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Low-cost materials yield high resolution assessment of anatomic knowledge in surgical residents

Humza Y. Saleem, MD, Yazan AlJamal, MBBS, Nicholas Prabhakar, BS, Mohamed Baloul, MBBS, Parvathi Balachandran, MBBS, David Farley, MD*

Mayo Clinic, Department of Surgery, Rochester, MN

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ABSTRACT

Introduction: Knowledge of anatomy is essential for surgeons. We sought to determine whether it is possible to effectively assess and differentiate the anatomic knowledge of general surgery residents, using pieces of fabric and yarn.

Methods: Postgraduate years 2, 3, and 4 general surgery residents were assessed during a simulation-based assessment known as the Surgical X-Games. Residents were allowed 3 minutes to assemble the anatomic structures of the right upper quadrant region and 2 minutes to create the right lower quadrant of the abdomen, using colored felt and yarn. One point (each) was given for naming and placing the structures in the correct position. A checklist was used to assess trainees with a maximum combined score of 150 points.

Results: A total of 34 residents (postgraduate year 2 = 16, postgraduate year 3 = 8, postgraduate year 4 = 10) participated in the 2017 fall Surgical X-Games and 31 residents (postgraduate year 2 = 13, postgraduate year 3 = 9, postgraduate year 4 = 9) participated in the spring Surgical X-Games. Total scores increased respective to the level of clinical training in both the fall Surgical X-Games (postgraduate year 2 = 77, postgraduate year 3 = 84, postgraduate year 4 = 93, $P = .04$) and the spring Surgical X-Games (postgraduate year 2 = 94, postgraduate year 3 = 101, postgraduate year 4 = 109). We observed significant improvement in the right upper quadrant, right lower quadrant, and total scores from the fall to the spring postgraduate year ($P < .001$).

Conclusion: Surgical residents showed an increase in mean anatomical scores from postgraduate years 2 to postgraduate years 3 to postgraduate years 4, using low-fidelity models. This inexpensive, 5-minute test based on a simple checklist may offer surgical educators insight in to residents' anatomic knowledge and potential readiness for clinical rotations.

Introduction

Anatomic knowledge is an essential component for training and performing surgery.[1,2] Anatomy is usually taught in the first year of medical school. Surgical interns often enter residency with knowledge of human anatomy that is subpar, rusty, and inadequate for surgical residency. As surgical residents progress through their training, their knowledge of anatomy should increase with clinical exposure.[2] However, beyond the occasional staff query or American Board of Surgery In-training Examination (ABSITE) question, anatomy is rarely tested objectively.

Assessment of anatomic knowledge may be limited because of a lack of an efficient and easily accessible method that can be incorporated into the busy schedules of residents. Traditionally, anatomic knowledge has been tested through paper exams or cadaveric oral examination. Cadaver oral examination is an excellent testing technique because the learning is applied in an actual human body.[3] However, running a cadaver lab is expensive and such testing is limited to being held in a certified cadaver lab.[4] Simulation methods, such as virtual reality (VR), simulated based screens, or three-dimensional (3D) printed models have provided newer, novel techniques.[5,6] Such advanced simulation methods are also expensive, which may be why they are not used ubiquitously.[7] A quick, cheap, and reliable method would be more ideal.

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* Reprint requests: David R. Farley, MD, Mayo Clinic, 200 1st Street SW, Rochester, MN, 55905.

E-mail address: Farley.david@mayo.edu (D. Farley).

