Telemedicine in vascular surgery: Feasibility of digital imaging for remote management of wounds

Douglas J. Wirthlin, MD, Syam Buradagunta, BA, Roger A. Edwards, ScD, David C. Brewster, MD, Richard P. Cambria, MD, Jonathan P. Gertler, MD, Glenn M. LaMuraglia, MD, Diane E. Jordan, BS, Joseph C. Kvedar, MD, and **William M. Abbott, MD,** *Boston, Mass.*

Purpose: **Telemedicine coupled with digital photography could potentially improve the quality of outpatient wound care and decrease medical cost by allowing home care nurses to electronically transmit images of patients' wounds to treating surgeons. To determine the feasibility of this technology, we compared bedside wound examination by onsite surgeons with viewing digital images of wounds by remote surgeons.**

Methods: **Over 6 weeks, 38 wounds in 24 inpatients were photographed with a Kodak DC50 digital camera (resolution 756 × 504 pixels/in^2). Agreements regarding wound description (edema, erythema, cellulitis, necrosis, gangrene, ischemia, and granulation) and wound management (presence of healing problems, need for emergent evaluation, need for antibiotics, and need for hospitalization) were calculated among onsite surgeons and between onsite and remote surgeons. Sensitivity and specificity of remote wound diagnosis compared with bedside examination were calculated. Potential correlates of agreement, level of surgical training, certainty of diagnosis, and wound type were evaluated by multivariate analysis.**

Results: **Agreement between onsite and remote surgeons (66% to 95% for wound description and 64% to 95% for wound management) matched agreement among onsite surgeons (64% to 85% for wound description and 63% to 91% for wound management). Moreover, when onsite agreement was low (i.e., 64% for erythema) agreement between onsite and remote surgeons was similarly low (i.e., 66% for erythema). Sensitivity of remote diagnosis ranged from 78% (gangrene) to 98% (presence of wound healing problem), whereas specificity ranged from 27% (erythema) to 100% (ischemia). Agreement was influenced by wound type ($p < 0.01$) but not by certainty of diagnosis ($p > 0.01$) or level of surgical training ($p > 0.01$).**

Conclusions: **Wound evaluation on the basis of viewing digital images is comparable with standard wound examination and renders similar diagnoses and treatment in the majority of cases. Digital imaging for remote wound management is feasible and holds significant promise for improving outpatient vascular wound care. (J Vasc Surg 1998;27:1089-1100.)**

Telemedicine is an evolving field that combines telecommunications and information technologies to provide remote medical care and ranges from activities as simple as telephone consultation to technology as complex as telesurgery.[1] Electronic transmission of clinical images for remote consultation is one component of telemedicine that has been successfully implemented and tested in the fields of dermatology, pathology, and radiology.[2-8] Moreover, Kvedar et al.[9] observed that as many as 83% of dermatologic diagnoses could accurately be made by viewing still digital images. Accordingly, we hypothesized that still digital images could precisely represent vascular

From the Department of Surgery (Drs. Wirthlin, Brewster, Cambria, Gertler, LaMuraglia, and Abbott), and the Partners Telemedicine Center (S. Buradagunta, D. E. Jordan, and Drs. Edwards and Kvedar), Massachusetts General Hospital; and Harvard Medical School.

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Reprint requests: Douglas J. Wirthlin, MD, Department of Surgery/ Division of Vascular Surgery, Massachusetts General Hospital, WAC 458, Boston, MA 02114.

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surgery wounds and that wound evaluation and management based on viewing digital images would closely match that of evaluation and management based on bedside examination. Validation of this hypothesis would suggest that digital imaging coupled with telemedicine could be implemented to enhance outpatient wound care. For example, using current technology, visiting nurses could photograph patients' wounds and transmit the digital images over a short period of time to the treating surgeon, thus allowing surgeons to manage wounds remotely. Remote wound management, in turn, has the potential to decrease the frequency of office visits, prevent unnecessary "urgent" wound evaluations, and shorten hospital stay for patients with wound complications.

This potential application of telemedicine is particularly appealing because of the frequency and chronic nature of wound complications in vascular surgery, the large consumption of resources to treat these wounds, and the shift of health care from the hospital to the outpatient setting. Johnson et al.[10] observed that 40% to 50% of patients who undergo lower extremity bypass procedures have a nonhealing ulcer that may require several months to heal despite a functioning bypass graft. Also, of those patients who undergo lower extremity bypass procedures, 20% to 30% will have a wound complication that will lengthen hospitalization and necessitate prolonged wound care.[11-13] Moreover, as suggested by Calligaro and others who have evaluated the impact of care pathways in vascular surgery, there is increasing pressure to shorten hospitalization and decrease the cost of care.[14,15] Thus the purpose of this study is to determine the accuracy of wound evaluation and management based on viewing digital images as an initial step in testing the feasibility of implementing digital imaging for remote wound management.

PATIENTS AND METHODS

The feasibility of digital imaging for remote wound diagnosis was evaluated by comparing wound evaluation and management based on viewing digital images of wounds with evaluation and management based on examining wounds at the bedside. Surgeons who examined wounds directly were labeled *onsite surgeons,* and surgeons who viewed digital images were labeled *remote surgeons.* The onsite surgeons' wound evaluation and management constituted the "gold standard" in this study. Fig. 1 shows an overview of the study design. The experimental protocol was approved by the Institutional Review Board of Massachusetts General Hospital (Accession #9607618), and all subjects gave informed consent.

