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Virtual Surgical Skills Training in a High School Summer Program

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ABSTRACT

BACKGROUND The COVID-19 pandemic has disrupted components of traditional education with shifts toward virtual platforms. This report describes the virtual approach to basic surgical skills training during a high school program in the summers of 2020 and 2021.

METHODS Two 2-week sessions were held by Zoom (Zoom Video Communications) with 99 students in 2020 and 198 students in 2021. Each student was sent surgical supplies and instruments. Interactive lectures were held each morning, and basic surgical skills instruction was provided each afternoon. After the session, survey links were distributed to students to complete an anonymous 37-item questionnaire regarding surgical skills confidence, simulation kit satisfaction, and technical difficulties.

RESULTS Of the 297 students, 270 (90.9%) completed the questionnaire, including 91 (91.9%) in 2020 and 179 (90.4%) in 2021. On a scale of 1 (fair) to 5 (excellent), students in 2020 and 2021 reported similar confidence in instrument handling (4-5: 90.0% vs 86.3%; $P = .38$), suturing skin (4-5: 88.9% vs 82.8%; $P = .19$), and thoracic aorta suturing (4-5: 73.3% vs 73.6%; $P = .97$). Students reported greater confidence in 2020 in knot tying (4-5: 98.9% vs 87.9%; $P = .002$), coronary vessel suturing (4-5: 82.2% vs 65.5%; $P < .001$), and valve model suturing (4-5: 68.5% vs 50.3%; $P = .005$) than students in 2021. Students had similar satisfaction rates with the program (extremely or somewhat satisfied: 92.3% vs 86.0%; $p = .51$) between 2020 and 2021.

CONCLUSIONS Virtual education carries the potential for basic surgical skills training for a more widespread audience with less access to direct surgical education. Further research is needed to optimize teaching finer surgical skills.

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The COVID-19 pandemic has contributed to societal disruption and educational disparities resulting from transition to virtual platforms. Whereas limited broadband access and unstable home environments are some challenges, virtual education demonstrates substantial potential beyond the pandemic. For instance, although surgical training is traditionally experiential, virtual learning can be effective for certain educational components relating to medical knowledge, patient care, and surgical skills for medical students, residents, and surgeons.[1,2] With the uncertainty regarding the ongoing pandemic and the development of more infectious variants, further advancements in virtual surgical education spotlight the utility of remote training.[3,4]

The Cardiothoracic Surgical Skills Summer Internship (CSSSI), initiated as an in-person program in the late 1990s in the Department of Cardiothoracic Surgery at Stanford University, was designed to educate high school students in cardiothoracic surgical anatomy, physiology, and basic technical skills. The program operates through tuition and departmental funding, has no marketing budget, and recruits students through a searchable, publicly available website; in other words, all participants independently discovered and applied to the program. CSSSI shifted to a virtual platform in the summers of 2020 and 2021 because of the COVID-19 pandemic. Virtual training provided an opportunity to educate a large number of students from various geographic regions; contingent on technologic concerns, such an approach can be more inclusive than previous in-person programs.

Interactive surgical skills programs have shown promise for promoting student engagement and

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confidence.[5-9] Conducting surgical education through a virtual format but at similarly rigorous standards as in-person programming offers the potential for widespread, accessible basic surgical training at the medical student and resident levels. In this study, we describe our virtual approach and present survey results of participants in the summers of 2020 and 2021 to assess program effectiveness and challenges.

MATERIAL AND METHODS

CSSSI was conducted using a virtual platform during the summers of 2020 and 2021. Two 2-week sessions were held by Zoom (Zoom Video Communications) with 50 students in session 1 and 49 students in session 2 (total, 99) in 2020 and 100 students in session 1 and 98 students in session 2 (total, 198) in 2021. This study was approved by the Institutional Review Board at Stanford University.

Before each session, each student was sent a package that included a specially made surgical trainer (Chamberlain Group), shoelaces for knot tying, a commercially available boxed suturing kit, packs of sutures, and the following instruments: Metzenbaum scissors, a Mayo Hegar needle holder, DeBakey tissue forceps, mosquito hemostat, Castroviejo needle holder, and Gerald forceps.

