The Use of a Low-Fidelity Simulator to Improve Vascular Anastomosis Skills of Residents during the COVID-19 Pandemic

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Background: To evaluate a workshop using a low-fidelity simulator for training vascular surgery residents in vascular anastomosis during the COVID-19 pandemic.
Design: Prospective, controlled, single-center.
Methods: Vascular surgery residents at the São Paulo University Medical School were enrolled in the COVID Group (five post graduation year 3 residents) or Control Group (five PGY-4 residents). The COVID Group was trained via a vascular anastomosis workshop. The residents were evaluated using Objective Structured Assessment of Technical Skills (OSATS), Final Product Analysis and time to perform the procedure. The number of anastomoses performed by the residents were calculated. Data were subjected to statistical analysis, and $P < 0.05$ was considered significant.
Results: There was a significant reduction in the number of vascular anastomoses performed by the residents between the COVID group and the control group (mean 22.6 ± 7.76 vs. 35.2 ± 3.9, $P = 0.01$, Student's *t*-test). Before the workshop, 80% of the residents from the COVID group failed to perform a vascular anastomosis on the simulator. During the workshop, there was improvement in the Objective Structured Assessment of Technical Skills (OSATS) score (initial: 16.5, interquartile range (IQR) 0, under supervision: 25, IQR 5, and at the end of the workshop: 26.5, IQR 2.5; $P = 0.049$, Friedman's test) and in the Final Product Analysis (initial: 14.5, IQR 6, under supervision: 26.5, IQR 4.625, end of the workshop: 27, IQR 4, $P = 0.049$, Friedman's test). Time was not significantly different (initial: 35.6, IQR 2.77; under supervision: 25.8 min, IQR 4.53; $P = 0.07$, Friedman's test). The residents' technical scores were stable 6 months after the training, and there was no difference between their final scores and those of the control group. The residents from the COVID Group reported an improvement in their knowledge, technical skills and confidence after the workshop.
Conclusions: A workshop using a low-fidelity simulator improved vascular surgery residents' skills and confidence in vascular anastomosis during the pandemic year, when they performed fewer surgical procedures.

Type of Research: Single-center, prospective, controlled study.

Key Findings: COVID-19 reduced the number of vascular anastomoses performed by our residents by 33%, leading to a decrease in surgical technical skills and low confidence. A workshop improved residents' technical scores (OSATS score, Final Product Analysis) to the level of the residents from the previous year and restored their confidence.

Take home Message: A vascular anastomosis workshop using a low-cost simulator improved the residents' technical scores and restored their confidence.

Funding: This research was supported by Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, Laboratório de Investigação Médica (LIM-02, CG- 83.505).

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Ann Vasc Surg 2022; 83: 87–96
https://doi.org/10.1016/j.avsg.2022.03.032

Manuscript received: February 22, 2022; manuscript accepted: March 30, 2022; published online: 6 April 2022

INTRODUCTION

Vascular anastomosis is a complex procedure in which a poorly placed stitch or inadequate knot which creates the potential for blood loss, vascular occlusion or even death.[1] Previous studies have shown that trainee participation during infrainguinal bypass procedures are associated with an increased early postoperative graft failure,[1–3] greater operative time, greater odds of blood transfusion, and a longer hospital stay than procedures performed by an attending surgeon alone.[2]

To prevent these kinds of complications, surgical laboratories, whose benefits have already been demonstrated for vascular anastomosis, could be employed.[4–7] The basic technique can be learned on a simulator before the operative procedure, and the learned skills can lead to improved performance in the operating room (OR), with a higher level of competence after skill training.[3,8] However, access to vascular surgery simulations is limited.[9]

Furthermore, there is a concern among surgical educators that graduating trainees are unprepared to independently practice the full spectrum of vascular surgery[3]; this situation has worsened during the COVID-19 pandemic, which has caused suspensions of elective surgery for several months worldwide and reduced the number of surgeries performed by trainees.[10,11]

For this reason, the present study aimed to evaluate a workshop using a simple, low-cost, low-fidelity simulator to train vascular surgery residents in vascular anastomosis with the intention of better preparing them for the OR. It was developed during the first year of the COVID-19 pandemic in Brazil in response to a request from its residents.

