

# Prospective cohort study on surgeons' response to equipment failure in the laparoscopic environment

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## Abstract

**Background** Equipment malfunction accounts for approximately one-fourth of surgical errors in the operating room. A serious game was developed to train surgeons in recognizing and responding to equipment failure in minimally invasive surgery (MIS) adequately. This study determined the baseline performance of surgeons, surgical residents, surgical novices, and MIS equipment technicians in solving MIS equipment failure.

**Methods** The serious game included 37 problem scenarios on the subjects lighting and imaging, insufflation and gas transport, electrosurgery, and pathophysiological disturbances. The scenarios were validated by laparoscopic surgeons and MIS equipment specialists. Forty-nine licensed surgeons, surgical residents, medical students, and MIS equipment specialists played four sessions on the serious game at a surgical convention. Scores on different outcome parameters were compared between groups of a different MIS experience.

**Results** Laparoscopic equipment specialists solved significantly more MIS equipment-related problems than surgical novices, intermediates, and experts (68.9 vs. 51.0 %, 51.4, and 45.0 %, respectively,  $p = 0.01$ ). Laparoscopic equipment specialists required significantly fewer steps to solve a problem accurately (median of 1.0 vs. 2.0

for the other groups). Most notably, experienced surgeons were unable to outperform novice and intermediate groups. Experienced surgeons took less time to solve the problems, but made more mistakes in doing so.

**Conclusions** Experienced surgeons did not outperform inexperienced surgeons in dealing with laparoscopic equipment failure. These results are worrying and need to be addressed by the surgical community.

**Keywords** Surgical procedures, minimally invasive · Equipment failure · Serious game · Medical errors · Risk management · Education, medical

The increase in complex technology has greatly enhanced possibilities in minimally invasive surgery (MIS), but has also increased the mental workload for the operating personnel [1]. A systematic review shows that equipment-related problems account for approximately one-in-four surgical errors [2]. During the majority of MIS procedures, equipment malfunction will occur, such as failure of electrosurgery, gas and light transmission, instrumentation, and electronic circuits [3, 4]. This leads to time delays and threatens patient safety in approximately one-fifth of the cases [3]. Although surgeons and operation room (OR) assistants train in laparoscopic equipment handling, it does not prevent malfunctions from happening [2]. Legislation in The Netherlands states that the user carries final responsibility for proper functioning of medical technology [5], requiring the laparoscopic surgeon to be able to deal with malfunctions. Legislation stated that hospitals are responsible for proper training and maintenance of skills in handling medical technology [6, 7].

Two aspects may compromise the surgeon's ability to deal with equipment malfunctions in the OR. During

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surgery, the surgeon has to divide his or her attention between surgical field, surgical team, and OR surroundings. It has been shown that the human brain is incapable of recognizing subtle alterations [8] or unexpected events [9] in stressful circumstances. Secondly, current training seems not to ensure the skills needed to solve equipment-related problems. Although surgeons in developed countries receive basic laparoscopy training on the principals of MIS (Fundamentals of Laparoscopic Surgery course [10] or equivalent), a recent survey among participants in the advanced laparoscopy courses showed that knowledge from the course is barely preserved over time, especially concerning instrumentation and MIS access [11].

A serious game was developed to train surgical trainees in recognizing and dealing with MIS equipment malfunctions. A serious game is defined as “interactive computer application ... that has a challenging goal, is fun to play and engaging, incorporates some kind of scoring mechanism, and supplies the user with skills, knowledge or attitudes useful in reality” [12]. This serious game aims to train surgical residents in handling common and less common problems related to pneumoperitoneum, gas and visual transmission, and electrosurgery, and recognizing pathophysiological disorders related to MIS.

This study determined the baseline performance of surgeons, surgical residents, and medical students in recognizing and solving MIS equipment failure scenarios. We hypothesized that the experienced laparoscopic surgeons would outperform lesser experienced surgeons—because of the requirements by their surgical registration and because of practical experience. Secondly, we hypothesized that laparoscopic equipment specialists (i.e., technical equipment specialists involved in manufacturing laparoscopic equipment) would outperform all surgical levels of expertise in solving equipment problems.

