Using an Individual Procedure Score (IPS) before and after the ASSET course training to benchmark a hemorrhage-control performance metric

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Objective: Test with an individual procedure score (IPS) whether an unpreserved cadaver trauma training course including upper and lower limb vascular exposure improves correct identification of surgical landmarks, underlying anatomy, and shortens time to vascular control.

Design: Prospective study of performance of three vascular exposure and control procedures (axillary, brachial and femoral arteries) using IPS metrics by two co-located trained evaluators before and after training with the Advanced Surgical Skills Exposure for Trauma (ASSET) course. IPS, including identification of anatomical landmarks, incisions, underlying structures, and time to completion of each procedure was compared before and after training using repeated measurement models.

Setting: Audio-video instrumented cadaver laboratory at University of Maryland School of Medicine

Participants: Forty-one 2nd – 6th year surgical residents from surgical programs throughout Mid-Atlantic States who had not previously taken the ASSET course were enrolled, 40 completed the pre-post –ASSET performance evaluations.

Results: After ASSET training, all components of IPS increased and time shortened for each of the three artery exposures. Procedure steps performed correctly increased 57%, anatomic knowledge increased 43% and skin incision to passage of a vessel loop twice around the correct vessel decreased by a mean of 2.5 minutes. An overall vascular trauma readiness index, a comprehensive IPS score for three procedures increased 28 % with ASSET Training,

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Conclusions: Improved knowledge of surface landmarks and underlying anatomy is associated with increased IPS, faster procedures, more accurate incision placement and successful vascular control. Structural recognition during specific procedural steps and anatomic knowledge were key points learned during the ASSET course. Such training may accelerate acquisition of specific trauma surgery skills to compensate for shortened training hours, infrequent exposure to major vascular injuries, or when just-in-time training is necessary. IPS is a benchmark for competence in extremity vascular control.

Key Words: clinical competence, psychomotor performance, hemorrhage control skill, educational measurement instrument, observational evaluation, open vascular surgical procedures, resident education

Competencies: Medical Knowledge, Practice Based Learning and Improvement, Systems-Based Practice, Patient Care

Introduction:

Bleeding is the leading cause of preventable early death in military and civilian casualties. The rate of vascular injury in modern combat is five times greater than reported in previous wars. Extremity vascular injuries represent between 50 and 70% of all injuries treated during Operation Iraqi Freedom [1,2]. Hemorrhage was identified as the predominant mechanism of death in 80% of battle casualties who died of potentially survivable wounds after hospital admission, including 31% from extremity wounds and 21% from junctional wounds [3]. Trauma surgeons must maintain proficiency in the surgical exposure and control of major blood vessels, a key factor in reducing preventable deaths[4-5]. However various factors have resulted in an overall decrease in vascular surgical trauma training including limits on surgical training hours, a reduction in penetrating trauma nationwide, less injury from motor vehicle crashes due to improved vehicular protection and use of interventional radiological approaches to control acute hemorrhage[6-7]. As a result, surgeons lack access to these combat surgical skills in civilian practice prior to military deployment.

The Advanced Surgical Skills for Exposure in Trauma (ASSET) course was developed to fill this training gap. The course is a human cadaver-based 1-day course developed by the American College of Surgeons Committee on Trauma and adopted by military pre-deployment training platforms to teach surgeons how to expose and control major blood vessels. Vascular exposure is the requisite first step in achieving control of major hemorrhage [8] and the course reviews all of the major vascular exposures in the body. ASSET training includes 59 procedures, and has been shown to increase self-confidence in performing these procedures [9]. However no objective assessment of training outcomes has been done. None of the currently available surgical skills performance metrics were designed for emergency trauma surgery assessment or

trauma-specific procedures [10-16]. Thus, a benchmark is needed to standardize individual surgeon's performance evaluations for emergency hemorrhage control. We tested the hypothesis that a novel assessment method, individual procedure score (IPS), can quantify the outcome of ASSET training among residents using combat-relevant upper and lower extremity emergency vascular exposure and control scenarios.

