# DEVELOPMENT OF A VASCULAR SURGERY SIMULATION CURRICULUM: FROM DESIGN AND IMPLEMENTATION TO STUDYING THE IMPACT OF PEER-ASSISTED LEARNING ON SKILLS ACQUISITION

by

RUTVI PATEL

DISSERTATION

Presented to the Faculty of the Medical School
The University of Texas Southwestern Medical Center
In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF MEDICINE WITH DISTINCTION IN MEDICAL EDUCATION

The University of Texas Southwestern Medical Center
Dallas, TX

ACKNOWLEDGMENTS

I am thankful to Dr. Deborah Farr for her mentorship which was essential for successful completion of this project. I would also like to thank Drs. Bala Ramanan, Mujtaba Ali and Gregory Modrall for their enthusiastic involvement in the development and implementation of this vascular curriculum. I am grateful to Dr. Dorothy Sendelbach for her encouragement and guidance throughout this process, and to Dr. Aditee Ambardekar for her support as thesis committee member.

A special thanks to my family and friends for their unconditional moral support through the years. Lastly, this curriculum could not have been implemented without help from the UT Southwestern Simulation Center staff and its residents. The materials and instruments required for implementation of the curriculum and study were funded by the UT Southwestern Simulation Skills Center.

Thank you all for your support!

ABSTRACT

DEVELOPMENT OF A VASCULAR SURGERY SIMULATION CURRICULUM: FROM DESIGN AND IMPLEMENTATION TO STUDYING THE IMPACT OF PEER-ASSISTED LEARNING ON SKILLS ACQUISITION

RUTVI PATEL
The University of Texas Southwestern Medical Center, 2019
Supervising Professor: Deborah Farr, M.D.

**Background**: In the last few decades, increasing emphasis has been placed on moving residents' early learning curves out of the operating room into a simulated environment. In response, ample research focusing on development/validation of instructional modules, simulators and assessment methodologies has been conducted. However, evaluation of the best methods of implementing these curriculums is lagging behind, and there is currently no standardized method of disseminating surgical simulation curriculums.
**Objective**: The goal of this project was two-fold: to create a standardized vascular surgery simulation curriculum for junior surgical residents, and to conduct a study evaluating the effects of Peer-Assisted Learning (PAL) on surgical skills acquisition and learner confidence.
**Methods**: Instructional materials (video + written instructions, task trainers) for a simulated end-to-side vascular anastomosis procedure were created in collaboration with vascular surgery faculty. Using the end-to-side anastomosis as the procedure being taught, 45 PGY 1-3 general surgery residents were randomized to Solo or PAL practice. Learners in the Solo arm practiced independently, whereas learners in the PAL arm practiced with a same-level peer while employing PAL techniques such as roleplaying and providing peer feedback. Pre-test and post-test videotaped performances were recorded, and assessed by 2 experts who were blinded to group, test and learner. Survey questionnaires were used to gauge participant confidence.
**Results**: Learners showed significant improvement in their post-test checklist scores, global rating scores and self-reported confidence in comparison to their pre-test scores (all $p < 0.05$). There were no significant differences in pre-test outcome measures (checklist, global ratings, time taken, self-reported confidence) between Solo and PAL groups. Comparing post-test outcomes between groups, PAL learners had significantly higher global ratings ($p = 0.02$) and significantly lower time to anastomosis completion ($p = 0.01$); there were no significant differences in self-reported confidence ($p = 0.25$).
**Conclusion**: This project resulted in the development and implementation of a standardized simulated vascular surgery curriculum for junior surgical residents at UT Southwestern Medical Center. Our study shows that learners who practiced with a peer showed better skill acquisition. With no current standardization in dissemination of simulation curriculums, it is important to study methods that enhance skill acquisition, and subsequently incorporate these techniques into future simulation curriculums through curricular reform.

TABLE OF CONTENTS

# CHAPTER ONE: INTRODUCTION AND PURPOSE

The purpose of this project was two-fold:

1. Developing instructional materials for a simulated vascular surgery curriculum geared towards resident education at UTSW Simulation Skills Center. This would consist of developing learning goals/objectives, creating efficient written and video instructions for standardized teaching, determining optimal practice duration and number of required sessions, and finding adequate performance metrics for objective evaluation of resident progress/verification of proficiency.
2. Examining the impact of Peer-Assisted Learning (PAL) on the acquisition of surgical skills among surgical residents. Using our simulated vascular surgery curriculum of end-to-side anastomosis as the procedure being taught, we aimed to design a study comparing conventional/solo learning to Peer-Assisted Learning (PAL), and to determine whether PAL results in better skill acquisition and increased participant confidence.

# CHAPTER TWO: CURRICULUM DESIGN AND DEVELOPMENT

## BACKGROUND

In the last two decades, there has been a paradigm shift in the approach towards teaching surgical skills, with early psychomotor learning moving out of the operating room into a simulated practice environment. The use of simulation for surgical skills acquisition is rapidly increasing due to a variety of factors: ACGME mandated 80-hour work week restriction for residents, ACGME's requirement for surgical residency programs to provide skills laboratory training opportunities, rising ethical concerns about patient safety, technological advances, and benefits of providing a low-stress/low-consequence environment for learners [1-3]. In addition, education research shows that deliberate practice—well-defined and level-appropriate tasks, provision of immediate feedback, and opportunities to perform the task repeatedly—have invaluable benefits for technical skill acquisition. Unfortunately, many components of deliberate practice cannot be achieved ideally in the operating room where procedures are governed by patient availability and condition.

In the field of vascular surgery, these concerns are amplified by diminishing trainee exposure to open vascular procedures due to new minimally invasive and endovascular interventions rapidly replacing conventional open operations [3,4]. In addition, the specialized nature of this field (usage of instruments like Castroviejo needle holders, Potts scissors) and technically complex procedures (requiring proficient foundational surgical skills) make it a challenging rotation for junior surgical residents. Moreover, although simulation training has been extensively—and repeatedly—proven to result in better skill acquisition and skill transfer in the operating room for laparoscopic and endoscopic procedures [5-7], similar strength of evidence in vascular procedures is lacking. For all the above-mentioned reasons, we determined that incorporation of a simulated vascular surgery curriculum into residents' simulation schedule would be extremely beneficial.

The American College of Surgeons and Association of Program Directors in Surgery (ACS/APDS) has created an instructional module for vascular anastomosis (Phase 1; Module 16)[8]. Our first goal was to use these ACS/APDS instructions and results of a few previous studies as a backbone for the creation of a vascular surgery skills curriculum geared towards resident education at UT Southwestern Simulation Skills Center. We planned on creating an instructional video, written instructions including tips/tricks to complement ACS/APDS instructions, along with surveys for gauging participant satisfaction and self-perceived confidence. These surveys also include questions aimed at gathering feedback on the quality and level of instructions, time involvement expectations etc. to subsequently improve this curriculum for future residents.

## LEARNING GOALS AND OBJECTIVES

The primary purpose was creation of a standardized, structured, cost and time-effective curriculum with the following learning goals and objectives:

*Learning Goals:*

- To familiarize junior general surgery residents with vascular instruments, basic steps/technique for a vascular anastomosis, and solidify foundational open surgical skills.
- Help junior residents feel more prepared and confident in the OR during their vascular rotations.
- Move the early learning curve for open vascular procedures out of the operating room, so that faculty can entrust and incorporate junior residents with more autonomy in the operating room.

*Learning Objectives:*

- By the end of this curriculum, residents will:
    - Be able to name/recognize all the surgical instruments used in the module.
    - List and perform all essential steps of the anastomosis procedure (as measured on the evaluation checklist).
    - Perform the hands-on procedure at least 3 times on the low-fidelity task trainer.
    - Be effective first assistants.

Prior simulation research shows that for early learners, low-fidelity models are sufficient for motor learning to occur [9,10]. To this effect, our goal was to create a cost-effective, easily reproducible, easily manageable, low-fidelity task trainer that is realistic enough for residents to practice basic anastomotic principles and surgical technique.

As shown in Figure 1, we used a cylindrical model constructed from foam and felt for creating a foundational base. A Penrose drain (0.25 inch diameter) functioned as native "artery"; PTFE graft material was used to perform an end-to-side anastomosis to the native "artery" using a 6-0 Prolene suture. Our model is identical to other widely-used low-fidelity models for vascular anastomosis that have established construct validity [11-14].

