ORIGINAL RESEARCH

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Feasibility of Tele-Training to Acquire Sublingual Microcirculatory Images

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ABSTRACT

Background: Recent advances in device technology and image analysis software used to assess the sublingual microcirculation have expanded clinicians' understanding of hemodynamics beyond assessments of blood pressure and end-organ function to provide unique insight into blood flow at the tissue level. Similarly, significant advances in virtual education and telemedicine have transpired recently, especially during the coronavirus disease (COVID-19) pandemic. However, the training of clinicians to acquire microcirculation images continues to rely on in-person instruction, which can be limited by available local expertise and resources, as well as geographic access to instructors.

Objective: Our project aimed to test the feasibility of deploying an online curriculum in combination with tele-guidance versus an in-person guided approach to instruct novices to understand basic principle of microcirculatory function and to acquire sublingual microcirculatory images.

Methods: After participating in brief didactics, 14 participants were divided into two groups to acquire microcirculatory images on a healthy volunteer. Each participant either *1*) obtained images after an in-person demonstration or *2*) obtained images with tele-guidance by using FaceTime technology. We recorded individual microcirculation quality scores, necessary time to acquire each image, percentage of correct theoretical

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questions on assessments, participant satisfaction with the curriculum, and participants' degree of confidence with image acquisition.

Results: Participants' image quality scores (14.7 vs. 23.6, $P = 0.3$) and time to acquire images (191.2 vs. 199.4 s) did not significantly differ. In addition, participants' scores on theoretical knowledge assessments improved over the course of training (19.0% vs. 54.8%, $P < 0.05$).

Conclusion: This feasibility study provides a novel framework for how to successfully deploy asynchronous education and telemedicine to direct novices to acquire sublingual microcirculatory images. Using technological advances to teach microcirculation may enhance wide-scale adoption of a promising clinical monitoring tool for critically ill patients.

Keywords:
microcirculation; education; telemedicine; resuscitation

The microcirculation is composed of a complex network of small (i.e., diameter <20 μm) blood vessels (i.e., arterioles, capillaries, venules) and serves as the ultimate site for tissue oxygen delivery (1). The sublingual microcirculatory bed, which reflects splanchnic perfusion because of their similar embryonic origin, serves as a valuable source of clinical information such as the identification of early shock states. For example, impaired microcirculation can still exist despite normal macrocirculatory hemodynamic measurements (e.g., heart rate, blood pressure, cardiac output) (2, 3). In addition, unique microcirculatory patterns consistent with specific disease states facilitate therapeutic interventions to recruit the microcirculation (4).

Several practical and convenient sublingual handheld video microscopes (HVMs) (5) facilitate image acquisition and image analysis, but certain facets of the process required to acquire clinically meaningful data remain unwieldy and therefore have limited its widespread adoption. Historically, manual image analysis required significant time (e.g., ⩾20 min per image) and technical training. However, a novel algorithm has reduced this time considerably (i.e., 1–2 s per image) (6). Despite recent promising advances in image analysis, a standardized approach to guide manual acquisition of handheld images remains unavailable.

To adequately interpret images for clinical and research purposes, HVM users must skillfully recognize image artifacts and other confounders to generate an accurate image quality score. Unfortunately, the lack of standardization in training, image grading, and other variables often results in up to 44% of acquired images having unacceptable quality scores (7). Expert groups have lobbied for enhanced standardization in the form of the development of image scoring systems (8) and specialized training to acquire images acceptable for analysis (1). Although experts within the field offer high-quality comprehensive courses (9) on microcirculation image acquisition and analysis, they demand significant time for in-person training from a limited number of specialists. The need for physical distancing resulting from the global coronavirus disease (COVID-19) pandemic has also complicated traditional in-person didactics, further highlighting the need for novel methods of training personnel using HVM. The advent of telehealth can improve access to health care, defray cost, and potentially even provide telementoring opportunities in procedural care and device operation (10). For example, whereas many ultrasound experts have, in the past, favored in-person image acquisition and training, recent studies have documented the ability to conduct ultrasound image acquisition and interpretation remotely with commercially available devices and software. In addition, tele-intensivists can effectively guide novices in acquiring point-of-care ultrasonographic images that guide clinical decisions (11). Such findings enabled widespread application of ultrasound capabilities even in areas with limited resources and without local ultrasound interpretation expertise (11–14).

In this context, our study deployed a standardized curriculum to sublingual HVM novices with the goal of obtaining adequate-quality images of the sublingual microcirculation. In addition, we used tele-guidance for image acquisition in a cohort to determine the feasibility of training learners across geographic and spatial barriers.