MATERIALS AND METHODS

This study was performed at the São Paulo University Medical School from March 2020 to March 2021. It was approved by the ethics committee at Plataforma Brasil (www.saude.gov.br/plataformabrasil, CAAE 04557518.9.0000.0068).

The number of bypasses and arteriovenous fistula was performed by the post graduation year 3 (PGY-3) residents as the main surgeon was assessed based on our medical records. We calculated the number of anastomoses as the number of arteriovenous fistulas plus 2 times the number of bypasses.

Trial Design

Prospective, single-center study.

Participants

Vascular surgery residents from São Paulo University Medical School in 2020, the first year of the COVID-19 pandemic in Brazil. All residents were enrolled.

In our institution, the vascular surgery residency consists of 2 years and starts after 2 years of general surgery residency. During the first year in vascular surgery residency (PGY-3), the residents are expected to learn vascular anastomosis and perform arteriovenous fistulae and infrainguinal bypasses, and diagnostic arteriography, catheter implantations and amputations. During the second year of vascular surgery (PGY-4), residents usually perform endovascular limb angioplasties and aortic and carotid open and endovascular procedures.

COVID group: PGY-3 residents.

Control Group: PGY-4 residents who performed their anastomosis training during a regular year at our institution.

Intervention

After the first COVID peak in Brazil in 2020, before elective surgeries restarted, PGY-3 residents were trained via a vascular anastomosis workshop using a low-fidelity simulator produced in our laboratory (*Laboratório de Investigação Médica* - LIM02 FMUSP). The simulator consists of a silicone tube connected to a pulsatile flow pump and placed inside a box made in polymer simulating skin with a longitudinal incision (Fig. 1).

On arrival at the laboratory, residents from both the groups were given basic surgical instruments, suture material and a segment of 8-mm polytetrafluoroethylene (PTFE; GORE, Elkton, MD) and asked to perform an end-to-side anastomosis without training or formal instruction. The assistant was a senior vascular surgeon instructed to behave passively, only performing movements required by the residents. Two senior vascular surgeons evaluated and scored the procedure. The PGY-4 residents were evaluated at this moment alone, and their score was considered the control score we sought to achieve with the workshop.

Then, a lesson on standard anastomosis techniques was delivered. A 30-min period was dedicated to didactic teaching, which included detailed information on the step-by-step construction of an end-to-side vascular anastomosis, with a live demonstration of an ideal anastomosis using a polytetrafluroethylene (PTFE) graft to the silicone tube