## Methods

### Participants

Forty-five surgeons, surgical residents, and medical students from different hospitals in the Netherlands were recruited at the Dutch Surgical Society’s annual convention, May 30th and 31st, 2013. None of them had previous exposure to the serious game. Six laparoscopic equipment specialists were recruited from the firm that designed the MIS equipment featured in the serious game. Two surgeons were excluded because they had no experience with the type of laparoscopic equipment represented in the serious game.

All 49 participants received a standardized hands-on instruction by trained instructors and one trial-session

(3 min). This did not include teaching on equipment malfunctions. All participants played a minimum of three sessions on the serious game. Performance was analyzed and compared between groups of different levels of experience: (*surgical*) *expert* (performed > 100 MIS procedures as primary surgeon), *intermediate* (performed 1–99 MIS procedures as primary surgeon), *novice* (no experience with MIS as primary surgeon), and *MIS equipment specialists* (manufacturer-affiliated equipment specialists).

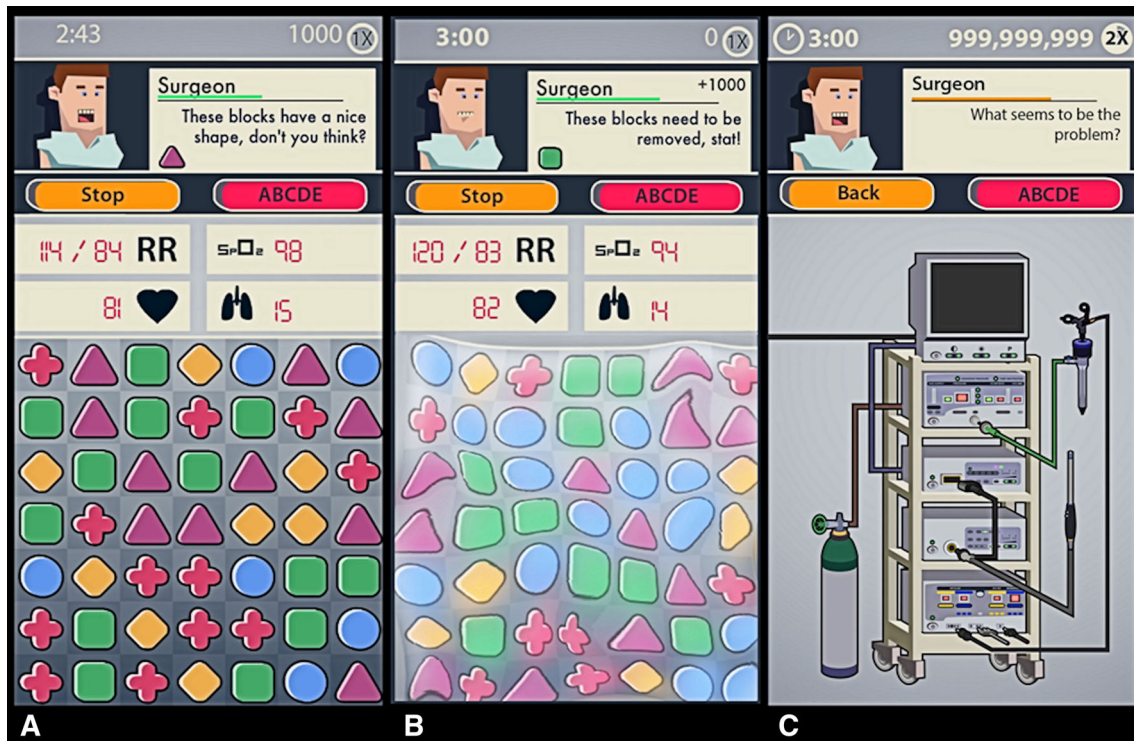
The participants filled out a questionnaire on demographic information, experience with MIS, MIS equipment training, and videogame experience.

### Serious game

Learning objectives of the serious game (Weirdbeard Inc., Amsterdam, The Netherlands) were (1) recognizing and (2) handling equipment-related events during the performance of an unrelated task, thereby aimed to improve vigilance toward events outside the direct operative field. The educational content was embedded in an entertaining game, as is customary in serious gaming [13]. The main interface (Fig. 1A) displayed a mini-game (a game inside a game). The mini-game was used because of its captivating properties, ensuring players’ attention and motivation to play. Although the mini-game’s content was unrelated to surgery, the gameplay was virtually embedded in the laparoscopic tower and thus influenced by equipment failure. The screen and lighting were influenced by the laparoscopic monitor output and gameplay by electrosurgical functioning. Auditory and visual signals from the OR appeared throughout the game. This required the player to retain awareness of his or her surroundings, comparable to the live OR setting.

