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ABSTRACT

Simulation offers the most efficient adjunct in education and "refresher" training of medical personnel. However, simulation devices and facilities are expensive and the combination of cost, distance from the training centers, and professional constraints prevent medical personnel in rural and remote regions from simulation-based training. We have demonstrated that fiscal and logistic barriers can be overcome by the implementation of distance simulation methods that we have already developed. However, whenever High Fidelity Patient Simulators are used in a multi-unit training environment (e.g., mass casualties) the problems of simulator incompatibility may introduce major problems in the orchestration and control of the simulated events. The paper discusses problems of international large scale "just-in-time" training and the initial solutions to simulation-based preparation of medical personnel using multiple simulators simulator sites separated by ultra-long distances

Keywords

medical simulation, medical readiness, medical education, distance learning, simulation, EMS, Internet, high fidelity patient simulators

INTRODUCTION

Simulation and Medical Training

In similarity to aviation, large-scale introduction of simulation-based medical training (Isenberg, Gordon, Safford and Hart, 2001; Karnath, Frye and Holden, 2002) may result in significant progress towards reduction of diagnostic and procedural errors, improvement of confidence and preparedness, and enhanced medical readiness (O'Donnell, Fletcher, Dixon and Palmer, 1998; Marshall, Smith, Gorman, Krummel, Haluck and Conney, 2001; Morgan and Cleave-Hogg, 2002; Hammond, Bermann, Chen and Kushins, 2002). While quantitative studies are needed to prove the translation of simulation-derived improvement into daily clinical practice, the already available data indicate that simulation may have a substantial and positive impact on the quality of training and clinical performance of individuals (King, Pierce, Higgins, Beattie and Waltman, 2000; ; Watterson, Flanagan, Donovan and Robinson, 2000; ; Forrest, Taylor, Postlethwaite and Aspinall, 2002; Block, Lottenberg, Flint, Jakobsen and Liebnitzky, 2002; Rosenblatt, Abrams, NY Soc. Anesthesiol. Inc, Comm. Cont. Med.

Educ. and Remed., Remed. Sub-Comm., 2002; Weller, Bloch, Young, Maze, Oyesola, Wyner, Dob, Haire, Dubridge, Walker and Newble, 2003) and medical teams (Murray and Foster, 2001; Holcomb, Dumire, Crommett, Stamateris, Fagert, Cleve, Dorlac, Dorlac, Bonar, Hira, Aoki and Mattox, 2002) with the consequent improvement of patient safety (Gordon, Wilkerson. Shaffer and Armstrong, 2001; Rall, Schaedle, Zieger, Naef and Weinlich, 2001; Fellander-Tsai, Stahre, Anderberg, Barle, Bringman, Kjellin, Ramel, Strinnlund, Carlson and Wredmarm, 2001; Murray, Boulet, Woodhouse, Kras and McAllister, 2002.)

Our previous publications (von Lubitz and the MRT Team, 2000; von Lubitz, Pletcher, Treloar, Wilkerson and Wolf, 2000; von Lubitz, Freer, French, Hawayek, Montgomery, Levine and Wolf 2001) have extensively discussed the need for simulation-based training of medical personnel. The conceptual incompatibility of the existing training platforms ("solid" simulation devices such as High Fidelity Patient Simulators versus VR-based devices) has been successfully overcome by the creation of a "medical flight simulator" [von Lubitz et al., 2000; von Lubitz et al., 2000; von Lubitz et al., 2001; von Lubitz, 2002) in which High Fidelity Patient Simulator (METI) has been incorporated as a centerpiece of a dynamic VR-rendered environment (CAVE). Other investigators using procedure training devices provided convincing evidence of the efficacy of training performed in VR environments (Agazio, Pavlides, Lasome, Flaherty and Torance, 2002; ; Gallagher and Satava, 2002; Seymour, Gallagher, Roman, O'Brien, Bansal, Andersen and Satava, 2002). Even more importantly, highly complex "total VR" surgical training systems have been developed and tested during the past few years (Caudell, Summers, Holten[4th], Hakamata, Mowafi, Jacobs, Lozanoff, Lozanoff, Wilks, Keep, Saiki and Alverson, 2003) indicating the direction of the training trend at large centers of academic medicine.