Patients. Vascular surgery inpatients at the Massachusetts General Hospital from March 18, 1996, to May 5, 1996, were invited to participate. Eligible patients included those inpatients who had recently undergone a lower extremity bypass procedure or amputation or were admitted for a wound healing problem (nonhealing ulcer, necrotic/gangrenous toes, cellulitis). Approximately 36% of total eligible patients were included in this study, and eligible patients who did not participate were excluded as a result of factors beyond the control of the study: busy clinical activity, inability to coordinate digital imaging with onsite wound evaluation, and refusal to consent. Twenty-four inpatients (six female and 18 male) with 38 separate wounds were photographed. The wounds were categorized as follows: postoperative incision (n = 16), amputation site (n = 3), necrotic/gangrenous toes (n = 11), and nonhealing ulcer (n = 8). The number of wounds per extremity and wound category were assigned on the basis of the onsite surgeons' examination and chart review. For postoperative incisions, any area of the incision with a wound complication that might independently influence wound evaluation was considered a separate wound.

A brief history (age, sex, reason and date of admission, medical and surgical history, vascular physical examination, and treatments rendered from admission to the time of imaging) on each patient was obtained by chart review.

Digital photography and image display. During morning rounds, a nonphysician without any formal photography training (S. B.) photographed all wounds using a digital camera (Kodak DC 50, Eastman Kodak Co., Rochester, N.Y.; resolution 756 × 504 pixels/in^2, single CCD chip, 24-bit color). Table I describes our imaging protocol. Seventeen of the 38 wounds were photographed on more than one day, rendering 45 image sets for comparison and 183 total images. Images were stored as highest-quality JPEG[16] files (Joint Photographic Experts Group, a compression algorithm for digital images) and were converted to a Microsoft Powerpoint slide presentation to be viewed on a computer monitor (Mitsubishi 91TXM at the maximum attainable resolution). Fig. 2 shows examples of wound images.

All images were graded by a nonsurgeon, nonmedical photographer (E. R. M.) using a rating system developed to grade the image quality of standard 35 mm photographs.[9] Images were assigned a

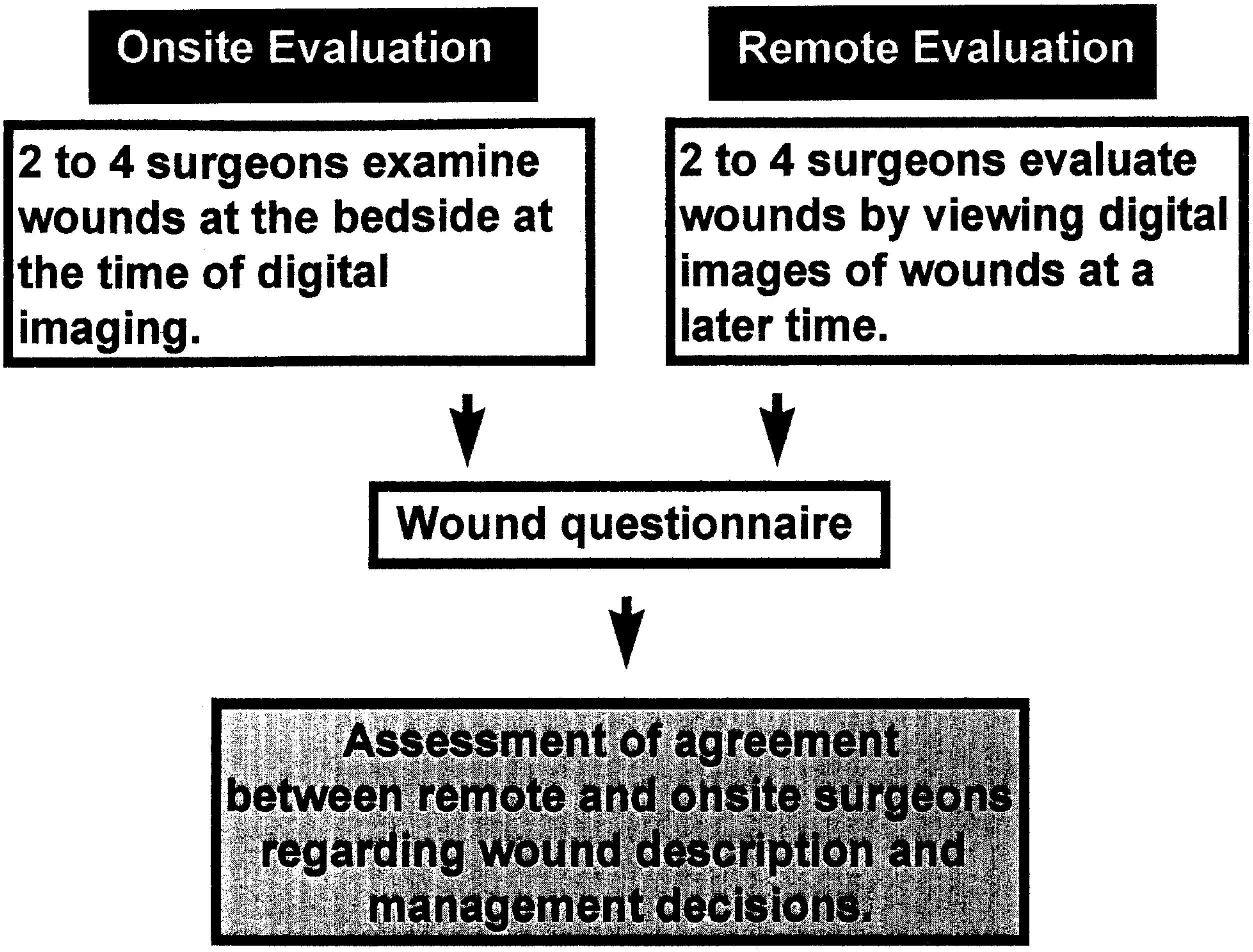

Fig. 1. Study design. Using a standard questionnaire and bedside wound examination as the "gold standard," the feasibility of digital imaging for remote wound management was measured by concordance between bedside and remote surgeons.

