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Advanced laparoscopic skills: Understanding the relationship between simulation-based practice and clinical performance

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ABSTRACT

Introduction: The advanced laparoscopic skills (ALS) curriculum was created to address the need for improved laparoscopic training for senior surgical trainees. It focuses on the domain of laparoscopic suturing and consists of 6 tasks with established proficiency benchmarks. Tasks are performed using a standard laparoscopic box trainer. This study examines whether practicing on the ALS curriculum could translate to improved clinical suturing.

Methods: Surgery residents from four institutions participated in the study. Performance of the 6 ALS tasks and performance of a porcine gastrojejunostomy (GJ) and Nissen fundoplication were assessed before and after training. Video-recorded performance was de-identified and scored by three experts using both time and a previously published assessment instrument. Paired t-tests examined performance differences before and after the curriculum. Pearson correlations examined the relationship between performance on the porcine and ALS tasks.

Results: Twelve residents (PGY1-8) from 4 institutions completed the study. Average practice time on ALS tasks was 6.25 weeks (range 1–14 weeks) and 254 min (range 140–600min). Combined ALS task time decreased from 2748s ± 603s to 1756s ± 281s ($p < 0.001$). Each of the 6 task times significantly improved ($p < 0.05$). Total errors decreased from 5.8 ± 3.2 to 3.7 ± 1.9 ($p < 0.05$). Average GJ times decreased from 1043s ± 698s to 643s ± 183s ($p = 0.055$). Average Nissen times decreased from 990s ± 531s to 685s ± 265s ($p < 0.05$).

Conclusion: Dedicated practice on the six ALS tasks led to decreased suturing time and fewer errors when completing both GJ and Nissen suturing in a porcine model. Further studies will be undertaken to determine the optimal application of the ALS task set in advanced laparoscopic training.

Introduction

As surgical training continues to evolve towards competency-based education, it is critical that new skills curricula are developed with similar objectives. Currently, there are fundamental level skill assessments of laparoscopic, endoscopic and robotic skills (FLS, FES, FRS) that are widely used. However, increasing evidence suggests that the basic laparoscopic skills currently required of general surgery trainees falls short of ensuring the safe and independent performance of many minimally invasive procedures. The evidence for this need is well documented, based largely on survey data from all relevant stakeholders, including residents, fellows and program directors.[1–4] Therefore, a need exists to improve the skills

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and readiness of graduating chief residents with respect to advanced laparoscopic surgery.

The Advanced Laparoscopic Skills (ALS) curriculum has been developed to help meet this educational demand.[5] Based on a previously published needs assessment,[6] the greatest curriculum deficit in advanced laparoscopy relates to advanced laparoscopic suturing skills. Thus, this area is the focus of the ALS curriculum and is addressed in a set of 6 previously described tasks: needle positioning, offset forehand suturing, offset backhand suturing, suturing under tension, suturing in a confined space and continuous suturing. Prior work has demonstrated evidence of content validity,[7–10] by querying multiple experts, from both the United States and Canada for input on the curriculum. Evidence of internal structure validity has been demonstrated[5] with high (0.99) inter-rater reliability in assessment of ALS tasks and by eliminating tasks that did not differentiate between performance of different levels of skill.[10] Additional validity evidence for ALS demonstrates how performance on ALS relates to other variables. For example, it has already been demonstrated that performance on this curriculum discriminates between surgeons with expert, intermediate, and beginner levels of laparoscopic surgical skills.[8] However, we have yet to show if performance on the ALS tasks relates to relevant clinical performance. In this study, we employ a porcine tissue models for this purpose because of the multiple confounding variables involved in measuring outcomes in the clinical setting. Thus, the goal of this study was to assess if proficiency based practice in a box trainer on ALS tasks translates to improved performance on a porcine Nissen fundoplication and gastrojejunostomy model.

Methods

Participant recruitment and site selection

Surgery residents were recruited from 4 participating institutions. Inclusion criteria included successful completion of the Fundamentals of Laparoscopic Surgery exam. No other inclusion or exclusion criteria were used. All sites had previously participated in ALS-related studies, having thus completed the associated rater training for standardization of task set up, video-based instruction and task assessment.