During the serious game, a fixed amount of MIS-related problem scenarios occurred that inhibited further gameplay (Fig. 1B). These scenarios were designed and tested to resemble real equipment problems or malfunctions and pathophysiological disorders related to MIS. The equipment problems included screen and lighting, gas transport, and electrosurgery problems (Table 1). This educational content was validated by two independent laparoscopic surgeons and five MIS equipment specialists. The problem scenarios were presented in written form with the correct solutions, leaving the content experts to choose between “valid” and “invalid.”

If an equipment problem was recognized by the player by pressing a button, he or she would enter a problem-solving mode. This displayed a simulated MIS unit (Fig. 1C), with lightsource (Olympus Exera II CLV 180), insufflator (Olympus UHI-3), videoprocessor (Olympus Exera II CV-180), laparoscopic camera (EndoEYE HD Video Laparoscope), and electrosurgical unit (Surgmaster UES-40, all Olympus Corporation, Tokyo, Japan). By assessing the equipment settings and displays, the player



**Fig. 1** The serious game (screenshots). **A** Main screen, with mini-game (*below*), the patient's vital signs, and a supervising surgeon (*above*). **B** During the mini-game, the player deals with problem scenarios that resemble real-live problems in MIS, for example, the

could reason the cause of the problem and execute the action to solve the problem. Upon successful completion, or after 4 failed attempts, the player entered the mini-game mode again. Extra points could be obtained by choosing efficient problem-solving strategies, enhancing the player's motivation to deal with the content.

### Measurement

The software automatically calculated the participants' performance by the following parameters: problems recognized and solved, time required identifying the problem (problem recognition time), and the time required solving the problem (problem-solving time). Additionally, the number of steps to solve the problem was measured, including the number of correct and incorrect steps. These were used to calculate the participants' strategic efficiency in solving problems. Problem scenarios that were consistently not solved (overall problem-solving rate <10 %) were analyzed for mistakes and withheld from analysis to optimize content validity.

### Statistical analysis

Problem recognition, problem solving, and accuracy scores were measured per problem, and compared using non-

blurred screen. **C** After the player recognizes the problem scenario, he or she can solve it by selecting the correct action on a simulation of the MIS equipment

parametric testing. Problem-solving time was calculated using a Kaplan–Meier curve and Log-Rank test.

The effect of the game on problem-solving capability was assessed using a random intercept linear regression model: a random effects model with one fixed intercept and a random intercept for each group. The random intercepts were compared to the overall random intercept value of 0. Statistical uncertainty was addressed by estimating 95 % confidence intervals (CI).

Analyses were performed using IBM Statistical Package for Social Sciences version 20 (IBM corp., Armond, NY, USA) and R version 2.15 (R Foundation for Statistical Computing, Vienna, Austria).

## Results

### Characteristics

Forty-three participants from thirty hospitals in the Netherlands were included in the analysis, and six laparoscopic equipment specialists from the equipment manufacturer. Demographic characteristics are described in Table 2. The (surgical) expert and laparoscopic equipment specialists groups were significantly older than novice and intermediate groups (one-way ANOVA with post hoc Bonferroni,

$p < 0.01$ ). The novice group had significantly more female participants (Chi square,  $p = 0.02$ ). Equipment specialists had significantly less videogame experience than the other groups (Chi square,  $p = 0.02$ ).

Participants completed four sessions with an average of 5.0 problem scenarios per session. There were no significant differences in the distribution of the 37 problem scenarios among the participants of groups (Chi square test,  $p = 0.84$ ).

Problem scenarios with a failure rate  $>90\%$  were submitted to a post hoc evaluation. As a result, 7/37 problem scenarios were excluded from the analysis. Flaws were found in the graphical and auditory presentation of these seven scenarios that could have compromised the test's validity (Table 1).