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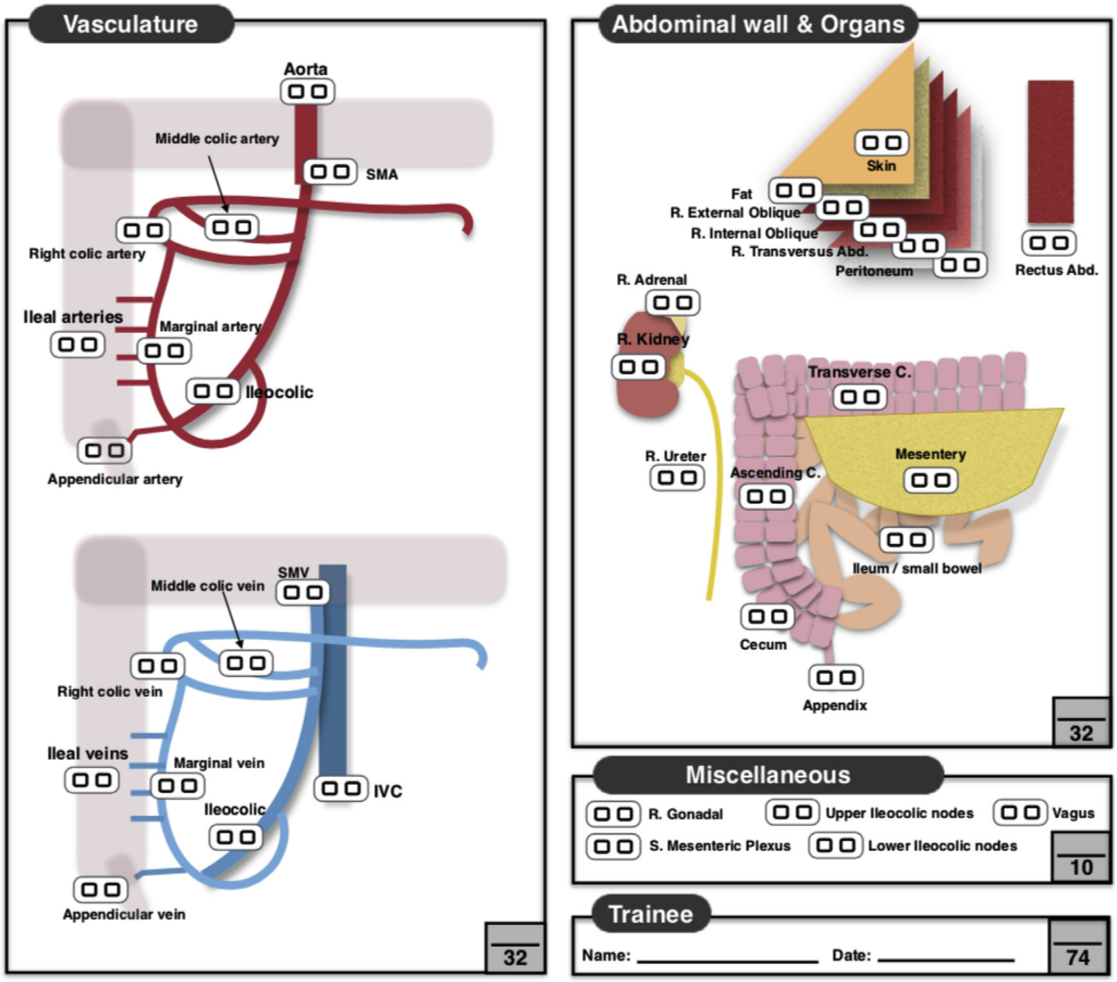

Figure. RLQ score sheet.

We sought to create a simulation-based testing method for evaluating surgical residents' anatomic knowledge. The method needed to be inexpensive, reproducible, and rapid so that it could be used in a 9-minute objective structured clinical examination (OSCE) station.

Methods

Post graduate year (PGY) 2, PGY 3, and PGY 4 categorical general surgery (GS) residents at Mayo Clinic, Rochester, MN, are required to participate in a simulation-based OSCE, known as the Surgical X-Games (SXGs). The SXGs were started in 2012 and take place biannually within our simulation center. Identical OSCE stations are held in the fall and spring. Residents rotate through a minimum of 6 different knowledge and skill-based assessments, each lasting 9 minutes.

The "Anatomy Station" was designed to identify the breadth and depth of resident anatomic knowledge and its variance from year to year. Five distinctive models of different anatomic areas have been created, but only the right upper quadrant (RUQ) and right lower quadrant (RLQ) models were selected as locations for our assessment. Various colored pieces of felt were cut in to 2D-shaped organs. Red, blue, and yellow yarn was used to simulate arteries, veins, and nerves, respectively. Residents were asked to assemble the anatomic region, using the felt and yarn structures, being careful to name and place structures correctly in relation to other structures. Residents were given 3 minutes to complete the RUQ region and 2 minutes to complete the RLQ region, consecutively. Residents repeated the same stations in the spring of 2018.

Two independent score sheets were constructed. Score sheets for the regions were divided into organs, vessels, nodes, and nerves. Each structure allows the examinee to garner 2 points—1 point for the correct name and another point for the correct placement in relation to its surrounding structure. A total of 76 points (38 structures) and 74 points (37 structures) were allocated to the RUQ and RLQ regions, respectively. An example of the RLQ score sheet is provided (Figure).