Portions of this manuscript have previously appeared in abstract form at the Society of Critical Care Medicine Critical Care Congress in 2020 (15).

METHODS

Project Design and Oversight

We conducted a prospective feasibility study of healthcare professionals at a single academic medical center according to Strengthening the Reporting of Observational Studies in Epidemiology guidelines. Our research team members have extensive clinical and research experience using sublingual HVM imaging. The lead research team member (J.S.) underwent formal training via completion of the comprehensive Microcirculation Academy training course (9). Our study protocol (HP-00089022) was approved by the University of Maryland, Baltimore Institutional Review Board.

Setting and Participants

Targeted participants for the study included registered nurses, medical residents, and physicians undergoing critical care fellowship training who provide bedside care within the medical intensive care unit at our institution. Inclusion criteria were age >18 years, employment in the capacity previously described, and no significant experience with sublingual HVM imaging. Eligible participants were recruited via e-mail and completed a screening survey. Qualifying participants were scheduled for training sessions.

Materials

Our team used the CytoCam device (Braedius Medical B.V.), a handheld microscope connected to a computer and display monitor, to acquire sublingual HVM images. The device is an incident darkfield HVM device that uses pulsed light emitted at a 530-nm wavelength to visualize the sublingual microvasculature and erythrocytes. To acquire images, the user can control various parameters, including positioning in the sublingual space, illumination, focus, and clip duration. Postacquisition cropping of the original electronic file can eliminate artifacts or movement that could interfere with the ability of the associated device software (CytoTools 1.7.12, Braedius Medical B.V.) to interpret the images. Our team designed a curriculum for HVM novices that used current consensus statements, evidence-based reviews, prior experiences of research team members, and texts regarding medical education development (16). The curriculum included a brief (15 min) online-based module that focused on HVM image acquisition and was introduced to all participants. In addition, participants designated to the "in-person group" underwent a 15-minute in-person demonstration and practice session and a brief (2–3 min) discussion on the importance of image quality on a project. The online module included basic theoretical knowledge regarding sublingual microcirculation, step-by-step basic device operation, review of commonly implemented quality scores, and several real clips demonstrating both adequate and inadequate images. Sample clips were collected by our group on a healthy volunteer to clearly illustrate parameters necessary for a quality clip, such as *1*) illumination, *2*) duration, *3*) focus, *4*) content, *5*) stability, and *6*) pressure (8).

A series of three online evaluations were administered to each participant at three time points: *1*) before training ("evaluation A"), *2*) immediately after online training ("evaluation B"), and *3*) immediately after in-person training ("evaluation C"). Each evaluation included components to assess a user's self-reported confidence on a five-point Likert scale and self-reported satisfaction on a five-point Likert scale. In addition, theoretical knowledge was queried with multiple-choice questions, and practical knowledge including HVM clips with adequate or inadequate quality, focusing on a single abnormality with one of the six previously described parameters. Overall, each evaluation consisted of a total of two theoretical and nine practical questions, and each contained an equal distribution of abnormal parameters. Evaluations were administered electronically via the Qualtrics survey platform (Qualtrics).

Sessions that required tele-guidance instruction used a smartphone with video-conferencing capabilities (FaceTime; Apple Inc.) that was stabilized with a tripod to focus on the CytoCam display screen. This configuration allowed the experienced HVM user to view the screen during image acquisition to provide real-time audio feedback to the study participant.

Procedures

After an initial enrollment survey that included questions on basic demographics and clinical experience, participants were sequentially assigned to one of two groups: *1*) in-person group, which included live demonstration, independent image acquisition, and tele-guidance image acquisition; or *2*) "tele-guided group," which entailed providing tele-guidance image acquisition alone (Figure 1). Each participant completed evaluation A before the online training module, and then they immediately completed evaluation B. Participants were then scheduled for a live, in-person session correlating to the in-person group or tele-guided group about 24–48 hours after completion of evaluation B. The in-person group demonstration included a standardized walk-through, lasting about 5–10 minutes, and was led by an experienced user who demonstrated device use on a healthy volunteer.