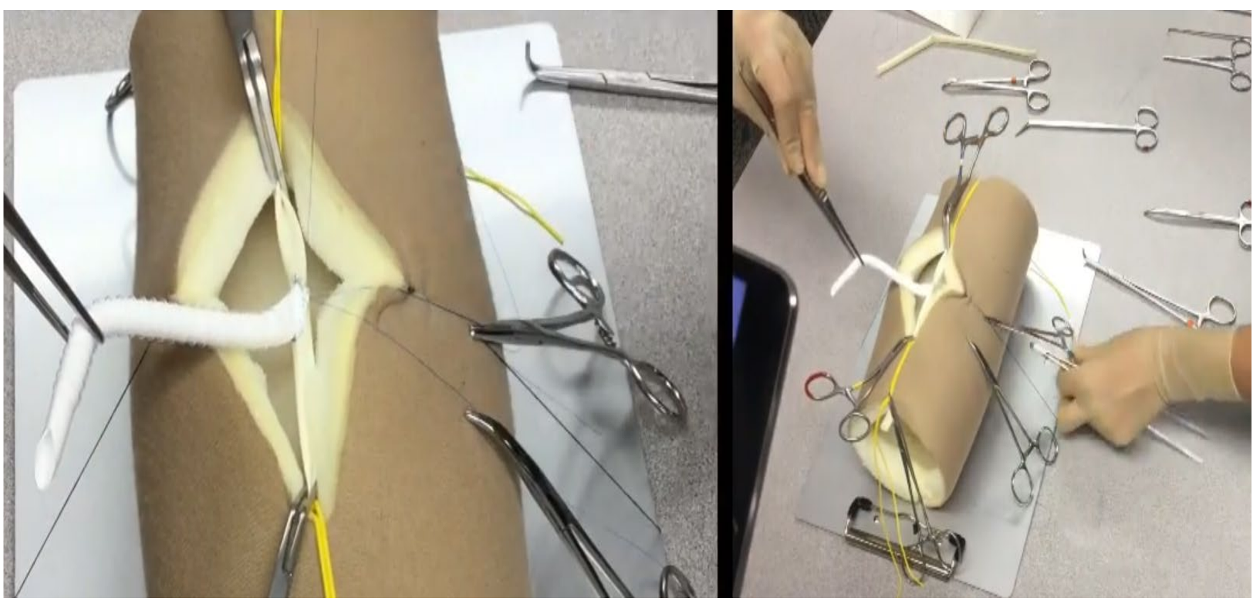


*Figure 1. Low-fidelity task trainer created for hands-on practice of an end-to-side vascular anastomosis procedure.*

WRITTEN INSTRUCTIONS

Using previously validated ACS/APDS step-wise instructions[8] as a backbone, we created our own written instructions, with the aim of:

1. Providing not only step-wise instructions, but also incorporating teaching points from experienced faculty (i.e. "pro tips"), surgical technique, ergonomic hand/body positioning, bite movement/directionality (for effortless suturing and better operational outcomes). According to our informal needs assessment and resident performance feedback collected from vascular surgery faculty, these aspects of instruction—which would not only result in better technique, but also standardization in learning this procedure—are absent in the existing validated instructions for vascular anastomosis, and most simulation curriculum instructions in general.
2. Incorporating a big-picture plan of action (i.e. "roadmap") in addition to the detailed step-wise instructions, so learners can easily familiarize themselves with both the major steps of the procedure as well as the intricate details of each step.
3. Including instructions for being an effective first assistants.
4. Highlighting common mistakes/pitfalls made by junior residents.
5. Adding personally created, individualized visual illustrations demonstrating road-maps, suture directions, needle placement and angle, etc. to prevent word-heavy instructions (see Appendix A for written instructions).

INSTRUCTIONAL VIDEO

We had certain goals in mind before creating our own instructional video for better quality and teaching efficacy:

1. Per our own observations and discussion with other experienced faculty, we realized that current simulation videos routinely use either an exclusively "zoomed out" perspective of the procedure (where the learner can visualize the entire simulation model and body/hand positioning, but details of individual suture bites are lost) or an exclusively "zoomed in" perspective (with a focus on individual bites, but ergonomic details of body/hand positioning in relation to the model are lost). Hence, we aimed to make an instructional video where both aspects are preserved, showing simultaneous zoomed out/zoomed in perspectives side-by-side.
2. We found no existing instructional videos that taught an end-to-side anastomosis procedure on a similar low-fidelity model as ours; existing videos typically practiced on a higher fidelity model (with emphasis placed on extra maneuvers such as "clearing the adventitia", discussion on layers of vessels etc. that were out of scope for basic teaching of this technique). To provide level and context-appropriate instructions, we deemed it essential to create an instructional video detailing the procedure on our own low-fidelity simulation model to parallel our written instructions. Our instructional video can be viewed here: https://www.youtube.com/watch?v=P2aQ8-uqQGA

EVALUATION METRICS

Our goal was to incorporate a succinct, faculty-friendly evaluation in order to accurately track learner progress through practice. To this effect, we used a previously validated Verification of Proficiency Evaluation Form (Figure 2). This assessment was developed by Southern Illinois University (SIU) and incorporates both Checklist and Global Rating Scale (GRS) components [15,16]. It was considered optimal to have both checklist and GRS components since they are fundamentally different evaluation measures. While checklists evaluate surgical maneuvers and have high-interrater reliability[17] (minimizing subjectivity in grading), GRS evaluate holistic surgical behaviors and are shown to be better differentiators of performances[18].

**Vascular Anastomosis Evaluation Checklist** **Video ID:___________________**

| Steps | Satisfactory Performance | | Comments |
|---|---|---|---|
| Oblique incision in artery 2x diameter of graft lumen with #11 blade | Y | N | |
| Avoids back wall injury to "artery" | Y | N | |
| Cuts end of graft into an S-shape | Y | N | |
| Correctly places double-ended suture at heel of anastomosis | Y | N | |
| Securely ties knot on outside of anastomosis at heel | Y | N | |
| Completes back wall of anastomosis (sutures approx 1 mm apart) | Y | N | |
| Completes front wall of anastomosis (sutures approx 1 mm apart) | Y | N | |
| Securely ties knot on outside of anastomosis near toe (off-set laterally) | Y | N | |

| Economy of Time and Motion | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| | Many unnecessary / disorganized movements | | Organized time / motion, some unnecessary movement | | Maximum economy of movement and efficiency |

| FINAL RATING: | OTHER SUMMATIVE COMMENTS: | EVALUATOR: | |
|---|---|---|---|
| ☐ Demonstrates competence<br>☐ Requires further practice | | ______________________ | |

SIU SOM Dept of Surgery, General Surgery Residency Program OSATS Spring 2004
Adapted for UTSW PAL vs. Solo learning study (2/12/2018)

*Figure 2. VOP Assessment by SIU, adapted for our vascular surgery curriculum. Assessment form consists of a task-specific, dichotomous, 8-point checklist score and a Global Rating Scale marked on a Likert Scale from 1 to 5.*

In addition, we designed a pre-test survey to gauge baseline exposure to this procedure and initial self-perceived confidence (Figure 3), and a post-test survey to gauge learner enjoyment/satisfaction of the curriculum and exit self-perceived confidence (Figure 4).

**PRE-TEST SURVEY:** **TRAINER ID#:____________**

1. Current level of training:
   - ☐ MS1
   - ☐ MS2
   - ☐ MS3
   - ☐ MS4
   - ☐ PGY1
   - ☐ PGY2
   - ☐ PGY3
   - ☐ PGY4
   - ☐ PGY5

2. Have you observed or performed any vascular anastomosis procedures before this study?
   - ☐ Yes
     - State the number of times procedure was observed:_________
     - State the number of times procedure was performed:_________
   - ☐ No

3. For each of the questions below, please circle a response that best characterizes your opinion of the statement

| | **Strongly disagree** | **Disagree** | **Neutral** | **Agree** | **Strongly Agree** |
|---|---|---|---|---|---|
| I feel knowledgeable about the steps of an end-to-side vascular anastomosis procedure | 1 | 2 | 3 | 4 | 5 |
| I feel confident about my ability to perform an end-to-side vascular anastomosis independently | 1 | 2 | 3 | 4 | 5 |

*Figure 3. Pre-test survey questionnaire for participants to capture baseline demographic information, gauge baseline exposure to the procedure, and baseline self-reported confidence.*

**POST-TEST SURVEY:** **TRAINER ID#:_____________**

1. For each of the questions below, please circle a response that best characterizes your opinion of the statement:

| | Strongly disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| I feel knowledgeable about the steps of an end-to-side vascular anastomosis procedure | 1 | 2 | 3 | 4 | 5 |
| I feel confident about my ability to perform an end-to-side vascular anastomosis independently | 1 | 2 | 3 | 4 | 5 |
| Overall, I enjoyed this simulation curriculum and found it satisfactory | 1 | 2 | 3 | 4 | 5 |
| The sessions were an efficient use of my time | 1 | 2 | 3 | 4 | 5 |
| I would participate in similar simulation training sessions in the future | 1 | 2 | 3 | 4 | 5 |
| I would recommend these simulation sessions to other students | 1 | 2 | 3 | 4 | 5 |

2. The following questions pertain to the instructional video:

| | Strongly disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| The instructional video was easy to follow (i.e. taught at an appropriate level) | 1 | 2 | 3 | 4 | 5 |
| The instructional video effectively taught anastomosis setup and appropriate surgical instruments | 1 | 2 | 3 | 4 | 5 |
| The instructional video effectively taught steps of the anastomosis procedure | 1 | 2 | 3 | 4 | 5 |

3. Which set of written instructions did you find more helpful [pick one]?
   - ☐ ACS/APDS Curriculum (Module 16)
   - ☐ Anastomosis Tips and Tricks
   - ☐ Both equally helpful

4. Additional comments or suggestions for improvement: ________________________________________
_____________________________________________________________________________

*Figure 4. Post-test survey questionnaire for participants, designed to gauge exit self-perceived confidence and elicit curriculum feedback for future improvement.*

COMPILATION OF INSTRUCTIONAL MATERIALS

- Instructional Materials:
    - Low-fidelity simulation model for end-to-side vascular anastomosis
    - Written instructions (+ tips/tricks)
    - Instructional video

- Performance Metrics:
    - Verification of Proficiency (VOP) Evaluation form
    - Pre- and post-test survey questionnaires to gauge subjective improvement and gather feedback

This project resulted in a new standardized vascular surgery simulation curriculum (with in-house written + video instructions, low-fidelity simulation models, approved budget and procurement of instruments, logistical planning of sessions etc.) which has been piloted and subsequently incorporated into the general surgery resident simulation curriculum at UT Southwestern Medical Center.