### Group performance

All participants were able to recognize most of the equipment problems (novice group 97.7 %, intermediate group

96.4 %, (surgical) expert group 98.9 %, and MIS equipment specialists 98.4 %). The MIS equipment specialists solved significantly more problems than the other groups (68.9 % vs. 51.0, 51.4, and 45.0 %, for novice, intermediate, and expert groups, respectively, Kruskal–Wallis,  $p = 0.015$ ). An unexpected finding was that the (surgical) expert group solved fewer problems than the novice and intermediate groups. This finding was non-significant. Subgroup analysis showed that the licensed surgeons performed similar to the surgical residents within the expert group (44.8 vs. 44.5 %,  $p = 0.97$  (Mann–Whitney U)).

Figure 2 shows the efficiency with which the participants solved the problem scenarios, in terms of accuracy of the individual steps (Fig. 2A), and the time that the participants required to solve a problem (Fig. 2B). The MIS equipment specialists required a median of 1.00 steps to solve a problem (IQR 1.00–3.00), (surgical) experts 3.00 (1.00–4.00), intermediate 2.00 (IQR 1.00–4.00), and

**Table 1** Problem scenarios included in the serious game content

Category	Scenario type	Problem scenarios in the serious game ( <i>n</i> )	Problem scenarios excluded from analysis ( <i>n</i> )	Reason
Screen/lighting	Blurred screen	1		
	Condensation on screen	1		
	Flashing screen	1		
	Moving image	1	1	Scenario did not fit camera represented
	Discoloration	5		
	Darkened screen	3		
	Light screen	3	1	Graphical misrepresentation of lighted screen in one scenario
	Black screen	6	2	- Graphical misrepresentation of a display-signal - Graphical misrepresentation of stand-by button
Gas transport/ pneumoperitoneum	“No signal” sign	1		
	Smoke on screen	1		
	Intra-abdominal pressure too high	2	1	Game not fitted with correct action required in scenario
	Insufflation insufficient	2		
	Obstructed gas chain	1		
Electrosurgery	Empty gas supply	1		
	Electrosurgery alarm	1		
	Electrosurgery does not function	2	1	Sound dysfunction
Pathophysiology	Electrosurgery insufficient	1	1	Sound dysfunction
	De-oxygenation	1		
	Arrhythmia	1		
	Hypotension	2		

Specific problems can have multiple causes, represented in column “Number of scenarios.” Seven scenarios were excluded from analysis due to graphical or auditory misrepresentation

**Table 2** Demographic characteristics of study participants, grouped according to experience in MIS (in numbers unless stated otherwise)

Demographic characteristics		Novice (No MIS experience)	Intermediate (1–99 MIS procedures)	Expert (>100 MIS procedures)	Equipment specialists
N		12	14	17	6
Function	Student	6	0	0	0
	Resident	6	13	5	0
	Specialist	0	1	12	0
	Product expert	0	0	0	6
Sex	Male	33 %	71 %	82 %	66 %
Age	Mean (SE)	25.6 ( $\pm$ 0.7)	31.6 ( $\pm$ 0.9)	43.5 ( $\pm$ 2.6)	40.5 ( $\pm$ 2.8)
Videogame experience (past or presence)		81 %	92 %	86 %	33 %
Laparoscopic equipment training	Basic MIS course	0 %	78 %	60 %	0 %
	Advanced MIS course	0 %	7 %	0 %	0 %
	Other	0 %	0 %	0 %	100 %

novices 2.00 (IQR 1.00–4.00). This was statistically significant (Kruskal–Wallis,  $p = 0.03$ ). The MIS equipment specialists had a higher proportion of correct steps in problem solving (median of 1.00 (IQR 0.50–1.00) versus experts 0.50 (IQR 0.00–1.00), intermediate 0.50 (IQR 0.00–1.00), and novice 0.50 (IQR 0.00–1.00). The differences between MIS equipment specialists and the other groups were statistically significant, (Mann–Whitney  $U$ ,  $p = 0.01$  vs. expert group;  $p = 0.05$  vs. intermediate group, and  $p = 0.02$  vs. novice group). Figure 2B shows the time required to solve problems. It shows that MIS equipment specialists required on average more time to solve problems than other groups. The MIS equipment specialists required significantly longer to solve the problem than other groups, but performed better. This inequality was statistically significant (Log-rank,  $p = 0.04$ ).