The sophisticated High Fidelity Patient Simulators (HFPS) and less complex single-procedure simulators provide the less technically complex and more accessible medical training tools. HFPS units are preeminently suitable to train personnel (Lary, Pletcher and von Lubitz, 2003) in rapid diagnosis and management of complex emergency and trauma events. Nonetheless, HFPS units are sufficiently complex to require dedicated support personnel and facilities. Moreover, despite decreasing acquisition price (the phenomenon that also characterizes VR environments) the purchasing and operating costs are high (Morgan and Cleave-Hogg, 2001; Schaefer[3rd] and Grenvik 2001) and place simulation-based training beyond the means of smaller organizations (von Lubitz, Levine and Wolf, 2002). It is, however, likely that the expanded use of simulating devices in teaching pre-clinical subjects, use in non-traditional setting e.g., training of veterinarians (Modell, Cantwell, Hardcastle, Robertson, Pablo, 2002), physiology education (Tan, Ti, Suresh, Ho, Lee, 2000) or pharmacology [unpublished] will significantly broaden their applicability across several disciplines and may spread the expenditure more evenly. Highly innovative operational framework of training centers (Lary, Pletcher and von Lubitz, 2003) may also help to reduce the immediate costs of access even further.

During the past 4 years we have proposed, developed and tested under routine operational conditions a new approach intended to breach the tradition of stationary simulation centers and make simulation-based medical training available to essentially anyone with an Internet connection (Treloar, Beier, Freer, Levine, von Lubitz, Wilkerson and Wolf, 2001; von Lubitz, Levine and Wolf, 2002; von Lubitz, Carrasco, Gabbrielli, Levine, Ludwig and Poirier, 2003). The concept is based on free access to the central simulation facility and its HFPS machines from a remote sites located anywhere in the world, and permits training under the guidance of a centrally located expert teacher. Despite its demonstrable usefulness [Treloar, Beier, Freer, et al., 2001; von Lubitz, Carrasco, Gabbrielli, et al. 2003), the operational applicability of the concept was limited due to the problems in successful operation of more than a single HFPS unit. Yet, the need to operate several HFPS devices simultaneously essential when training involves mass casualties, or when the machines used as the constituents of the training federation (Proctor and Creech, 2001) are the product of more than one manufacturer.

PRACTICAL CONSIDERATIONS IN MULTI-PLATFORM HFPS TRAINING ENVIRONMENT

The environment

When several dispersed HFPS units are either controlled from a central training facility or accessed by the remote learners, the only means to ensure uniformity of training is to assure full compatibility of both physical and operational characteristics of the simulation devices. This aspect becomes critical when the training center has either the overriding remote control of all distributed HPFS units, or when the center serves as the "expertise headquarters" (von Lubitz, Montgomery and Russell, 2000; von Lubitz, 2002; von Lubitz, Carrasco, Gabbrielli, et al., 2003) during simultaneous, real-time training of large numbers of dispersed learners, e.g., in multi-simulator training of international medical intervention teams (e.g., just-in-time preparation for mass casualties caused by the acts of terrorism, natural disasters, etc., see von Lubitz, Carrasco, Fausone, Gabbrielli, Kirk, Lary, Levine, Patricelli, Pletcher, Stevens and Wroblewski, 2004.)

While the two principal HFPS systems in existence (Laerdal and METI) have practically identical anatomical features and generate very similar profile of training-relevant output, the conceptual basis of their software/hardware interaction differs significantly. As a result of these differences, combining both systems into a unified, remotely accessible training environment poses practical difficulties.

In the simplest setting of multiple simulators, all devices can be easily slaved to the same high speed CPU/high RAM (~1 GHz/~2 GB) control computer located at the central training facility. While this solution permits simultaneous or individual remote operation of the federated HFPS units by the **same manufacturer**, centralized and simultaneous remote control of dispersed, collaborating simulators built by **different manufactures** is severely impeded by software incompatibility of the machines.

From the medical point of view, voice commands given by the remote trainee to the personnel at the simulator host site (the central training facility) are the most realistic. The distance separating the remote trainee from the HFPS notwithstanding, this approach approximates real-life actions of a medical team. The use of separate computers dedicated solely to the control of federated HFPS units by the same manufacturer provides a more automated solution. Yet, in a fast-paced environment of a multi-patient scenario, such control, particularly if remotely executed by the trainees with little or no background in computer operations, may become very cumbersome. In trying to overcome the need for simultaneous machine control, the trainees' attention will rapidly shift from the main subject (medical training) to the frantic attempts at mastering unfamiliar technology. Clearly, the essential attribute of simulation – situational realism – will deteriorate and decrease effectiveness of training.

Simulator-bridging software that automatically translates commands given from the control interface of one system into the commands that are understood by the simulator of a different and otherwise incompatible brand is the most effective solution to multi- HFPS environments. It is also technically the most complex since, in the absence of commercially available products, the software bridge must be developed as a private venture at the user's facility. Thus, from the technical and fiscal point of view, the most suitable placement of the software bridge is at the central (hub) control facility at which all signal processing takes place. The latter solution is identical to the concept of Medical Application Software Provider (Med-ASP) that we proposed in one of our earlier publications (Lary, Pletcher and von Lubitz, 2003.)