From Monday to Friday, interactive lectures were held from 9 AM to 12 PM, with skills sessions held between 1 PM and 3 PM (Figure 1). The lectures were given by cardiothoracic surgery residents and faculty in the Department of Cardiothoracic Surgery and the Division of Cardiovascular Medicine and were delivered at a medical student level; students were not quizzed or examined on the material. Additionally, the morning session included peer-based learning activities, such as a career panel and cardiothoracic surgical trivia. Afternoon skills sessions covered basic surgical skills (knot tying, instrument handling, and suturing skin), as well as surgical skills specific to cardiothoracic surgery (coronary vessel suturing, valve model suturing, and thoracic aorta suturing) (Figure 2). Surgical skills instruction was presented to students by videoconferencing using an overhead camera with a zoom lens and autofocus capability (Figure 3). Through students orienting their device cameras on their work, instructors and program teaching assistants consistently provided immediate personalized feedback in general group sessions and smaller breakout sessions, which ranged from 5 to 10 students. Office hours were held daily after the afternoon skills session from 3 PM to 5 PM to clarify course content and answer general questions regarding the practice of medicine. The final Friday of each session included project presentations where students collaborated in small groups to propose an innovative concept or device. All sessions were recorded and made available for students for review. The virtual program was similar to the in-person program in terms of surgical skills and lecture content, although social events had to be approximated. Additionally, the 2020 and 2021 sessions were standardized with no change in student recruitment strategy, curriculum, or surgical skills faculty.

Survey assent and consent forms were electronically distributed to all 297 students enrolled in the program in 2020 and 2021, with assent forms signed by students aged younger than 18 years and consent forms signed by parents of minors or students aged 18 years or older. At the end of each session, survey links were distributed through Zoom chat and email invitation to complete an anonymous 37-item, Internet-based questionnaire (Qualtrics). Survey questions covered items such as surgical skills confidence, number of hours spent practicing surgical skills, simulation kit satisfaction, and technical difficulties. The survey was designed as an annual program evaluation, but having already been conducted for both the 2020 and 2021 iterations of CSSSI, it offered a unique opportunity to evaluate the effectiveness of virtual surgical skills training with differing class sizes.

Descriptive statistics are presented as counts with percentages or median with interquartile range; the

	9am - Lecture	10am - Lecture	11am - Lecture	1-3pm - Lab
Week 1				
Monday	Orientation	General anatomy	Cardiac anatomy	Knot-tying
Tuesday	Cardiac physiology	Cardiopulmonary bypass	Surgical pictionary	Instrument handling
Wednesday	Coronary artery disease	Coronary artery bypass graft	Coronary case studies / Ethics debate	Pig heart prosection
Thursday	Electocardiogram	Echocardiogram & cardiac stress test	Career panel	Instrument handling/suturing
Friday	Congenital anatomy	Congenital surgery	Congenital cases	Suturing
Week 2				
Monday	Lung	Esophagus	Thoracic cases / Interdisciplinary discussion	Coronary vessel suturing
Tuesday	Aortic valve anatomy	Aortic valve surgery	Thoracic trivia	Coronary vessel suturing
Wednesday	Mitral valve anatomy	Mitral valve surgery	Valve case studies / Hospital scenes	Valve suturing
Thursday	Thoracic aorta	Transplant	Cardiac trivia	Thoracic aorta suturing
Friday	Project presentations	Project presentations	Project presentations	Project presentations

FIGURE 1 A 2-week schedule for the 2021 program with morning lectures from 9 AM to 12 PM and afternoon skills session from 1 PM to 3 PM.