# CHAPTER THREE: DETERMINING IMPACT OF PEER-ASSISTED LEARNING ON SKILLS ACQUISITION AND CONFIDENCE

## BACKGROUND

### *Establishing 'Best Practices' for Implementation of Surgical Simulation Curriculums*

As discussed previously, there has been a significant drive to shift early surgical skill acquisition from the operating room into a more simulated environment. In response to this shift, a lot of work has been directed towards validation and testing of different instructional modules, task trainers and simulators of varying fidelities, and development of assessment methodologies to distinguish between learners and accurately gauge skill acquisition/clinical transfer. However, little progress has been done towards determining the best ways in which this information is disseminated; research is lagging on finding the optimal way in which training is delivered (i.e. how/how often/when/where). As a result, there are no established 'best practices' or standardized methods of disseminating simulation curricula for surgical residents. Although all programs are mandated to have a surgical simulation curriculum for their residents, execution and incorporation of simulation curricula is still varied and program-specific in the absence of a standardized method of implementation. Incorporating a new simulation-based curriculum is inherently challenging for a variety of reasons: the necessity of demanding an extra time commitment from work-overloaded residents and faculty, increasing costs and limited resources. Hence, determining which methods of curriculum implementation are most effective, cost and time-efficient ("best practices") is essential.

Limited prior research in comparing mode of delivery of educational content for procedural skills shows better skill acquisition through distributed practice (vs. mass practice) and better improvement with self-directed, repetitive practice, but no difference between lengths of training (3 weeks vs. 6 weeks), or interval between practice schedules (weekly vs. monthly) [19-22]. Studies evaluating long-term skill retention showed a decay in skills compared to post-test performance immediately after training [20,21].

*Peer-Assisted Learning (PAL) in surgical education*

Peer-Assisted Learning (PAL) is broadly defined as learning activities where people from similar social groupings—who are not professional teachers—help each other learn; this includes peer tutoring, feedback, observation, role playing, peer-facilitated discussions etc. The beneficial impact of same-level PAL ("Buddy System") in accelerated skill acquisition and better retention has been consistently proven in many studies assessing non-technical skills, resulting in its widespread employment in medical education [23]. However, similar strong evidence for psychomotor skills is lacking; studies evaluating generalizability of PAL to procedural skills are very few, and limited to very simple motor tasks [24-26]. To our knowledge, no prior studies have evaluated the impact of a PAL-based simulation curriculum in the acquisition of complex surgical skills such as a vascular anastomosis procedure. To this effect, we aim to compare the impact of same-level PAL versus solo learning on skill acquisition and participant confidence, while using our simulated vascular surgery curriculum (specifically, an end-to-side anastomosis procedure) as the skill being taught. We hypothesize that participants learning with a same-level peer ("buddy system") while utilizing PAL techniques such as roleplaying and providing peer feedback will show higher improvement in skills and self-perceived confidence compared to those who practice independently.

## METHODS

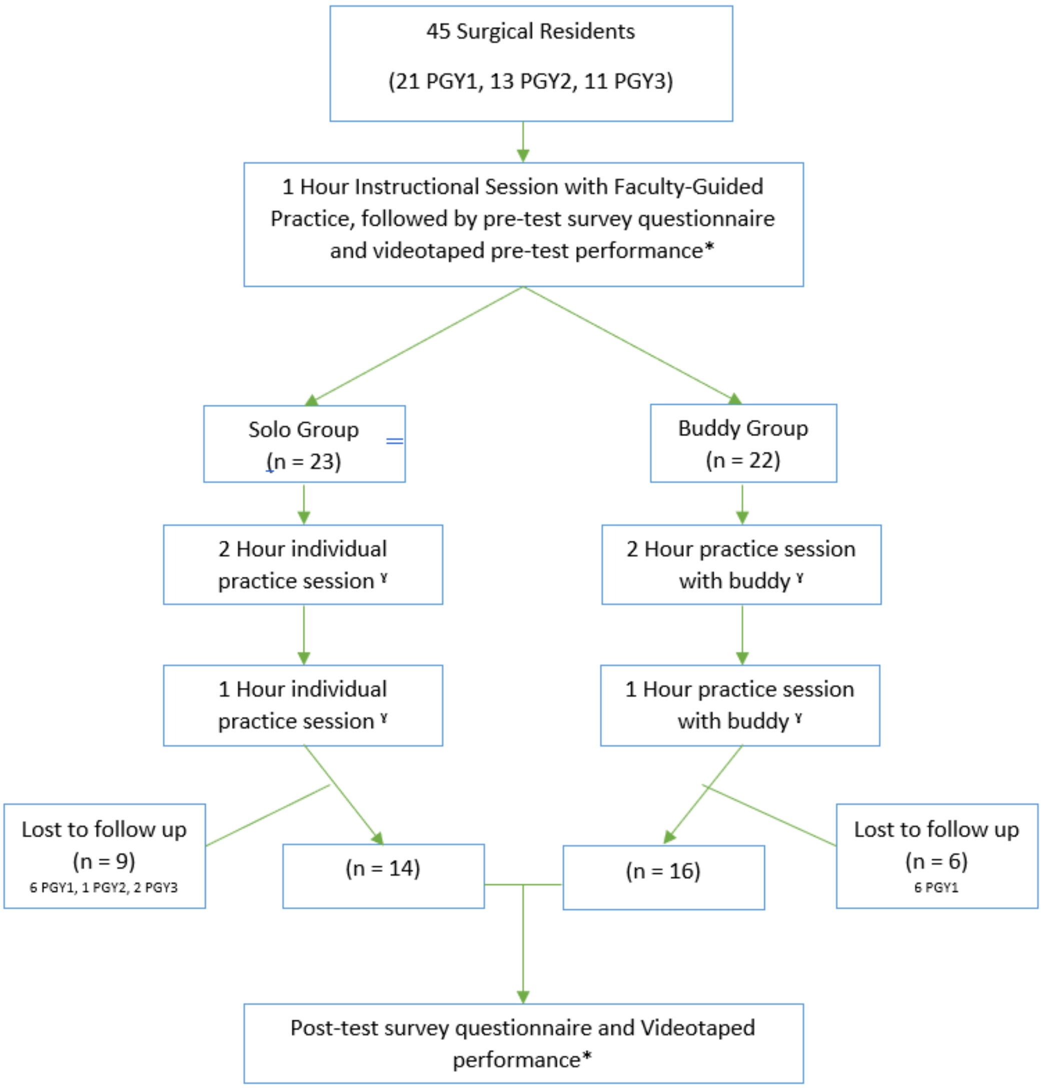



*Figure 5. Consort diagram for Solo vs. PAL study.*

**Videotaped performances were evaluated by 2 expert vascular surgeon faculty who were blinded to learner, test and randomization.*

*ᵞ Vascular surgery faculty were present at all practice sessions to teach the curriculum in a standardized manner and provide guidance.*

*Participants*

The study received approval from the Institutional Review Board (IRB) at the UT Southwestern Medical Center. Forty-five general surgery residents (21 PGY1, 13 PGY2, 11 PGY3) volunteered to participate in the study. All learners filled out a survey questionnaire to determine baseline confidence and prior exposure to the vascular anastomosis procedure.
For randomization, learners were stratified according to their post-graduate levels and randomized via a computerized method into one of 2 groups: Solo Learning (n = 23) and Peer-Assisted Learning (n = 22).

*Training Conditions and Instructional Materials*

The training was divided into 4 sessions:

· Session 1: Instructional session (1 hour) + Pre-test videotaping/survey

Prior to randomization, all participants received an hour-long instructional session, which consisted of watching the video and performing the hands-on procedure in conjunction with the vascular faculty. At the end of the session, participants recorded their videotaped pre-intervention performance.

· Session 2: Hands-on Practice time (2 hours)

Prior to this session, learners were randomized into Solo or PAL groups. While Solo group learners practiced independently on their task trainer, PAL group were assigned to share a task trainer with another learner of the same PGY level. PAL group was instructed to practice their skills in collaboration, role-playing "primary surgeon" and "first assist" roles, while alternating these roles for equal time spent in each role. The “first assist” was instructed to provide his/her “primary surgeon” with immediate, explicit verbal feedback and assistance while the “primary surgeon” performed the procedure.

- Session 3: Hands-on practice time (1 hour) + Post-test videotaping/survey

This session was structured identically to session 2 (hands-on practice time for both groups where Solo group practiced individually while PAL group practiced with their assigned buddies). At the end of this session, all learners recorded a videotaped post-test performance and filled out a post-test survey questionnaire.

Of note, all learners received identical instructional materials (written instructions, instructional video and same low-fidelity task trainers as detailed in Chapter 2); total time allocated for the curriculum was also identical between groups. Vascular surgery faculty were present at all the practice sessions for guidance/direction and were instructed to allocate their time approximately equally between both groups.