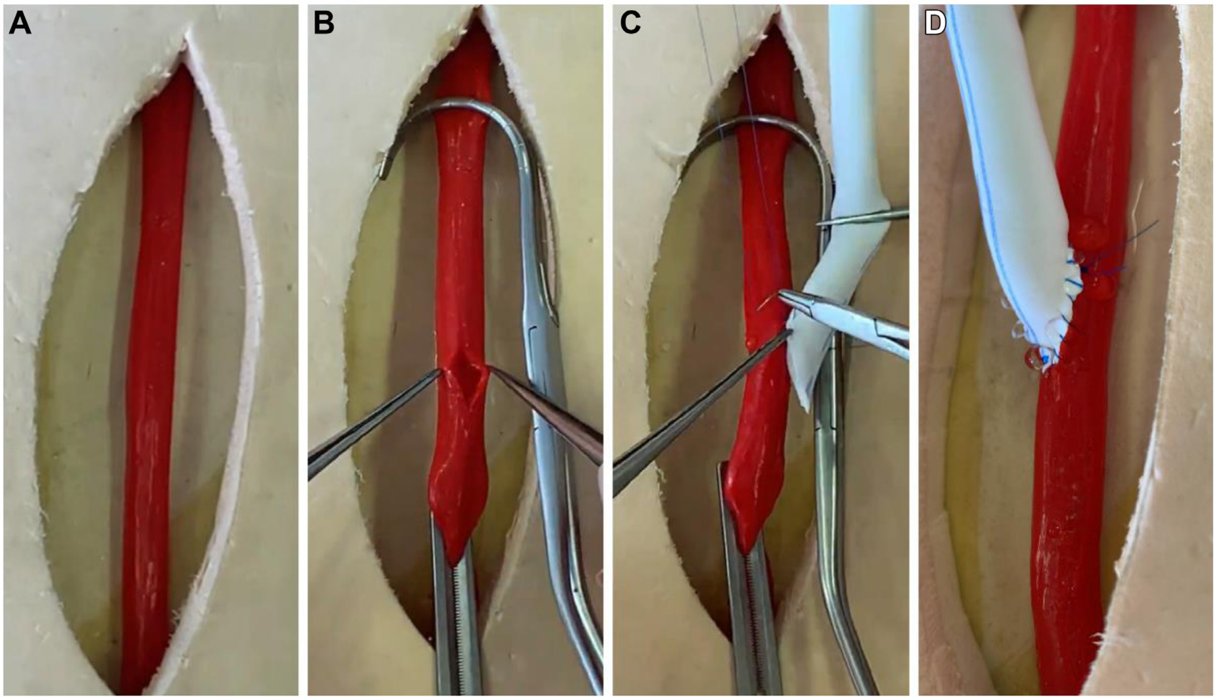

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Fig. 1. Low-fidelity simulator for vascular anastomosis training. **(A)** Simulator consisting of a silicone tube connected to a pulsatile flow pump. **(B)** Vascular clamps in place and arteriotomy performed. **(C)** Vascular anastomosis confection. **(D)** Final aspect of the vascular anastomosis and analysis of leakage after removal of the vascular clamps.

of the simulator, performed by the most experienced surgeon in our department.

Residents in the COVID group performed the anastomosis again under the supervision of the same senior vascular surgeons who assisted the first anastomoses, but now they were instructed to guide the procedure, if necessary.

After that, residents practiced in 2 additional, individual training sessions (total 3 weeks, approximately 1 hr/week). During these sessions, the anastomoses were performed under supervision and with feedback from a senior vascular surgeon.

At the end of 1 month, the residents from the COVID group performed one more training session, where their evaluation was made (final workshop), and the same occurred at the end of their PGY-3.

End Points

Time to Perform the Procedure.

Objective Structured Assessment of Technical Skills (OSATS) score,[12,13] which analyzes tissue, time and motion, instrument handling, knowledge of the instruments, use of assistants, flow of operation and forward planning, and knowledge of the procedure. The score varies from 8 to 45, with lower scores indicating worse performance. Finally, a final binomial analysis of the procedure was performed (pass or fail) based on the evaluator impression of the resident's entire performance and the quality of the anastomosis after the pulsatile flow was released.

Final Product Analysis[14]: The characteristics evaluated included the size of the arteriotomy, anastomotic angle, space and depth of the sutures, appropriate use of vessel clamps and leakage. The score ranges from 7 to 35, with lower scores indicating worse performance.

After the workshop, the residents from the COVID group were asked to complete a survey regarding the number of surgeries performed and a subjective questionnaire analyzing confidence in performing the procedure.

Quantitative data regarding the number of anastomoses performed by the residents were gathered, mainly arteriovenous fistulae and infrainguinal bypasses.

The anastomoses of the COVID group were evaluated by 2 senior surgeons at baseline (before the training started), after instruction/

Table I. Resident physician characteristics

	COVID group	Control group	*P* value	Test
Age	30 (30−31)	30 (30−30)	$P = 0.9$	Mann−Whitney
Female	66.7%	60%	$P = 0.82$	Fisher Exact Test
Total number of surgeries performed				
Number of bypasses[a]	45	70	$P = 0.85$	Chi-squared
Number of arteriovenous fistulae[a]	33	45	$P = 0.85$	Chi-squared
Number of vascular anastomoses[b]	123	185	$P = 0.00034$	Chi-squared
Analyses by resident				
Number of bypasses/resident	8.8 (±3.1)	13.4 (±2.96)	$P = 0.04$	Student *t*
Number of arteriovenous fistulae/resident	5.2 (±2.28)	9 (±2.55)	$P = 0.037$	Student *t*
Number of vascular anastomoses/resident	22.6 (±7.76)	35.2 (±3.9)	$P = 0.01$	Student *t*

[a]Number of bypasses and arteriovenous fistulae where the resident was the main surgeon.
[b]Number of vascular anastomoses performed by a resident as the main surgeon: number of bypasses multiplied by 2, plus the number of arteriovenous fistulae.

under supervision, at the end of the workshop and at the end of PGY-3, which occurred 6 months after the workshop. The COVID group's baseline and outcomes with the senior surgeons' help were evaluated on the first day of the workshop. The control group was only evaluated at baseline. The senior surgeons conducted the evaluations during the workshop; therefore, they were not blinded to the groups or the timing of the training.

