Telemedicine with mobile devices and augmented reality for early postoperative care

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***Abstract*— Advanced features are being added to telemedicine paradigms to enhance usability and usefulness. Virtual Interactive Presence (VIP) is a technology that allows a surgeon and patient to interact in a "merged reality" space, to facilitate both verbal , visual, and manual interaction. In this clinical study, a mobile VIP iOS application was introduced into routine post-operative orthopedic and neurosurgical care. Survey responses endorse the usefulness of this tool, as it relates to The virtual interaction provides needed virtual follow-up in instances where in-person follow-up may be limited, and enhances the subjective patient experience.**

I. INTRODUCTION

"Telemedicine" is a paradigm that digitally brings patients and providers together, allowing real time interaction across geographic distances [1]. Telemedicine is being increasingly used to enhance healthcare access to underserved and rural areas, while extending specialty care to these regions. However, telemedicine systems are diverse in its formats and capabilities. For example, a basic telemedicine service can use standard bidirectional web cameras to capture patient and provider for real time visual and verbal communication. More advanced systems may add other features, such as camera control, telestration and digital image processing – to name a few. Some platforms use digital workstations, while more mobile device platforms are emerging [2]. The usefulness of each system depends on the patient care circumstance being serviced. Circumstances that favor communication, such as history-taking or counseling, would require only two-way audiovisual interaction – whereas, physical examination and image review may require more advanced digital interaction techniques [3].

We have previously introduced a system, termed "virtual interactive presence" or (VIP), with augmented reality (AR). In this system, visual fields from both participants, are digitally merged into a common field, so that both participants see the same local image stream (e.g., the patient), while the remote participant (e.g., the provider) can virtually interact to provide complex visual instruction. The system has been previously used for an expert surgeon to virtually mentor a training surgeon [4] (telementoring), collaborate in complex microsurgical dissection (tele-collaboration) [5] and orthopedic procedures [6].

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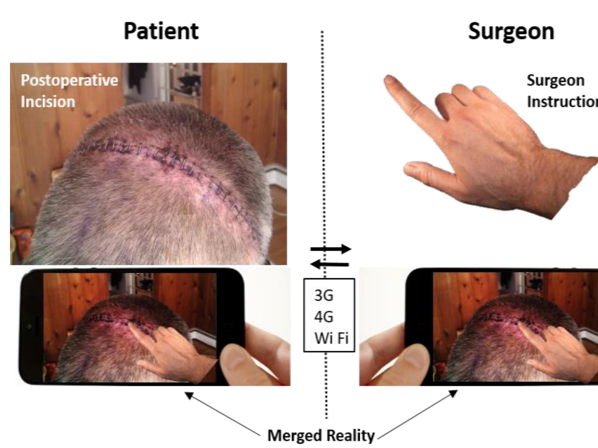
After discharge from the hospital, the post-operative period is a critical time, when patients are vulnerable to surgical complications, but are outside the direct vision of the health care team. Moreover, postoperative care typically requires more physical interaction, such as wound dressing manipulations, and palpation, and other maneuvers. In a typical telemedicine system with only audiovisual interaction, the provider is limited to verbal communication and gesturing. However, VIP offers a paradigm in which the physician can virtually examine the patient, "as if he/she were there." In this paper, we describe a mobile device VIP system, with AR features, that enable such interaction, and our experience with a clinical trial that explores its utility.

II. METHODS

A. Core VIP Technology

VIP technology is a commercially available system, provided by *HelpLightning* (Birmingham, AL) as a free mobile device. The basis of the paradigm is described in [4] and [5] (Fig. 1). In brief, bidirectional video feed is captured, using standard and commercially available cameras (e.g. mobile device camera) at the site of the provider (remote location) and the patient (field location). Video streams are stored into local data structures at each site. The foreground of the remote feed is segmented from the background layer, and then superimposed onto the field feed. Both participants see the same hybridized feed, allowing provider to interact virtually with the patient (Fig. 1).