*Training Logistics*

As detailed above, the planned curriculum required a time commitment of ~4 hours per learner; this was similar to the practice time required to reach proficiency in prior research studies consisting of a simulated open vascular anastomosis procedure. Additionally, since prior studies showed better skill acquisition through distributed practice vs. mass practice, this instructional time is divided over 3 sessions. Interval time between sessions was shown to be irrelevant for skill acquisition, and hence, we were flexible in this aspect, which was eventually dictated by resident schedule and availability (we did strictly keep time intervals identical between all learners—2 weeks between sessions—to avoid confounding our results).

*Outcome Measures*

As mentioned previously, videotaped performances were recorded pre- and post-intervention. These were evaluated by two expert raters (vascular surgery faculty) blinded to randomization group, postgraduate level and test (pre-test or post-test).

Our outcome measures were as follows:

1. Previously validated Verification of Proficiency assessment (Figure 2), consisting of:
    a. Checklist Score (Max Score of 8)
    b. Global Rating Score (Likert 1-5) for economy of time and motion
2. Time Taken for Completion (mins; measured as time interval between picking up the first surgical instrument to completion of the last knot)
3. Self-reported Confidence (Likert 1-5; reported on survey questionnaires)

*Statistical Analysis*

Differences between demographic variables between Solo and PAL groups were calculated using Chi-Squared tests (for categorical variables) and ANOVA tests (for continuous variables). Given non-parametric distribution of data, Mann-Whitney U test was used to calculate differences between Solo and PAL groups. Comparison of pre-test and post-test outcomes for learners was performed using Wilcoxon signed-rank test. Inter-rater reliability was calculated using Intra-Class Coefficient (ICC). All tests were performed at the 5% significance level with SPSS software (Version 25 for Windows). Statistical analysis was performed using the Intention to Treat principal.

## RESULTS

### *Interrater Reliability*

Interrater Reliability for the 2 expert evaluators, as measured by Intra-Class Coefficient, was 0.86 and 0.83 for Checklist and Global Rating Scale outcome measures respectively. Given the excellent interrater reliability, only one evaluator's scores were used to perform the statistical analysis.

### *Comparison of Baseline Demographics and Outcome Measures between Groups*

Both Solo and PAL groups were well matched at baseline. There were no significant differences in baseline demographic characteristics or prior exposure to the procedure between Solo and PAL groups (Table 1). In addition, there was no significant difference in pre-intervention outcome measures between both groups: Checklist scores ($p = 0.76$), Global Rating Scale ($p = 0.17$), self-reported confidence ($p = 0.38$), or time to completion ($p = 0.83$).

*Table 1. Comparison of demographic characteristics and prior experience between Solo and PAL groups.*

| | Solo Group (n = 23) | Buddy Group (n = 22) | p-value |
|---|---|---|---|
| Post-Graduate Year, n (%) | | | 0.908 |
| PGY1 | 11 (47.8) | 10 (45.5) | |
| PGY2 | 7 (30.4) | 6 (27.3) | |
| PGY3 | 5 (21.7) | 6 (27.3) | |
| Sex, n (%) | | | 0.335 |
| Male | 8 (34.8) | 10 (45.5) | |
| Female | 15 (65.2) | 12 (54.5) | |
| # of vascular anastomosis observed, Median (SD) | 4 (9.6) | 5.5 (11.4) | 0.266 |
| # of vascular anastomosis performed, Median (SD) | 2 (9.9) | 3.5 (7.7) | 0.928 |

*Comparison of Pre-test to Post-test Outcome Measures*

There was statistically significant improvement in checklist scores ($p < 0.001$), global rating scale ($p = 0.01$) and self-perceived confidence ($p < 0.001$) from pre- to post-intervention for all learners (as anticipated). In contrast, time taken for anastomosis completion was not significantly different between pre- and post-intervention performances ($p = 0.64$). There was a general tend towards increased time to completion for solo group and decreased time to completion for PAL group, but none of these trends were statistically significant.

*Comparison of Post-test Outcome Measures between Groups*

When evaluating post-test performances, there was a significant difference between global rating scores ($p = 0.02$) and time to completion ($p = 0.01$) between Solo and PAL groups. There was no difference between checklist scores and self-reported confidence between both groups ($p = 0.34$ and 0.25 respectively).

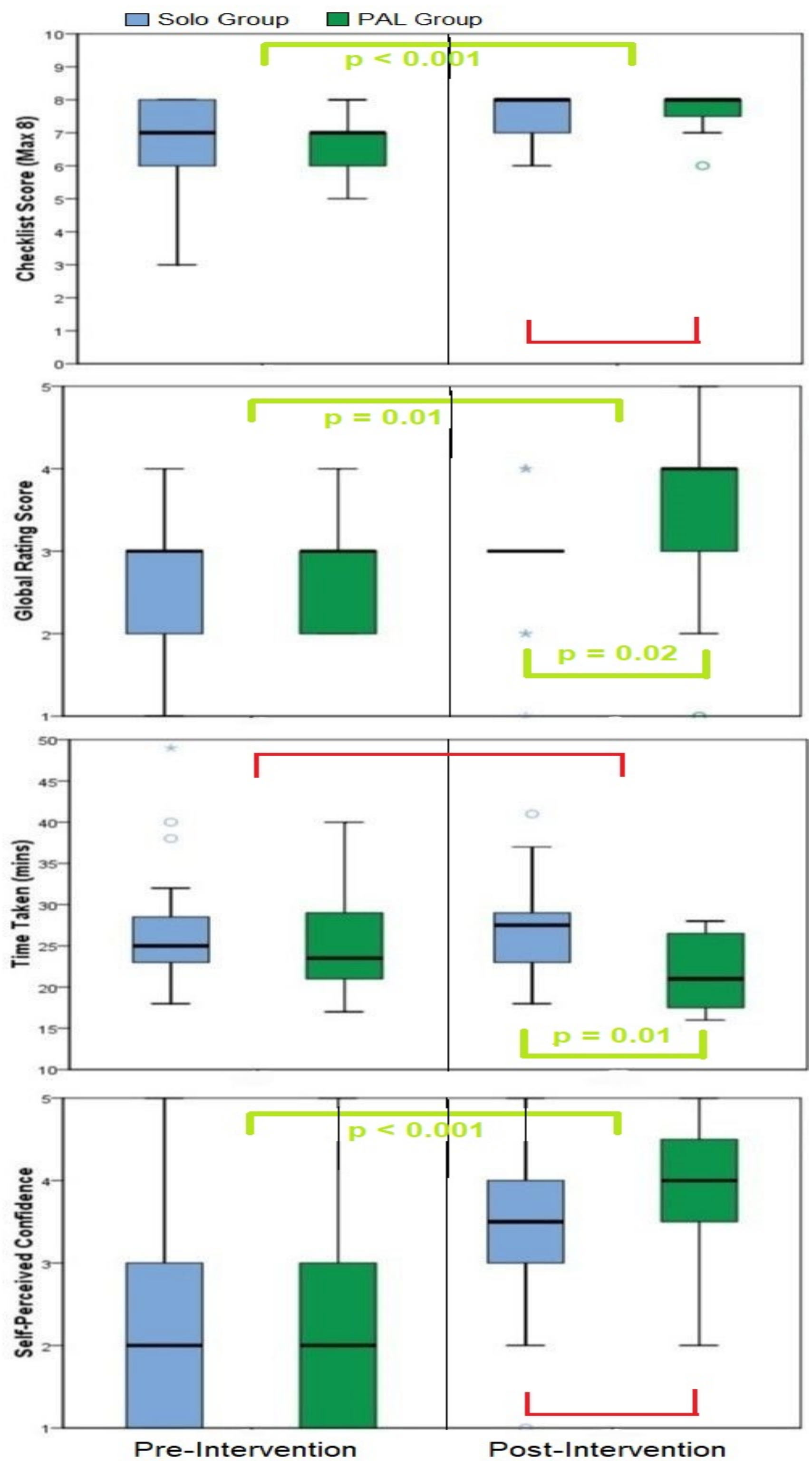



*Figure 6. Box plots of all outcome measures. The bar represents the median, the box 25th to 75th percentile, and the whiskers the range of data. Pre- and post-intervention scores are plotted for checklists, global ratings, time taken and self-reported confidence for Solo (blue) and PAL*

*(green) groups. Significant differences between groups ($p < 0.05$) are highlighted green, and non-significant differences are highlighted in red.*

*Learner Survey Responses for the Instructional Video and Overall Curriculum*

Post-test survey questionnaires were completed by 33 residents. Overall participant ratings were positive for the instructional video and overall curriculum (Figures 7 and 8).

