing to the PGY-5, and 37%, 27%, and 31% when compared with the PGY-2. The difference in single layer repair time was not significant between the EP, the PGY-5, nor the PGY-2.

For intubation, only a single value for the nonexpert PGY-2 was captured so no statistical analysis could be run. However, the PGY-2 (novice) took twice as long as the EP to intubate the simulated patient. Actual times taken for the surgical procedures are presented in **Table III** along with the effect size for each procedure. The MOOTSkE average was 2.59 with a standard deviation of 0.34.

DISCUSSION

The results suggest the potential for a strong correlation between years of training and time to complete an appendectomy (Fig. 2). This correlation fits a logarithmic curve with a 58% time reduction occurring by year 2 and 84% by year 5, meaning that the MOOTSkE in this study is a factor of 2

Table I. Average Time by KSA and Significance by *P*-Value from Student's *t*-Test.

	EXPERT	PGY-5 TO EXPERT				PGY-2 TO EXPERT				NSP COMPARED TO EXPERT			
		TIME	DF	*t*-STAT	*P*-VALUE	TIME	DF	*t*-STAT	*P*-VALUE	TIME	DF	*t*-STAT	*P*-VALUE
Appendectomy	410 s	498 s	1	−2.06	0.176	645 s*	1	−24.65	0.002	973 s*	1	−22.21	0.002
Multilayer 12-cm repair	299 s	351 s	1	−0.71	0.549	405 s	1	−1.39	0.299	766 s*	1	−10.02	0.010
Single layer 12-cm repair	132 s	193.5 s	1	−1.4	0.296	193 s	1	−1.24	0.341	370 s*	1	−6.25	0.025
Endotracheal intubation†	38 s					73 s							

KSA = knowledge, skills, and abilities; PGY-5 = 5th year surgical resident; PGY-2 = 2nd year surgical resident; DF = degrees of freedom; NSP = nonsurgeon physician.
*Significant difference ($P < 0.05$); †reference time is Emergency Medicine doctor's mean.

Table II. Comparison of Non-Surgeon Physician (NSP) to Non-Expert Surgeons.

	NSP COMPARED TO PGY-5			NSP COMPARED TO PGY-2		
	DF	*t*-STAT	*P*-VALUE	DF	*t*-STAT	*P*-VALUE
Appendectomy	1	−9.86	0.010*	1	−13.92	0.005*
Multilayer 12-cm Repair	1	−7.26	0.018*	1	−5.96	0.027*
Single layer 12-cm Repair	1	−3.06	0.092	1	−2.6	0.102

PGY-5 = 5th year surgical resident; PGY-2 = 2nd year surgical resident; DF = degrees of freedom; NSP = nonsurgeon physician (EP).
*Significant difference ($P < 0.05$).

between a novice and an expert. The intubation data may also support this given the similar magnitude of the effect, though we urge caution in drawing conclusions based on the single point of comparison.

However, the small sample size and number of simulations means that this value should not be taken as a definitive answer. This study is more valuable for its demonstration of the ability to detect a difference than its conclusion of the magnitude of this difference, though the magnitude may be useful for future studies when conducting a power analysis to determine sample size and/or number of simulations.

It is also worth noting that an attending Emergency Physician is not naïve to surgical methods. Lower KSA providers, such as physicians who have not completed Emergency Medicine residency or nonphysician crew medical officers, may take significantly longer to perform this procedure.

Another interesting finding is the lack of a significant MOOTSkE between the EP and the surgical residents for the single layer repair while the MOOTSkE with the ES was significant. Single layer tissue repair is a common procedure for both specialties. However, surgeons perform the procedure multiple times a day at the close of surgeries in the operating room, while Emergency Physicians perform it regularly for patients with skin lacerations in the Emergency Department. Given this, one might expect that there would be no time difference between attending physicians from either specialty. However, the regularity of the procedure for surgeons compared to the episodic nature of it for Emergency Physicians may provide a clue. A logarithmic learning curve predicts that the greatest learning effect will appear early in training, with subsequent MOOTSkE reductions taking progressively longer to manifest. Based on this, one would expect to see progressively shorter times based on number of times the procedure is performed and, indeed, when the single layer repair times are plotted on a graph against years of surgical training, they neatly fit a logarithmic curve, with the R^2 value slightly lower than in the other curves (Fig. 2). This supports the conclusion that the confusing significance pattern may be a result of insufficient power from the miniscule sample size. It is also possible that the EP is simply not as skilled with suturing and additional training and or experience will decrease their procedure times.

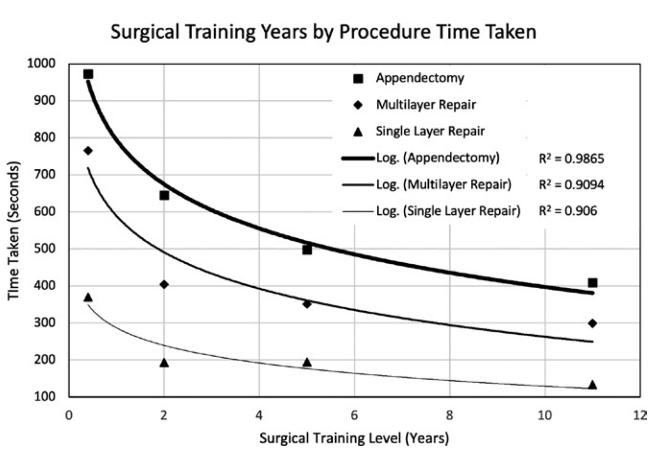

Fig. 2. Years of surgical training (x-axis) by time required to perform procedure.