Methods:

All study procedures involving human subjects received Institutional Review Board approval by the University of Maryland, and the US Army Office of Research Protection. Cadavers were supplied by, and cadaver use procedures approved by the State Anatomy Board of Maryland and the US Army Office of Research Protection. General surgery residents and trauma fellow research subjects were recruited through surgical programs in Maryland, District of Columbia, Pennsylvania, Delaware, New Jersey, Virginia and New England. Residents enrolled were provided with a study participation payment, in addition to ASSET course registration and travel to and from the University of Maryland, School of Medicine, Baltimore, for study participation before and within 2 weeks after completing the ASSET course. All residents underwent a formal consent process, had an opportunity to ask questions and completed informed consent before participation. Participants completed a demographics questionnaire (years in residency, numbers of upper and lower extremity vascular procedures performed), then performed axillary (AA), brachial (BA), and common, superficial and profunda femoral artery (FA) vascular exposure procedures on unpreserved cadavers guided by a standardized script. The script included a patient scenario, patient management knowledge questions, and marking of the planned surgical incision, followed by completing the indicated procedure. To ensure capture of all procedures, responses to questions, and surgeon commentary on their actions, each research subject wore a

head mounted laser-directed head camera (Looxcie LX2 Looxcie, Inc. Sunnyvale, CA 94089) and headset boom microphone (Clear-com CB222/Clear-com CC-95 headset Clear-Com, LLC, Alameda, CA 94501). Audio and video recordings were also made from ceiling-mounted microphones (Shure MX202 Ceiling Mic Shure Inc. Niles, IL) and pan-tilt zoom (PTZ) cameras (Vaddio Ceiling View 70 PTZ Camera Vaddio, Minnetonka, MN 55305) at each location, and wall-mounted overview cameras at each of 6 instrumented cadaver table locations.

Metrics Development: The performance evaluation metrics for three upper and lower extremity vascular control procedures were developed and validated in four steps: Step 1) Experts were interviewed regarding critical knowledge of exposures of AA, BA, and FA. For each procedure the experts discussed patient management, decision-making strategies, anatomic landmarks, structures, and common errors and complications. Step 2) Ten expert attending trauma surgeons (fellowship trained, 2-40 years in practice) performed the procedures on unpreserved cadavers and were audio-video-recorded providing commentary and teaching points as though they were demonstrating to students while performing the procedures in the operating room. Cognitive work analysis methodology was applied, including process-tracing, the recording of both “thinking out loud” and more structured didactics [17-19]. Ten surgical residents (years 2-4 of training) who had not taken the ASSET course were then audio-video -recorded performing the same vascular exposure procedures. Step 3) A consensus conference of 5 experts developed procedure- specific performance metrics by reviewing both sets of Step 2 videos. Previously described metrics such as Objective Structured Assessment of Technical Skill [20] Procedure Based Assessment [21] and orthopedic competence evaluation [22] were considered in this discussion to develop the content that best captured the key components of expert performance

for each procedure. Step 4) A script was developed for each vascular exposure and control procedure. Appendix A1 shows the script and performance assessment for AA. The Individual Procedure Score (IPS) was based on five components including knowledge, anatomy, patient management questions, indications, posed in the script and observation of procedural steps, technical and non-technical skills and duration of cadaver surgery as shown in Table 1. Objective components of IPS included landmarks, skin marking, timing, skin incision placement, correct identification of artery, veins and nerves, and occurrence of errors in anatomic structure identification. Subjective components included proper use of instruments, tissue handling, adequacy of visual field, continually progresses towards end goal etc as shown in the axillary artery script. The time from skin incision to passage of a double vessel loop around the identified vessel was recorded. As shown in the AA script, responses included yes/no answers for knowledge questions or checklists for procedural steps and Likert scales for surgical technical skills. The IPS was summed from each response (each of the 3 procedures had differing numbers of questions) and then normalized to a percentage correct with a scale of 0-100. Scores of < 50 were grouped together for debriefing descriptive purposes. Subjective global ratings were scored for comparison, but were not included in the IPS score. Expert input was utilized to designate each metric as an essential response or action (2 points, bold in the script), additional knowledge (1 point), or error (2 points if uncorrected and 1 point if corrected, red in the script). Next the script was tested to evaluate a further group of ASSET untrained surgeons and modified iteratively with consensus input. Modifications in the last consensus included evaluating individual components of procedures and limiting the time allowance for each procedure to 20 minutes, as some untrained surgeons took an hour to complete a single procedure. This final script, together with a 20 minute countdown from skin incision, was programed into a mobile