Figure 3 shows learning curves of the individual participants in time during subsequent serious gaming sessions in a random intercept linear regression model. The serious game's effect on MIS equipment specialists' performance was estimated as an improvement of 0.13 per session (95 % CI  $-0.012$  to 0.29). The effect of serious gaming on other groups was limited: novices 0.01 (95 % CI  $-0.07$  to 0.09); intermediate  $-0.04$  (95 % CI  $-0.14$  to 0.08); (surgical) experts 0.00 (95 % CI  $-0.11$  to 0.10). None of the effects could be considered statistically significant, but a trend was visible in the MIS equipment specialist group. There was no difference in effects between experts and novices.

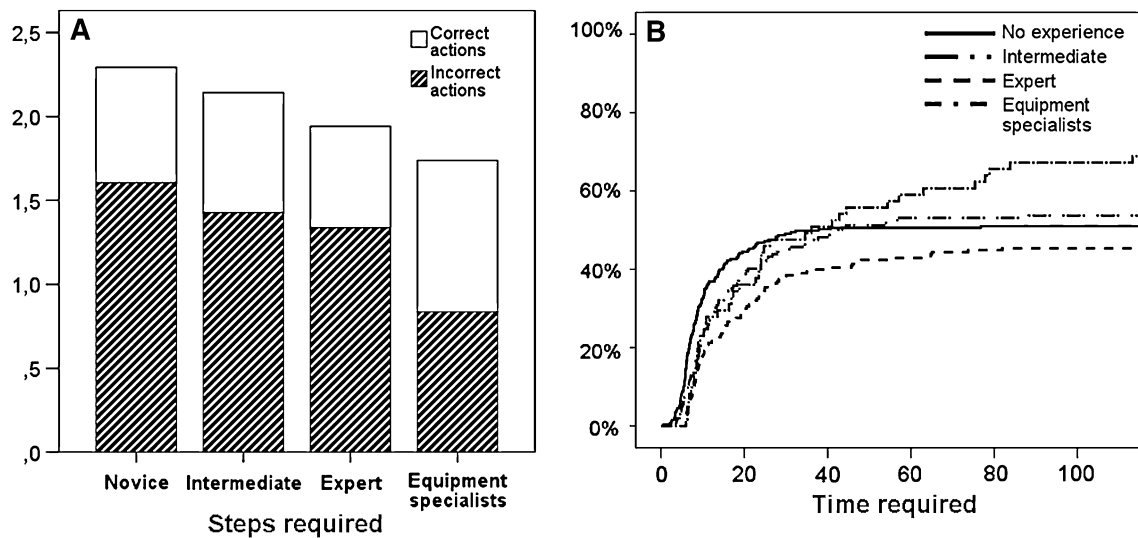
## Discussion

Our prospective cohort study showed that laparoscopic surgeons and experienced surgical residents who performed over >100 MIS procedures as primary surgeon

were unable to solve equipment-related problems in MIS more effectively than novices. Experienced surgeons were quick to choose a troubleshooting strategy, but failed as often as inexperienced personnel, while laparoscopic equipment experts acted more deliberately and with more precision. The serious game that was used showed acceptable construct validity, as the manufacturer-affiliated laparoscopic equipment specialists performed better than surgical groups, in conformity with the study hypothesis. None of the laparoscopic equipment specialists had played the serious game before. Re-analysis of the problem scenarios in the serious game was performed to identify erroneous problem scenarios.