Table I
Fall X-Games results

Categorical year	PGY 2 (n = 16)	PGY 3 (n = 8)	PGY 4 (n = 10)	P values
RUQ score max = 76				
Mean (± SD)	46.25 (± 11.8)	51.75 (± 10.2)	57.50 (± 7.2)	**.02**
Range	**26–66**	**34–66**	**44–68**	
RLQ score max = 74				
Mean (± SD)	31.13 (± 8.6)	32.00 (± 9.1)	34.50 (± 5.7)	.59
Range	**12–40**	**22–48**	**22–42**	
Total score max = 150				
Mean (± SD)	77.38 (± 16.6)	83.75 (± 14.9)	92.9 (± 8.7)	**.04**
Range	**52–106**	**60–114**	**78–08**	

Table II
Spring X-Games results

Categorical year	PGY 2 ($n = 13$)	PGY 3 ($n = 9$)	PGY 4 ($n = 9$)	P values
RUQ score max = 76				
Mean (± SD)	55.61 (± 9.1)	59.88 (± 7.8)	62 (± 3)	.13
Range	**42–76**	**51–74**	**58–66**	
RLQ score max = 74				
Mean (± SD)	38.30 (± 13.1)	41.56 (± 11.7)	47.33 (± 8.5)	.21
Range	**24–62**	**16–58**	**38–58**	
Total score max = 150				
Mean (± SD)	93.92 (± 20.6)	101.44 (± 18)	109.33 (± 9.8)	**.03**
Range	**72–138**	**67–132**	**94–123**	

A passing (satisfactory) score for this station was 50 points for the RUQ and RLQ regions. Residents not achieving this score during the spring SXGs were required to undergo remediation to pass their academic PGY and advance to the next PGY level.

The station was graded by a medical graduate using a checklist, and residents actively performed the task. Overhead video recording was used to verify scores. Results were analyzed using JMP 13 software (SAS Institute, Cary, NC). Statistical analysis was performed using the Student's t test, with a significance level set at 0.05.

Results

A total of 34 residents (PGY 2 = 16, PGY 3 = 8, PGY 4 = 10) participated in the 2017 fall SXGs (Table I). RUQ anatomy scores increased respective to the clinical year ($P = .02$), and RLQ scores did not ($P =$ NS). Total scores (RUQ + RLQ region scores) for the station increased respective to the advancing PGY classes ($P = .04$).

A total of 31 residents participated in the spring SXGs (PGY 2 = 13, PGY 3 = 9 PGY 4 = 9 [Table II]). A total of 30 residents participated in both fall and spring SXGs (PGY2 = 13, PGY3 = 8, PGY4 = 9). Both the RUQ and RLQ scores showed no intervariability ($P =$ NS); however, total scores increased respective to the advancing clinical year ($P = .03$). Residents often made similar mistakes with certain anatomic structures (Table III). Table IV presents an outlines of the top 5 structures, which all residents had correct in the spring SXGs. Resident scores between the 2017 fall and 2018 spring SXGs showed a significant improvement for RUQ ($P < .01$), RLQ ($P < .01$), and total score ($P < .01$).

A total of 11 residents (PGY 1 = 6, PGY 2 = 3, PGY 4 = 2) failed the RLQ region, and only 1 PGY 1 failed the RUQ region in the spring SXGs. All residents remediated their respective regions and went on to pass the station with a score of 50+ in their first attempt.

Table IV
Structures all residents had correct in spring X-Games

	RUQ structures	RLQ structures
PGY2	Portal vein	Superior mesenteric artery
	Superior mesenteric vein	Appendicular artery
	Right hepatic artery	Appendix
	Right hepatic duct	
	Left hepatic artery	
PGY 3	Gastroduodenal artery	Skin
	Inferior vena cava	Right external oblique muscle
	Portal vein	Right internal oblique muscle
	Right and left hepatic artery	Right kidney
	Right and left hepatic vein	Ileum
PGY 4	Celiac trunk	Right colic artery
	Common hepatic artery	Ileocolic artery
	Inferior vena cava	Appendicular artery
	Right and left hepatic duct	Skin
	Transverse colon	Fat

Discussion

This simplistic, prospective study of PGY 2, PGY 3, and PGY 4 surgical residents utilizes an inexpensive, hands-on anatomy assessment that offers the following important concepts:

- A detailed oral and spatial anatomy examination can be consistently delivered in 2 to 3 minutes,
- A low-cost assessment tool that can differentiate learners by anatomic knowledge,
- More clinically experienced surgical trainees (PGY 4s) scored higher than less clinically experienced surgical trainees (PGY 2s) on this simple anatomy test, and
- This quick, inexpensive anatomy assessment may offer educators and learners a useful tool for identifying strengths and weaknesses before embarking on real surgical rotations.

