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Original Article

Original Homebuilt Off-the-Job Training System for Vascular Surgeons: System Analysis and Assessment

Jun Nitta, MD, Takafumi Akai, MD, PhD, Kazuhiro Miyahara, MD, Kazumasa Hanada, MD, and Katsuyuki Hoshina, MD, PhD

Objective: We assessed the effectiveness and appropriateness of our original off-the-job training (Off JT) system using data acquired from recruited medical students and doctors.
Materials and Methods: We presented our original homebuilt Off JT system, which is simple and inexpensive. In our unique system, we performed anastomosis at the bottom of a plastic pot, which mimics the actual open surgical procedure at a deep site. There were four evaluation points: (A) operating time, (B) performance of anastomosis by semi-automatically analyzing the image with the coefficient of variation (standard deviation/length) of the "bite" and the "pitch," (C) scoring of the total surgical skill evaluated by the trainers according to the Operative Performance Rating System (OPRS), and (D) the relationship of these three factors (A, B, and C).
Results: The procedural time and coefficient of variation of the bite and pitch decreased and the OPRS score increased after training. There was a strong correlation between procedural time, anastomotic performance, and OPRS score.
Conclusion: The effectiveness of our original homebuilt system was shown by reduced procedural time, improved anastomotic quality, and increased OPRS score.

Keywords: off-the-job training, vascular surgeon, suture, anastomosis, simulation

Division of Vascular Surgery, Department of Surgery, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan

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Corresponding author: Katsuyuki Hoshina, MD, PhD. Division of Vascular Surgery, Department of Surgery, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
Tel: +81-3-5800-8653, Fax: +81-3-3811-6822
E-mail: hoppy-tky@umin.ac.jp

Introduction

Most surgical training systems are similar to an apprenticeship, and young surgeons have learned and improved their surgical skills mostly via on-the-job training (On JT) by their mentors. In fields, such as cardiovascular surgery and neurosurgery, where one small mistake can be fatal, On JT is a difficult concept. In addition, because the operative area is limited, less-experienced surgeons have fewer opportunities to operate than general surgeons; thus, they rely on off-the-job training (Off JT) systems or simulation items instead of undergoing On JT.[1–3] Although the vascular surgery field is broad and requires specific skills, relatively less-invasive procedures, such as arteriovenous (AV) fistula surgery for hemodialysis patients or high ligation of the varix in the lower extremities, is often performed by less-experienced doctors that provides them with some On JT opportunity.

In 2017, the Japanese Board of Cardiovascular Surgery announced that 30 h of Off JT experience will be required for new cardiovascular specialist applicants. Responding to this announcement and considering recent social requests, the Japanese Society for Vascular Surgery created the Off JT working group to create a new Off JT framework. Thus far, there has not been a versatile Off JT system that can be used in any institution with less-experienced surgeons. Therefore, in our department, we aimed to develop a simple, inexpensive Off JT system that can be used at any institution with medical students and less-experienced surgeons.

Methods

Homebuilt Off JT system

To evaluate the system, we selected anastomoses of the artificial graft/tube as the main training maneuver. In addition, we set up the procedure to limit the movement of the trainee's hand. To simulate the operative setting for vascular anastomosis, especially in the deep sites of the abdomen or popliteal fossa, we used a plastic pot with a

hole in the bottom in which the graft/tube was to be fixed (**Fig. 1**). The materials used in this system were purchased at 100-yen shops where almost all items can be bought for 100 Japanese yen. We created and uploaded videos of the method to YouTube with limited disclosure and narrated in Japanese. [(1) Creation version. https://youtu.be/xVuETCj2Kzc, (2) Practice version. https://youtu.be/0sKEfOPChLY].