Statistical Analysis

Quantitative discrete and categorical ordinal variables are displayed as medians and interquartile ranges (IQRs) and were analyzed using the Mann−Whitney or Kruskal−Wallis test with the post-hoc Dunn test. Categorical nominal variables were analyzed with the chi-squared test or Fisher's-exact test. For quantitative continuous variables with a normal distribution, Student's *t*-test was used. For repeated measurements of qualitative ordinal variables, Friedman's test and the Dunn-Bonferroni post hoc test were used.

The interclass correlation coefficient (ICC), analyzing consistency, and their 95% confident intervals were calculated based on a mean rating ($k = 2$) and a 2-way mixed-effects model. Interpretation of ICC values: less than 0.5, poor reliability; 0.5−0.75, moderate reliability; 0.75−0.9, good reliability; and greater than 0.9, excellent reliability.[15,16] The scores shown are the mean value of the 2 observers' scores.

The R software v 1.4.1106 (R Foundation for Statistical Computing, Vienna, Austria) was used. A P value < 0.05 was considered statistically significant, and all reported P values are two-sided.

RESULTS

Each group consisted of 5 residents, which is the total number of vascular surgery residents in our institution. There was no difference comparing the age or sex of the residents of the 2 groups; nevertheless, significantly fewer vascular anastomoses were performed by the residents of the COVID group than by those of the control group, as shown in Table I.

This reduction occurred mainly during the first semester of 2020, when elective surgeries were cancelled due to COVID-19, as shown in Figure 2. This was a natural consequence of the reduction in the total number of surgeries performed in our hospital during this period; the number of bypasses was reduced by 25% and the number of arteriovenous fistulas was reduced by 87.5% compared with the first semester of the previous year, as shown in Table II. Figure 3 shows a timeline created to clarify the timing of the evaluations, correlating with the mean number of anastomoses performed by the residents, the start of the COVID-19 pandemic and the surgical practice in our institution.

The residents' impression of a lack of expertise was confirmed in our initial analysis, in which 80% of the trainees from the COVID group failed to independently perform a vascular anastomosis on the simulator. The resident who passed the initial test had performed 7 anastomoses before the workshop, the last of which was performed just 2 days before the workshop. The other residents from the COVID group performed an anastomosis a month or more before the evaluation.

During the workshop, there was improvement in all the scores analyzed. The OSATS score improved from 16.5 (IQR 0) to 25 (IQR 5) to 26.5 (IQR 2.5) ($P = 0.049$, Friedman's test). Final Product Analysis