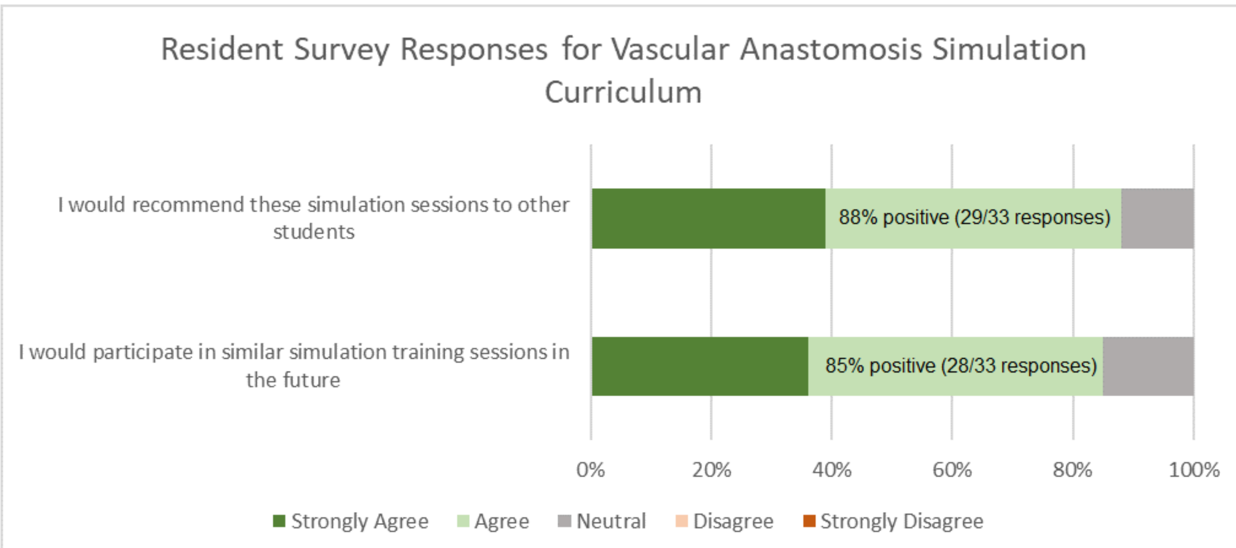



*Figure 7. Resident survey responses for vascular anastomosis simulation curriculum (n = 33).*

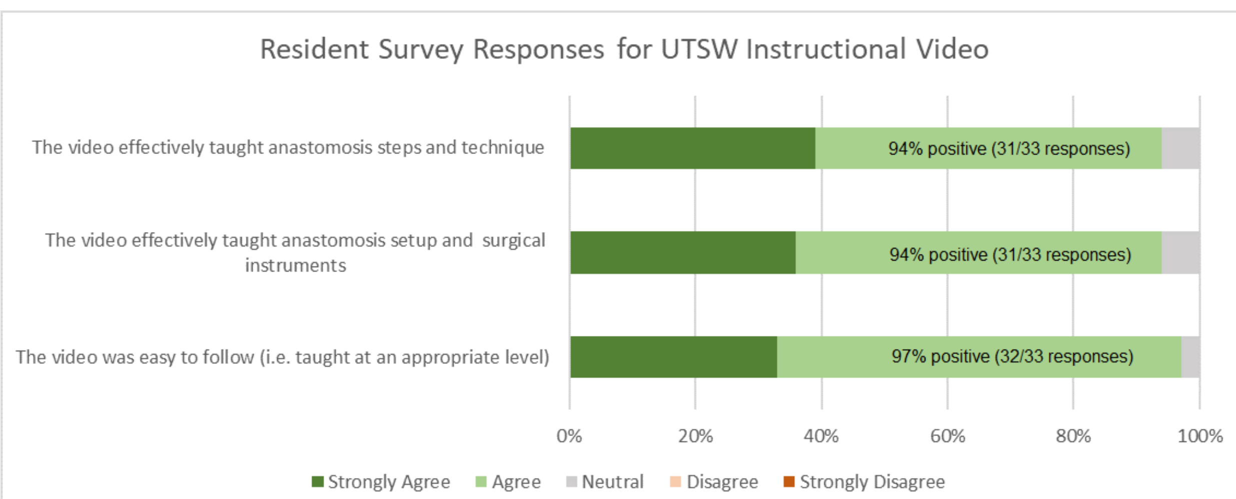



*Figure 8. Resident survey responses for instructional video.*

# DISCUSSION

Our results demonstrate that learners randomized into Peer-Assisted Learning (PAL) group showed better skill acquisition, as measured by their significantly higher global rating scale scores and lower time taken for completion, in comparison to solo learners. To our knowledge, this is the first study to generalize beneficial impacts of PAL to surgical skill acquisition. Although PAL has been extensively—and repeatedly—shown to have better skill acquisition for non-technical skills such as history-taking, motivational interviewing, problem-based learning, communication skills training etc., there are some inherent differences in skills with psychomotor components that might present generalizability challenges. For instance, learning with a peer directly impacts (shortens) the amount of hands-on practice time for the learner, reducing the opportunity for repetitive hands-on practice, going directly against principal components of deliberate practice. In addition, there is a risk of receiving inaccurate feedback from a same-level peer and incorporating/solidifying these mistakes through repetition for technical/procedural skills. On the other side, PAL offers benefits such as conjoined problem solving, more abundant (and timelier) feedback compared to faculty oversight, better camaraderie and task engagement, the added perspective of observing a peer on the same learning curve perform the procedure and providing peer feedback resulting in better personal understanding of the task, emphasis on co-operative learning which is similar to real-life operating room conditions etc. Our results would suggest that the disadvantage of having less individual hands-on practice time and possibility of receiving inaccurate feedback are outweighed by the advantages presented by PAL resulting in better skill acquisition compared to solo learning.

*Explaining Differing Results in Checklists and Global Rating Outcome Measures*

Although post-intervention global ratings were significantly higher in PAL learners compared to solo learners as hypothesized, post-intervention checklist scores did not differ significantly between both groups, contrary to our initial hypothesis. However, there are several explanations for these findings. Firstly, the median post-intervention checklist score for both groups was 8 (which is also the maximum possible score for this outcome measure); hence, it is likely that both groups were maxed out on this outcome measure after ~4 hours of deliberate practice, and there was no scope to detect further differences beyond a certain point. Secondly, checklist scores and global rating scales are fundamentally different outcome measures. While checklists are binary evaluators of surgical maneuvers (i.e. whether a particular task was performed or not), global rating scales are more holistic evaluators of surgical behaviors (i.e. how well the procedure was performed). Prior studies have shown that global rating scales have a higher construct and concurrent validity in comparison to checklists, and they are much better differentiators of performance levels [18]. In addition, checklists have erroneous weightage for complex procedures such as ours. For instance, the same weightage of 1 point is allocated to 'cutting end of graft into a spatulated shape' and 'completing entire back wall of the anastomosis with all suture bites approximately ~1 mm apart'. For these reasons, even though checklists add value in terms of offering high inter-rater reliability, ability to measure drastic changes in performance with added practice (like charting pre-test vs post-test improvement), and providing the learner with more explicit feedback on exactly what part of the procedure is missing or requires additional practice, global ratings are much more adept at differentiating between performances (especially with maturing skills since learners max out on their checklist scores).

*Addressing Trends in Time to Completion (mins)*

For this outcome measure, our results are not consistent with most other studies involving surgical task acquisition, which generally show that learners with better acquisition (i.e. better scores) take less time. Time to completion is a widely used outcome measure for surgical skill acquisition and retention [11,14,]. It is well regarded that with added practice, decreased time is not a reflection of haste but economy of time and motion. Instead of observing a consistent, linear, inversely proportional relationship between checklist/global ratings and time as prior studies, our data showed a more inconsistent, parabolic relationship instead. In our case, the *worst and the best* scores took the least amount of time for completion.  One explanation is that the previous trials were studying simpler/quicker tasks such as knot tying, suturing, fundamental laparoscopic/endoscopic skills where time taken is measured in seconds; vascular anastomosis might be a more lengthy and complex psychomotor task consisting of multiple components where median time taken for completion was 25-30 minutes in comparison.

*Limitations and Opportunities for Improvement*

As previous studies demonstrate, the ultimate value of an intervention is not determined by performance measured immediately post-training, but after a time delay (i.e. by measuring retention weeks or months post-training). To this effect, given our promising results, future studies can study skill retention/decay as well as clinical transfer which were beyond the scope of our study.

Although research shows that lower-fidelity is sufficient for early learners, more clinically relevant outcome measures can be added for PGY3s such as assessment of patency of the anastomosis, anastomotic narrowing, and bleeding time post-completion for more meaningful endpoints, more sophisticated practice, and nuanced feedback. Additionally, hand motion analysis can be used as an outcome measure to objectively track economy of motion, especially given that our time taken to completion did not provide results consistent with previous studies for this complex task.

A total of 15 participants (9 Solo and 6 PAL learners) were lost to follow-up, and did not finish the post-test at the end of 3 practice sessions (Figure 5). Although the number of participants lost to follow up is roughly similar in both groups, this is a higher attrition rate compared to other studies, even after factoring in the distributed practice study design where participants are expected to voluntarily attend multiple sessions which typically (expectedly) have higher attrition. Our attrition rate includes 3 videotaped performances that remained ungraded by the expert evaluators because of poor quality/visibility. In addition, because of manpower limitations, individualized make-ups and customized testing timelines could unfortunately not be provided for learners who were unable to attend secondary to being post-call, on vacation or sick leave etc.