application running on an Android^R tablet. During the evaluation, the instructions and questions were read out loud from the application by a script reader. To standardize presentation, questions and instructions were repeated once, if needed, but no prompting or further instruction was provided to the participating surgeons. Using the same touch-screen application, one evaluator read the script and completed responses, while the other completed responses, and also debriefed the participant surgeons after completion of the test surgical procedures. At the end, the application uploaded the 120-200 individual evaluation points for each of the three procedures and provided a summary score that could be printed and given to the study participant.

Evaluator Training and Inter-Rater Reliability Testing: Evaluators were trained using video clips from expert and untrained surgeon performances to illustrate components of surgical performance to be evaluated. Evaluators were trained individually, either in person or by video teleconference. Inter-rater reliability of 5 trained evaluators blinded to expert or novice video **as previously reported** had intra-class correlation coefficients (ICC) [23] of 0.7 – 0.94 depending on the particular IPS procedure and technical points described in Table 1. This preliminary training and testing has been previously described [24].

Self-Reported Confidence Pre-Post- ASSET training: Self-reports of confidence in performing upper and lower extremity traumatic injury procedures were obtained before and after ASSET training.

Statistical analyses: Pearson's correlation coefficient was used for assessing association of global ratings and IPS evaluations. The difference between each correlation before and after training was tested with Fisher's Z transformation. ICC ratings (0.7 good, ICC > 0.8 excellent, ICC > 0.9 outstanding) were used to assess the consistency among measurements and the

reliability of the evaluator before and after training. Comparisons of pre- and post-ASSET surgical performance scores among resident surgeons were analyzed by repeated measurement models. A linear mixed model that included surgeon background of clinical exposure (clinical years of training), evaluator's experience (physician versus non-physician), and individual surgeons as random variables was used for each of the continuous measurements and a generalized linear mixed model was employed for each of binary outcomes. Scatter and vector plots were prepared using SigmaPlot (Systat Software, Inc., San Jose, CA 95131) Statistical Analysis Systems (SAS) v 9.3 (Cary, NC 27513) was used for analyses with $p < 0.05$ considered significant.

Results:

Demographics: Within a 9 month interval, 41 surgical residents and fellows were enrolled. Two co-located evaluators completed 40 evaluations before and within two weeks after completion of the 1-day ASSET course. One surgeon was evaluated on the pre-training procedures and completed the ASSET course but did not return for follow-up and was excluded from the study. The 40 participants who completed all study evaluations (23/40 were male) were mean $\pm$ standard deviation [SD] age 30.7 $\pm$ 5.7 years, had residency training of 3.5 $\pm$ 1.2 years (range 2- 6 years) and had performed 105 $\pm$ 48.9 previous trauma patient treatments or evaluations.

Inter-Rater reliability and consistency by ICC: Among 4 separate evaluators, (two before training and a different two after ASSET training), the ICC for IPS for AA was 0.91 with confidence interval (CI) 0.86-0.95. For FA the ICC was 0.94 (CI 0.90- 0.96) and for BA 0.84 (CI 0.75- 0.90). The ICC for the individual components of the IPS for the three procedures is shown

in Table 2. These ICC are all excellent to outstanding. The linear mixed model analysis showed no evaluation difference between physician or non-physician evaluators.