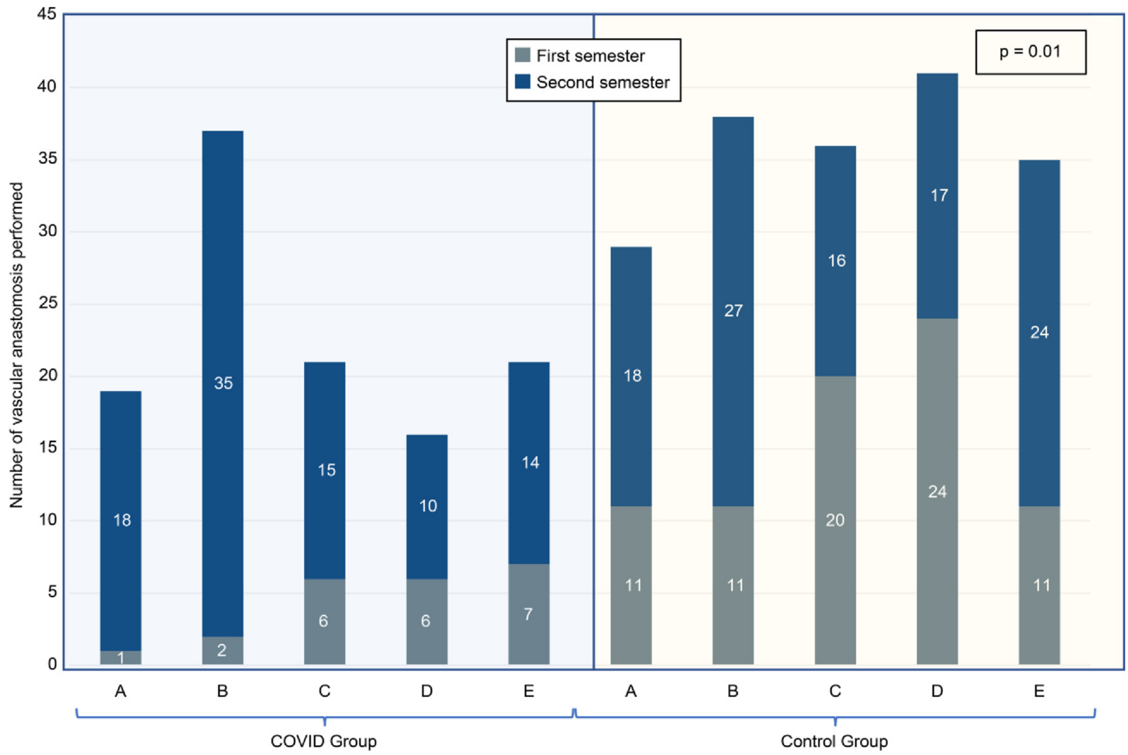

Fig. 2. Number of vascular anastomoses performed by vascular surgery residents at São Paulo University Medical School during their PGY-3, comparing the pandemic year with the previous year, analyzed by semester. Student's *t*-test was used to compare the mean number of anastomoses by group.

Table II. Number of bypasses and arteriovenous fistulae comparing the first COVID-19 pandemic year with the previous year

	Number of bypasses	Number of arteriovenous fistulae
2019 First Semester	40	24
2020 First Semester	30	3
Difference comparing the semesters (%)	**−25 %**	**−87.5%**
2019 Second Semester	49	20
2020 Second Semester	35	27
Difference comparing the semesters (%)	**−28.5%**	**+35 %**

The numbers in bold is the difference comparing the semesters in %.

started on 14.5 IQR 6; under supervision, it progressed to 26.5 IQR 4.625 and 27 IQR 4 at the end of the workshop ($P = 0.4979$ Friedman's test). The post hoc test did not find a significant difference for either the OSATS score or the Final Product Analysis. Time was reduced from 35.58 min (IQR 2.77) to 27.5 min (IQR 8.29) under supervision and to 25.85 min (IQR 4.53) at the end of the workshop, but there was no significant difference ($P = 0.07$, Friedman's test). Comparing the scores of the 2 observers, the ICC was excellent for the OSATS score (ICC = 0.908, 95% CI 0.759−0.967) and good for the Final Product Analysis (ICC = 0.9, 95% CI 0.729−0.965).

Before the workshop, all the residents had already studied the theoretical part of the procedure performed at least one anastomosis in the OR. Nevertheless, when they were left to perform the surgery independently, they were lost within the steps (therefore, they scored low in time and motion and operation flow), the best position of the hand and needle holder to perform a good stitch (low score in instrument handling), and they did not know how to use the assistant, as