Enrollment and training course

The study protocol was approved by the Institutional Research Ethics Committee of The University of Tokyo Hospital (No. 11567). We recruited medical students and doctors to participate in our training course using this Off JT system. We defined the sizes of grafts/tubes as large (14–20 mm in diameter), middle (6–8 mm), and small (1–3 mm). To determine the procedures' difficulty, we set up a simple anastomosis on a flat table for the basic procedure (1 point) and increased the degree of difficulty by 1 point each by adding a small tube/graft anastomosis and by performing the maneuver at a deep site (**Fig. 1**).

The enrolled trainees provided informed consent to participate in this study. They chose among three training courses, short (8 h), middle (16 h), and long (24 h), and prepared a training plan by combining types of anastomosis (1 point was converted to 0.5 h). Considering that the Off JT would be evaluated with the training time, we established the point system. First, the trainees received an orientation; during the training period, they were instructed about the procedure by the trainer (a vascular surgeon who had graduated at least 7 years previously).

Evaluation points (A–D)

Initially, the recruited trainees performed two types of anastomosis: large-to-large graft/tube and small-to-small graft/tube. (A) The operative time was measured before and after the training. (B) The anastomosed graft was evaluated by semi-automatically analyzing the image. We focused on the balance of the sutured threads; then we defined "bite" as the length of a stitch across the graft/tube and "pitch" as the interval between stitches (**Fig. 2**). The sutured graft/tube was sandwiched between transparent acrylic plates, and the image was captured two-dimensionally. After removal of the artifacts, we extracted the stitch lines and performed labeling, hue conversion, saturation, and smoothing processing (**Fig. 2**). We calculated the coefficient of variation (CV = standard deviation/length) to see balance of each stitches. (C) The procedure was evaluated by the trainers according to the Operative Performance Rating System (OPRS)[4] for the "creation of AV fistula." From the clinical assessment form, we selected five items that were relevant to our Off JT procedures: (1) suturing graft, (2) instrument handling, (3) respect for tissue, (4) time and motion, and (5) operative flow (**Table 1**). (D) We analyzed the relation of the two independent parameters, the operative time and performance of the anastomosis (CV of the bite and the pitch), and the OPRS score.

Statistical analysis

Statistical analysis was performed using JMP® 9.0 software (SAS Institute Inc., Cary, NC, USA) and Origin Pro2018b® software (Light Stone Corp., Tokyo, Japan). The categorical variables were expressed as numbers and percentages and the continuous variables as mean ± standard deviation or standard error. Group differences were evaluated

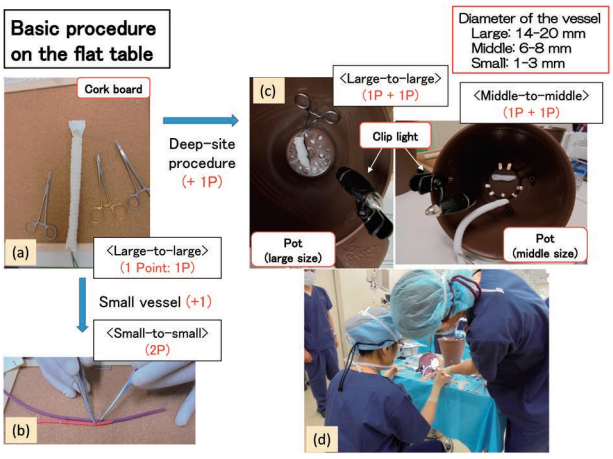


Fig. 1 Setup of the training system. (**a**) Basic procedure: anastomosis on the flat table. (**b**) Anastomosis of the small tubes. (**c**) Anastomosis at the deep sites. (**d**) Instruction by the trainers.