photographic quality rating (0 [unreadable] to 5 [perfect quality]). Using this grading system, a score of 4 is highest quality rating attainable with our digital camera because the resolution, color range, image memory, and lighting are inferior to standard 35 mm photographs. However, there are a number of "higher-end" digital cameras with photographic features and characteristics more similar to standard 35 mm cameras that would have scored consistently higher than the camera used in this study.

Wound evaluation. Wounds were evaluated by two to four onsite surgeons and two to four remote surgeons. Table II shows the number of evaluations completed and the level of surgical training of the evaluators (five vascular attendings, five vascular fellows, and six surgical residents). Onsite surgeons examined each wound at the bedside near the time of digital imaging and had no restrictions in method of examination, for example, palpation, olfaction, viewing from multiple angles, and time of evaluation. The setting (lighting, patient position, and background) during onsite examination matched the setting during digital photography. In most cases, onsite surgeons were involved in the care of the patient, and occasionally when an onsite surgeon was not the treating surgeon a brief history was given before examining the wound.

Remote surgeons evaluated wounds by viewing images on a computer monitor some time after digital imaging. Before viewing wound images, remote surgeons were given a brief medical history of each patient. There was no time limit for viewing images and remote surgeons were allowed to scroll back and forth among different views of the wounds. No image manipulations such as magnification, color enhancement, or contrast enhancement were used.

Table I. Imaging protocol

Camera (Kodak DC50) settings
Auto focus, auto flash, auto exposure
Lighting
Window shade closed, overhead examination light on
Position of patient
Supine
Presentation of wound
Blue pad under extremity
Transparent ruler and patient identifier number placed adjacent to wound
Photographs taken (image set)
View of entire extremity (camera 40 inches from wound)
View of thigh (camera 20 inches from wound)
View of leg and foot (camera 20 inches from wound)
Close-up views* (camera 18 inches from wound with lens set on telephoto)

*Close-up views were taken of specific wounds (gangrenous/necrotic toes or nonhealing ulcers, and areas along a postoperative incision with a wound complication). The composition and number of close-up views taken per extremity were determined by an onsite surgeon.

Table II. Wound evaluations

	Onsite	*Remote*
Attending	7	55
Fellow	76	65
Resident*	16	0
Total	99	120

*Only two of six residents had completed less than 4 years of training.

Table III. Wound questionnaire*

Wound descriptors	Present	Not present
Gangrene		
Necrosis		
Erythema		
Cellulitis/infection		
Ischemia†		
Granulation tissue		
Wound management decisions	Yes	No
Wound healing problem present		
Need for examination within 24 hr by MD		
Need for hospitalization		
Need for antibiotics		
Need for debridement		

*The following additional wound descriptors and management decisions were asked but not used for analysis because of either infrequent occurrence, limited clinical significance, vagueness of surgeon response, or poorly phrased question: (1) ecchymosis; (2) exposed bypass graft; (3) nonhealing wounds; (4) exposed tendon/bone; (5) edema; (6) drainage; (7) bedrest; (8) dressing changes; and (9) leg elevation.
†This descriptor was added to the questionnaire 4 weeks into the study.

After evaluating wounds, both onsite and remote surgeons completed a standard wound questionnaire, which addressed questions regarding wound description and wound management. Surgeons answered either "yes," "no," "present," or "not present" to each question and recorded a level of certainty for each response (1 [not certain] to 10 [absolutely certain]; Table III).

Statistical methods. All data were collected, stored in Microsoft Excel files, and imported into SAS (SAS Institute Inc., Cary, N.C.) for statistical analysis. Descriptive analysis was performed for the following endpoints: image quality (mean and range), certainty of response (mean and range), and agreement among and between surgeon groups (mean percent agreement and kappa values for each wound descriptor and management decision). In addition, prevalence of agreements and disagreements along with two variations of kappa values, kappa(nor) and kappa(max)[17] were calculated (see Appendix). In an attempt to control for surgeon variation, agreement between remote and onsite surgeons was calculated in three different subsets of cases based on the level of agreement among onsite surgeons: (1) all cases; (2) only those cases in which onsite surgeon agreement was greater than 67%; and (3) only those cases in which onsite agreement was 100%. Ultimately, agreement was measured in five different categories: category I, agreement among onsite surgeons; category II, agreement among remote surgeons; category III, agreement between remote and onsite surgeons for all cases; category IV, agreement between remote and onsite surgeons only in those cases in which onsite surgeons agreement was greater than 67%; and category V, agreement between remote and onsite surgeons only in those cases in which onsite surgeons agreement was 100%.

To determine factors that influenced concordance, logistic regressions with dependent variables (certainty of response, agreement between onsite and remote surgeons, and disagreement between onsite and remote surgeons) and explanatory variables (onsite vs remote surgeon, level of surgical training, and wound type) were performed. Data sets for multivariate analysis were generated using the SAS-based random number generator to randomly eliminate remote and onsite evaluations in excess of two per wound. A p value of 0.01 was considered significant rather than using a p value of 0.05 with Bonferroni correction for multiple comparisons.