Figure 1. Schematic of VIP paradigm



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B. *Mobile Implementation*

The HelpLightning application, as described above, is encoded in iOS (Apple, Cupertino, CA) for use on mobile devices (iPhone, iPad, iPad Mini). Encryption of health protected information was performed with use of the WebRTC framework (Google Inc., Mountainview, Ca), that includes the Advanced Encryption Standard (AES) 128-bit encryption. All encryption methodologies were approved by the University of Alabama at Birmingham Privacy and Security Offices for use in the study. Information exchange was delivered across a 3G/4G mobile network, or an available Wi-Fi network.

The mobile application interface (Fig. 2) allows each user to configure the experience by selecting a mode of communication (e.g. “Receive Help”, “Give Help”, or “Face to Face”). Other options include the ability to “freeze” and an image for documentation and storage in the electronic health record. Digital annotation is possible, using a freehand draw tool, or arrow and line tools.

C. *Prospective Clinical Trial*

Patients scheduled to undergo neurosurgical or orthopedic procedures with one of three suregons (BAP, EWR, BLG) were screened pre-operatively. Inclusion criteria were: 1) at least 18 years of age, 2) scheduled for an elective surgical procedure requiring post-operative wound evaluation, 3) capable of carrying out the protocol, 4) access to an iOS mobile device capable of video transmission via a 3G/4G or Wi-Fi network. Exclusion criteria were 1) inability to give informed consent, 2) anticipation of a complex postoperative course, 3) no access to an iOS device with mobile capability, or 4) postoperative scheduling conflicts. The clinical protocol was approved by the University of Alabama at Birmingham Institutional Review Board.

All enrolled patients were assisted with the download of the mobile application, or given a hard copy of the installation process. A virtual session was scheduled within several days of patient discharge, prior to the patient’s first in-person follow-up with the primary surgeon or a local provider. The session typically included verbal interaction regarding subjective clinical course, a virtual visual inspection of the wound, and virtual interaction with the surgeon if required. During the session, the patient or designate (e.g. spouse) could follow the surgeon’s hands or instruments to accomplish the task).

Figure 2. Mobile application user interface.

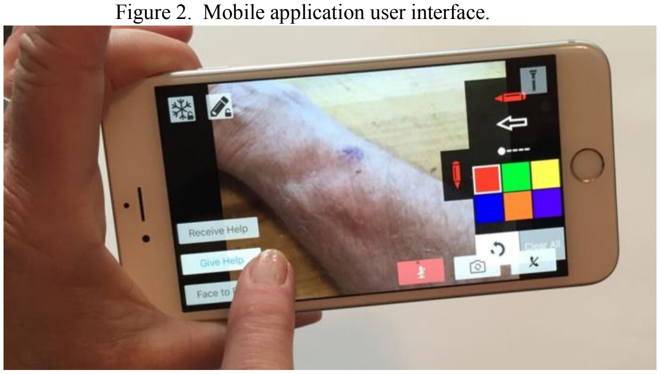

Figure 3. Postoperative interaciton between patient and surgeon.

After the session, patients and surgeons were required to complete questionnaires regarding their respective experiences. Each questionnaire consisted of 15 questions with Likert scale responses of 1 (strongly disagree) to 5 (strongly agree), and the option to provide free text comments. “Overall agreement” was calculated as the total number of “4” or “5” ratings. Questionnaires were administered in-person if direct follow-up was available, or by email or phone. Questions clustered around areas of “usefulness”, “usability”, and “overall experience” Six questions of the patient and surgeon questionnaires were similar, and allowed study of concordance. Descriptive statistics were performed, and a paired student’s t-test was used to compute significance. All patient study information was stored on a secure database (REDCapTM, Version 6.9.3, Vanderbilt University).