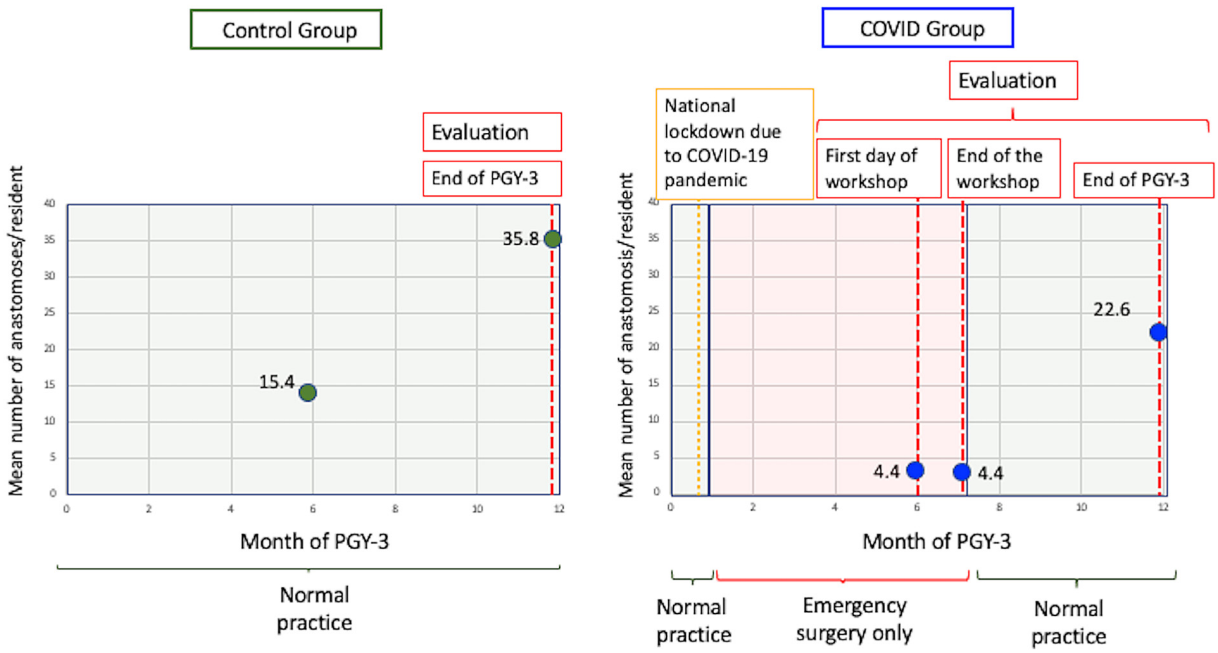

Fig. 3. Timeline showing the time of the evaluations, the mean number of anastomoses performed by the residents, the start of the COVID-19 pandemic and the surgical practice in our institution.

shown by a detailed analysis of the OSATS scores (Table III).

Figure 4 shows the progression of the residents during the workshop and compares it with that of the control group. The Kruskal–Wallis test revealed differences in the OSATS scores ($P = 0.00843$), Final Product ($P = 0.03$) and time ($P = 0.04$). For the OSATS score and time, the Dunn post-hoc test showed that the difference was between the initial values of the COVID group and the values obtained at the end of their PGY-3 (OSATS score: median 16.5, IQR 0 vs. 30, IQR 2.5, P adjusted = 0.0006; time: median 35.6, IQR 2.77 vs. 25.1, IQR 0.64, P adjusted 0.036). For the Final Product Analysis, the post hoc test did not show a difference comparing the timing between groups.

The final results of the COVID group were directly compared to the control group and no significant difference in any of the outcomes was found at the end of PGY-3, as shown in Table IV.

The residents answered a questionnaire, and the results are shown in Table V.

DISCUSSION

During the first semester of 2020, there was a drastic reduction in the number of surgeries performed in our hospital due to the first wave of the COVID pandemic. Subsequently, our residents complained of insufficient knowledge and low confidence in performing a vascular anastomosis, and they were worried about the return of routine, when the number of surgeries would increase to address the unattended patients during the first COVID wave. As an answer to the residents' demand, a vascular anastomosis workshop was organized using a low-fidelity, low-cost simulator produced at our lab. The workshop improved the residents' technical skills and their confidence. The final evaluation of technical scores was not different from that of the control group, which consisted of the residents who underwent vascular anastomosis training during the previous year.

The ideal number of vascular anastomoses for achieving proficiency is not well established. In Europe, 30 open vascular procedures of intermediate complexity are required to apply for the European Union of Medical Specialists, including bypass, arteriovenous fistulas, catheters and surgical treatment of varicose veins,[17] which can be achieved in 2 to 5 years of vascular surgery training.[18] McCallum et al. evaluated 125 trainees in the USA and reported that the mean number of vascular bypasses performed during their training program was 43.4 (minimum 10, maximum 98)

Table III. Analysis of residents results and progression using Objective Structured Assessment of Technical Skill (OSATS) scale