Study Protocol

As shown in Fig. 1, all residents were assessed at baseline on the ALS suturing tasks. Baseline performance of both a laparoscopic Nissen and laparoscopic gastro-jejunostomy on a porcine tissue model was also assessed. In order to standardize performance and assessment conditions, a porcine tissue model used in prior suturing assessments[11] was used (Figs. 2 and 3). All sites used the same porcine-tissue model, the preparation of which was clearly protocolized. For the Nissen suturing task, the porcine stomach was placed in a box trainer. The site of the intended sutures needed to create the Nissen wrap were marked with indelible ink on the stomach and esophagus, directing the trainee to complete 3 intracorporeal stitches. For the gastro-jejunostomy, a loop of bowel was brought to the stomach and anastomosed by the proctor with a linear stapler firing. The trainee was then required to close the resultant enterotomy with a single running suture.

In advance of the pre-test, all participants were provided instructional procedural videos for each task. On the day of the pre-test, participants were provided instructions for each task, according to a standardized script, and given as much time as needed to complete each task. Performance on each task was timed and video-recorded.

Participants were then asked to practice independently on the ALS tasks to pre-defined proficiency benchmarks, and to record both the amount of time spent practicing and the total number of repetitions. A final assessment of both the ALS tasks and the two porcine-based suturing tasks was completed when participants achieved proficiency benchmarks or were no longer available for practice (ie change in rotation). Participant performance on both the Nissen and gastro-jejunostomy suturing tasks were again timed and video-recorded for subsequent scoring.

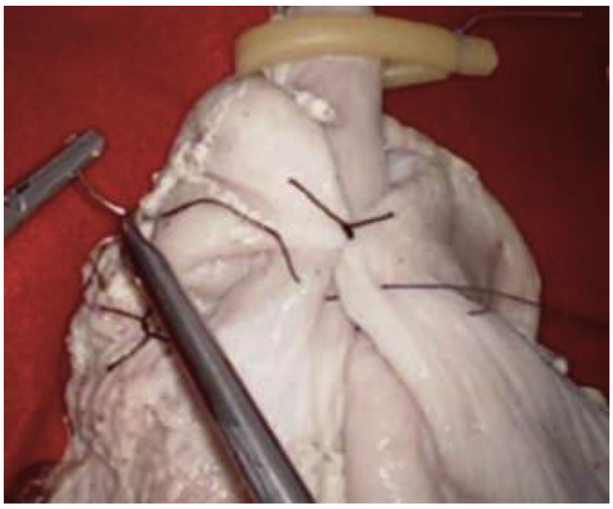

Fig. 2. Porcine-tissue model of laparoscopic Nissen fundoplication.

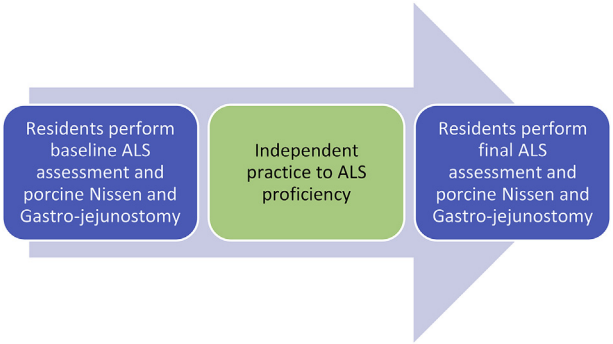

Fig. 1. Study protocol.

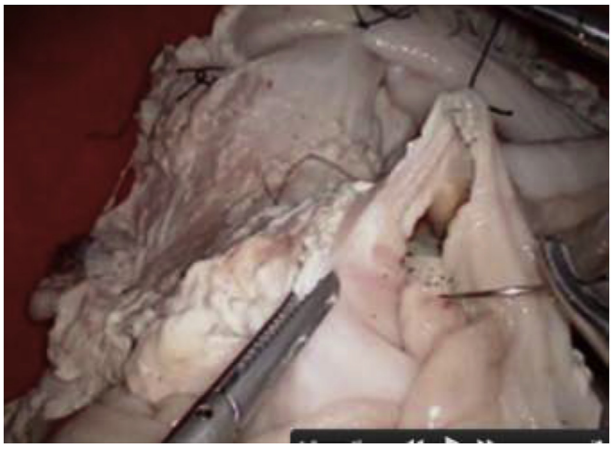

Fig. 3. Porcine-tissue model of laparoscopic gastro-jejunostomy.