III. Results

Fifty-one patients were enrolled, with 31 participating an interaction, and 30 completing the questionnaire. Most common procedures of those completing the study, included Deep Brain Stimulation (6, 19.3%), craniotomy (5, 16.6%), knee/shoulder arthroscopy (8, 26.7%). The average age of the complete participant was 53.7 years (20-81 years) and 16 (53%) were male. Only 37% of respondents have used video chat applications “often” or “very often”, characterizing a relatively naïve cohort. The average post-operative days to remote interaction was 6.9 days (2-24 days). The average ratio of call attempts to success was 2.2 (1-8 attempts). Of the 20 participants that failed to complete the study, 6 (30%) never answered the call, and 6 (30%) had technical difficulties with the application set-up. Poor network connection, wrong devices, and inability to use the applications made up the remainder of attrition. Fig.2 shows a typical interaction between patient and surgeon.

A. *Patient Experience*

In general, patients gave strong ratings on “usefulness”. Of 27 patients receiving a virtual inspection of the wound, 26 (96%) voiced “overall agreement” that this practice was useful. Of these 27 patients, 18 patients received some instruction regarding wound care, of which all 18 (100%) patients yielded “overall agreement” on its usefulness. Regarding instruction on durable medical equipment (braces, slings, etc.), 12 patients received virtual instructions, of which all 12 (100%) rendered “overall agreement” on its usefulness.

Regarding the usability of the application, 27 of 28 (96%) patients “overall agreed” that virtual instructions allowed for an accurate following of the task. Less strongly, however, 23 of 28 (82%) “overall agreed” that they were clear on which issues were appropriate to discuss via remote application, with 1 patient disagreeing.

In total, patients rated the overall VIP experience, positively with an average score of 4.6 (out of 5), with 27 (90%) patients gave an “overall satisfied” rating. On 29 patients responding to the questions, 27 (93%) and 28 (97%) patients “overall agreed” that remote virtual interaction was superior to telephone or email/text messaging communications, respectively.

There were two instances in which the protocol led to undesirable experiences. In the first case, a patient that had incisional bleeding unsuccessfully attempted to contact the surgeon via the application, delaying the decision to go the emergency department by 6 hours. In the second case, a patient had a seizure, and the family also attempted to use the application for help unsuccessfully. Both patients were ultimately managed without complication or long-term effect.

B. Surgeon Experience

Surgeons were generally satisfied with the interactions, although to a lesser degree than patients. In terms of “usefulness”, of 29 interactions receiving a virtual inspection of the wound, 26 (89.6%) surgeons “overall agreed” on the usefulness of the inspection. Conversely, 3 (10%) were “unsatisfied” with wound visualization. Of 8 physicians delivering instructions on wound care, 8 (100%) were “overall satisfied”. Similarly, of 9 physicians rendering instructions on durable medical equipment, 9 (100%) were “overall satisfied” with the interaction.

Physicians had a relatively more critical view of the overall experience than the respective patients. The average satisfaction score was 4.2 (out of 5), with 26 of 30 responses (86.6%) voicing “overall satisfaction”. Physicians generally agreed that the virtual interaction was more useful than a phone call (93%) and text/email (86.6%). In one instance, the application misrepresented the incision healing process, due to variable video quality (e.g. “pixelated” appearance).

C. Patient-Surgeon Comparisons

Six survey questions were similar for both surgeon and patient, and included usefulness with 1) wound inspections, 2) wound dressings, and 3) durable medical equipment ; superiority to 4) phone calls, and 5) text/email interaction; and 6) the overall experience (Table 1). This analysis endorses the following hypotheses:

- Both patients and surgeons agreed that the interaction provided reassurance (98%), but patients were more likely to strongly agree (69% vs. 57%).
- Patients and surgeons felt similarly that dressing changes and equipment management interactions were useful (96% vs. 91%), but patients were more likely to strongly agree about its usefulness (77% vs. 56%).
- Patients and surgeons felt that interactions were generally superior to a phone call, and text/email communications. However, the patients were significantly more likely than surgeons, to find the virtual interactions more useful than text-email ($P<0.05$).
- Patients and surgeons were generally satisfied overall with the interaction (90% vs. 83%), but patients were significantly more likely to be satisfied ($P<0.05$). Moreover, patients were more strongly satisfied with the interaction (70% vs. 37%).