Evaluating Surgeons Before and After ASSET Training: Using IPS evaluation of participants before and after training, significant improvement ($p < 0.001$) occurred for each of the 3 artery exposures (Fig 1). Note that no floor or ceiling effect was observed in the IPS metric within the range of resident performance evaluated. Changes in performance of exposure and vascular control for the three procedures, included a 43 % increase in the anatomy component and a 57% increase in the procedural steps component. A comparison of IPS score components of anatomic knowledge and surgical performance before and after training shows that all these metrics were significantly different ($p < 0.001$) with the exception of management components (which were not part of the training) (Table 3). When IPS data related to procedure time, landmarks, incision placement, correct artery identification and successful vascular control (the essence of surgical hemorrhage control) are considered together for axillary, brachial and femoral arteries these components of IPS were all significantly ($p < 0.001$) improved with ASSET training. Time to complete the AA, BA, FA vessel exposure and control decreased significantly ($p < 0.001$) by a mean of 1.9- 3.1 minutes (Table 4)..

What vascular exposure steps were changed with ASSET training? Pre- versus post- training identification of correct anatomic surface markings, skin incision, technical skills and procedural steps showed significant improvement for AA, BA, and FA exposure (Figure 2 and Table 4). Correct placement of surface landmarks and skin incision occurred more often for all 3 procedures after ASSET training (Figure 3 all differences $p < 0.001$). When these results are graphically represented as vectors of correct vascular control procedural steps or change before and after training several potentially interesting training requirement data are revealed. Some

surgeons were performing well as judged by landmark and procedural steps even before ASSET training. Two surgeons showed no improvement with training (Fig 3).

Comparison of clinical year of residency data: When all these data are considered by clinical year of training (2nd - 6th year) no significant difference ($p = 0.2$) in IPS among these surgeons is noted, with the exception of a significant difference in management ($p = 0.003$) and knowledge ($p < 0.001$) for AA anatomy ($p = 0.03$) and procedural steps ($p = 0.008$) for BA anatomy and knowledge (both $p < 0.001$) in TRIVasc.

Correlation of IPS with Global Ratings: In addition to the IPS, evaluators gave one independent global rating of surgeon performance which subjectively summarized the evaluators' overall impressions of the surgeons' knowledge and skill, and four global ratings evaluating management, anatomy, technical skills and readiness to independently perform the procedure. Table 5 shows the Pearson's Correlation coefficients (r) values of IPS to an overall evaluator global rating of surgeon performance and the four other global ratings. IPS for AA, BA, and FA are shown pre- and post- ASSET training. The IPS was significantly different ($p < 0.001$ by Fisher's Z transformation) from the subjective overall global ratings of surgeon performance before and after training for all procedures with the exception of overall global evaluator rating to perform FA exposure after ASSET training. All of the four global ratings evaluating management, anatomy, technical skills and readiness to independently perform the procedure were different ($p < 0.001$) from the IPS (Table 5). These data, considered along with the results in Tables 3 and 4 support the use of IPS as a metric for competency in vascular exposure and control in comparison to the five subjective global ratings.

Self-Reports before and After ASSET training: After ASSET training self-reported confidence increased significantly ($p < 0.001$). Among 12 study participants the questions in the self-report surveys were obtained four times: before and after the pre-ASSET assessment and again before and after the post-ASSET assessment. On a Likert scale of 1 (= no) to 5 (= complete), all participants reported scores 4 or greater for upper and lower extremity trauma for understanding anatomy and comfort level for exposing major vasculature, compared to scores of less than 2.5 before the ASSET training. Figure 4 shows pre- and post- evaluation confidence results for 12 participants who completed these evaluations both before and after ASSET training. Overall, no differences in self-confidence were reported pre- and post assessment before ASSET training ($p = 0.2$), however, some did report decrease in confidence post-evaluation before ASSET training for selected procedures, that is, the participants did not initially realize how much they did not know about these procedures[25]. However after ASSET training, surgeons gave the highest Likert confidence score for these same procedures.

Discussion:

Many recent reviews have detailed the state of observational tools for assessing surgeon performance, competency, technical skills, psychomotor skills, and skills acquisition measurement [10-16, 26-32]. However, none of those measures are specific for trauma-related emergency surgical procedures, which have unique temporal and management criteria, nor is individual surgeon performance measured systematically or specifically during residency training [32]. The present study of trauma-specific vascular procedures shows that correct identification of surface landmarks, incisions and procedural steps can be documented and the IPS increased for vascular exposure and control after ASSET training. The IPS metric

documents competency in vascular control procedures. The benefit of ASSET training was shown to occur regardless of clinical year of training.