Sensitivity and specificity of remote wound evaluation were calculated for wound diagnoses, including presence of a wound healing problem, necrosis,

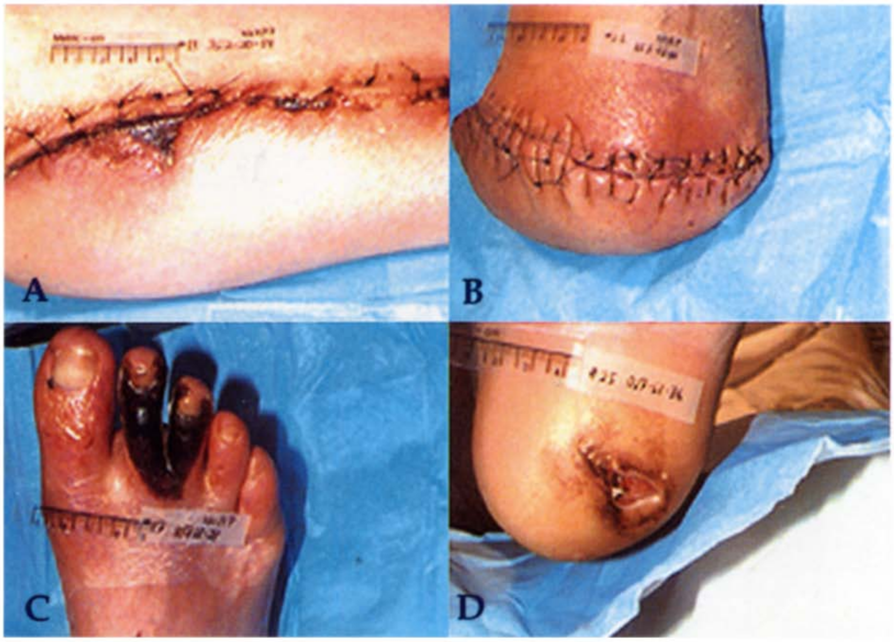

Fig. 2. Example of images representing each wound category. **A,** Postoperative incision; **B,** amputation; **C,** gangrenous/necrotic toes; **D,** nonhealing ulcer. Wounds were photographed from vascular surgery inpatients with a Kodak DC50 digital camera during morning rounds.

ischemia, erythema, granulation, gangrene, and cellulitis/infection. Results were derived from two subsets of cases—greater than 67% agreement among onsite surgeons (category IV) and 100% agreement among onsite surgeons (category V). Sensitivity was calculated as the number of "present" responses by remote surgeons divided by the total number of opportunities for remote surgeons to respond "present" when onsite surgeons agreed (as defined in category IV and V) to "present." Specificity was calculated as the number "not present" responses by remote surgeons divided by the total number of opportunities for remote surgeons to respond "present" when onsite surgeons agreed (as defined in category IV and V) to "not present."

RESULTS

There were no wound complications associated with the imaging process, and imaging took approximately 5 to 7 minutes per patient. Remote surgeons spent an average of 3 to 5 minutes viewing images of each patient. The mean quality index for all image sets was 3.3, with a range of 2.7 to 3.8, and none of the images were considered unusable.

For wound descriptors, the average certainty ranged from 9.5 to 9.9 among onsite surgeons and 8.2 to 9.8 among remote surgeons. Certainty was lowest for detection of ischemia and cellulitis among both onsite and remote surgeons. For wound management decisions, the average certainty ranged from 9.6 to 9.8 among onsite surgeons and 9.4 to 9.7 among remote surgeons. Certainty was lowest for use of antibiotics and need for hospitalization among both onsite and remote surgeons. Attending surgeons compared with other evaluators recorded lower certainty (certainty less than 10) when diagnosing erythema (odds ratio [OR], 0.06; $p = 0.007$). Otherwise, certainty was not influenced by remote versus onsite location, level of training, or wound type.

Table IV shows the average percent agreement and kappa values regarding wound descriptors, and Table V shows the average percent agreement and kappa values regarding wound management decisions. Prevalence data, kappa, kappa(nor), and kappa(max) for category V are shown in Table VI. The specificity and sensitivity of remote wound diagnosis are shown in Table VII.

The level of surgical training was not associated ($p > 0.01$) with agreement or disagreement between remote and onsite surgeons for both wound description and management. Wound type (nonhealing ulcer compared with postoperative incision) positively influenced concordance between remote and onsite surgeons when diagnosing gangrene (OR,

Table IV. Average percent agreement regarding wound descriptors

Wound descriptors	*Category I Agreement among onsite surgeons (n = 45)*	*Category II Agreement among remote surgeons (n = 45)*	**Category III Agreement between onsite surgeons vs remote surgeons (n = 45)*	*†Category IV Agreement between onsite surgeons vs remote surgeons*	*‡Category V Agreement between onsite surgeons vs remote surgeons*
Necrosis	80% κ = 0.53	90% κ = 0.33	83% κ = 0.60	91% (n = 37) κ = 0.78	95% (n = 34) κ = 0.90
Granulation tissue	81% κ = 0.34	92% κ = 0.44	80% κ = 0.44	91% (n = 33) κ = 0.64	93% (n = 31) κ = 0.45
Ischemia§	80% κ = 0.70	83% κ = 0.50	78% κ = 0.70	91% (n = 8) κ = 0.00	91% (n = 7) κ = 0.00
Gangrene	85% κ = 0.77	93% κ = 0.64	74% κ = 0.55	77% (n = 39) κ = 0.53	81% (n = 37) κ = 0.62
Cellulitis/infection	67% κ = −0.04	81% κ = 0.08	62% κ = 0.24	65% (n = 33) κ = 0.08	69% (n = 27) κ = 0.00
Erythema	64% κ = 0.22	86% κ = 0.28	60% κ = 0.12	65% (n = 30) κ = 0.02	66% (n = 28) κ = 0.02

*Comparison made in all cases.
†Comparison made only in subset of cases when onsite surgeons agreed greater than 67%.
‡Comparison made only in subset of cases when onsite surgeons agreed 100%.
§Ischemia data available for 10 patients only.
κ = kappa value.