### *Implications for Clinical Practice*

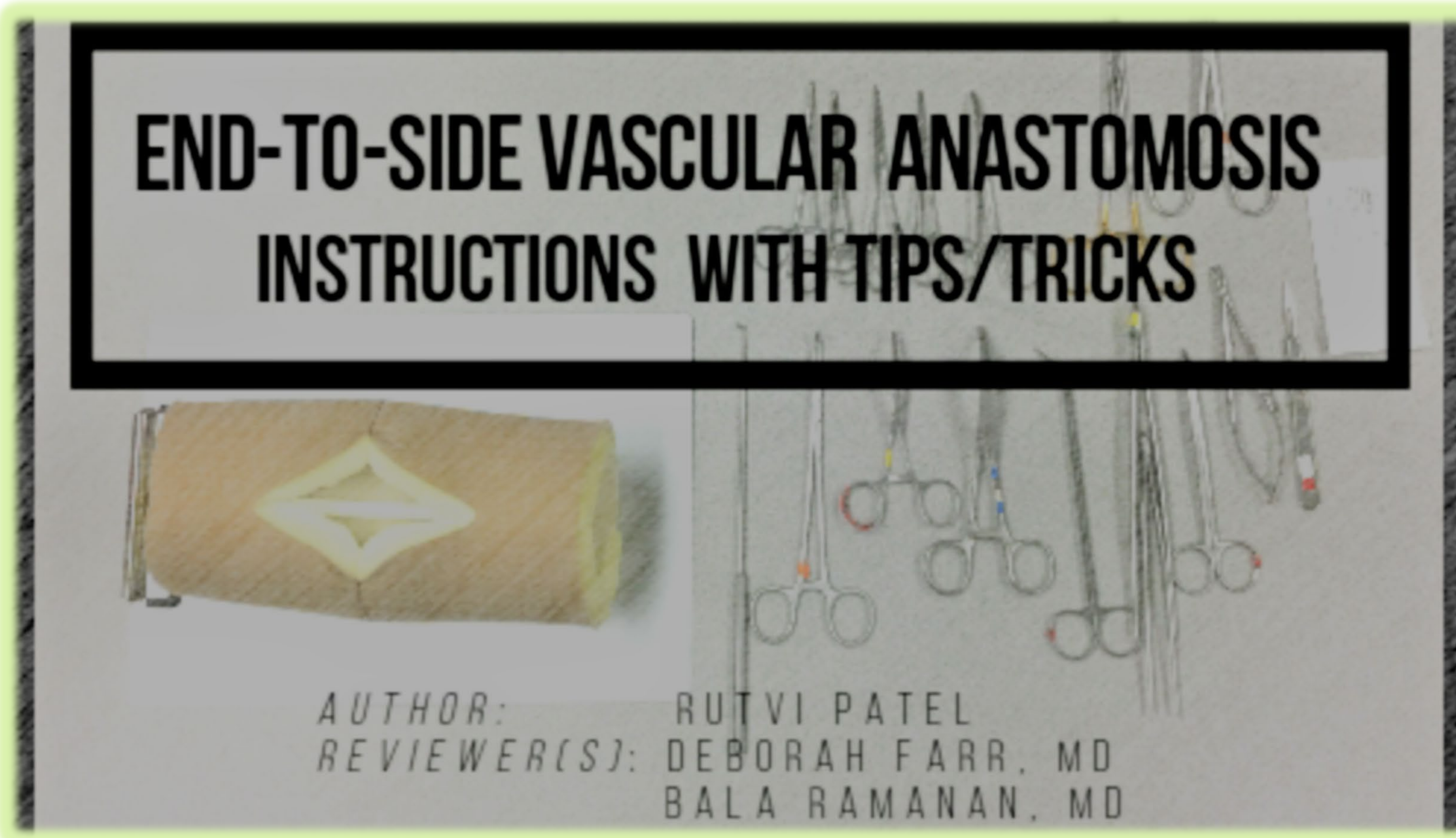
Given the resource-limited nature of surgical education (work-overloaded faculty/residents and ACGME-hour restrictions, cost-limitations) and lack of standardization in implementation of surgical simulation curriculums, there is a need for more research geared towards establishing best practices for dissemination. Our study shows promising results of enhanced skill acquisition for peer-assisted learning in comparison to solo/conventional learning which is currently the predominant method of dissemination for simulation curriculums geared towards novice surgical residents. Our results are relevant to the design of future surgical simulation skills-based curricula since they introduce a new variable to the delivery of educational content for teaching surgical skills: buddy practice. Peer-assisted learning might be a better, and more cost- and time-effective alternative to conventional solo-learning methods that are the predominant means of surgical skills training today.

REFERENCES


1. Sadaba JR, Urso S. Does the introduction of duty-hour restriction in the United States negatively affect the operative volume of surgical trainees? *Interactive CardioVascular and Thoracic Surgery*. 2011;13(3):316-319.
2. ACGME Home. ACGME Home. http://www.acgme.org/. Accessed February 15, 2017.
3. Bath J, Lawrence P. Why we need open simulation to train surgeons in an era of work-hour restrictions. *Vascular*. 2011;19(4):175-177.
4. Schanzer A, Steppacher R, Eslami M, Arous E, Messina L, Belkin M. Vascular surgery training trends from 2001-2007: A substantial increase in total procedure volume is driven by escalating endovascular procedure volume and stable open procedure volume. *Journal of Vascular Surgery*. 2009;49(5):1339-1344.
5. Zendejas B, Brydges R, Hamstra SJ, Cook DA. State of the Evidence on Simulation-Based Training for Laparoscopic Surgery. *Annals of Surgery*. 2013;257(4):586-593.
6. Dawe SR, Pena GN, Windsor JA, et al. Systematic review of skills transfer after surgical simulation-based training. British Journal of Surgery. 2014;101(9):1063-1076.
7. Singh S, Sedlack RE, Cook DA. Effects of Simulation-Based Training in Gastrointestinal Endoscopy: A Systematic Review and Meta-analysis. Clinical Gastroenterology and Hepatology. 2014;12(10).
8. ACS/APDS Surgery Resident Skills Curriculum. American College of Surgeons. https://www.facs.org/education/program/resident-skills. Accessed February 15, 2017.
9. Anastakis DJ, Regehr G, Reznick RK, Cusimano M, Murnaghan J, Brown M, et al. Assessment of technical skills transfer from the bench training model to the human model. *Am J Surg* 1999;177:167-70.
10. Matsumoto ED, Hamstra SJ, Radomski SB, Cusimano MD. The effects of bench model fidelity on endourological skills: a randomized controlled study. *J Urol* 2002; 167:1243-7.
11. Wilasrusmee C, Phromsopha N, Lertsitichai P, Kittur DS. A new vascular anastomosis model: relation between outcome and experience. *J Thoracic Cardiovasc Surg*. 2010;139: 1275-81.
12. Hance J, Aggarwal R, Stanbridge R, Blauth C, Munz Y, Darzi A, et al. Objective assessment of technical skills in cardiac surgery. *Eur J Cardiothoracic Surg*. 2005; 28: 157-62.
13. Pandey VA, Wolfe JH, Lindahl AK, Rauwerda JA, Bergqvist D. Validity of an exam assessment in surgical skill: EBSQ-VASC pilot study. *Eur J Vasc Endovasc Surg*. 2004; 27:341-8.
14. Datta V, Mandalia M, Mackay S, Chang A, Cheshire N, Darzi A. Relationship between skill and outcome in the laboratory-based model. *Surgery*. 2002; 131:318-23.

15. Sanfey, Hilary, and Gary Dunnington. Verification of Proficiency: A Prerequisite for Clinical Experience. *Surgical Clinics of North America*, vol. 90, no. 3, 2010, pp. 559–567.
16. Sanfey, Hilary, et al. Verification of Proficiency in Basic Skills for Postgraduate Year 1 Residents. *Surgery*, vol. 148, no. 4, 2010, pp. 759–767.
17. Kopta JA. An approach to evaluation of operative skills. Surgery 1971;70: 297–303.
18. Regehr G, MacRae H, Reznick RK, et al. Comparing the psychometric properties of checklists and global rating scales for assessing performance on an OSCE format examination. *Acad Med* 1998;73:993–7.
19. Moulton C-AE, Dubrowski A, Macrae H, Graham B, Grober E, Reznick R. Teaching Surgical Skills: What Kind of Practice Makes Perfect? *Transactions of the Meeting of the American Surgical Association*. 2006;124:66-75.
20. Robinson WP, Schanzer A, Cutler BS, et al. A randomized comparison of a 3-week and 6-week vascular surgery simulation course on junior surgical residents' performance of an end-to-side anastomosis. *Journal of Vascular Surgery*. 2012;56(6):1771-1781.
21. Mitchell EL, Lee DY, Sevdalis N, et al. Evaluation of distributed practice schedules on retention of a newly acquired surgical skill: a randomized trial. *The American Journal of Surgery*. 2011;201(1):31-39.
22. Price J, Naik V, Boodhwani M, Brandys T, Hendry P, Lam B-K. A randomized evaluation of simulation training on performance of vascular anastomosis on a high-fidelity in vivo model: The role of deliberate practice. *The Journal of Thoracic and Cardiovascular Surgery*. 2011;142(3):496-503.
23. Tai J, Molloy E, Haines T, Canny B. Same-level peer-assisted learning in medical clinical placements: a narrative systematic review. *Medical Education*. 2016;50(4):469-484.
24. Demaria S, Berman DJ, Goldberg A, Lin H-M, Khelemsky Y, Levine AI. Team-based model for non-operating room airway management: validation using a simulation-based study. *British Journal of Anaesthesia*. 2016;117(1):103-108.
25. Milani BY, Majdi M, Green W, et al. The Use of Peer Optic Nerve Photographs for Teaching Direct Ophthalmoscopy. *Ophthalmology*. 2013;120(4):761-765.
26. Bruwaene SV, Win GD, Miserez M. How much do we need experts during laparoscopic suturing training? *Surgical Endoscopy*. 2009;23(12):2755-2761.