ALS task performance was video recorded, de-identified and scored using previously published metrics of time and error.[5] Videos of all porcine tissue suturing were also de-identified. Performance was assessed by 3 expert raters using a slightly modified existing assessment instrument for laparoscopic suturing [12] (Fig. 4). Reviewers first calibrated the instrument using a small subset of de-identified videos, leading to the identification of three out of 29 elements that did not apply to the porcine-tissue based suturing tasks. These three steps were consequently not scored for the purposes of this study, leading to a total maximum score of 26 rather than 29 for each porcine tissue suturing task (Fig. 5).

Data were analyzed with paired t-tests comparing pre- and post-intervention scores. Pearson correlations examined the relationships between performance on the two porcine suturing tasks and the ALS tasks.

Results

Twelve residents from 4 institutions ranging from PGY1-8 completed the study. Programs ranged in size from 3 to 12 categorical residents per year. Most were general surgery residents, with one OB/GYN and 2 CT surgery residents participating.

For each of the 6 tasks, individual task times significantly improved (Table 1). Combined ALS task time decreased from 2748s ± 603 s at baseline, to 1756s ± 281s ($p < 0.001$) following ALS practice. Total errors decreased from 5.8 ± 3.2 to 3.7 ± 1.9 ($p < 0.05$). Within individual ALS tasks, number of errors decreased significantly for the continuous suturing task (2.5 ± 2.0 errors pre vs. 1.0 ± 1.3 errors post, $p < 0.05$). Average gastro-jejunostomy suturing times decreased between baseline and final assessments (1043s ± 698s pre vs. 643s ± 183s post, $p = 0.055$) while the scores on the assessment instrument did not change significantly (15.4 ± 4.1 pre vs. 16.7 ± 2.3 post, $p = 0.190$). Average Nissen suturing times decreased from 990s ± 531s–685s ± 265s ($p = 0.016$) while scores did not change significantly (17.8 ± 3.4 pre vs. 18.7 ± 3.8 post, = 0.372) (Table 2).

Average practice time on ALS tasks was 254 min (140–600min) spread over 6.25 weeks (1–14 weeks).

			Yes=1, No=0
Needle position-1	1	Held at ½ to 2/3 from the tip	
	2	Angle = 90° ± 20°	
	3	Uses tissue or other instruments for stability	
	4	Attempt at positioning (3 or <3)	
Needle driving through tissue-1 (entry to incision)	5	Entry at 60°-90° to the tissue plane	
	6	Driving with one movement	
	7	Single point of entry through tissue	
	8	Removing the needle along its curve	
Needle position-2 (incision to exit)	9	Held at 1/2 to 2/3 from the tip	
	10	Angle- 90° ± 20°	
	11	Uses tissue or other instrument for stability	
	12	Attempts (3 or <3)	
Needle driving-2 (incision to exit)	13	Driving with one movement	
	14	Removing the needle along its curve	
Pulling the suture through	15	Needle on needle holder in view at all times	
	16	Using pulley concept or walking along the suture	
Technique of knots	17	Two-handed overwrap/underwrap followed by same or if one-handed, one followed by the other	
	18	Correct C loop (no S or O loops)	
	19	Smoothly executed throw, no fumbles	
	20	Correct inverse C loop (no S or O loop)	
	21	Smoothly executed throw, no fumbles	
	22	Knot squared (capsized reef/surgical)	
	23	Correct third C loop (no S or O loops)	
	24	Smoothly executed throw, no fumbles	
Knot slippage	25	Knot left loose to slip	
	26	Knot slippage attempts 3 or <3	
Knot quality	27	All throws squared	
	28	Not too tight or too loose	
	29	All knots laid on the side (not over the incision)	
		Total Score (maximum 29)	

Fig. 4. Suturing assessment instrument (Moorthey et al.).