Subsequently, a small-group discussion lasting about three minutes emphasized the consequence of quality image acquisition to the in-person group. The in-person group participants were then tasked with independently obtaining three images adequate for interpretation according to current standards on a healthy volunteer. Time limitations

	In-Person Group		**Tele-Guided Group**	
		Evaluation A		
Asynchronous Learning	Online Training Module	15 *minutes*	Online Training Module	15 *minutes*
		Evaluation B		
Live In-Person Session	In-Person Demonstration	5-10 *minutes*	Tele-Guidance Image Acquisition	17 *minutes*
	Independent Image Acquisition	17 *minutes*		
	Tele-Guidance Image Acquisition	17 *minutes*		
		Evaluation C*		
Summary	Total time	54-59 *minutes*	Total time	32 *minutes*

Figure 1. Overview of the schedule of for participant group including evaluation, individual training components, and corresponding time duration. *Occurred 24–48 hours after evaluation B.

included a total of 17 minutes per session to record three images and 5 minutes to record an individual image. The images were saved to an original file, which was cropped by an experience user (J.S.) in a blinded fashion to eliminate any artifacts while optimizing image duration. These clips were subsequently analyzed by another experienced user (A.R.D.) blinded to time point of acquisition and group according to the quality-scoring system (8). In addition, the research team recorded the time required for each individual image acquisition, and, if an image was not obtained within the allotted 5-minute time period, a default of 5 minutes was recorded. Immediately afterward, participants were tasked with obtaining three images adequate for interpretation under tele-guidance from a remote, experienced user. The guidance offered was a result of the organic interaction between the participant and experienced user. The same time constraints applied. After the live, in-person session, participants then underwent evaluation C immediately. The tele-guided group participants only received the tele-guidance portion of image acquisition.

Analysis

After image acquisition and standardized postacquisition processing, an experienced user blinded to the group allocation individually scored each image according to a standardized quality imaging score system well described in HVM imaging literature (8). Individual scores for six parameters (illumination, duration, focus, content, stability, and pressure) were assigned a score of 0 (good), 1 (acceptable), and 10 (unacceptable). In addition, the summative score was reported with less than 10 and greater than or equal to 10 being associated with an adequate image and inadequate image for interpretation, respectively.

Statistical software (SPSS; IBM) was used. Quantitative variables were summarized with means and standard deviations. Categorical variables were analyzed via Pearson chi-square test and Fisher exact test. Continuous variables were analyzed via Mann-Whitney U exact test. Repeated-measures analysis of variance was used to compare the percentage of correct evaluations measured serially by each subject between each evaluation session. Paired t test was used to compare image quality and acquisition time results obtained within each participant.

RESULTS

A total of 14 participants, enrolled between January 2020 and March 2020, were divided evenly into the two groups. We terminated the study early because of physical distancing measures in response to the onset of the COVID-19 pandemic. Table 1 reviews basic demographics for participants. For the overall group, the median age for participants was 31.0 years. No significant differences existed between the groups' sexes and professional roles.

The participant quality scores for microcirculatory images are found in Table 2. The average image quality scores improved nonsignificantly in the in-person group from independent capture to the tele-guidance capture (20.6 ± 14.1 vs. 14.7 ± 9.0, $P = 0.54$), whereas the tele-guidance capture scores were 23.6 ± 12.5 (Massey quality-score range, 0–60; with <10 indicating an acceptable-quality image). The most common parameter to receive a failing score among the recorded images was pressure, stability, and focus in the in-person group's independent capture, in-person group's tele-guidance capture, and tele-guided group's tele-guidance capture, respectively.

The average time for the in-person group to collect an image independently was 175.0 ± 94.1 seconds, and the time to capture an image under tele-guidance was nonsignificantly higher at 191.2 ± 104.3 seconds ($P = 0.710$). Comparatively, the tele-guided group captured each image under tele-guidance in an average time of 199.4 ± 102.0 seconds, which did not significantly differ overall from the in-person group.

Table 3 displays the percentage of correct answers per participant for each evaluation over time. Overall, the participants answered a higher percentage of questions correctly from before the online training module to after it (19.0% ± 14% to 80% ± 13%, $P < 0.0001$),

Table 1. Demographic characteristics for participants

Characteristic	In-Person + Tele-guided Group	Tele-guided Group	*P* Value	Overall
Age, yr, median (interquartile range)	31 (28.5–33)	31 (29–31.5)	0.710	31 (28.5–32)
Sex, *n* (%)			0.704	
Male	3 (42.9)	3 (42.9)		6 (42.9)
Female	4 (57.1)	4 (57.1)		8 (57.1)
Occupation, *n* (%)			0.549	
RN	4 (57.1)	2 (28.6)		6 (42.9)
Resident	1 (14.3)	2 (28.6)		3 (21.4)
Fellow	2 (28.6)	3 (24.9)		5 (35.7)

Definition of abbreviation: RN = registered nurse.