An important part of surgeon evaluation is the consistency and reliability of evaluators.

Conscious or unconscious biases are present in many types of performance assessments, and ensuring that any assessment tool includes rigorous well defined parameters is critical. The consensus development of the IPS metric identified specific characteristics and steps that a trained evaluator can implement, with limited room for unconscious bias. Indeed, when we assessed metrics scores between evaluators the inter rater reliability is high and consistent. Of particular note are the near-perfect ICC evaluator agreement on components of IPS including procedural steps, landmarks (except for BA) and time. BA had the lowest among all ICC coefficients for surface landmarks, and the lower evaluator agreement may reflect the absence of bony landmarks and mobile soft tissues associated with BA skin incision. Correlations of the subjective global ratings and objective metrics contained within the IPS are not as robust as the ICC agreements suggesting that the objective scoring method is more consistent and reliable than the traditional subjective evaluation method. We concluded that improved knowledge of local anatomy resulted in correct incision placement using surface landmarks taught in the ASSET course. Anatomic structural recognition and specific procedural steps were the key knowledge gained during the 1-day training course. As such, ASSET training may help accelerate acquisition of emergency surgery specific skills to compensate for shortened training hours, for military surgeons preparing for war or whenever just-in-time training is necessary. Anatomic knowledge, including surface landmarks and incision placement, although accounting for only some of the total IPS score accounted together with procedural steps for a disproportionate amount of ASSET training improvements in the IPS metric and are key to successful trauma

surgeon training. These data support ASSET training as a mechanism to increase performance in vascular exposure and control. Focused training in surgical vascular anatomy can result in very significant performance improvements after a single day of training, however the sustained impact of such training requires further study.

Many of the previously reported observational tools measuring surgeon technical and non-technical skills were developed and validated on simple part-task-trainer simulators (knot tying, laparoscopic peg board movement etc) [33,34] the fidelity and validity of such metrics for evaluation of open surgery in the operating room is inadequate. There is very little good data describing precisely what surgeons do when performing surgery. Much of surgeon performance data is focused on team, rather than individual, surgeon performance [11, 14, 15,31] and there is no consensus on the objective analysis of technical performance by clinicians[31]. There are no benchmarks for evaluation of individual surgeon performance, nor is there agreement on how such metrics might improve clinical outcomes [11,14, 31]. In the present study, preliminary expert video recording captured recurrent and interrelated factors in communication and task performance and facilitated identification of individual, and technical constraints that characterize ASSET training. A key to development of these novel metrics was recording of expert “thinking out loud” and formally structured didactics as these experts did the selected procedures, providing a platform for measuring the complexity of individual surgeon performance. [17-19].

Trauma surgery is a very complex task requiring rapid performance of motor tasks while simultaneously integrating knowledge of variations in anatomy, differences in trauma presentation, indication/contraindications for selecting approaches, and anticipation of team member engagement during this concatenation of tasks. Thus learning and skills acquisition may

not follow a smooth power law function trajectory as documented for simple task training in laboratory settings. For complex tasks insight acquired during key encounters or training may reorganize knowledge or add new constraints that result in step-wise changes in capability [35].

Strengths: Use of a standardized script in which all enrolled surgeons were asked exactly the same questions and evaluated performing the procedures with the same metrics is a strength and lends consistency to this study. Surgery performed on an unpreserved cadaver is generally considered to be the ‘gold standard’ of surgical simulation. Video recording from both a head mounted camera and an overhead camera and use of three separate audio capture systems allowed us to capture all events along the same audio-video timeline. Use of the mobile application facilitated multiple different sequences of scripts, and ensured all evaluations were collected. Sufficient funding to support ASSET training, travel and accommodation (where needed), allowed scheduling of surgeons 3 months in advance and coordination with timing of ASSET courses. (These occurred independent of this study avoiding training bias). We were thus able to schedule 40 surgeons to be evaluated twice and return within 2 weeks of training, with only one loss to follow-up. In this study surgeons worked unassisted with no input from the evaluators, so only individual performance was evaluated.