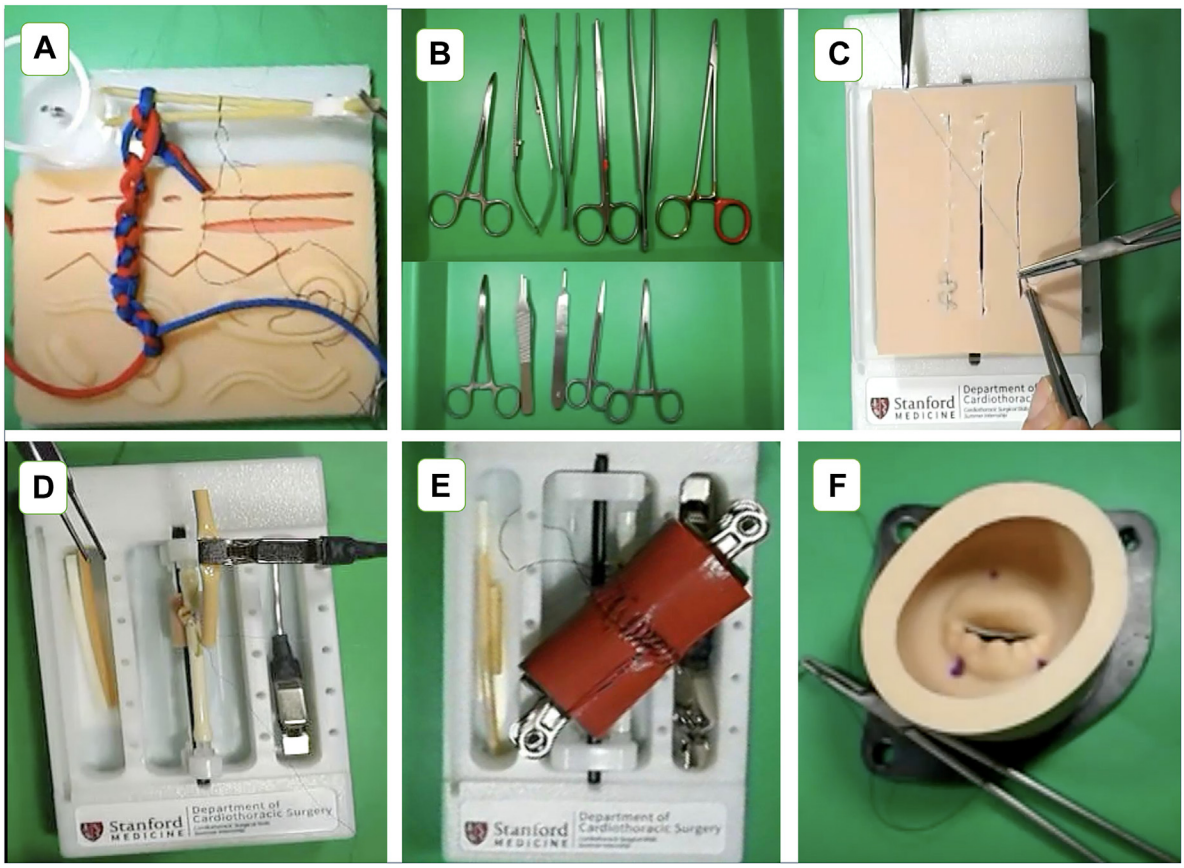

FIGURE 2 Screenshots from skills sessions demonstrating (A) knot tying, (B) instrument handling, (C) suturing skin, (D) coronary vessel suturing, (E) thoracic aorta suturing, and (F) valve model suturing.

χ^2 test and unpaired t test were used for 2-group comparisons. All statistical analyses were performed using Stata 17 software (StataCorp).