Table V. Average percent agreement regarding wound management decisions

Wound descriptors	*Category I Agreement among onsite surgeons (n = 45)*	*Category II Agreement among remote surgeons (n = 45)*	**Category III Agreement between onsite surgeons vs remote surgeons (n = 45)*	*†Category IV Agreement between onsite surgeons vs remote surgeons*	*‡Category V Agreement between onsite surgeons vs remote surgeons*
Wound healing problem	95% κ = 0.75	95% κ = 0.31	87% κ = 0.43	92% (n = 39) κ = 0.48	91% (n = 39) κ = 0.48
Emergent examination	64% κ = 0.17	80% κ = 0.41	74% κ = 0.59	89% (n = 29) κ = 0.41	86% (n = 26) κ = 0.44
Need for hospitalization	85% κ = 0.04	85% κ = 0.15	79% κ = 0.26	87% (n = 42) κ = 0.67	84% (n = 39) κ = 0.80
Antibiotics	68% κ = 0.28	80% κ = 0.05	63% κ = 0.39	71% (n = 38) κ = 0.39	69% (n = 30) κ = 0.40
Debridement	74% κ = 0.50	78% κ = 0.18	60% κ = 0.30	66% (n = 38) κ = 0.30	63% (n = 35) κ = 0.23

*Comparison made in all cases.
†Comparison made only in subset of cases when onsite surgeons agreed greater than 67%.
‡Comparison made only in subset of cases when onsite surgeons agreed 100%.
κ = kappa value.

4.1; p = 0.0001), granulation (OR, 17.4; p = 0.0001), and determining the need for debridement (OR, 10.0; p = 0.0001). However, nonhealing ulcer was associated with *decreased agreement* between remote and onsite surgeons regarding need for antibiotics (OR, 0.4; p = 0.009) and need for hospitalization (OR, 0.2; p = 0.0003) and *increased disagreement* between remote and onsite surgeons regarding cellulitis/infection (OR, 3.1; p = 0.006) and need for emergent examination (OR, 8.6; p = 0.0001).

DISCUSSION

Telemedicine has been in development for more than 30 years and has experienced rapid growth in the 1990s. Proponents of telemedicine envision several valuable applications: providing specialty care to underserved areas, increasing the efficiency of existing medical resources, expanding a hospital's service area, and attracting international health care dollars to the United States. Moreover, Perednia and Allen[18] predict that by 2000 many physicians will be directly or indirectly involved in clinical telemedicine. Telemedicine is already an integral tool in most radiology practices, and there is ongoing development and clinical investigation of telemedicine in almost all medical fields.

This investigation is the first to critically evaluate the feasibility of using digital images for remote wound management. The main objective of this study was to establish the "proof of concept" of digital imaging before implementing this technology in vascular surgery home care. Implementation of telemedicine requires validation of quality of care, ease of use, cost-effectiveness, and acceptance by both patients and physicians. Our observations from this preliminary investigation suggest that digital photography in conjunction with telemedicine can

Table VI. Kappa and prevalence data for wound management decisions and descriptors in category V*

	Kappa	*Kappa(nor)*† (2 Po – 1)	*Kappa(max)*† ($Po^2/[1-Po]^2+1$)	*A true (+)*	*B false (–)*	*C false (+)*	*D true (–)*	*n*‡
Wound management decisions								
Wound healing problem	0.48	0.79	0.79	55	2	5	4	33
Emergent examination	0.44	0.44	0.48	20	4	10	16	25
Need for hospitalization	0.80	0.83	0.83	13	3	1	29	23
Antibiotics	0.40	0.40	0.45	19	7	11	23	30
Debridement	0.23	0.70	0.70	2	1	9	54	33
Wound descriptors								
Necrosis	0.90	0.91	0.91	43	1	2	20	33
Granulation tissue	0.45	0.67	0.68	6	2	8	44	30
Ischemia§	0.00	0.67	0.68	5	1	0	0	3
Gangrene	0.62	0.62	0.64	25	7	7	35	37
Cellulitis/infection	0.00	0.22	0.32	0	0	21	33	27
Erythema	0.02	0.19	0.30	28	6	16	4	27

*Comparison made only in subset of cases when onsite surgeons agreed 100%.
†*Po* = proportion of agreements as defined by Lantz et al.[17] See appendix for explanation of Kappa(nor) and Kappa(max).
‡*n* = number of cases.
§Ischemia data available for 10 patients only.

Table VII. Sensitivity and specificity for wound descriptors

	**Agreement category IV*		*†Agreement category V*	
Descriptor	*Sensitivity*	*Specificity*	*Sensitivity*	*Specificity*
Wound healing problems	98%	53%	98%	53%
Necrosis	98%	82%	98%	87%
Ischemia	88%	100%	88%	100%
Erythema	87%	26%	89%	27%
Granulation	77%	97%	82%	96%
Gangrene	75%	82%	78%	85%
Cellulitis/infection	71%	65%	NA	66%

*Calculations performed on subset of cases in which onsite surgeons agreed greater than 67%.
†Calculations performed on subset of cases in which onsite surgeons agreed 100%.

provide quality remote wound care using a relatively simple and cost-effective protocol.