Limitations: The IPS assessment method is labor and resource intensive and is specific to the procedures evaluated, although there are many commonalities. The mobile application software can be easily revised to add new procedures. Evaluator bias is a factor in such studies as this. We tried to minimize bias, by pairing trainees with different evaluators before and after training. However, we could not prevent evaluators from knowing that the surgeons had taken the ASSET course within 2 weeks of their second evaluation. This knowledge may have caused the

differences between evaluators overall global ratings of surgeon performance and IPS before and after training. Evaluators may have been biased to give higher global ratings if they knew that the participants were recently trained. Alternatively, the IPS may be missing facets of performance that are particularly relevant at the higher levels of skill which were captured by the evaluator's overall performance rating. Lastly the surgeons were not stressed as occurs in a busy trauma center, there was no bleeding, hematoma or tissue damage as there would be in live trauma patient situations and there were no support personnel.

Conclusion:

Overall this study showed the value and efficacy of ASSET training to increase performance of major vascular exposure and control procedures..Focused training in vascular exposures through the ASSET course improved knowledge of surface landmarks and underlying anatomy both of which are associated with faster procedures, more accurate incision placement and successful vascular control. These key features of skill acquisition after training could be incorporated into skill refreshing plans for surgeons and help understand the impact of various training methods to further improve training outcomes. There is no current mechanism for assessing the durability or degradation of these skills once obtained. The IPS appears to be useful as a benchmark to assess competence after training, to identify skill durability and to measure adequacy of a surgeon's skill to control major vessels to the upper and lower extremities.

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	Knowledge	Anatomy	Management/ Indications	Procedural	Technical Points
What structures could be injured?	✓	✓			
What are the physical findings? (AA and FA only)	✓		✓		
Are there any additional studies to be performed?	✓		✓		
What is your plan for the patient?	✓				
What interventions are important/ are there any systemic consequences of delayed diagnosis? (FA only)	✓		✓		
How would you position and prep the patient for surgery?	✓	✓			

How do you plan to gain control of the bleeding vessel? (BA only)	✓	✓	
What are the landmarks?		✓	✓
Performance checklist/ time to complete procedure.		✓	✓
Technique Points.			✓
Expert Discriminators.			✓
What are the consequences of ligating the artery?	✓	✓	
What are the pitfalls or common errors when performing this procedure?	✓	✓	

Table 1: Five components of the Individual Procedure Score (IPS) calculations are knowledge, anatomy, management/indications/procedural steps (time to complete the procedure), technical points and time to complete the procedure. Table 1 shows where these data are obtained from the script. Details of each item in the Table 1 e.g. technique points and expert discriminators can be found by reference to Appendix 1A showing a complete script for the Axillary Artery exposure procedure. Table 1 shows the commonalities of IPS across Axillary Artery, Brachial Artery, and Femoral Artery scripts.

	Axillary Artery	Brachial Artery	Femoral Artery
IPS	<i>0.91</i>	<i>0.84</i>	<i>0.94</i>
Anatomy	<i>0.89</i>	<i>0.78</i>	<i>0.91</i>
Knowledge	<i>0.74</i>	<i>0.67</i>	<i>0.77</i>
Management	<i>0.71</i>	<i>0.58</i>	<i>0.82</i>
Procedural Steps	<i>0.97</i>	<i>0.89</i>	<i>0.95</i>
Landmarks	<i>0.90</i>	<i>0.51</i>	<i>0.76</i>

Time	<i>0.97</i>	<i>0.98</i>	<i>1.0</i>
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Table 2: Intra-Class Correlation Coefficients (ICC) for components of Individual Procedure Score (IPS) and for IPS for each of Axillary, Brachial, and Femoral Artery by pairs of evaluators before and after training.