RESULTS

Of the 297 students in the CSSSI sessions, 270 (90.9%) completed the questionnaire; the response rates were 91 (91.9%) in 2020 and 179 (90.4%) in 2021. In total, those in 2020 comprised 33.7% of the total survey responses, whereas those in 2021 comprised 66.3%. Women represented the majority of participants in 2020 and 2021 (73.6% vs 74.9%; $P = .37$). Of the 297 students who completed the program over the 2 years, 132 (44.4%) were from the San Francisco Bay Area, 50 (16.8%) were from California but outside the Bay Area, 91 (30.6%) were from the United States but outside California, and 24 (8.1%) were from outside the United States

On a scale of 1 to 5 from "fair" to "excellent," students in 2020 and 2021 reported similar confidence in instrument handling (proportion of 4-5: 90.0% vs 86.3%; $P = .38$), suturing skin (4-5: 88.9% vs 82.8%; $P = .19$), and

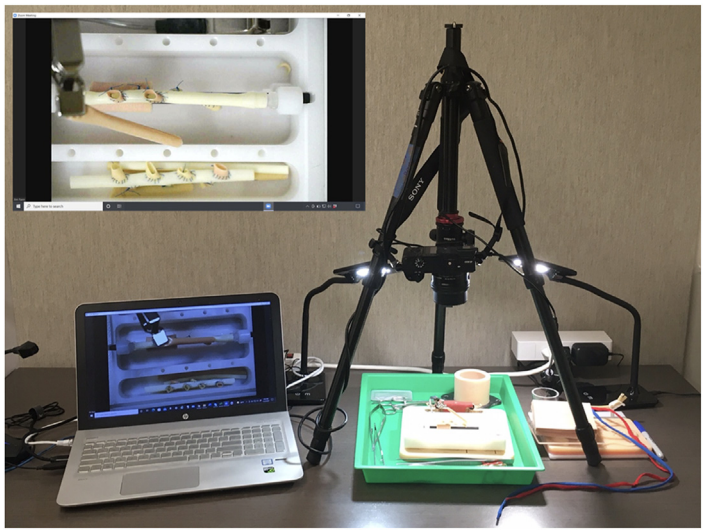

FIGURE 3 Overhead camera and videoconferencing setup for afternoon surgical skills sessions. (Inset) A Zoom screenshot shows excellent detail of a coronary anastomotic model.

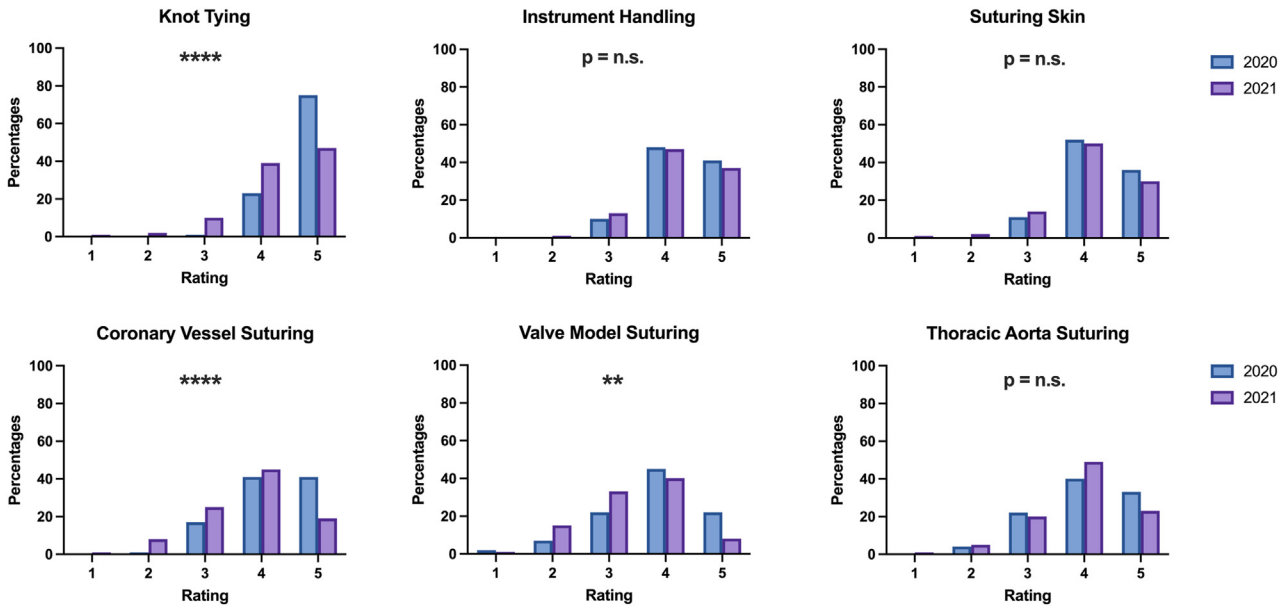

FIGURE 4 Confidence in 6 surgical skills for students in the 2020 program and those in the 2021 program. (n.s., not significant; double asterisks, P <.01; quadruple asterisks, P <.0001.)