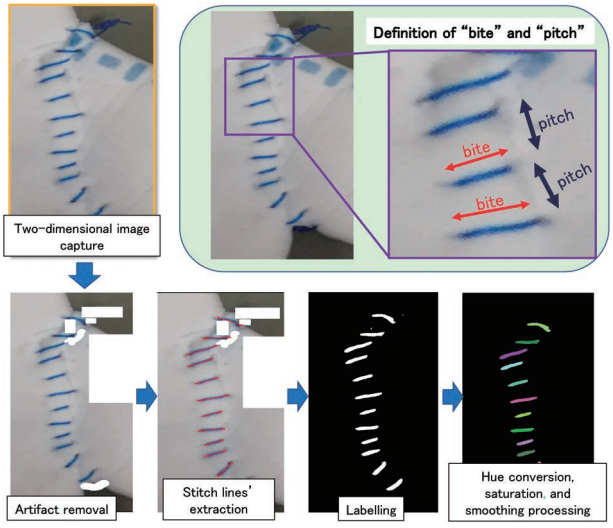


Fig. 2 The process of the segmentation processing and the definition of the bite and the pitch.

Table 1 Operative Performance Rating System as modified for this study (referred to the home page of the American Board of Surgery: http://www.absurgery.org/default.jsp?certgsqe_resassess)

1. Suturing graft				
Poor	Fair	Good	Very good	Excellent
1	2	3	4	5
Sutures from adventitia to intima on artery; inappropriate thickness/spacing of bites		Generally pierces graft and vessels at 90 degrees and passes from intimal surface out of artery		Independently sews with correct needle angle and at the correct orientation throughout the anastomosis
2. Instrument handling				
1	2	3	4	5
Tentative or awkward movements, *often* did not visualize tips of instrument or clips poorly placed		Competent use of instruments, *occasionally* appeared awkward or did not visualize instrument tips		Fluid movements with instruments *consistently* using appropriate force, keeping tips in view, and placing clips securely
3. Respect for tissue				
1	2	3	4	5
Frequent unnecessary tissue force or damage by inappropriate instrument use		Careful tissue handling, *occasional* inadvertent damage		*Consistently* handled tissue carefully (appropriately), minimal tissue damage
4. Time and motion				
1	2	3	4	5
Many unnecessary moves		Efficient time and motion, some unnecessary moves		Clear economy of motion, and maximum efficiency
5. Operative flow				
1	2	3	4	5
Frequent lack of forward progression; frequently stopped operating and seemed unsure of next move		Some forward planning, reasonable procedure progression		Obviously planned course of operation and anticipation of next steps

using the paired t-test for continuous variables with JMP® 9.0 software, and the correlation among the items using simple linear regression analysis with Origin Pro2018b® software. A p-value <0.05 was considered significant.

Results

Cohort 1

Among the 32 trainees who were recruited, we analyzed 19 cases with pre- and post-training data. The average training time was 12 ± 6.2 h (13 trainees for short, 3 for middle, and 3 for long courses). Seventeen participants were men, and two were women.

(A) Procedural time (time/1 stitch). We measured the anastomosis time and divided the time by the number of stitches (s). For small vessels, the procedural time significantly decreased (73 ± 5.9 vs. 51 ± 3.5 s, $p<0.0001$; pre-training vs. post-training). For large vessels, the time similarly decreased (60 ± 6.0 vs. 43 ± 3.7 s, $p=0.001$) (**Fig. 3**).

(B) Anastomosis quality (bite and pitch). The smaller value of CV means more appropriately balanced anastomosis. For small vessels, CV of the bite (0.29 ± 0.016 vs. 0.25 ± 0.011, $p=0.051$) as well as that of the pitch (0.30 ± 0.029 vs. 0.21 ± 0.012, $p=0.013$) of pre-training tended to decrease. For the large vessel, CV of the bite (0.31 ± 0.018 vs. 0.24 ± 0.016, $p=0.013$) as well as that of the pitch (0.32 ± 0.013 vs. 0.26 ± 0.011, $p=0.0014$) decreased (**Fig. 3**).

Cohort 2

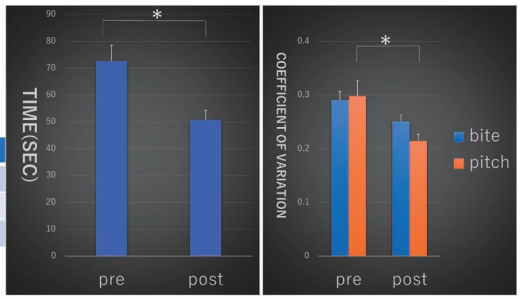
Among the trainees of Cohort 1, 11 cases had pre- and post-training OPRS data. The average training time was 12 ± 6.6 h. Ten participants were men, and one was a woman.