The potential quality of remote wound care was determined using bedside examination as the frame of reference and evaluating concordance between remote and onsite surgeons. Concordance of response based on viewing various imaging media versus more conventional evaluation (hard-copy radiographs, glass slides, or patient examination) has been used to validate new technology in teleradiology, telepathology, and teledermatology.[9,19-21] In our study, agreement between remote and onsite surgeons for both wound diagnosis and management was high (63% to 95%) and was comparable with concordance observed in teledermatology (83%).[9] Using onsite evaluation as a reference, remote surgeons were able to make equivalent diagnoses in 66% to 95% of image sets and recommend comparable management in 66% to 92% of cases. We also observed that the level of disagreement between remote and onsite surgeons equaled the disagreement among onsite surgeons, suggesting that the imaging media did not independently impact agreement. Moreover, wound healing problems and specific wound conditions are readily detected by digital images, as demonstrated by the sensitivity of remote wound diagnosis (71% to 98%). These observations suggest that in general remote wound management via digital imaging will render care comparable with conventional evaluation.

Kappa values generated trends similar to percent agreement, that is, the range of kappa values among onsite surgeons (–0.04 to 0.75) was comparable with that of remote versus onsite surgeons (0.00 to 0.90), and when kappa values were low among onsite surgeons, values were similarly low between remote and onsite surgeons. In only one parameter (need for debridement) was the kappa value in category V less than 0.4, whereas the corresponding kappa value in category I was greater than 0.4 (a kappa value less than 0.4 denotes "marginal reproducibility").[23] Our data also depicted the base rate problem in kappa statistics described by Lantz et al.[17] and Spitznagel et al.[22] in which kappa values may be skewed by prevalence. For example, in several instances (i.e., presence of wound healing problem, granulation tissue, and ischemia) high percent agreement was associated with a low kappa value because of unevenly distributed prevalence. Correcting for uneven prevalence using kappa(nor) increased the concordance between onsite and remote surgeons (see appendix). Thus when there was reproducible agreement among onsite surgeons, digital imaging succeeded in that agreement between remote and onsite surgeons was high in these cases.

Certainty of remote wound evaluation and management was no different than that of onsite surgeons, and contrary to the experience in teledermatology the certainty of diagnosis varied little and did not influence agreement.[9] However, the certainty level was universally high, which may represent a response construct among surgeons (surgeons are more likely to respond "10"—completely certain). Nonetheless, viewing digital images did not appear to influence surgeons' certainty of wound diagnosis and management.

Using our imaging protocol, remote wound care may be limited by decreased ability to accurately represent erythema. Agreement between remote and onsite surgeons was lowest for erythema (66%), cellulitis (69%), and management decisions that routinely follow the diagnosis of cellulitis, such as antibiotics (66%) and urgent examination (71%). Several factors may explain this observation including variable sensitivity of surgeon examination, learning curve of remote diagnosis, and purely technological factors related to digital imaging.

Of these, variation of surgeon examination appeared to have the greatest impact, as shown by percent agreement and kappa values (poor onsite agreement appeared to be associated with decreased agreement between remote and onsite surgeons). Variation among physicians has been documented in other fields[24-31] and has been cited as a limitation of evaluating wound infections after vascular surgery.[11] Thus without a criterion standard for wound description or management, we used bedside examination as the "gold standard" and observed considerable disagreement among onsite surgeons. For example, onsite surgeons disagreed in approximately one third of cases regarding the presence of erythema or cellulitis and regarding important management decisions such as need for urgent evaluation and hospitalization. Also, we observed similar variation among remote surgeons. Thus physician variability, as in other investigations, limited our ability to evaluate this technology and may have adversely impacted concordance regarding erythema and cellulitis. In an attempt to control for surgeon variation, we stratified cases according to level of onsite agreement and observed increasing concordance between remote and onsite surgeons (cellulitis, 62% to 65% to 69%). Unfortunately, because of small patient numbers we were unable to simultaneously control for remote and onsite surgeon variability. Finally, physician variation observed in this study and other investigations of wound complications speaks to the complexity of managing vascular wounds and begs for evaluation/technology that can more objectively evaluate erythema and cellulitis.

There is likely a learning curve related to remote wound management that may have impacted concordance of diagnosing erythema and cellulitis. For example, multivariate analysis showed that remote surgeons were less certain of diagnosing cellulitis compared with making other diagnoses. Multivariate analysis also showed that disagreement regarding erythema and cellulitis was more likely for nonhealing ulcers compared with other wound types. We observed that remote surgeons appeared more hesitant to render diagnoses and treatments during their initial remote evaluations compared with later evaluations. Moreover, remote surgeons "overdiagnosed" and "overtreated" wounds compared with onsite surgeons, that is, remote surgeons more often diagnosed erythema and more often prescribed antibiotics. This is depicted in the high number of false positive results when remote surgeons disagreed with onsite surgeons (16 of 22 for erythema and 21 of 21 for cellulitis; Table VI). Accordingly, the sensitivity of remotely diagnosing erythema was high (87%), whereas the specificity was low (26%). Thus, at present, erythema is readily diagnosed and may at times be "overdiagnosed" because of extra caution on the part of remote surgeons. However, with continued experience we would expect the accuracy of detecting and treating erythema/cellulitis to improve.