Table 2. Participant quality score and time to acquire microcirculatory images

Variable	Independent Capture	Tele-guidance Capture	*P* Value
In-person + tele-guided group			
Average quality score (SD)	20.6 (14.1)	14.7 (90.0)	0.54
Total no. of adequate images	7	11	—
Total no. of participants with ⩾1 adequate image	5	7	—
Most common parameter to receive failing score*	Pressure	Stability	—
Average time to capture (SD), s	175.02 (94.11)	191.21 (104.31)	—
Tele-guided group			
Average quality score (SD)	—	23.6 (12.5)	0.3[†]
Total no. of adequate images	—	9	—
Total no. of participants with ⩾1 adequate image	—	6	—
Most common parameter to receive failing score*	—	Focus	—
Average time to capture (SD), s	—	199.43 (101.91)	—

Definition of abbreviation: SD = standard deviation.
*Identifying the most common parameter to receive a score of 10 among the collection of recorded images.
[†]Comparing average quality scores between in-person + tele-guided group and tele-guided group.

as well as from before training to after its completion (19% ± 14% to 55% ± 23%, $P < 0.0001$). Interestingly, the percentage of correct answers declined from before in-person training to after an in-person training session ($P < 0.001$).

See Table E1 in the data supplement for participants' self-reported degree of confidence (i.e., from not confident [1] to completely confident [5]) longitudinally over three evaluations. Notably, participants in both groups demonstrated an increase in confidence scores from evaluation A to evaluation B ($P = 0.002$) and evaluation A to evaluation C ($P = 0.0003$). No significant difference existed between

Table 3. Participant performance on evaluations longitudinally over training period

Participant Number	Evaluation A (% *correct*)	Evaluation B (% *correct*)	Evaluation C (% *correct*)
In-person + tele-guided group			
Subject 1	0	55.6	55.6
Subject 2	11.1	88.9	66.7
Subject 3	11.1	88.9	77.8
Subject 4	0	66.7	77.8
Subject 5	44.4	88.9	22.2
Subject 6	22.2	88.9	11.1
Subject 7	22.2	77.8	66.7
Average (SD)	15.9 (15.5)	79.4 (13.5)	54.0 (26.8)
Tele-guided group			
Subject 1	33.3	77.8	44.4
Subject 2	11.1	66.7	55.6
Subject 3	44.4	100	55.6
Subject 4	22.2	100	88.9
Subject 5	11.1	66.7	22.2
Subject 6	11.1	77.8	55.6
Subject 7	22.2	77.8	66.7
Average (SD)	22.2 (12.8)	81.0 (13.9)	55.6 (20.3)
Overall average (SD)	19.0 (14.1)	80.2 (13.2)	54.8 (22.8)

Definition of abbreviation: SD = standard deviation.

the in-person group and the tele-guided group at each evaluation time point. Participants demonstrated a decrease in the proportion of "not confident" during evaluation A to C from 78.6% to 0%. Interestingly, no significant changes in confidence were reported between evaluation B and evaluation C. In addition, degree of confidence regarding the ability to operate the HVM device significantly improved from evaluation A to C (21.4–64.3%, $P = 0.027$). The subdivision of reasons accounting for lack of confidence in image acquisition is reported in Table 4.

The participants' self-reported satisfaction scores on a five-point Likert scale were generally favorable, as measured at evaluation C. Overall, 85.7% reported being "very satisfied" with training, and no significant difference existed between the two groups.

DISCUSSION

HVM imaging technology and semiautomated analysis have permitted

Table 4. Participant confidence regarding device operation reported at evaluation time points

Variable	Evaluation A		Evaluation B		Evaluation C	
	In-Person + Tele-guided Group	Tele-guided Group	In-Person + Tele-guided Group	Tele-guided Group	In-Person + Tele-guided Group	Tele-guided Group
Confidence, *n* (%)						
Yes	1 (14.3)	2 (28.6)	2 (28.6)	4 (57.1)	5 (71.4)	4 (57.1)
No	6 (85.9)	5 (71.4)	5 (71.4)	3 (42.9)	2 (28.6)	3 (42.9)
Device operation	3 (33.3)	4 (50.0)	2 (40.0)	3 (100)	1 (25.0)	1 (33.3)
Patient education and consent	0 (0)	1 (12.5)	0 (0)	0 (0)	2 (50.0)	0 (0)
Gathering acceptable quality clips	6 (66.7)	3 (37.5)	3 (60.0)	0 (0)	1 (25.0)	2 (66.7)

the bedside physiological monitoring of sublingual HVM imaging of critically ill patients (17). The relatively limited availability of expert educators within the field, lack of clearly prescribed objective curricular content, relatively low yield of quality images reported in multiple studies, and physical distancing mandated by a global pandemic have collectively highlighted the need for a process to assist novices in acquiring HVM images. Our study demonstrates the feasibility of deploying a standardized curriculum for novices with and without tele-guidance for HVM image acquisition. The lack of observed statistically significant differences between these methods for image quality or time to image acquisition suggests that tele-guidance may suffice for HVM image acquisition and training.