An oral approach to testing anatomy allows for a faster-paced assessment compared with written exams. Clough et al[5] demonstrated that an oral approach to anatomic evaluation in medical students was far more time effective, accurate, and superior to more traditional methods. We believed that an oral approach was paramount to the station's success, because it allowed for a faster paced assessment that would be difficult with more traditional written exams. Although the model is 2D, having trainees place the

Table III
Most common mistakes in both X-Games

	RUQ structures		RLQ structures	
	Fall	Spring	Fall	Spring
PGY2 (number of residents)	Celiac plexus (16)	Choledochal nodes (12)	Right gonadal artery (16)	Superior mesenteric plexus (13)
	Cystic node (16)	Caudate lobe (11)	Lower ileocolic nodes (16)	Vagus nerve (13)
	Choledochal nodes (13)	Vagus nerve (11)	Vagus nerve (14)	Right gonadal artery (13)
	Caudate lobe (13)	Celiac plexus (11)	Upper ileocolic nodes (14)	Marginal vein (11)
	Pancreatic duct (2)	Right gastric artery (10)	Middle colic artery (11)	Ileal vein (11)
PGY 3 (number of residents)	Vagus nerve (8)	Ascending colon (7)	Upper ileocolic nodes (8)	Marginal vein (8)
	Celiac plexus (8)	Celiac plexus (7)	Vagus nerve (8)	Ileal vein (7)
	Left hepatic duct (7)	Ampulla of vater (6)	Lower ileocolic nodes (8)	Marginal artery (7)
	Right gastric artery (7)	Caudate lobe (6)	Superior mesenteric plexus (8)	Right gonadal artery (7)
	Ampulla of vater (7)	Cystic nodes (5)	Ileal arteries (7)	Lower ileocolic Nodes (7)
PGY 4 (number of residents)	Caudate lobe (9)	Vagus nerve (9)	Upper ileocolic nodes (10)	Marginal vein (9)
	Vagus nerve (9)	Caudate lobe (7)	Lower ileocolic nodes (10)	Right gonadal artery (9)
	Pancreatic duct (8)	Pancreatic duct (6)	Ileal artery (10)	Vagus nerve (9)
	Ampulla of vater (6)	Choledochal nodes (6)	Marginal vein (9)	Ileal vein (8)
		Celiac plexus (6)	Superior mesenteric plexus (8)	Ileal artery (8)

structures accurately (ie, right renal artery must be placed posterior to the IVC) offers some sense of whether learners truly understand the anatomy in a 3D world. Residents were only given a second point if they placed the structure in the correct anatomic position in respect to surrounding structures.

The anatomy station required less than $10 worth of fabric and yarn to construct and just 5 minutes to implement per resident. Alternative methods of assessment, such as a cadaver- based oral exam, would have been a financial burden. Cadavers themselves can cost up to $3,000 each. Adding in the cost to screen donors, paying for transportation, accounting for cremation prices (up to $3,200), and the cost to preserve cadavers and staff the lab, it can become incredibly expensive to run a cadaver lab.[6] Fitzpatrick et al[8] demonstrated some efficacy with cadavers and anatomical teaching. Virtual reality has also been described as costly because of the complex, scarce computer hardware and software that it necessitates.[7] The 3-D printers have been utilized in a simulation-based curriculum setting to improve anatomic knowledge in residents.[9] Powder 3-D printers can range from $70,000 to $100,000, with additional costs for materials and maintaining the printer. The models that are typically printed usually range in the thousands of dollars, but have been steadily decreasing with time. The 3-D printing could become a more affordable solution in the near future.[10] Ultimately, this study used an anatomy model that is inexpensive, but effective, and offered useful data to educators and trainees alike.