		Pooled Vascular mean $\pm$ SD	Axillary Artery mean $\pm$ SD	Brachial Artery mean $\pm$ SD	Femoral Artery mean $\pm$ SD
Overall Knowledge	Pre	0.5 $\pm$ 0.01	0.44 $\pm$ 0.02	0.62 $\pm$ 0.03	0.5 $\pm$ 0.02
	Post	0.56 $\pm$ 0.01	0.5 $\pm$ 0.02	0.69 $\pm$ 0.02	0.56 $\pm$ 0.02
	diff	0.06**	0.06**	0.06**	0.06**
Anatomic	Pre	0.46 $\pm$ 0.02	0.44 $\pm$ 0.03	0.57 $\pm$ 0.03	0.38 $\pm$ 0.07
	Post	0.71 $\pm$ 0.02	0.69 $\pm$ 0.02	0.74 $\pm$ 0.03	0.76 $\pm$ 0.06
	diff	0.25**	0.24**	0.17**	0.39**
Management	Pre	0.42 $\pm$ 0.02	0.35 $\pm$ 0.02	0.59 $\pm$ 0.03	0.43 $\pm$ 0.02
	Post	0.44 $\pm$ 0.01	0.37 $\pm$ 0.02	0.58 $\pm$ 0.03	0.46 $\pm$ 0.02
	diff	0.02	0.02	-0.01	0.03*
Procedural Steps	Pre	0.39 $\pm$ 0.03	0.43 $\pm$ 0.04	0.49 $\pm$ 0.04	0.3 $\pm$ 0.05
	Post	0.65 $\pm$ 0.02	0.73 $\pm$ 0.03	0.67 $\pm$ 0.03	0.59 $\pm$ 0.05
	diff	0.26**	0.3**	0.18**	0.29**
IPS	Pre	0.48 $\pm$ 0.01	0.46 $\pm$ 0.02	0.56 $\pm$ 0.02	0.45 $\pm$ 0.02
	Post	0.63 $\pm$ 0.01	0.61 $\pm$ 0.02	0.69 $\pm$ 0.02	0.6 $\pm$ 0.02
	diff	0.15**	0.15**	0.13**	0.15**
Significance of difference demarked as $\alpha=0.05$: ** $p < 0.001$; * $p < 0.05$					

Table 3: Comparison of Individual Procedure Score (IPS) components before (Pre) and after (Post) training for Axillary, Brachial, Femoral artery exposures and a pooled score using linear mixed models. Note all performance metrics are significantly different after training ($p < 0.001$) with the exception of Management components (not part of training).

		Axillary Artery	Brachial Artery	Femoral Artery		
		mean $\pm$ SD	mean $\pm$ SD	mean $\pm$ SD	mean $\pm$ SD	mean $\pm$ SD
Procedure Time (mins‡)	Pre	9.7 $\pm$ 0.89	10.9 $\pm$ 1.05	15.8 $\pm$ 1.02		
	Post	7.2 $\pm$ 0.81	8.9 $\pm$ 0.97	12.6 $\pm$ 0.96		
	diff	-2.5**	-1.9**	-3.1**		
Landmarks	Pre	0.34 $\pm$ 0.06	0.5 $\pm$ 0.06	0.53 $\pm$ 0.05		
	Post	0.73 $\pm$ 0.05	0.63 $\pm$ 0.05	0.76 $\pm$ 0.05		
	diff	0.39**	0.13**	0.23**		
Adequate Incision ¥	Pre	0.25 $\pm$ 0.05	0.76 $\pm$ 0.08	0.36 $\pm$ 0.1		
	Post	0.82 $\pm$ 0.05	0.97 $\pm$ 0.08	0.77 $\pm$ 0.09		
	diff	0.57**	0.21**	0.41**		
Correct Artery ID ¥	Pre	0.57 $\pm$ 0.08	0.62 $\pm$ 0.09	SFA†	PFA†	CFA†
				0.62 $\pm$ 0.09	0.48 $\pm$ 0.1	0.47 $\pm$ 0.1
	Post	0.96 $\pm$ 0.07	0.95 $\pm$ 0.08	0.95 $\pm$ 0.08	0.82 $\pm$ 0.09	0.85 $\pm$ 0.09
				0.33**	0.34**	0.38**
Controls Arteries ¥	Pre	0.36 $\pm$ 0.05	0.63 $\pm$ 0.1	0.59 $\pm$ 0.09	0.46 $\pm$ 0.1	0.42 $\pm$ 0.1
	Post	0.84 $\pm$ 0.05	0.88 $\pm$ 0.09	0.92 $\pm$ 0.08	0.81 $\pm$ 0.1	0.82 $\pm$ 0.09
	diff	0.47**	0.26**	0.33**	0.36**	0.4**