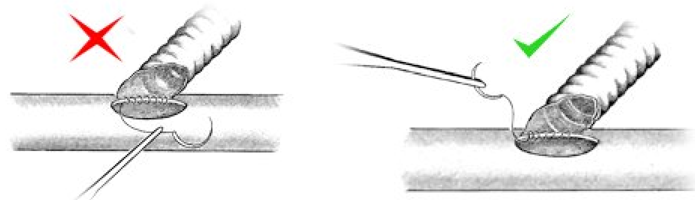
APPENDIX A: WRITTEN INSTRUCTIONS



## END-TO-SIDE VASCULAR ANASTOMOSIS INSTRUCTIONS (WITH TIPS AND TRICKS)

### General Tips:

- ☐ Never grasp the monofilament suture between forceps (this damages the suture).



- ☐ Grasping the needle with fingers (vs. forceps) for loading onto on the needle driver is acceptable.
- ☐ Vessels are delicate and easier to damage compared to other tissues, so handle them gently and cautiously. Avoid grasping them harshly between forceps!
- ☐ When suturing arteries, always take needle bites *"inside out"* to prevent dissection and plaque dislocation. Here, we will treat the native vessel on our simulation model as an artery. Remember, ***native vessel = artery = inside out directionality*** of needle bites. Consequently, needle bites on the vascular graft will be *"outside in"*.

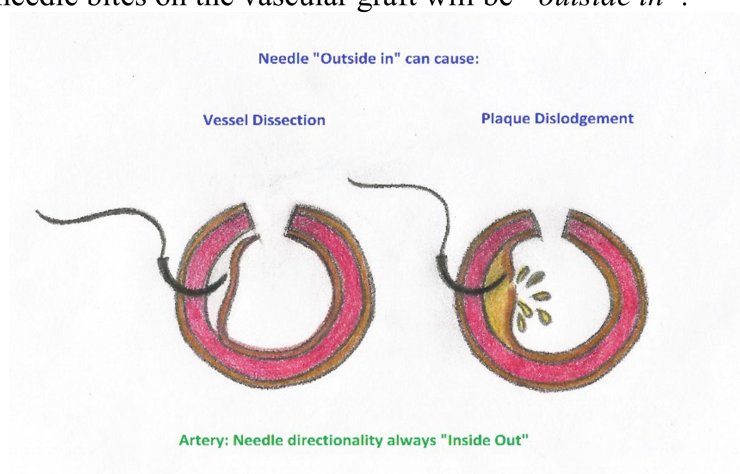



*Figure 9. Complications of 'Outside In' bites in arteries*

- ☐ The goal is to create an **oval-shaped** anastomosis with an **everted** graft edge (using evenly spaced bites and evenly distributed tension).

### Arteriotomy

- ☐ Mark the length of the planned longitudinal incision (mid-line on the vessel's anterior surface**; incision length= 2x diameter** of vascular graft lumen)
- ☐ Lightly lift the anterior wall of the vessel with your non-dominant hand using the DeBakey forceps to separate it from the posterior wall (to **prevent back wall injury** from the blade incision)
- ☐ Bring the #11 blade down at a **45° angle** and pierce the vessel wall to enter the lumen. Extend the incision slightly further *without retracting the blade from the lumen*. A single-

sweep incision (avoiding blade retraction and re-incision) prevents creation of small bleeding holes in the vessel wall.

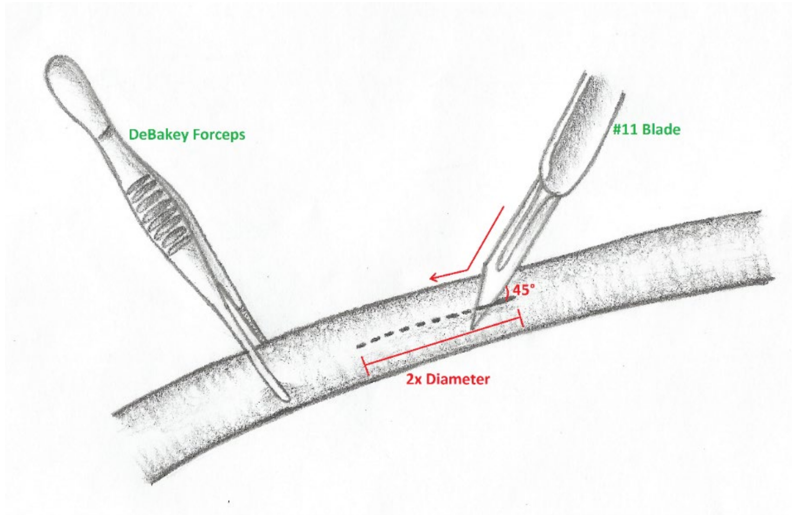



*Figure 10. Correct technique for initial incision*

- ☐ Extend arteriotomy with Potts scissors. Ensure that scissor blades stay in the *same plane as the extending incision (i.e. parallel to the vessel's longitudinal axis)*, taking care not to damage posterior vessel wall (see Figure 3 below).

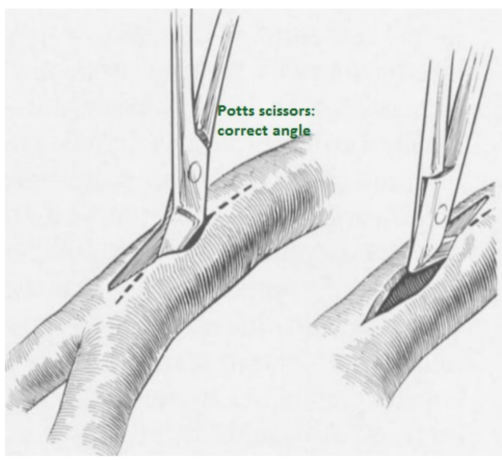



*Figure 11. Correct technique for arteriotomy extension*

**<u>Graft Preparation</u>**

- ☐ Graft edge should be the **same size/length** as the arteriotomy. *Flatten* the edge of the graft as much as possible by pressing firmly between fingers and mark the intended length/shape prior to cutting.

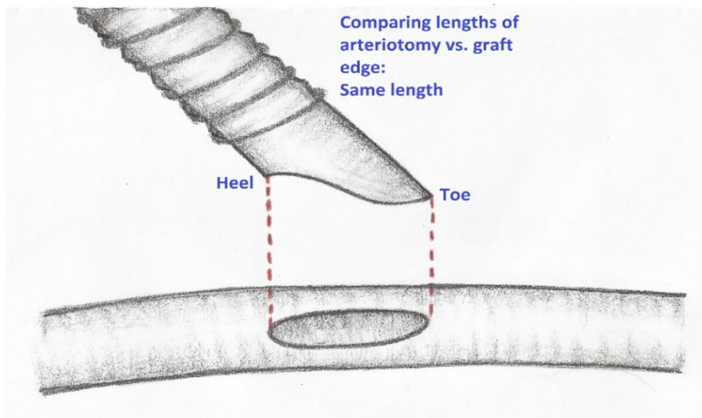



*Figure 12. Comparing length of arteriotomy vs. graft edge*

- If unsure, err on the side of a longer graft edge (can be adjusted later during the anastomosis) vs. a smaller graft edge.

☐ Create an **S-shaped incision** to avoid narrowing at the toe of the graft (see Figure 5 below). A wide, blunted toe ensures an oval-shaped anastomosis and decreased risk of stenosis at the heel and toe.

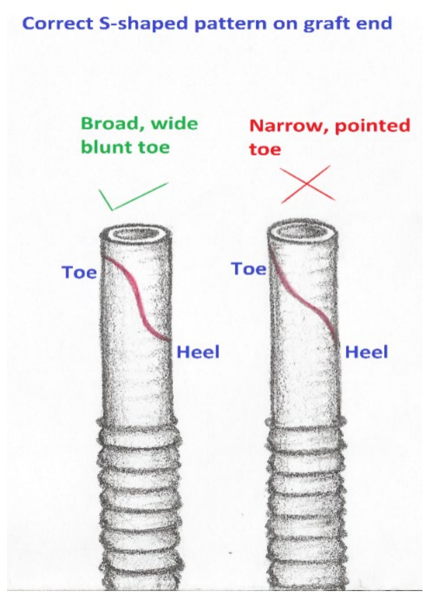



*Figure 13. S-shaped incision to achieve a wide, blunted toe*

**<u>Anastomosis</u>**

<u>General Tips and Technique</u>:

☐ Load needle at a **45° angle** with the needle-driver for maximum possible maneuverability.

☐ To take a bite, begin by **pronating** the needle-holder so that the needle will pierce the vessel/graft wall at a **90° angle**. Then drive the needle through the vessel wall by supinating the needle-holder (this **rotating wrist movement** is key to a smooth, atraumatic bite). Correct yourself/your buddy each time to ensure proper technique on every bite! Keeping the needle perpendicular to the vessel wall allows the curvature of the needle to traverse as atraumatically as possible, preventing oblique needle holes that bleed.