Using color-coded felt and yarn to simulate organs, vasculature, and nerves has been shown to aid in both learning and differentiation of structures.[10] In our station it was important to use different colors to allow residents a sense of familiarity in which they could examine the unused materials and resolve the missing structures not yet placed within the anatomic area. Low-fidelity models have been shown to be as effective as high-fidelity equivalents.[11,12] In this time-pressured assessment, the low cost and durable pieces of material held up well and offered differential scoring of our trainees. We have used the same felt and yarn pieces for the past 6 years.

Anatomy scores of our GS residents increased with clinical experience. As residents progress through their training, they are increasingly exposed to operative anatomy, didactic sessions, and informal staff questioning, which comprehensively contribute to improved anatomic knowledge.[3] An increase in scores from the fall SXGs to the spring SXGs can also be attributed to familiarity with the station itself.[13] Given that the pieces of fabric and yarn can be easily placed into a plastic bag, we are further encouraged that trainees now “check-out” this reusable resource and practice moving such pieces quickly in preparation for their SXGs assessment. We believe that such at-home repetitions offer sequential learning opportunities and greater retention of knowledge.

The anatomy station effectively establishes a foundation for simulation-based anatomic assessments, but its true clinical relevance may be in finding candidates in need of remediation. Residents scoring below a certain score can be identified for potential coaching and additional instruction. Through remediation, residents can resolve critical deficits.[14] We offer Friday afternoon sessions after the SXGs to work through surgical anatomy and practice the skill of rapidly placing anatomic pieces. The station can also be used as a preoperative test that determines whether a resident or medical student has enough baseline anatomic knowledge to participate in an operation. It could become a criterion for trainees to “scrub in.” Trainees with poor anatomic knowledge often find operating procedures less educational and garner less hands-on operative experience.[15]

This study has the following numerous limitations: one institution, one 9-minute OSCE station, small numbers of examinees, just two anatomic regions tested, and a high stakes/pressure examination. We were restricted by the number of residents in our GS program. This ultimately led to an underpowered study. In addition, we only used two anatomic locations for assessment. Therefore, not providing a holistic assessment of anatomic knowledge. However, cholecystectomy (RUQ) and appendectomies (RLQ) are common operations for GS residents. The Accreditation Council for Graduate Medical Education case log data from 2017 suggest that of the 1,007 cases performed by the average GS resident, at least 212 of those cases involve the RUQ (liver = 10, pancreas =10.5, biliary = 125.6) or RLQ (appendix = 65.4), suggesting that these regions play a vital anatomic role in a trainee’s education.[16] Colectomy, enterectomy, adrenalectomy, nephrectomy, and vascular procedures push that total toward 300 cases among RUQ and RLQ abdominal regions.

Another important limitation of this study is that we did not have a control group for effective comparison. As part of our training curriculum, all trainees are evaluated twice a year on SXGs in which the anatomy station is part of. However, it is part of our future plan to proceed with a multi-institutional study assessing the effects of our interventions on our trainees compared with others (control group). Residents had a wide range of intervariability of anatomic knowledge within their respective classes. Perhaps the use of a formal didactic teaching session or a basic anatomic curriculum could help narrow this range and decrease the number of outliers.

Time constraints for the station could have restricted the amount of knowledge residents were able to demonstrate and could be a reason why RLQ region scores are lower than the RUQ region. Several residents ran out of time and had to be stopped. In addition, decreasing time for the task can increase both stress and inaccuracies.[17]

Our future research efforts will involve usage of both low-fidelity and low-cost materials and comparing them with 3-D printed organs and vasculature. This may provide a better yield of anatomic assessments.[10] Alternative anatomic assessment models include high-definition imaging and video assessment of intraoperative footage and diagnostic imaging. These methods provide an opportunity of in vivo assessment, which may be more clinically relevant, and we have been actively engaged in such research efforts.[18] The anatomy station should be expanded both in the number of residents and the anatomic locations assessed; amendments will be made in the upcoming SXGs.

In conclusion, the overarching goal of any assessment tool is to accurately and efficiently measure the level of knowledge in a learner. Simulation is at the forefront of tackling this problem in the surgical world. Our anatomy station within the SXGs is a novel effort that can quickly, effectively, and reproducibly test GS residents on their level of anatomic knowledge in an OSCE-type setting. The model sets the foundation for anatomic testing but needs further adjustments. Combining low-fidelity assessments with high-definition imaging and video assessment may offer further insight into surgical trainees’ knowledge of anatomy and highlight those learners that may benefit from remediation before their hands-on operative experience.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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