Taken as a whole, this pilot study suggests that MOOTSkE is likely to have a substantial effect on procedure time. Thus, MOOTSkE may have a considerably negative impact on available crew time during a mission. Our average measured effect was that a novice took an average of 2.5 times longer to perform a procedure under ideal circumstances and in a familiar environment. This difference is likely to increase when the circumstances are less than ideal and the environment unfamiliar, as they would be during a medical emergency in space. The silver lining is that the converse is also true: an experienced medical provider could cut the time spent on medical operations by more than half. This is particularly true if the MOOTSkE holds up for other aspects of medical care such as interpretation of clinical data, medical management decisions, and patient assessments. These tasks are harder to evaluate, but represent a critical part of all medical care and may be just as costly in terms of crew time.

One other aspect worth noting is that the EP in this study would not have been able to complete the procedure without expert guidance. While real-time, telemedical support was sufficient for the second EP appendectomy, the initial run was done in person. This is not surprising, given that emergency medicine and surgery are different specialties with vastly different training, but it does raise an important issue. While all physicians are highly trained, that training is not equal. Physicians trained in different specialties have different skillsets that may not have much overlap. Terrestrial medicine has long required a team approach which may be limited or even unavailable in space.[3] Furthermore, the distances at which exploration class missions operate mean they will not have access to real time telemedical guidance.[9,10] This may degrade many procedure outcome metrics, including MOOTSkE. These points make it unlikely that the skillset required by a true deep space exploration medical officer will fall neatly into any single terrestrial training paradigm. Determining the optimal training curriculum for such a practitioner will require substantial additional study.

Table III. Time Taken for Surgical Procedures by KSA Level and Novice to Expert Effect Size.

	EXPERT	PGY-5	PGY-2	NSP	EFFECT SIZE NSP TO EXPERT
Years of practice	11	5	2	0.4	
Appendectomy 1	419	540	646	949	2.26
Appendectomy 2	400	456	644	996	2.49
12-cm multilayer repair 1	345	408	344	762	2.21
12-cm multilayer repair 2	252	294	465	770	3.06
12-cm single layer repair 1	126	237	144	332	2.63
12-cm single layer repair 2	138	150	241	407	2.9
Average effect size					2.59 SD, 0.34

KSA = knowledge, skills, and abilities; PGY-5 = 5^{th} year surgical resident; PGY-2 = 2^{nd} year surgical resident; NSP = nonsurgeon physician (EP).

As a pilot study, the primary goals were to test the feasibility of our simulation method for capturing time data, estimate effect size, and identify areas for further study. Our method for capturing procedure time through low-cost procedure simulation and subprocedure analysis was successful. We were able to identify a potentially large effect of training level on procedure time that appears to follow a logarithmic curve. However, this study is limited in many ways.

First and foremost, it consists of a small sample size with participants only completing two simulations. Therefore, it is not possible to draw definitive conclusions about effect size without substantially increasing the number of participants and/or trials. Furthermore, the EP could not perform the procedure without guidance from an expert surgeon. This means that the time taken for the “novice” reflects the required time with real time instruction. The EP’s second attempt was done with remote guidance via a telemedicine set up and, anecdotally, required less instruction, but this too reveals a limitation of the study. Two appendectomies done in relatively quick succession by the same provider may demonstrate a training effect on time to complete the procedure. While the authors believe it unlikely that this effect would be substantial, and the magnitude seen in the experiment despite the small sample size argues against this, the potential cannot be entirely discounted and may affect the accuracy of our results.

Secondly, it is worth noting that the skills required for a successful appendectomy require KSA from at least two different terrestrial specialties: anesthesia and surgery. These specialties do not overlap in skillsets and, even in this study, the KSA required for intubation and surgery are not often present in the same provider without substantial additional training and practice. Therefore, MOOTSkE may be best evaluated by comparing experts on individual capabilities rather than tying it to terrestrial specialty expertise and potentially combining all aspects of a procedure together (as was done with skin closure and appendectomy) rather than measuring each individually (as was done with intubation and appendectomy).

Third, this study did not account for the time required to set up equipment, prep the patient, monitor the patient for recovery, nor any other associated medical tasks. This means that the operational cost of medical procedures is likely to be far greater than the procedure itself and this time should be investigated in future studies to ensure accurate time values and evaluate the operational significance (or lack thereof) for the MOOTSkE.

Finally, the study was conducted in a 1-G, nonspacecraft environment. It is unable to account for the effect of environmental differences on MOOTSkE. The comparison of procedure time between environments, however, may be an interesting follow-on study.

Future studies should seek to increase the simulation fidelity and address these limitations. Additionally, future studies would benefit from optimizing camera angles for the specific procedure and simulating a more continuous procedure, starting with equipment set up, patient prep, IV insertion, rapid sequence induction, surgery, and recovery. This will enable more accurate estimation of the procedure time cost. It is also worth devising a method for assessing the nonprocedural MOOTSkE skills alluded to above (clinical data interpretation, management decisions, and patient assessment). These skills could be tested for various KSA levels with and without clinical decision aids to assess both the MOOTSkE magnitude and methods for mitigating it.

In conclusion, this pilot study demonstrated a method for capturing the medical officer procedure time cost of a simulated appendectomy and several sub-procedures by provider experience level and suggests that the magnitude of the Medical Officer Occupied Time Skill Effect (MOOTSkE) on this procedure follows a logarithmic curve. It also suggests that provider skill level may have a substantial effect on available crew time which may be mitigated by flying higher skill level providers or through targeted training of crew medical officers.

This study is limited in many ways, including small sample size, limited number of tested medical capabilities, a simulation set up that may not accurately reflect mission conditions, and suboptimal camera angles. Future studies should seek to improve on these limitations.

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