Implementation of the ASP concept simplifies signal traffic and, by providing more effective processing, eliminates the annoying time lags that may render distance-based simulation training exceedingly unrealistic. Med-ASP concept assures that only the meaningful commands are passed within the simulator federation and also that exchange occurs at the maximum speed allowed by the available bandwidth.

Access and remote simulator control

Access from the periphery to the central facility and vice versa can be obtained either by using point-to-point connectivity, with each remote site having its own IP address and an allocated fast Internet connection, dedicated ISDN lines, or through a Web-based portal hosted at the central training facility. The Internet-based access without Quality of Service (QOS), although the simplest one, may become unreliable during extended (more than 1 hr) continuous transmission due to frequent connection interruptions and slow-downs, or up- and down-load loss of transmission speed. These problems are particularly annoying during long- or very long distance operations (e.g., transcontinental. or global.) Work in which ISDN-lines are routinely used is also the most expensive. Access through a Web portal necessitates its creation – a matter of technical complexity that is best accomplished by the technical personnel at the central simulation facility serving as a Med-ASP organization. However, with the portal located at the servers of the training facility, and with the significant part of the operational software necessary for the efficient training (HFPS control/translation software; remote camera control software, training scenario programs, etc.) accessible through such portal, multi-site activities become greatly facilitated. The peripheral sites are provided with a simple, intuitively understood simulator control interface displayed at the remote computer monitor and the operation of the simulator is performed either via point-and-click mouse interaction or, at a more sophisticated level, by touching appropriate controls on the touch-sensitive screen.

In summary, one of the principal role of the central training facility is that of a broad-concept ASP which, in addition to standard training activities aimed at a large number of distributed learners, provides simulation-centered software, supplies supporting electronic training elements, e.g., access to more traditional didactic tools, archives of previous simulation-based courses, testing materials, etc. In such configuration, prior experience indicates that transmission speeds of 128 Kbs are adequate to fulfill all the required tasks without any deterioration in the quality of image/voice/data elements.

OPERATIONS

For practical purposes, testing of the distributed multi-simulator training concept was conducted using two simulators. During operations between Ann Arbor, MI, USA and Laval, France two SimMan (Laerdal) HFPS units were used. One HFPS was located at the training center of MedSMART, Inc. in Ann Arbor while the second simulator was placed at the city exposition hall in Laval, France. The participants in Ann Arbor could interact with the conference participants (trainees) in Laval over a two-way real-time interactive video-conference, with full screen, full motion video and high-quality audio. Similar principles were used during subsequent series of training exercises performed between MedSMART Training facility in Ann Arbor, MI, Alpena (MI, USA) Medical Readiness Training Center of the Air National Guard, and the Training Center of Telecom Italia in L'Aquila, Italy. However, in the latter case two HFPS units manufactured by Laerdal, Inc. and METI, Inc. were used. Laerdal units were stationed in Ann Arbor, the METI device in Alpena, and the trainees at the Italian site had only the remote access to either machine. To eliminate concerns posed by opening military network at Alpena to civilian telecommunication traffic a dedicated high-speed LAN was used to link simulators placed at physically separated locations (approximately 250 km apart). In either case, real-time interactivity and simulator control were accomplished using high-end video conferencing systems at all locations, with an ADSL Internet connection bridging all sites. ADSL Internet connection was selected to test the performance of the relatively unsophisticated telecommunication link that would be relatively common at technically less advanced locations yet offering both the simplicity of the set-up and an acceptable stability during the transatlantic operations. It must be emphasized, however, that HFPS remote control can be implemented over any type of wide area link, including a standard telephone connection (Treloar, Beier, Freer, et al., 2001), dedicated private line (Treloar, Beier, Freer, et al., 2001; von Lubitz, Carrasco, Gabbrielli, et al., 2003,) or via the Internet (von Lubitz, Montgomery and Russell, 2000) and the section on training for First Responders at www.med-smart.org].

One of the critical factors during training was the dependence of the overall quality of sound and image on the bandwidth (speed) and latency (delay) of the Internet connection. A minimum of 128 kilobits per second sustained transfer rate is required for real-time video conferencing. With round-trip latencies exceeding 200 milliseconds, delays would be noticeable (similar to the delay encountered over a satellite telephone call.) Constant measurement of latencies and bandwidth variation between Laval and Ann Arbor indicated a relatively low average latency (below 100 milliseconds round trip) with sufficient average bandwidth (sustained >300 Kb/sec.) that was adequate to prevent imagery delays (pixellation.) Transmission stability allowed us to conduct contiguous, and essentially uninterrupted, sessions lasting 1 to 4 hrs each.