thoracic aorta suturing (4-5: 73.3% vs 73.6%; P = .97) (Figure 4). However, students in 2020 reported greater confidence in knot tying (4-5: 98.9% vs 87.9%; P = .002), coronary vessel suturing (4-5: 82.2% vs 65.5%; P < .001), and valve model suturing (4-5: 68.5% vs 50.3%; P = .005) compared with students in 2021. The 2020 cohort spent more hours practicing their surgical skills outside the program (5-10 hours: 12.1% vs 8.4%; 10+ hours: 7.7% vs 1.7%; P = .019), although the 2021 cohort spent a greater number of hours watching surgical skills recording outside the program (3-5 hours: 9.9% vs 14.5%; 5-10 hours: 3.3% vs 6.7%; P = .033) (Figure 5).

In terms of programmatic quality and satisfaction, both groups expressed similar attitudes regarding the utility of watching peers practice surgical skills online (somewhat helpful: 44.0% vs 40.8%; extremely helpful: 25.3% vs 31.8%; P = .33) and their ability to understand online instructor skills demonstrations (somewhat well: 46.2% vs 46.4%; extremely well: 48.4% vs 41.9%; P = .38) (Table 1). Students also had similar rates of technical difficulties (14.8% vs 13.4%; P = .77) and expressed

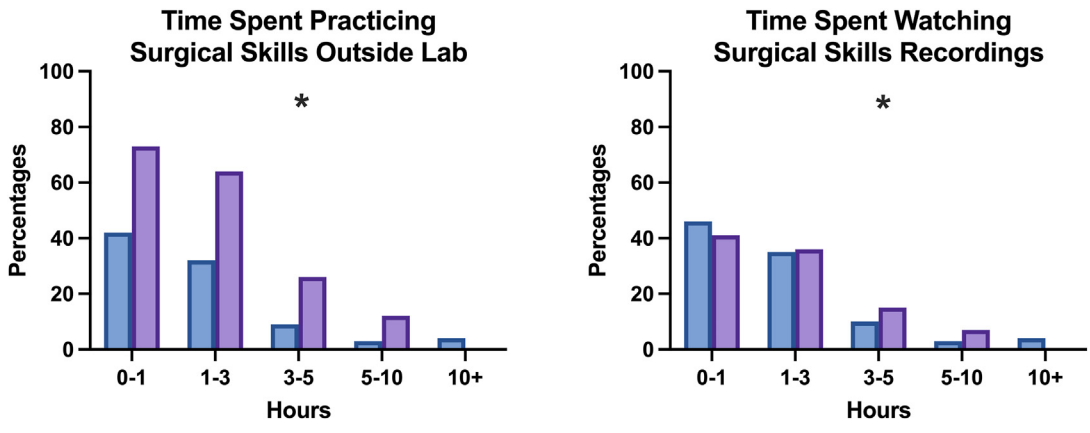

FIGURE 5 Number of hours practicing surgical skills for students in the 2020 program and those in the 2021 program. (Asterisk, P <.05.)