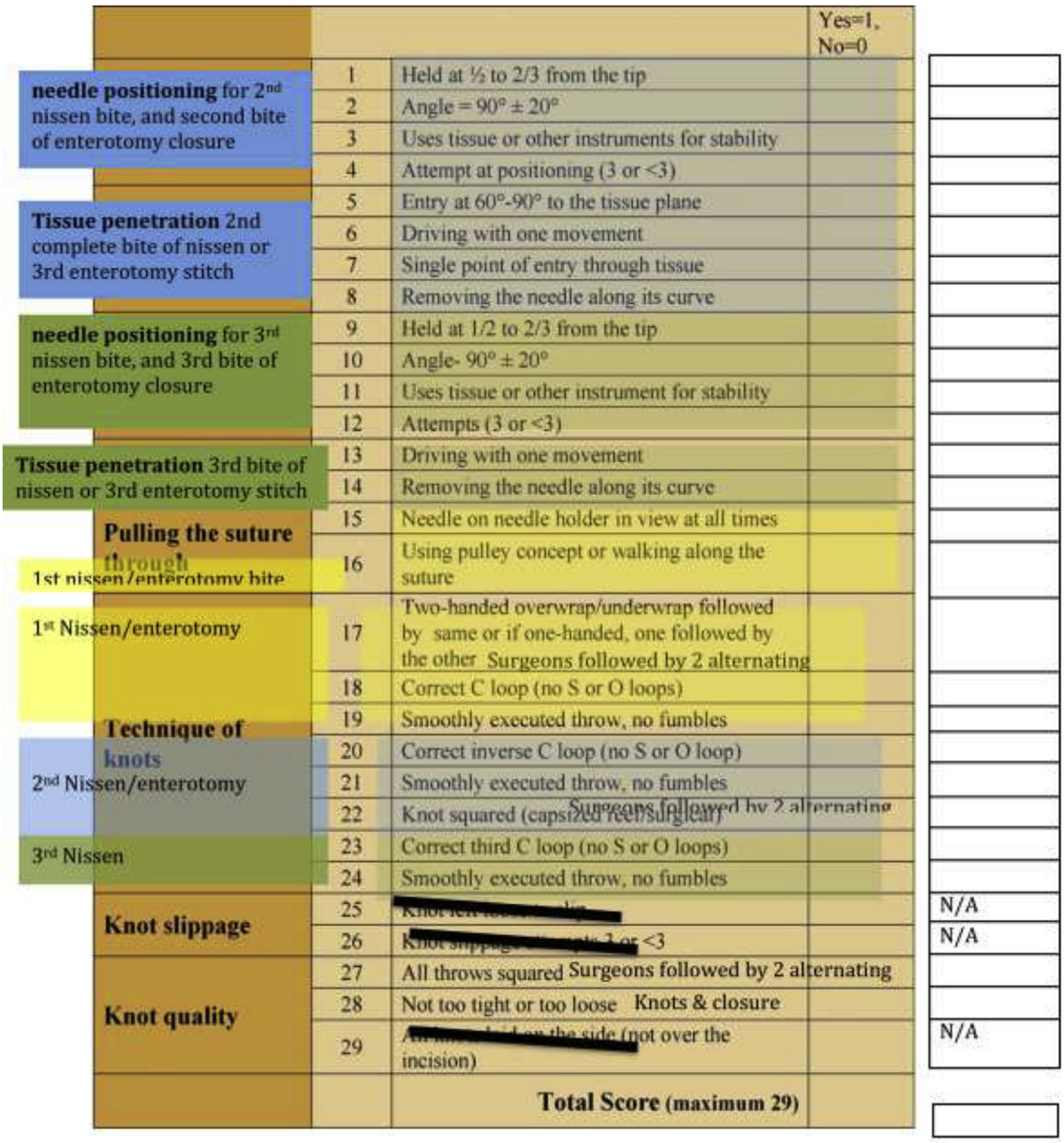

Fig. 5. Modified laparoscopic suturing assessment (Moorthey et al.).