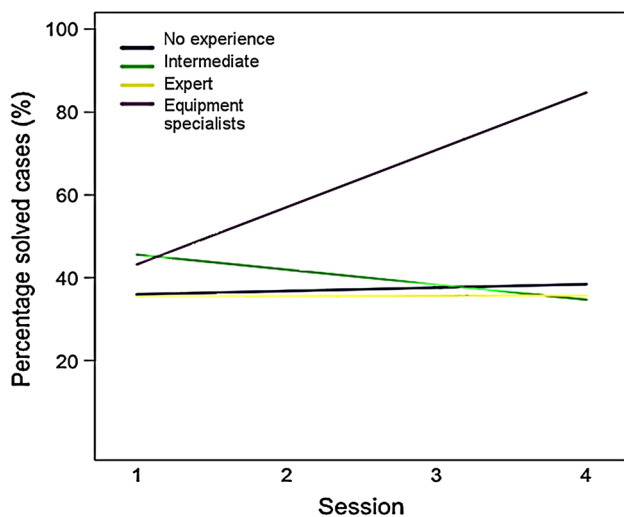
Nearly one equipment malfunction occurs during every surgical procedure [2]. Specific analyses of MIS procedures showed equally high equipment failure rates (one or more events occurring in 42–87 % of the MIS procedures) [3, 4, 14, 15]. Fluid, gas, and lighting problems occurred in approximately 36 % of the equipment malfunctions, followed by surgical instruments (29 %), electrical circuits (22 %), and imaging (12 %) [3]. Malfunctions lead to delays (up to 7 % of the operation time) and form a threat to patient safety in approximately one-fifth of the cases [3]. Checklists seem to reduce the amount of equipment failures by 50 %, but do not prevent malfunctions, leaving problem-solving capabilities to the individual surgeon highly relevant [15].

It seems imperative that the staff responsible for using medical technology knows how to deal with equipment malfunctions. The authors believe that a single course on equipment malfunctions during the start of the surgical curriculum (i.e., FLS), as is currently accustomed, is insufficient training for the full length of a surgeon's career. This is backed by results from a survey among participants of advanced laparoscopic courses in 2011,



**Fig. 2** Efficiency of the participant groups in solving problem scenarios in the serious game. **A** shows the number of steps required (in numbers), with proportions of correct and incorrect steps shown.

**B** shows an inversed survival analysis of the time required to solve a problem (in seconds). The moment of problem solving was chosen as the event



**Fig. 3** Random effects model of the effect of the serious game on participants' performance in time, per study group

showing knowledge deficits on the principles of MIS, while most participants had partaken basic laparoscopy courses [11]. Possibilities for continuous training throughout the laparoscopic surgeon's careers on managing equipment problems should be explored.

Limitations of this study included the following. The serious game does not provide a one-on-one representation of the laparoscopic operation room. More experienced participants are presumably more familiar to the real MIS setting and may thus have a greater disadvantage. However, this does not explain that the laparoscopic equipment experts outperformed them. As long as the *functional* fidelity of a simulation is adequate (i.e., all the cues in the

simulation that represents the decision-making process are represented adequately in the simulation), skills transfer is similar to simulations with high *physical* fidelity (i.e., physical appearance of the construct is highly realistic) [16]. The results show adequate construct validity.

A second problem is that the results do not indicate a learning curve in novice, intermediate, and (surgical) expert groups, whereas laparoscopic equipment specialists do show a learning curve. This could be explained as a shortcoming of the serious game, as trainees do not seem to learn from the game within the first three sessions. However, it is quite plausible that learners need to “warm up” and familiarize with the game-based environment (all groups start with an equally low problem-solving rate in the first session). The laparoscopic equipment experts seem to require the least time to “warm up.” Future research should, therefore, determine complete learning curves.

A limitation to the study results is the limited size of the laparoscopic equipment specialists group (6 compared to 18, 15, and 12 in the other groups). For a more robust test, more technicians would be required. Still, the differences in performance in our study are of a magnitude ensuring statistical significance.

## Recommendations

The results indicate that surgeons are currently under-equipped with strategies to handle MIS equipment failure appropriately. This is alarming and requires further exploration, as MIS equipment failure is common and often precipitates surgical errors [2, 3]. Two solutions to this problem are plausible. The presence of personnel with

similar training to MIS equipment technicians in the OR could assist in equipment malfunctions, comparable to on-board technicians in aviation. However, equipment malfunctions are not limited to office hours, and availability of specialized personnel is usually scarce during evening and night hours.

A second solution is to improve learning outcome of laparoscopic training courses by making them recurrent over time and incorporating hands-on training in handling non-routine events. Such training would not only improve individuals' problem-solving capabilities. Surgeons may not spontaneously choose to train with medical technology, but could also lead to earlier problem recognition and thus reduce delays. Serious games combine fun and entertaining videogame characteristics with skills training and provide the possibility to test and assess trainees, monitor progress, and award certifications [13]. A system of skills upkeep and accreditation could aid long-term skills preservation.

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**Ethical approval** This study did not require approval of the local research ethics committee.

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