TABLE 1 Satisfaction and Quality Indicators for Students in the 2020 Program and Those in the 2021 Program

Program Year	2020, N = 91, n (%)	2021, N = 179, n (%)	*P* Value
How satisfied were you with the simulation kit?			.17
Extremely unsatisfied	3 (3.3)	13 (7.3)	
Somewhat unsatisfied	2 (2.2)	0 (0.0)	
Neutral	1 (1.1)	5 (2.8)	
Somewhat satisfied	19 (20.9)	38 (21.2)	
Extremely satisfied	66 (72.5)	123 (68.7)	
How helpful was it to be able to watch fellow students do surgical skills training online?			.33
Extremely unhelpful	0 (0.0)	1 (0.6)	
Somewhat unhelpful	3 (3.3)	1 (0.6)	
Neutral	24 (26.4)	46 (25.7)	
Somewhat helpful	40 (44.0)	73 (40.8)	
Extremely helpful	23 (25.3)	57 (31.8)	
Unknown	1 (1.1)	1 (0.6)	
How well could you understand the online skills demonstrations?			.38
Extremely not well	0 (0.0)	1 (0.6)	
Somewhat not well	1 (1.1)	5 (2.8)	
Neutral	3 (3.3)	15 (8.4)	
Somewhat well	42 (46.2)	83 (46.4)	
Extremely well	44 (48.4)	75 (41.9)	
Unknown	1 (1.1)	0 (0.0)	
Did you have any technical difficulties? (Yes)	13 (14.8)	22 (13.4)	.77
How was your Zoom connectivity overall?			.68
Extremely bad	0 (0.0)	0 (0.0)	
Somewhat bad	2 (2.2)	6 (3.4)	
Neutral	6 (6.6)	12 (6.7)	
Somewhat good	39 (42.9)	61 (34.1)	
Extremely good	42 (46.2)	88 (49.2)	
Unknown	2 (2.2)	12 (6.7)	
How personalized was the program?			.32
Extremely impersonal	4 (4.4)	3 (1.7)	
Somewhat impersonal	16 (17.6)	22 (12.3)	
Neutral	18 (19.8)	45 (25.1)	
Somewhat personal	43 (47.3)	70 (39.1)	
Extremely personal	7 (7.7)	26 (14.5)	
Unknown	3 (3.3)	13 (7.3)	
How satisfied are you with the program?			.51
Extremely unsatisfied	0 (0.0)	1 (0.6)	
Somewhat unsatisfied	2 (2.2)	2 (1.1)	
Neutral	2 (2.2)	8 (4.5)	
Somewhat satisfied	29 (31.9)	42 (23.5)	
Extremely satisfied	55 (60.4)	112 (62.6)	
Unknown	3 (3.3)	14 (7.8)	
Would you recommend the program to a friend?			.48
No	1 (1.1)	4 (2.2)	
Yes	88 (96.7)	161 (89.9)	
Unknown	2 (2.2)	14 (7.8)	

TABLE 2 Common Themes of Survey Responses From Students in the 2020 Program and Those in the 2021 Program[a]

Themes	2020, N = 91, n (%)	2021, N 179, n (%)
What was the biggest challenge you faced with knot tying?		
Conceptual issues (eg, pacing, initial understanding)	26 (28.6)	30 (16.8)
Technical issues (eg, rotating suture correctly, suture control)	45 (49.5)	88 (49.2)
Technologic issues (eg, blurry camera, inconsistent connection)	9 (9.9)	24 (13.4)
Nothing	11 (12.1)	37 (20.7)
What was the biggest challenge you faced with instrument handling?		
Conceptual issues (eg, choosing the correct instrument)	5 (5.5)	26 (14.5)
Technical issues (eg, needle angles, instrument grip)	70 (76.9)	107 (59.8)
Technologic issues (eg, blurry camera, inconsistent connection)	6 (6.6)	27 (15.1)
Nothing	10 (11.0)	19 (10.6)
What was the biggest challenge you faced with suturing?		
Conceptual issues (eg, choosing an appropriate suture angle)	12 (13.2)	18 (10.1)
Technical issues (eg, puckering of skin, unevenness)	62 (68.1)	118 (65.9)
Technologic issues (eg, blurry camera, inconsistent connection)	7 (7.7)	11 (6.1)
Nothing	10 (11.0)	32 (17.9)

[a]Questions relate to challenges learning technical surgical skills in a virtual format.