Correlations

Better times on final gastro-jejunostomy (GJ) but not Nissen performance times were associated with better initial ALS performance (GJ: $r = 0.61, p < 0.05$; Nissen: $r = 0.41$, $p = 0.181$). Fewer initial ALS errors was associated with better GJ and Nissen performance. (GJ: $r = 0.619$, $p < 0.05$, Nissen: $r = 0.62$, $p < 0.05$).

Table 1
Individual ALS task times at baseline and following completion of ALS practice to proficiency (Final).

Task Description:	Baseline (sec)	Final (sec)	Change	SD	P value
Needle Handling	260	125	−135	62	<0.001
Offset Forehand	389	206	−183	147	0.001
Offset Backhand	386	201	−184	179	0.004
Continuous	635	514	−121	125	0.007
Tension	705	492	−213	216	0.006
Confined	372	216	−156	147	0.004

Proficiency

Needle handling proficiency was achieved by 11/12 trainees, while only 1/12 achieved proficiency on confined space suturing (Table 3). Only 1/12 participants achieved proficiency on all 6 tasks.

Practice time

As the majority of trainees did not reach proficiency on all ALS tasks during the course of this study (average of 6 weeks of practice), an estimate of the time needed to achieve proficiency was calculated. A product limit survival curve was used to determine "time to proficiency". As an example, for the back-hand suturing task, an estimated 12 weeks of practice (or 8 h) would be needed for 75% of our sample to achieve proficiency (Fig. 6).

Table 2
Suturing performance data for resident participants (N = 12). ALS task performance presented as both total time for completion of all 6 ALS tasks (Total ALS time) and number of tasks successfully passed. Porcine-tissue model suturing task (Gastro-jejunostomy and Nissen suturing) performance presented as both time to task completion and total score. All comparisons are between an individual's baseline performance, and their performance after practicing to proficiency on the ALS tasks. (GJ: Gastro-jejunostomy, ALS: Advanced Laparoscopic Suturing).

	Baseline (mean)	Final (mean)	Change	Standard Deviation	P value
Total ALS time (sec)	2748	1756	−991	511	<0.001
ALS tasks passed (out of 6)	0.3	2.2	1.8	1.7	0.003
GJ time (sec)	1043	643	−402	613	0.055
GJ score (max 26)	15.4	16.7	1.3	3.2	0.190
Nissen time (sec)	990	685	−305	372	0.016
Nissen score (max 26)	17.8	18.7	0.9	3.3	0.372

Discussion

In proficiency based education it is important to employ valid assessments along the continuum of training. While there has been a proliferation of fundamental level curricula for technical skills in surgery, there is a paucity of curricula developed for advanced level trainees. Our group has been engaged in a multi-institutional effort to build validity evidence for an advanced level curriculum for laparoscopic suturing using the modern validity framework.[13,14] The current study demonstrates how training on the ALS curriculum could relate to crucial downstream outcomes, specifically, to improved performance in the clinical setting. We chose the Nissen fundoplication and closure of a gastro-jejunostomy anastomosis as the clinical procedures to assess using the porcine tissue model. They were chosen because they are commonly performed, require advanced suturing for completion, and align well with skills emphasized by the ALS curriculum.

In this study, we determined that training on the ALS curriculum is feasible, and that skills improve significantly with dedicated ALS skills practice. It is notable, however, that only 1 out of 12 trainees achieved proficiency on all 6 suturing tasks. This may be due to the difficulty of the tasks, which were intentionally designed to challenge trainees with respect to instrument angles, tissue tension or camera perspective. Tasks also varied in difficulty level. Needle handling was the easiest tasks where the majority achieved proficiency, 4/6 tasks were moderately difficult where 30% achieved proficiency, while confined space suturing was the hardest, where only 1 person achieved proficiency.

Our analysis indicates that significantly more than 4 h of training would be required to raise the performance of the majority of trainees to previously benchmarked levels of proficiency. In all likelihood, this training should also involve active mentor feedback, which was not included in the methodology of this study. With improved practice conditions and additional time, we would expect more consistent achievement of proficiency, a hypothesis that should be evaluated in future studies.