Participants' longitudinal scores on theoretical and practical knowledge assessments improved from time points 1 to 2 and 1 to 3 during training. This trend suggests the effectiveness of the curriculum, including the online-based component addressing theory and practical aspects of acquiring skills pertinent to image acquisition. Interestingly, participants' scores from time points 2 to 3 declined, and several potential variables may account for this observation. Educational theory identifies several factors that contribute to skill decay, including task characteristics, participant characteristics, training methods, evaluation methods, retrieval intervals, and retrieval conditions (18). We believe that the uniquely complex, systematic, closed-loop nature of evaluating and integrating six individual components of an HVM image quality score largely account for this observed skill decay. Although all participants completed evaluations at time points 1 and 2 in an environment of their convenience and time point 3 at the location of the in-person training session, both environments should have provided suitable conditions for evaluation administration. In addition, whereas our rapid training program demonstrated improvements in image acquisition skills, future efforts can aim to optimize the training session frequency, duration, and content while emphasizing personalized training.

In-person training and tele-guidance groups both demonstrated similar times needed to acquire images and achieved similar image quality scores. The COVID-19 global pandemic has further highlighted the ability of telehealth to offer a medium to deliver high-quality care while avoiding unwarranted exposure to infectious agents (10, 19). As an example, through various modalities, surgeons with a focused expertise can impart remote guidance to surgeons seeking to advance practice and procedure (20). Several capabilities exist in telehealth, including hardware, videoconferencing software, and the ability to integrate with medical records, and the readily available smartphone with videoconferencing capabilities can provide a reliable medium for telementoring across many clinical scenarios (21, 22). The use of FaceTime videoconferencing with commercially available devices demonstrated high-quality ultrasonographic image visualization reliably enough to allow for clinical decisions (12). Our study proposes deploying tele-guidance in the field of HVM imaging, a prospect that seemed to appeal to our study participants on the basis of their evaluation responses.

This study does not aim to replace established HVM imaging consensus statements, principles, or training that leads to expert-level competency (1, 8, 9). Instead, we sought to test the feasibility of introducing a curriculum and deploying the first telementoring study to rapidly train novices to obtain HVM images. Participants in each category demonstrated similar outcomes in image quality scores and times to image acquisition. These comparable outcomes suggest the utility of our designed curriculum, including audiovisual content, in-person training, and telementoring, to achieve a working vocabulary in HVM imaging for trainees. Even though both groups of participants did not achieve expertise, we observed that both formats of training achieved comparable outcomes. We acknowledge the relatively low values of quality scores achieved for this study, which is similar to those reported in prior microcirculation studies. However, we believe these findings will guide future iterations of the curriculum, including adjustments in content, cognitive feedback, frequency and duration of training sessions, and inclusion of more than one telementor to provide remote education. The audiovisual software and devices used for this project should approach other commercially available technologies. However, reliable and adequate internet connectivity is important to reproduce our findings, as anecdotally poor connections can significantly impact HVM image quality during transmission. We acknowledge several limitations of this study, such as the use of cooperative, healthy volunteers for HVM imaging, which may limit the generalizability to critically ill patients. However, the foundational HVM imaging principles should still apply. In addition, the limited number of expert personnel within our group allowed only for a single judgment on the assignment of an individual quality score; however, the objective criteria used to make those assessments should have limited that expert reviewer's subjectivity. Assessment of skills beyond 24–48 hours was not performed, which limited the ability to assess longitudinal knowledge and skill retention. We hope that future studies using the concepts we present in our feasibility study include more participants, more images reviewed by multiple experts, opportunities to incorporate additional training sessions to improve quality-score values, and real patients to better characterize the potential role tele-guided acquisition of sublingual microcirculatory images may serve in routine clinical care.

Conclusions

Sublingual HVM imaging offers a promising prospect to holistically monitor a critically ill patient's hemodynamics. Our study highlights the feasibility of combining a brief audiovisual didactic course with tele-guidance to guide the novice in acquiring microcirculatory images. This study provides a potential framework for how to successfully overcome training challenges within the field of microcirculation that are related to limited available expertise and resources, as well as geographic constraints exhibited during the COVID-19 pandemic.

Author disclosures are available with the text of this article at www.atsjournals.org.

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