During training, all HFPS devices could be operated either under local or full remote control from all sites. Multi-site remote control of Laerdal and METI machines was made possible by proprietary HFPS bridging developed by MedSMART that utilizes digitized physiological outputs of one simulator as the controlling element of driving the other unit. Bridging software was loaded into the memory of the local (machine-slaved) control computers at either HFPS location. The machines were then programmed to allow either concerted or independent action, with the operational control seamlessly transferable between the operator stations in Ann Arbor, Alpena, Laval, or L'Aquila. Multi-site control capability allowed random introduction of unpredictable and confounding medical events (e.g., sudden hemorrhages, adverse drug reactions, or malfunctions of patient monitoring systems.) Introduction of medical unpredictability proved to be an important tool amplifying the sense of medical realism and urgency "suspension of disbelief".)

CONCLUSIONS

The efficacy of simulation-based distance training using the approach described in this paper has been published elsewhere (von Lubitz, Carrasco, Gabrielli, et al., 2003; von Lubitz, Carrasco, Fausone, et al., 2004.) Here, suffice to say that the majority of our remote trainees (89%, N=126) declared "very high satisfaction with the quality of training and technology," and stated a very high quality learning experience based on the use of remote access to medical simulation. From the technical point of view, our experiments show that a successful HFPS network can be created with moderate ease, and that such network can perform effectively at very large distances (over 7000 km between Laval/L'Aquila and Ann Arbor.) Importantly, while less sophisticated than pure VR-based medical training systems, HFPS networks utilizing concepts of Advanced Distributed Learning (ADL) are vastly cheaper to build, operate, and maintain compared to VR-based federations. Hence, they are also much more readily available to the majority of the medical personnel who work in the environment insufficient to support the expense and technical knowledge required by the advanced VR technology. In this context, it needs to be mentioned that the simulator-connecting software bridge that allowed simultaneous use of simulators produced by two different companies is not the optimal solution. A far more flexible platform would be based on a Web portal allowing greater ease of operations and – most significantly – essentially unlimited scaleability. It is the latter aspect that is probably the most critical in the context of large, global range simulator networks. While ideal, the latter solution also requires that machine-generated data are standardized using broadly agreed rules (e.g. HL7.) Surely, increasing use of HFPS devices and the need to combine them into collaborative "patient suites" will provide enough driving force to implement such standardization.

In similarity to VR-based medical training devices (Agazio, Pavlides, Lasome, et al., 2002; Seymour, Gallagher, Roman, et al., 2002, Gallagher and Stava, 2002; Bloom, Rawn, Saltzberg and Krummel, 2003,) both individual HFPS units and ADL networks utilizing them offer sufficiently high level of versatility and the associated "suspension of disbelief" to create highly efficient training tools (Myjak And Rosen, 2001; Pittini, Oepkes, Macrury, Reznik, Beyene and Windrim, 2002; von Lubitz, Carrasco, Gabbrielli, et al., 2003; von Lubitz, Carrasco, Fausone, et al., 2004.) Both VR and HFPS approaches to medical simulation have their advantages and disadvantages. Combining both may lead to a significant enhancement of both the efficacy and intensity of training (von Lubitz and the MRT Team, 2000; von Lubitz, Pletcher, Treloar, et al., 2000) and convert the present, largely explorative arena of medical simulation into an indispensable tool that simulation provides today in practically all aspects of aviation and maritime education and training.

In conclusion, we have demonstrated that, from the technology point of view, multisimulator environment in which distance is the most limiting factor, can be used a powerful training tool at both national and international scale. We have also shown that the tool is an effective one (von Lubitz, Carrasco, Gabbrielli, et al., 2003; von Lubitz, Carrasaco, Fausone, et al., 2004.) However, demonstration of usefulness does not obviate the need for further intensive, metrics-based research on the medical uses of simulation. The work of Gallagher and his colleagues (2002) points at the direction the future studies must take in order to prove convincingly the value of medical simulation. Other subjects, e.g., evaluation of human factors in medicine, testing of telemedical concepts and models, large scale simulation of healthcare operations (e.g., hospital simulation or healthcare management simulation starting at the individual patient level and ending on national-level administration of the related expenditures) come to mind as well. In similarity to defense and aviation, also in medicine simulation appears to open completely new and unprecedented possibilities.

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