Technological factors may have also had an impact on the accuracy of diagnosing erythema and cellulitis. Numerous factors influence image quality, including the photographer, lighting, resolution, and computer monitor. We purposely chose a digital camera priced at less than $1000 to test a protocol that would be feasible from a cost perspective when implemented in nursing home care. The resolution of the camera used in this study (756 × 506 pixels/in^2) has been shown to be adequate compared with higher resolutions for clinical diagnosis in teledermatology.[32] The single color chip, however, appears to be very sensitive to lighting and contains an infrared filter that depicts ultraviolet light as red color. This may have overrepresented red tones in images of vascular wounds. Subsequently, we have observed that lighting (incandescent versus fluorescent) alters the representation of erythema in patients with lower extremity cellulitis (unpublished data) and have since used polarizing filters to correct this characteristic of singlechip digital cameras. Despite this potential flaw, the image quality is excellent and provides enough visual information to appropriately manage the majority of wounds. Moreover, there are several cameras with higher resolution and multiple color sensors that may be needed to optimize remote wound management. Finally, this technology omits important components of physical examination, such as palpation and olfaction, that may allow for more accurate diagnosis. Nonetheless, digital imaging for remote wound diagnosis is intended as an adjunct to standard physical examination performed by the local care provider (home care nurse or physician).

Our observations suggest that health care providers of varied levels of training and background can successfully implement this technology with relatively low costs in terms of both time and equipment. All images were taken by an individual with no medical or photographic background after minimal training (6 to 8 hours). The photographic quality was universally good, and all images were considered clinically useful. Moreover, the imaging process was quick (5 to 7 minutes per patient) and did not complicate patient care. Since this project, vascular home care nurses have been trained in a short period of time (about 2 weeks) to photograph wounds and transmit images from patients' homes to the attending surgeon (Fig. 3).

Fig. 3. Wound images transmitted from a patient's home to the attending vascular surgeon during a home care visit. Images were taken by home-care nurses and transmitted with a lap top computer and standard phone line. **A,** Time zero. **B,** One month later.

Although we did not specifically evaluate cost, several observations suggest that this telemedicine application will be cost-effective. First, the digital camera is relatively inexpensive and decreased in price during the study period ($800 to $500). We expect that the cost of this technology will continue to decrease. Second, the equipment to view images is simple and relatively inexpensive (standard desk top computer, monitor, and software), and currently attending surgeons can access images of patients' wounds from their office computers or any other computer connected to the Massachusetts General Hospital network. The greatest cost of implementing of this telemedicine application has been the lap-top computers ($3500) used by home care nurses to transmit images from patients' homes. This cost could be easily offset by fewer office visits, emergency room evaluations, and shortened hospital stay. However, the ultimate cost-effectiveness will need to be proven in a prospective trial. Finally, our experience suggests that physician and patient acceptance of this technology is high, and currently nearly all eligible outpatients consent to digital imaging of their wounds.

However, a prospective trial of remote wound management in outpatients, evaluating the operational feasibility, quality of care, and cost-effectiveness is needed to further validate this technology. Also, further research of remote wound care must be coupled with accurate assessment of cost and quality of outpatient care, which at present, despite much data on inpatient care, are unknown.[33] Moreover, recent reports suggest that quality of home care may affect medical costs and outcomes,[33-35] which corroborates our experience with specialized vascular home care. Implementation of remote wound surveillance along with other applications in nursing home care could improve the quality of outpatient care and provide specialized care to remote locations. Also, we did not investigate the potential of image manipulation such as simultaneous display of wounds at varying time intervals, wound area measurement, and outlining of specific shades of redness. These techniques could allow for more objective wound evaluation. Finally, issues related to confidentiality, licensure, liability, and reimbursement, which have not been entirely resolved in other fields of telemedicine, must be considered in conjunction with development of this technology.[18]

Certainly, technology in digital imaging and electronic transfer of data will advance independent of health care trends, and continued research in telemedicine should capitalize on this progress. Technologic advancements that would complement digital imaging for remote wound management include: (1) development of an electronic patient record that incorporates digital images, radiographs, noninvasive laboratory data, and the hospital chart; and (2) development of equipment to collect and transmit vascular noninvasive data for remote graft surveillance.

CONCLUSION

This study suggests that digital imaging for remote wound management is feasible on the basis of high concordance between remote and onsite surgeons regarding wound evaluation and management. This application of telemedicine has the potential to improve the quality of current outpatient wound care while decreasing the cost by allowing home care nurses to photograph wounds and transmit images over any distance in a short period of time. This hypothesis needs to be verified in a prospective clinical trial assessing clinical outcomes and medical costs. The available technology in image media and electronic data transfer is advanced; however, the medical application of this technology is in its infancy. Telemedicine holds significant promise in vascular surgery but will require careful, well-designed research for development and validation of its clinical usefulness.

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APPENDIX.

As shown by Lantz et al.[17] and Spitznagel et al.,[22] kappa values can vary for a given level of agreement depending on the prevalence of agreements (true positives and true negatives) and disagreements (false positives and false negatives). Kappa(nor), a parameter derived from proportion of agreements (Po), has been suggested as a solution for the variability observed in kappa values where $Po = (a + d) / N$ and $Kappa(nor) = 2\ Po - 1$. Kappa(nor) corrects for asymmetry of prevalence and is equal to kappa only when there is symmetry of both agreements and disagreements. Kappa(max) is the maximum kappa value for a given prevalence of agreement and disagreement. Kappa(max) balances agreement in the two agreement categories and maximally skews disagreement in the disagreement categories using the equation. $Kappa(max) = Po^2 / (1 - Po)^2 + 1$. See references 17 and 22 for further discussion.

