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Journal
American Heart Journal, 137(2)

ISSN
0002-8703

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Publication Date
1999-02-01

DOI
10.1053/hj.1999.v137.92712

Video networking of cardiac catheterization laboratories

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Background The purpose of this study was to assess the feasibility and accuracy of a video telecommunication network to transmit coronary images to provide on-line interaction between personnel in a cardiac catheterization laboratory and a remote core laboratory.

Methods A telecommunication system was installed in the cardiac catheterization laboratory at Kaiser Hospital, Los Angeles, and the core laboratory at the University of California, Irvine, approximately 40 miles away. Cineangiograms, live fluoroscopy, intravascular ultrasound studies and images of the catheterization laboratory were transmitted in real time over a dedicated T1 line at 768 kilobytes/second at 15 frames/second. These cases were performed during a clinical study of angiographic guidance versus intravascular ultrasound (IVUS) guidance of stent deployment. During the cases the core laboratory performed quantitative analysis of the angiograms and ultrasound images. Selected images were then annotated and transmitted back to the catheterization laboratory to facilitate discussion during the procedure.

Results A successful communication hookup was obtained in 39 (98%) of 40 cases. Measurements of angiographic parameters were very close between the original cinefilm and the transmitted images. Quantitative analysis of the ultrasound images showed no significant difference in any of the diameter or cross-sectional area measurements between the original ultrasound tape and the transmitted images. The telecommunication link during the interventional procedures had a significant impact in 23 (58%) of 40 cases affecting the area to be treated, the size of the inflation balloon, recognition of stent underdeployment, or the existence of disease in other areas that was not noted on the original studies.

Conclusions Current video telecommunication systems provide high-quality images on-line with accurate representation of cineangiograms and intravascular ultrasound images. This system had a significant impact on 58% of the cases in this small clinical trial. Telecommunication networks between hospitals and a central core laboratory may facilitate physician training and improve technical skills and judgement during interventional procedures. This project has implications for how multicenter clinical trials could be operated through telecommunication networks to ensure conformity with the protocol. (Am Heart J 1999;137:241-9.)

See related Editorial on page 187.

This study was performed to assess the feasibility and accuracy of a video communication network to transmit coronary images in real time through commercial telephone lines to permit interaction between personnel in a cardiac catheterization laboratory and a remote core laboratory.

In current interventional cardiology laboratories, complex high-risk procedures are performed in an isolated fashion. New technologies that become available are learned by watching a course, or having a physician or an industry representative demonstrate the technique on a limited number of cases. After the training is complete, there are still issues of judgment and technical questions that may persist. In addition, specific areas of expertise may not be sufficient in a laboratory, such as in the interpretation of intravascular ultrasound (IVUS) images. To address these issues, a video teleconferencing system was installed to provide on-line monitoring, quantitative analysis, and interpretation of IVUS images during a randomized trial of coronary artery stenting with angiographic guidance alone and standard coumadin anticoagulation versus angiography plus IVUS guidance and no anticoagulation. This report will focus on the adequacy of the video telecommunication for transmission of

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0002-8703/99/$8.00 + 0 ***4/1/92712***

Figure 1

VTEL BK225 telecommunications module in operation at the core laboratory. First monitor *(left)* shows video image from catheterization laboratory at Kaiser Hospital (original is color image). Second monitor *(right)* shows angiogram from current patient. Core laboratory digitized the image, performed on-line measurements, annotated image with lumen dimensions, and transmitted annotated image back to catheterization laboratory.

angiograms and intravascular imaging studies on-line and not on the clinical trial.

Methods

To determine which system to use for this study and the appropriate frame rates, 3 video telecommunication products were reviewed. Videotape images of coronary angiograms and IVUS studies were transmitted to the telephone company (General Telephone Electronics, Norwalk, Calif) and rerouted back to the point of origin so that the transmitted and original videotape images could be viewed side by side. The images were transmitted at 128 KB/sec, 384 KB/sec, and 768 KB/sec at 15 frames/sec and 30 frames/sec to compare image quality. Although there was some motion artifact in the zoom mode with rapid changes in the spacial domain, a review panel of 3 physicians judged the image quality of the transmitted studies to be adequate at the higher transmission rates and at 15 frames/sec for the ability to recognize the size of the arteries and stenotic points on the angiograms and to outline the lumen and plaque on the ultrasound images.