comparable quality of Zoom connectivity (somewhat good: 42.9% vs 34.1%; extremely good: 46.2% vs 49.2%; $P = .68$). Although both groups of students reported a smaller ideal class size (40 [range, 30-50] vs 50 [range, 50-80]; $P < .001$), students in 2020 and in 2021 had similar satisfaction rates with their simulation kits (extremely satisfied or somewhat satisfied: 93.4% vs 89.9%;*P* 0.17) and the program as a whole (extremely satisfied or somewhat satisfied: 92.3% vs 86.0%; $P = .51$). In 2020, 96.7% of students would recommend the program to a friend compared with 89.9% of students in 2021 ($P = .48$).

Open written responses from students were reviewed to deduce themes among all survey respondents. For knot tying, students in both years reported technical issues, such as rotating the suture to establish a flat knot and ensuring a strong knot, as common challenges (49.5% in 2020 and 49.2% in 2021), as well as conceptual issues, such as the pace of skills sessions and the initial understanding of the concept (28.6% in 2020 and 16.8% in 2021) (Table 2). For instrument handling, technical

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TABLE 3 Primary Themes for Qualitative Survey Responses From Students in the 2020 Program and Those in the 2021 Program[a]

Themes	2020, N = 91, n (%)	2021, N = 179, n (%)
What worked well in the skills session?		
Easy to learn new information	10 (11.0)	36 (20.1)
Easy to earn new skills	38 (41.8)	56 (31.3)
Technologic convenience	31 (34.1)	65 (36.3)
Everything worked well	12 (13.2)	22 (12.3)
What did not work well in the skills session?		
Difficulty and fast pace of the program	18 (19.8)	37 (20.7)
Making connections with peers	26 (28.6)	40 (22.4)
Technologic issues	21 (23.1)	47 (26.3)
Unspecific feedback	18 (19.8)	41 (22.9)
Everything worked well	8 (8.8)	14 (7.8)

[a]Questions relate to benefits and challenges of online skills sessions.

challenges related to holding the instrument and guidance on the needle angles were common (76.9% in 2020 and 59.8% in 2021). For suturing, technical issues, such as puckering of the skin and unevenness of the suture, were the most prevalent challenges across the 2 years (68.1% in 2020 and 65.9% in 2021).

Additionally, when students were queried regarding what worked or did not work well in skills sessions, certain themes were evident (Table 3). The ease of learning new skills (41.8% vs 31.3%) and the technologic convenience of the program (34.1% vs 36.3%) were favorably considered by students in both years. Conversely, technologic issues with the camera and Zoom (23.1% vs 26.3%) and forming connections with other students and faculty mentors (28.6% vs 22.4%) were common student challenges.

COMMENT

In this study, students reported high satisfaction rates with virtual skills sessions, with 92.3% of students somewhat or extremely satisfied in 2020 and 86.0% somewhat or extremely satisfied in 2021 despite an increased class size. Overall, Zoom was a reliable medium for virtual training, with students favorably commenting on the technologic convenience and ability to review instructor recordings; attendance remained consistently higher than 90%. Despite some challenges, students also found the simulation kit as a useful tool for learning surgical skills.

Regarding specific skills, student confidence in finer surgical skills (eg, coronary vessel suturing and valve model suturing) declined from 2020 to 2021, whereas confidence in more gross surgical skills (ie, instrument handling, suturing skin, and thoracic aorta) was maintained. Of interest is that knot tying can be considered both a fine and a gross surgical skill: it was initially taught with red and blue shoelaces before transitioning toward sutures. In qualitative responses, students reported that finer motor skills were difficult to appreciate over videoconferencing, even with the camera's zoom lens, and they required greater support and guidance from the faculty. Conversely, students commented favorably on the ease and clarity of learning more gross surgical skills. These data suggest that virtual surgical skills training can be conducted with efficacy and participant satisfaction to a widespread audience, but altered approaches may be necessary to accommodate a greater number of students and to teach finer surgical skills.