Despite the inability of trainees to reach ALS proficiency benchmarks, we showed that practice for 4 h on the ALS curriculum decreased participant suturing times on a porcine tissue model. The increased efficiency reflected in the decreased task completion times is notable. A 30–40% time saving on the often time-consuming task of laparoscopic suturing is a clinically meaningful improvement. However, the lack of improvement on the scores generated by the laparoscopic suturing assessment instrument was also observed. This finding could be related to either actual lack of improvement on non-time related aspects of suturing (i.e. lost points for not removing the needle along the curve, or failing to use a pulley concept when pulling the suture through tissue) or the use of an inappropriate assessment instrument for this particular domain.

Regardless of the cause of the lack of improved suturing scores, we feel that a need exists for an assessment instrument designed specifically for clinical laparoscopic suturing. Although many technical skill assessment instruments have been described, very few focus on laparoscopic suturing specifically.[15–20] Having reviewed previously published instruments that involve laparoscopic suturing, we chose to use a 29 point check-list based instrument developed for urologic surgery suturing assessment by Moorthy et al. As noted in the methods section, however, we encountered several problems when attempted to apply this checklist to the porcine-tissue based suturing tasks, requiring subsequent modifications of the instrument prior to use in this study (Fig. 4). For example, ALS suturing does not mandate the use of a slip knot, or the importance of having all knots on one side of the incision, as the checklist requests. Another check list by Van Sickle et al. described an error based assessment tool for assessing laparoscopic suturing, but lacks published details explaining how the tool was developed. As we build validity evidence for a curriculum for advanced laparoscopic suturing, we may need to develop a better tool to assess clinical suturing expertise outside of a simulated lab setting.

Study limitations include the lack of a large sample size and the lack of patient specific outcomes, limitations commonly found in

Table 3
Tasks proficiency on ALS before and after practice.

ALS TASK	Achieved Proficiency Baseline	Achieved Proficiency Final
Needle Handling	0	11
Offset Forehand	1	4
Offset Backhand	2	3
Continuous	1	4
Tension	0	3
Confined	0	1

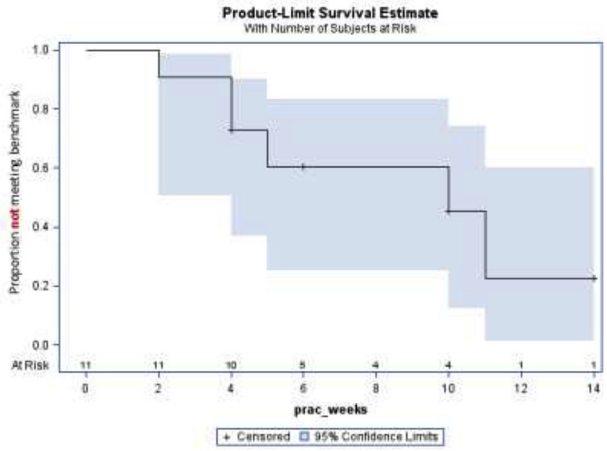

Fig. 6. Estimate of practice time to achieve proficiency for back hand suturing task.

educational research. The use of a multi-institutional approach to the study design allowed us to expand our study population and will likely be employed in subsequent ALS related research as a viable means of improving sample size. While this study did not evaluate patient specific outcomes, such as anastomotic leak or stricture rate, we do consider the use of a porcine-tissue based model to be a step closer to this recognized gold-standard, particularly in comparison to the alternative of pure simulation-based performance outcomes. In addition, it is extremely difficult to standardize the clinical experience and the amount of autonomy trainees receive in the clinical setting.

Conclusion

In this study, we build validity evidence for the use of the ALS curriculum to teach and assess advanced laparoscopic suturing skills. We show how practicing on the six ALS tasks resulted in improved performance on a porcine Gastro-jejunostomy and Nissen fundoplication suturing. The intentional difficulty of the ALS curriculum mandates significant practice, and will likely require most trainees to practice beyond the 4 h of practice time evaluated in this study. Further studies will be undertaken to determine how to optimize trainee skill acquisition and evaluate curriculum application in surgical training.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2019.01.024.

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