- ☐ Make sure each bite is in the intended position *before* piercing the graft. If a bite is placed in the incorrect position (i.e. too close or further away from the graft's edge than intended), continue with that bite vs. retracting and re-taking another bite. Graft is porous and has memory**;** any retracted holes will bleed.
- ☐ If you have an assistant, they should *"follow the suture"* to ensure that the trailing suture material is out of the way, avoiding tangles and maintaining even tension between suture bites (see Figure 6 below).

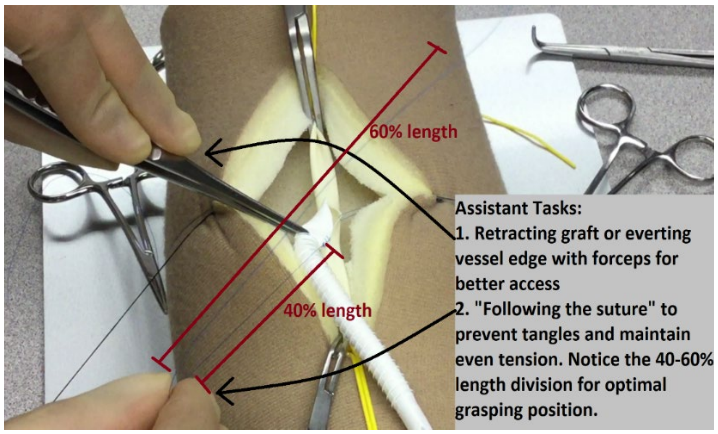



*Figure 14. Proper assisting technique*

Step-wise Tips and Technique:

- ☐ A roadmap for the anastomosis procedure is pictured below. Refer to the subsequent bullet points for more details on individual steps 1-4.

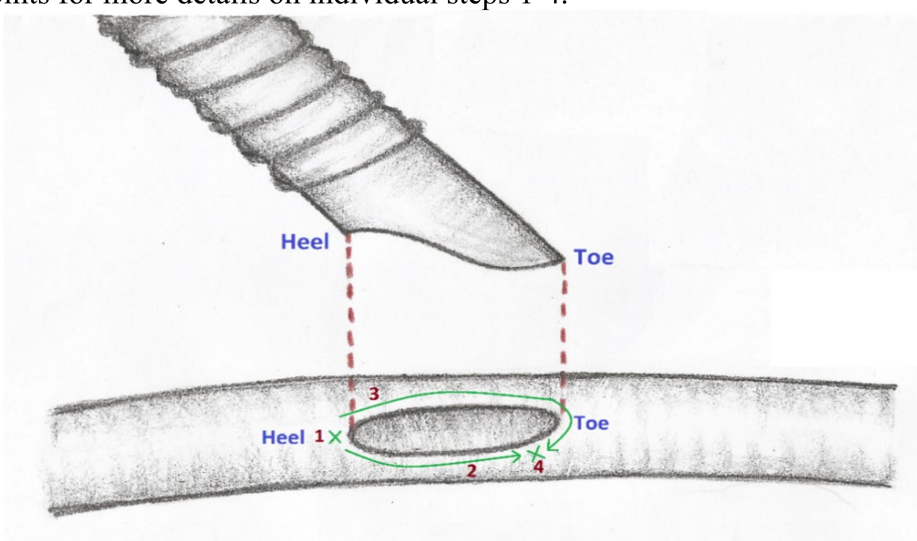



*Figure 15. Anastomosis Roadmap*

- ☐ **Step #1.** Secure graft to the vessel by placing 3 tight knots at the heel. This prevents purse-stringing of the anastomosis. Make sure both sides of the double-sided suture are approximately similar in length post knot-tying.

- Remind yourself and/or your buddy to place bites **inside out** on the artery (native vessel on simulation model) and **outside in** on the graft.

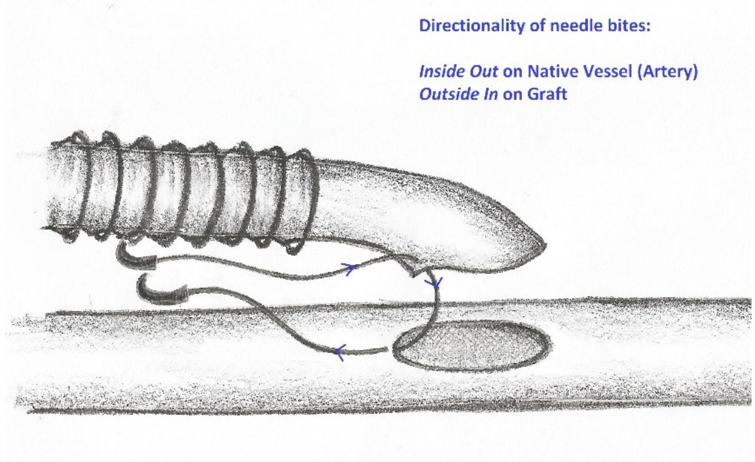



*Figure 16. Proper directionality of bites*

☐ **Step #2.** After securing the heel of the anastomosis, pick up one of the needles to complete ~2/3rds of one lateral wall for the anastomosis (refer to step 2 in Figure 7). Work your way from heel→toe with a continuous running suture, consistently placing bites ~1 mm apart (no strict requirement for number of bites on each side).

- Remind yourself/your buddy to place bites in a **radial fashion** (see Figure 9 below for radial vector directions of anastomotic bites; especially note the **4 diagonal corner bites placed at an exaggerated angle, further away from the edge compared to the other bites)**.

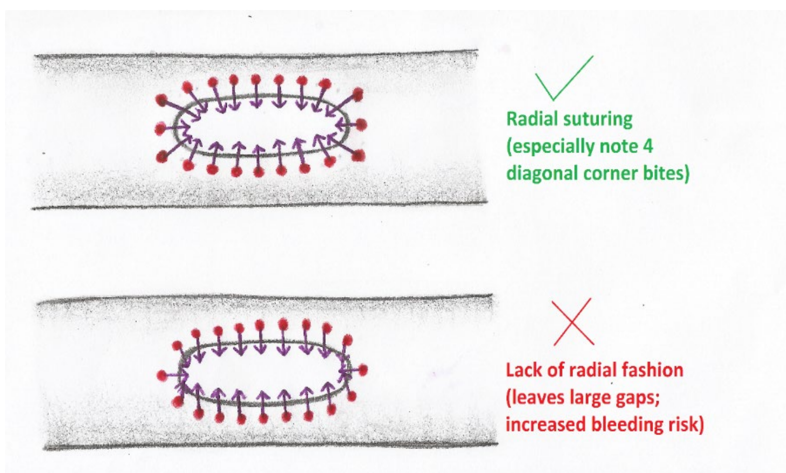
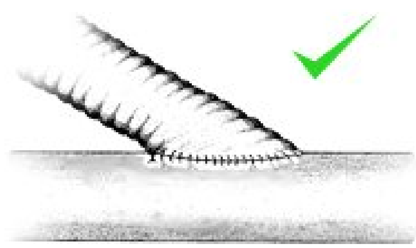



*Figure 17. Radial suturing*

- Make sure you/your buddy are ergonomically (and comfortably) positioned to enable smooth wrist rotation movements for effortless bites at a 90° angle in radial fashion. While keeping the simulation model fixed in place, position "the surgeon" facing perpendicular to the vector direction of each bite; if present, the assistant should always be directly facing the surgeon (vs. sideways).
- Half-way through this side wall, **compare size** of arteriotomy vs. graft. Trim toe of the graft to match arteriotomy size if needed.

- Stop suturing when you reach ~2/3rds the total length from heel→toe on this side.

- ☐ **Step #3.** Using the other needle-end of the double-sided suture, complete the other side of the arteriotomy, working from heel→toe in the exact same manner as step #2.
  - For this step, the "surgeon" can switch places with the assistant to continue forehand suturing, or remain in the original position for backhand suturing, depending on their comfort level. In either case, make sure directionality of bites (*inside out* on artery; *outside in* on graft) is maintained.
  - Continue placing bites, working around the toe, until you reach the other side of the anastomosis (i.e. your endpoint for step #2). You should end up with both sides of the double-sided suture *near* the toe of the anastomosis (not *exactly* at the toe, but off-set towards one lateral side, as shown in Figure 7).
- ☐ **Step #4.** Use a nerve hook to evert graft edge and adjust the suture line for evenly distributed tension between bites (even traction, no loose loops). Tie 8-10 knots before cutting the suture 1.5 cm away to prevent unraveling of the knots.
  - The toe tends to be the most vulnerable part of the anastomosis (i.e. the area most likely to leak; hard to fix) and hence, tying a knot at the toe is not preferred. Instead, knots should be tied on lateral sides of the vessel wall. In our case, suturing uneven lengths on either lateral side (steps 2 & 3) ensures that this final knot is off-set on a lateral side vs. directly at the toe of the anastomosis.
- ☐ Inspect posterior wall for injuries.



THE END!

VITAE

Rutvi Patel (July 30th 1992-present) grew up in India and graduated Summa Cum Laude from The University of Pittsburgh with a B.S. in Biological Sciences and B.A. in Sociology. She attended medical school at University of Texas Southwestern Medical Center, where she was drawn to surgical education and curriculum development because it was a combination of her previous backgrounds and interests: education, surgery and arts. This project enabled her to spend time creating hand-drawn illustrations, rehearse videography skills, spend one-on-one time with faculty and skills coaches practicing surgical skills, and find mentorship in the field of surgery,  all while creating a resident simulation curriculum!