(C) OPRS. The total OPRS score increased after training. For small vessels, the score changed from 10 ± 1.5 to 16 ± 1.6 ($p=0.0002$), and for large vessels, the score increased, but not significantly, from 12 ± 2.1 to 16 ± 1.7 ($p=0.057$).

(D) Relationship of evaluation factors. To evaluate the anastomosis quality, we summed the CV value of bite and pitch. To determine the relationship between time, quality, and total evaluation, we three-dimensionally demonstrated the distribution of each value (**Fig. 4**). There was a significant correlation both for small vessels ($R^2=0.89462$) and for large vessels ($R^2=0.90002$) (**Fig. 4**).

Small vessel

Small vessel	Pre(Ave±SE)	Post(Ave±SE)	P-value
Time(sec)	73±5.9	51±3.5	<.0001
CV of bite	0.29±0.016	0.25±0.011	0.051
CV of pitch	0.30±0.029	0.21±0.012	0.013



Large vessel

Large vessel	Pre	Post	P-value
Time(sec)	60±6.0	43±3.7	0.0010
CV of bite	0.31±0.018	0.24±0.016	0.013
CV of pitch	0.32±0.013	0.26±0.011	0.0014

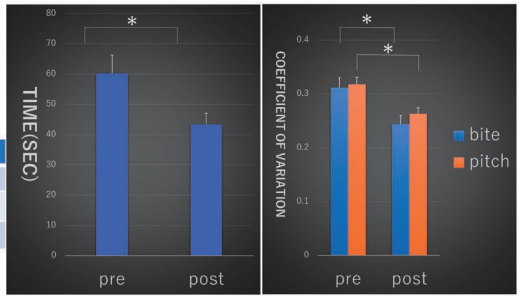
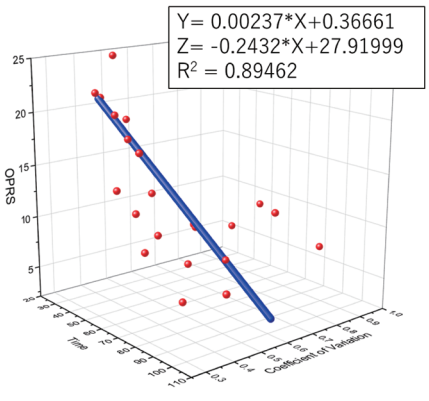


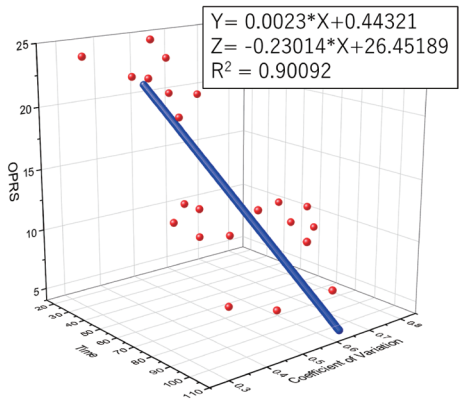
Fig. 3 Comparison of the time, the bite, and the pitch of pre- and post-training for both the small and large vessels.
CV: coefficient of variation; Ave: average; SE: standard error

Small vessel



Small vessel	pre	post	P-value
Time	70±6.2	53±4.3	0.0006
Total of CVs	0.59±0.060	0.44±0.023	0.022
OPRS	10±1.5	16±1.6	0.0002

Large vessel



Large vessel	pre	post	P-value
Time	63±7.6	45±5.1	0.018
Total of CVs	0.64±0.034	0.49±0.021	0.0031
OPRS	12±2.1	16±1.7	0.057

Fig. 4 The relationship between the time, the coefficient of variation (CV) of the bite and pitch, and the Operative Performance Rating System (OPRS).