†CFA: Common Femoral Artery; SFA: Superficial Femoral Artery; PFA: Profunda Femoral Artery

¥ Binary data analyzed with General Linear Mixed Model

Significance of difference demarked as $\alpha=0.05$: ** $p < 0.001$

‡ Minutes calculated to the 0.25 minute

Table 4: Objective components of Individual Procedure Score assessing steps in the vascular exposure for axillary, brachial and femoral arteries are shown, before (Pre) and after (Post) training and the difference (diff). All vascular exposure and control metrics are significantly improved with ASSET training ($p < 0.001$) using linear mixed model (procedure time, landmarks) and general linear mixed models for binary data¥.

		Global ratings				
		Evaluator Rating	Global Management	Global Anatomy	Global Technical skills	Global Readiness
Vascular TRI	Pre	<i>0.67</i>	<i>0.56</i>	<i>0.62</i>	<i>0.67</i>	<i>0.59</i>
	Post	<i>0.41</i>	<i>0.47</i>	<i>0.69</i>	<i>0.63</i>	<i>0.38</i>
Axillary IPS	Pre	<i>0.71</i>	<i>0.31</i>	<i>0.76</i>	<i>0.39</i>	<i>0.67</i>
	Post	<i>0.56</i>	<i>0.51</i>	<i>0.64</i>	<i>0.60</i>	<i>0.45</i>
Brachial IPS	Pre	<i>0.46</i>	<i>0.45</i>	<i>0.60</i>	<i>0.73</i>	<i>0.55</i>
	Post	<i>0.52</i>	<i>0.49</i>	<i>0.73</i>	<i>0.61</i>	<i>0.50</i>
Femoral IPS	Pre	<i>0.83</i>	<i>0.58</i>	<i>0.79</i>	<i>0.64</i>	<i>0.78</i>
	Post	<i>0.17</i>	<i>0.44</i>	<i>0.64</i>	<i>0.63</i>	<i>0.42</i>

Table 5: Pearson Correlation coefficients (r) before (Pre) and after (Post) training of Individual Procedure Scores (IPS) for performance of axillary artery (AA), brachial artery (BA) and femoral artery (FA) vascular exposure, in comparison to five subjective independently scored global ratings (overall performance, management, anatomy, technical skills and readiness to independently perform the procedures). Italics show $p < 0.001$ [$\alpha=0.05$] identifying that all subjective global ratings except FA Post are significantly different than the objective metrics included in IPS

Figure 1: Box and whisker plots of percent change in Individual Procedure Score (IPS) from baseline before training to after training (n=40) for Axillary, Brachial and Femoral artery exposures (box: mean±1SE; whisker: mean: mean±1SD).

Figure 2: Box and whisker plots of percent change in component scores of vascular procedures from baseline before training to after training (n=40) for combined vascular exposures (box: mean±1SE; whisker: mean: mean±1SD).

Figure 3: Panel A: Plots of Pre -ASSET (blue circles) and Post-ASSET (red circles) showing the aggregated change in correct vascular procedural steps and landmarks, for axillary, brachial and femoral arteries with training. Note that several surgeons already had both procedural steps and landmark scores in excess of 0.5 before training, and two surgeons showed a decrease in landmark score but this was accompanied by an increase in procedural steps score with training. Panel B; Percent (%) change in procedure and landmark scores with ASSET training. Red axes represent the no change thresholds. Note two surgeons who showed no change with training.

Figure 4: In 12 surgeons, self-reported confidence in performing upper and lower extremity vascular control procedures were obtained four times. These are plotted before and after the initial study evaluations and then before and after Advanced Surgical Skills Exposure for Trauma (ASSET) training.