Previous reports demonstrated the efficacy of surgical skills program, including boot camps for cardiothoracic surgical skills,[10-12] in improving participants' interest in surgery, surgical skills, and procedural competence.[6-8] Notably, these surgical skills programs were all conducted in person before the COVID-19 pandemic. The University of California Irvine Summer Surgery Program is 1 of the few surgery-focused summer programs for high school students, but they canceled their 2020 program and held in-person programming in 2021.[5] Virtual platforms for surgical education and skills training have long been used; however, most are compilations of videos or Internet-based programs without live programming and interaction.[1,2,9,13] Given the COVID-19 pandemic and the transition away from in-person education, we provide an early reports of a virtual surgical skills course and detail student challenges and confidence in technical skills.

Virtual skills training carries inherent disadvantages with audiovisual difficulties and the lack of hands-on instructor support. Conversely, it can offer certain benefits in the ability to provide many surgical skills demonstrations, recordings of instruction for future review, and access to a greater, more diverse cohort of instructors and students than would otherwise be possible. Although in-person CSSSI was able to host only 30 students in the laboratory because of space constraints, virtual training permitted instruction of 100 students simultaneously. Furthermore, the majority of students enrolled in CSSSI over the 2 summers came from outside the San Francisco Bay Area, including students from 11 other countries, and these students could have been otherwise unable to attend if the program had been held in-person. Given projected surgeon shortages in the United States and the broader import of training the global surgical workforce,[14,15] virtual education at rigorous standards offers an opportunity to augment basic surgical skills training around the world.

Although the surgical skills program may be scalable to accommodate a greater number of students, our finding that students preferred smaller class sizes and were less confident with finer surgical skills in the larger 2021 class suggests that certain pedagogic and technologic refinement may be necessary. Finer surgical skills are innately more difficult to teach over videoconferencing, especially given that complex 3-dimensional motions may not fully be appreciated through a 2-dimensional medium. In a larger class, live instructor feedback and immediate answers to student questions may also be less accessible. Offering greater instructional guidance and refining mechanisms for expert evaluation may better support students in their development of finer surgical skills. More comprehensive instruction of foundational skills (eg, greater focus on suturing skin before coronary vessel suturing) may represent another strategy to support students' learning more effectively. Finally, advances in virtual reality and augmented reality may offer opportunities to address dimensional limitations of videoconferencing platforms in the near future.

Our study has several limitations. First, students from lower socioeconomic backgrounds may not have applied to the program because they lacked a stable Internet connection and adequate computing capabilities. We provided a robust financial aid program but nonetheless recognize the self-selecting process through which students enroll in CSSSI. Selection bias may have also influenced our findings, with the most enthusiastic students responding to our survey. However, our overall response rate of 91% helps to ensure the representativeness of our cohort. We also relied on self-assessment to estimate confidence in surgical skills, and self-assessment may overestimate students' technical skills abilities compared with experts' independent evaluation.[16,17] Similarly, we were not able to evaluate students objectively, and given data limitations, we could not assess long-term skills retention or baseline factors that may have influenced outcomes, nor could we compare the virtual program with the in-person program. However, this study was not intended to assess students' skills proficiency comprehensively or compare in-person programming with virtual programming; the purpose was to demonstrate the feasibility of the virtual approach to skills training. We acknowledge that high school level surgical skills training may not translate to medical students or surgical residents, but identifying the benefits and challenges of virtual training can nonetheless help guide future efforts. Finally, although the primary differences between the 2020 and 2021 programs were class size and a year of experience with remote learning, there may be other differences between the 2 class cohorts that were not measured or controlled for, even though the faculty and curriculum were identical.

In conclusion, virtual education offers a satisfactory and potentially scalable means for surgical skills training. Refined approaches and technologies, however, may be necessary to accommodate a greater number of students. Further research is needed to ensure that finer surgical skills, such as coronary vessel suturing and valve model suturing, can be optimally taught to students. Virtual education carries the potential for basic surgical training for a more widespread audience with less access to direct skills education.

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The authors have no conflicts of interest to disclose.

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