Table 1. Patient vs. Surgeon Survey Responses

	Survey Question	*Patient Score*	*Surgeon Score*
1	… provided reassurance	4.8±0.5	4.6±0.5
2	… useful for wound instruction	4.7±0.5	4.5±0.5
3	… useful for instruction on durable medical equipment	4.8±0.5	4.7±0.5
4	... superior to phone call	4.8±0.5	4.5±0.6
5	…superior to text/e-mail (P<0.05)	4.7±0.5	4.4±0.8
6	… rate overall experience (P<0.05)	4.6±0.5	4.2±0.5

IV. Discussion

Telemedicine is evolving beyond the basic bidirectional video paradigm (e.g. “Skype”), to include more enhanced features, such as augmented reality. The VIP application not only allows verbal and “face to face” communication, but the added capability of virtual interaction appears to offer the patient assurance and improved satisfaction. While both surgeons and physicians were generally satisfied with the virtual interactions, patients tended to have a more strongly positive response, significant in two of the six questions. Therefore, in addition to the intrinsic clinical value of post-operative inspection to detect early complications, this study is able to conclude that VIP (and more generally, telemedicine) offers a distinct advantage in patient satisfaction and the subjective patient experience.

Telemedicine protocols have shown to be successful as substitutes for outpatient care, in terms of communication, patient satisfaction, and cost-minimization in a variety of subspecialties [7] [8] [9]. However, traditional telemedicine that involves bidirectional video has significant limits. For example, as each participant is seeing different images (e.g., each other’s face), it is difficult for a provider to display manual instruction with reference to a post-operative wound or medical equipment

The results of this clinical trial indicate that the VIP application is useful in clinical assessment, therapeutic instructions, and subjective reassurance. From the patient’s perspective, a post-operative evaluation is a relatively rare event, with few points for comparison. Therefore, the use of a new technology is likely to enhance patients' experiences. Surgeons, however, routinely provide post-operative evaluations, and are more likely to emphasize its shortcomings. Consequently, it is not surprising that surgeon's will report a more critical experience – and in fact, it is an indication that high expectations exist. Moreover, the post-operative visit is more likely to be seen as an inconvenience to patients, who carry the burden of travel, waiting, loss of work, and costs. For surgeons, the post-operative visit is routine. Therefore, an acceptable substitute will be seen more positively by patients.

The use of the application has several human and technical limitations. First, with only 59% of study enrollees able to schedule an online interaction, the technology is still constrained by the basic human difficulty of finding mutually agreeable appointments. However, with more staff experience with this paradigm, it is likely that scheduling difficulties can be overcome with upfront communication. Second, the patient's technical familiarity plays a crucial role in success, and it would be the responsibility of the surgeon (or staff) to ensure a basic level of proficiency before relying on these technologies for higher risk evaluations. Third, network difficulties can come into play during an interaction, causing image distortion and lagging that renders the session ineffective. Regardless of advancements in network technology (e.g. 3G/4G to 5G), countermeasures must be in place for network interruption.

Overall, there were several instances which highlight the need for expectation management with patients, who may develop an "overreliance" with the application. The two instances noted above that led to a care delay, can be mitigated with clear *a priori* communication that the VIP application (and more generally any telemedicine application) is not substitutive for standard urgent or emergent protocols (e.g. "dialing 911"). Additionally, as these sessions only capture a specific period of time, patients should be encouraged to remain vigilant of potential complications that may present intermittently (e.g. draining wounds) or non-visual signs (e.g. fevers).

A critical deduction of this study is the need for the VIP application, and all telemedicine paradigms, to be closely integrated with patient education, orientation, and policy guidance. With proper implementation, the use of telemedicine with augmented features, for routine follow-up can provide visual post-operative surveillance, while enhancing the overall patient experience.

V. Conclusions

The use of telemedicine and augmented reality adds significant value to remote post-operative interaction, with both patients and surgeons endorsing overall satisfaction. Patients, however, had a stronger positive reaction, highlighting the value of mobile telemedicine to the patient experience, and overall satisfaction. Implementation, patient education, and expectation management are key areas of future focus for advanced telemedicine paradigms.

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