Discussion

We developed a new Off JT system that is simple, inexpensive and can be used at any institution with medical students and less-experienced surgeons. The effectiveness and appropriateness of this system were confirmed by the learning curve, analysis of the anastomosis balance, and scoring by the trainers. In addition, we demonstrated the relationships among time, performance, and skill.

Specialized training is essential for professionals responsible for human life, such as a pilot. It is well known that pilots use simulators, which have reported to be useful and effective in improving their skills.[5] Recently, minimally invasive surgery, such as endovascular or laparoscopic surgery, has become more prevalent. New devices requiring more complicated operation procedures than those

used in an open surgery has motivated surgeons to use Off JT using simulators under specific circumstances. However, the increase in minimally invasive surgery reduces the chance for inexperienced surgeons to gain experience in open surgery.

Vascular surgeons still mostly perform open surgeries, even in the endovascular era; therefore, Off JT is necessary instead of traditional On JT. Recently, several authors have reported the effectiveness of simulation-based training systems.[6–9] However, Off JT simulators have not been widely available in most institutions. Therefore, the announcement made by the Japanese Board of Cardiovascular Surgery that Off JT will be mandatory for cardiovascular specialists was a recognition of a pressing need. We hope that our original, simple, and inexpensive system could be helpful.

In most Off JT studies, the training effectiveness has been demonstrated. Many objective assessments report skill improvement; however, the evidence level varies widely and is controversial.[10,11] OPRS has reportedly been found to be feasible, reliable, and valid.[4,12,13] Further details are available from the American Board of Surgery (http://www.absurgery.org/default.jsp?certgsqe_resassess). The assessment depends on an appropriate and realistic training system.[10,14] The OPRS score of the AV fistula version was thought to be suitable for our Off JT system, which basically consisted of graft anastomoses.

The procedural time is simple and easy to understand the indication of progress.[2,7] The quality of the anastomosis is another factor indicating skill improvement. To test the quality, the volume or degree of leakage was analyzed in some previous reports. However, it is difficult to quantify "leakage" because of differences in the graft/tube properties and needle thickness. Creating a system with loading pressure would require excessive time, space, and labor.[7,8,15,16] Our image-based analysis of the anastomosis—the balance of the stitch—requires image processing; however, it was able to illustrate the consistency of the repetitive anastomotic movement.

The most critical limitation of this study was the evaluation of the anastomotic stitches. We assumed that the length of the bites and the interval of the pitches should reflect the constant and stable balance of the anastomoses. However, the direction of the stitches should slightly change along the curved suture line. In addition, the balance of the visible thread might not necessarily coincide with that of the reverse side. With our method using CV, we might be able to evaluate only one aspect of the anastomotic balance. We believe that better, simpler, and easier methods should be developed.

The quality of education during the procedure is an important factor that might affect patient outcomes. At least one trainer was in attendance during the procedure. Initially, we thought that coaching was important, and we tried to ascertain how quality can be guaranteed. However, all the trainees were so engrossed in the anastomosis procedure that it resulted in the trainers providing a few technical tips per procedure. In addition, we had the impression that the instruction video we uploaded on YouTube could have reduced the burden of the trainers.

In this study, we found a strong correlation between the distribution of procedural speed and the quality and total evaluation of the skill (OPRS). Thus, for trained surgeons, procedural quality could correspond with procedural speed.

Conclusion

We presented a homebuilt, original Off JT system that is simple and inexpensive. The effectiveness of this system was shown by a reduction in the procedural time, improvement in the anastomotic quality, and increase in the OPRS score. There was a strong correlation between these factors.

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Disclosure Statement

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Author Contributions

Study conception: KHo
Data collection: TA, KM, KHa
Analysis: JN, TA
Investigation: KHo
Writing: JN
Critical review and revision: all authors
Final approval of the article: all authors
Accountability for all aspects of the work: all authors

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