DISCUSSION

Dr. James Estes (Boston, Mass.). I applaud your interest in looking in the technologic front here in terms of combining computers and medicine, and I enjoyed your talk. I have one question from a practical standpoint: where do you see this technology being applied, specifically, in terms of justifying the costs of the equipment for acquiring and transmitting digital information?

Dr. Douglas J. Wirthlin. I think the potential for this technology is enormous. We embarked on this project planning to implement digital imaging in outpatient management of vascular wounds to decrease cost of care while maintaining quality of care. The cost of equipment is minimal compared with the potential cost savings. However, this needs to be proven in a prospective trial.

Dr. Carl E. Bredenberg (Portland, Me.). Our experience thus far at Maine Medical Center with these types of techniques has been limited largely to shared educational conferences, particularly in vascular surgery, with Dave Pilcher and Michael Ritchie at the University of Vermont, and it's remarkable I think how lively and alive this is when you are using not these still cameras but with television. I'm still not sure, and this is in part perhaps in answer to the previous question, whether this is the good news or the bad news from an institution's point of view. For a rural network, for example, I could argue that to be able to visualize wounds of a patient up in Caribou, to visualize those down in Portland, and make decisions about whether or not to get the patient to Portland is clearly the good news. Now if, however, it is a patient in South Portland and this is being viewed on Fruit Street at the Massachusetts General Hospital, then I'm less persuaded that this is truly good news. This is not entirely speculation. For example, at Mercy Hospital in Portland the radiology department stationery carries the logo of the

Massachusetts General Hospital radiology department along with their own, so the implications of this technology are indeed far-reaching in many ways.

Dr. Wirthlin. In regards to your first comment, you mentioned that the video imaging was very useful. We use still digital images because the infrastructure requirements for transmitting video messages are much greater and more expensive. Also, the resolution of a still digital image is better than that of a video image.

In regards to whether this is good news or bad news, I think from a patient standpoint it is good news as long as the technology is developed and implemented properly. In terms of how this technology may be used at major medical centers is unclear at this time, and really this technology is in its infancy. There is much work that needs to be done before this can be implemented, for example, a clinical trial proving that this is safe and cost-effective.

Dr. David B. Pilcher (Colchester, Vt.). This is a very disturbing paper, because it seems to me that you are saying that we surgeons who talk to patients, who interact with patients when we are visualizing their wounds, can now be radiologists and just look at the still pictures. I don't think your conclusion that telemedicine has a value is not really valid. Your conclusion is that looking at still pictures is of value. That's not really telemedicine. That's a lot cheaper than telemedicine, as I think you just said—transmitting digital pictures doesn't require full telemedicine, nor does it allow the full potential, so I don't think you are really looking at telemedicine.

Dr. Wirthlin. The definition of telemedicine is very broad. Telemedicine can be as simple as a phone consultation, a 911 phone call, or can be as complex as telepresence surgery. This project was developed just to test the feasibility of digital imaging. In other words, how accurately does a digital image represent a wound? This is just the first step in the development of this technology, and you're right, we did not test the telemedicine application of digital imaging yet. That is the next project, in which home care nurses will transmit the images to the treating surgeons. The process of transmitting the digital images makes it a telemedicine application.

You're right, viewing a digital image is not equal to a standard physical examination, but it is comparable. Also, in terms of the impact this technology may have on the human element or patient-physician relationship, my impression during the study was that patients are very enthusiastic about this technology and would gladly pass up several office visits.

Dr. Thomas F. O'Donnell (Boston, Mass.). I would like to make just a short comment, Dr. Bredenberg, at least at New England Medical Center we're not setting up telemedicine units in "distant" Maine but rather in less-remote places like Argentina, United Arab Emirates, and Saudi Arabia. *(laughter)*

I have one question for the authors about cellulitis and erythema. Obviously visualization is one of the four components of a physical examination, but telemedicine does not let you touch the wound and sense the skin temperature or degree of induration. You don't get this important aspect of an examination on a picture so that the examining physician is unable to determine whether the skin is warm, which indicates cellulitis. Do you want to comment on that?

Dr. Wirthlin. Viewing a digital image in terms of detecting cellulitis and erythema will not be as good as the standard physical examination. Also, we observed that digital images actually overrepresent red tones and that further development in the technology is needed to improve the accuracy of detecting erythema and cellulitis.

Dr. Jens Jorgensen (South Portland, Me.). Maine is a big state, and there are some corners of our state that are further from Portland than New City is. About once a week I will see a patient who has driven 4 to 6 hours to come in for an appointment. Therefore if I get a call in the postoperative period from the patient or their physician that they are a little bit concerned about the appearance of the wound or the foot, it is oftentimes with a great deal of reticence that I say, "Why don't you swing by the office and I'll take a look". So I think this technology has a great deal of application in geographically disparate states such as Maine. I thought it was a great presentation, and I would like to thank you for bringing this material to this forum.

Dr. Joel A. Berman (Springfield, Mass.). I think that the issue here isn't so much whether this technology can supplant the physical examination of the part of the physician, but rather its application in comparing the evaluation of the visiting nurse with the evaluation of the surgeon on the basis of the images that you obtain. Have you given any consideration to comparing the accuracy of the description that the visiting nurse gives you with the evaluation of the physician on the basis of your images?

Dr. Wirthlin. We plan to evaluate that issue in the next phase of the study.