	COVID group			Control group		Kruskal–Wallis
	Initial	Senior Help	End of workshop	End of PGY-3	End of PGY-3	
	Median (25–75 IQR)	Median (25–75 IQR)	Median (25–75 IQR)	Median (25–75 IQR)	Median (25–75 IQR)	*P*
Respect for tissue	3 (2–3)	3 (3–375)	4 (3–4)	5 (4.5–5)	4 (4–4)	0.00002
Time and motion	1.5 (1–2)	3 (3–3)	4 (4–5)	3 (2.25–3)	4 (3–4)	0.00002
Instrument handling	2 (2–3)	4 (3.25–4)	4 (3.75–4.25)	5 (5–5)	4 (4–4.25)	0.00004
Knowledge of instruments	3.5 (3–4)	5 (4.25–5)	5 (4–5)	5 (4–5)	5 (5–5)	0.0007
Use of assistants	2 (2–2)	4 (3.25–5)	3 (3–3)	3 (2.5–4)	4 (3–5)	0.0002
Flow of operation	2 (1–2)	4 (3.25–4)	4 (4–4.25)	5 (3.5–5)	5 (5–5)	0.00001
Knowledge of the procedure	2 (1–2)	4 (3.25–4)	4 (3–4)	5 (4–5)	5 (5–5)	0.00003
OSATS	16.5 (16.5–16.5)	25 (22.5–27.5)	26.5 (26–28.5)	30 (28.38–30.875)	26.5 (23–27.5)	0.008
Pass (%)	20%	100%	100%	100%	100%	$P = 0.000003$ Fisher Exact Test

for trainees who had completed either a residency in vascular surgery (0 general surgery + 5 years of vascular surgery) or a fellowship in vascular surgery (5 years of general surgery + 2 years of vascular surgery).[19] We calculated the number of procedures performed by our residents to evaluate whether there was a real reduction due to the COVID-19 pandemic: during the first semester of 2020, each resident performed only 4.6 anastomoses on average versus 16.2 anastomoses/resident over the same period of the previous year. Consequently, 80% of the residents failed on their first attempt to perform an unassisted anastomosis using the simulator. There is no previous study in Brazil reporting the number of anastomoses performed by vascular surgery residents during their training for comparison.

A workshop was organized since numerous studies have demonstrated the successful acquisition of vascular anastomosis skills using both low-fidelity and high-fidelity simulators.[20,21] The curriculum of the workshop dictates how effective a particular simulator will be in providing clinically relevant and useful skills.[22] It is known that distributed practice (short practice sessions with intervals between sessions) results in better acquisition and retention compared with massed practice (practicing a task continuously in one long session).[11,23,24] The training interval is also important: simple tasks are better acquired with shorter intertraining intervals, whereas complex tasks appear to require a longer period of rest between task learning segments.[22] Mitchell et al.[22] described that four 1-hr training sessions led to a significant resident improvement at both 1-week and 1-month intervals. Robinson compared a 6-week workshop with a 3-week workshop and reported that a 6-week course provided no additional benefit.[20] In addition, in a busy residency program, participation in the laboratory should be mandatory.[25] With that in mind, our workshop was conducted over a 3-week period, with a 1-hr training session/week, as a mandatory activity.

There was an improvement in all the parameters analyzed in this study (OSATS, Final Product and time), although post-hoc tests could not show a significant difference comparing all the steps of the training, probably due to the small number of residents. Even so, the residents considered the workshop useful and perceived a significant improvement in their surgical skill, knowledge and understanding of the surgical procedure, with a consequent increase in their confidence.

The progressive deterioration of knowledge and skills when not used over extended periods is a

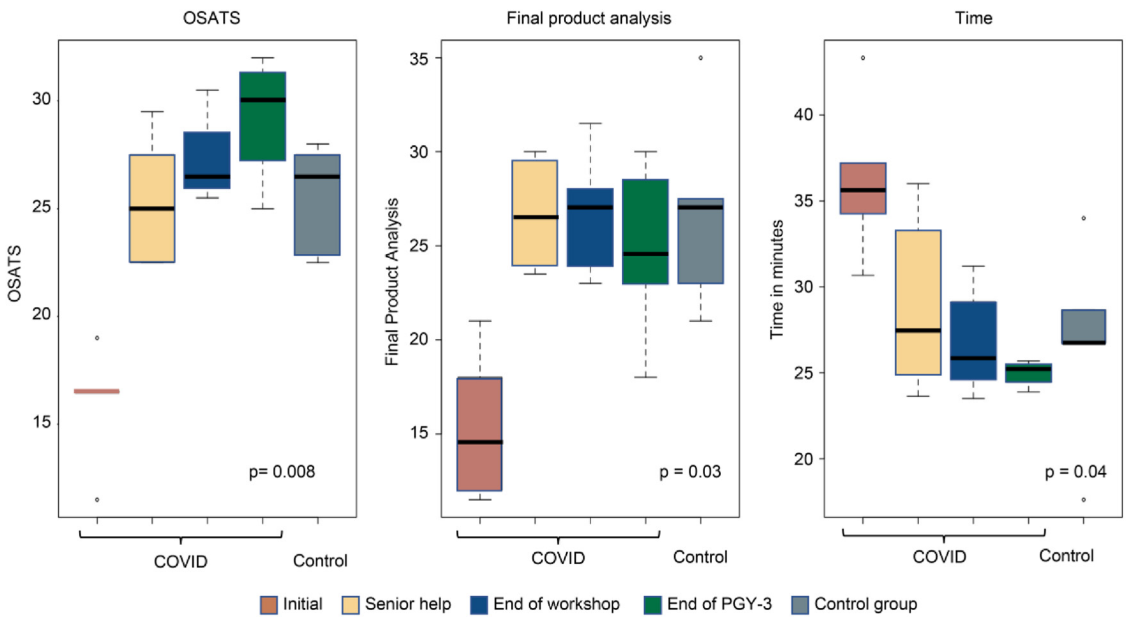

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Fig. 4. Progression of COVID-year residents and scores of the control group. The Kruskal–Wallis test was used to perform the statistical analyses.

Table IV. Technical evaluation of vascular anastomoses performed on a simulator at the end of PGY3 comparing the first COVID-19 pandemic year with the previous year

	Control group	COVID group	*P*
	Median (25–75% IQR)	Median (25–75% IQR)	Mann–Whitney test
OSATS	26.5 (23–27.5)	30 (28.4–30.8)	0.11
Final product analysis	27 (23–27.5)	24.5 (23–28.5)	0.92
Time	26.73 (26.73–28.66)	25.13 (24.72–25.36)	0.17

well-studied phenomenon.[22,24] This was avoided in our study since the residents performed a good number of vascular anastomoses after the workshop (on an average, 18.4 per resident for one semester). Therefore, there was no difference between the postworkshop scores and those obtained 6 months later.

This study has several limitations. Most importantly, this was a single-center study with a small number of residents. However, this is the total number of residents in our institution, and especially during the pandemic year, presential training involving different institutions was difficult to organize. In addition, this study does not illustrate the transferability of increased surgical skill on this model to the operating room. However, this kind of benefit to the surgical room has already been described with numerous types of simulator training for different skills. Finally, the senior surgeons who evaluated the procedures were not blinded, which can imply bias. Nevertheless, this was the most practical/feasible way of performing this evaluation.

Despite these limitations, this study shows that a 3-week workshop, with a mandatory 1-hr training session on low-fidelity simulators each week, improved vascular surgery residents' skills and confidence in vascular anastomosis. This was important during the first year of the COVID-19 pandemic, when the number of surgical procedures was reduced. Our results showed that the residents reached proficiency on vascular anastomosis, although they performed fewer surgeries compared to the previous year. Therefore, we intend to make this workshop a mandatory activity for the PGY-3 and evaluate whether it improves surgical results. We also intend to expand this training to other

Table V. Subjective questionnaire answered by the residents after the workshop

	Median (IQR25–75%)
Training was useful for	
Understanding the procedure	5 (5–5)
Improving technical skills	5 (4–5)
Improving the knowledge on the surgical material	4 (4–4)
Training helped to understand and better manipulate	
Needle holder	5 (4–5)
Potts's scissor	5 (4–5)
Prolene threads	4 (4–4)
Tweezers	4 (4–5)
Graft	4 (4–5)
Artery	3 (3–4)
Realism of the simulation	4 (3–4)
Training improves patient safety	5 (5–5)
Self-confidence in performing the procedure	
Before the workshop	2 (2–3)
After the workshop	4 (4–5)

Score using a Likert scale: 1 (totally disagree) to 5 (totally agree).

institutions and confirm the results with a larger number of residents.

CONCLUSION

A workshop using a low-fidelity simulator improved vascular surgery residents' skills and confidence in vascular anastomosis during the pandemic year, when they performed fewer surgical procedures.

This manuscript was edited for proper English language by American Journal Experts: Certification Verification Code 827D-E19F-7D12-9C17-60BP.

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