On the basis of this preliminary review, a point-to-point VTEL 225 KB telecommunication system (VTEL, Inc, Austin, Texas) was installed in the core laboratory at the University of California, Irvine, and connected with another VTEL 225 KB module 40 miles away in the cardiac catheterization laboratory at Kaiser Sunset Hospital, Los Angeles. The VTEL system uses proprietary data compression algorithms to transmit data over telephone lines. The compression ratio is approximately 200:1 and complies with H.320 standards for compression algorithms established by the International Telecommunication Union. The compression resolution was 352 × 288. The 2 laboratories were connected by a T1 phone line that can carry up to 24 channels. The VTEL system includes a multiple unit multiplexer (ASCEND multiband with T1 primary rate interface) to convert the data to an acceptable format for the phone lines. This system allows video signals to be digitally converted, compressed, and sent at 768 KB/sec using 12 of the telephone channels simultaneously. Images were transmitted at 15 frames/sec.

The VTEL telecommunications equipment had 2 27-inch television monitors (Sony Composite NTSC with 400-line resolution), 4 video inputs, and 3 microphone channels. One of the video inputs was connected to a mobile video camera that could be controlled at either the remote or local site to provide pictures of the personnel in the cardiac catheterization laboratory or the core laboratory. The second video input from the cardiac catheterization laboratory was connected to the television output of the radiographic system (Philips, Optimus 200 generator and Poly C arm). The third video input was connected to the IVUS machine (Hewlett Packard Sonus System). The operator at either laboratory could choose to send or receive any of the video signals. The 2 television monitors were used to show what was being sent from one laboratory and what was being received in the other laboratory. For example, the core laboratory could choose to look at the live fluoroscopy images, the cineangiograms replayed from the catheterization laboratory's digital cineangiogram loop (Angiotec model FMX3230, Liverpool, NY) or could switch the input to look at the video of the personnel working in the laboratory. The television camera also had remote control zoom capabilities so that the core laboratory could focus on equipment setup such as preparation of the stent on the balloon before insertion. On the second monitor, the core laboratory could choose to show images of personnel in the core laboratory, which was useful during discussions or could transmit images from the integrated computer system at the core laboratory.

Core laboratory computer system

In the core laboratory, the video images transmitted from the remote laboratory were passed through a video recorder (s-VHS Panasonic Model 1960) and then serially sent to the digitizing board of an Apple Power PC 8500 computer. Selected frames of the coronary angiograms or IVUS images were digitized at 640 × 480 pixels with software by AVID Video Shop (Avid Technology, Tewksbury, Mass). While the clinical case was in progress at the remote laboratory, measurements of lumen diameter from the angiograms, or plaque and lumen cross-sectional areas from the ultrasound images, were performed with public domain software (NIH Image v1.59). The images were analyzed with digital calipers with operator-defined edge detection. Previous studies have demonstrated good correlations between this technique and computer-defined edge detection.[1] The angiographic images were scaled with a 2X zoom mode and calibrated by the diameter of the guiding catheter. After an image was analyzed, it was moved to a second monitor attached to the computer. The output of the second monitor's video card was connected to the video input of the VTEL telecommunication system for transmission back to the remote laboratory. In this manner, the images originally downloaded from the remote laboratory could be measured and annotated with the results of the quantitative measurements written on the image and transferred back to the laboratory for their review during the case (Fig 1). In addition, the pointer from the computer mouse could be manipulated in real time over the image by the core laboratory personnel to identify certain structures while discussing salient features about the images with the operators in the catheterization laboratory.

Study protocol

The cases that were transmitted were part of a clinical trial of coronary artery stenting comparing standard angiographic guidance versus angiographic plus IVUS guidance. All patients received high-pressure inflations after stent delivery; however, the anticoagulation protocols were different. The purpose of the clinical study was to demonstrate the safety of not using coumadin after stent insertion, provided that the results were satisfactory as judged by the ultrasound observations.

Patients were randomly assigned to the angiographic or IVUS groups just before the procedure. Transmission of the case began before the intervention so that the clinical background and diagnostic angiograms could be reviewed. As the baseline angiographic images were digitized for quantitative measurements, the approach to the specific lesion was discussed between the physicians in the catheterization laboratory and the physicians in the core laboratory. There was open discussion of events during the case, as if the personnel from the core laboratory were visiting observers in the catheterization laboratory. Recommendations and exchange of ideas occurred concerning the choice of equipment, the lesion length, technical approach, how to deal with difficulties encountered during the case, the balloon size or inflation pressure, and the results of the angiographic measurements or interpretation of the IVUS studies.

When the angiographic result appeared to be satisfactory to the physicians in the catheterization laboratory and the core laboratory, a final set of angiograms was obtained and selected frames were chosen for quantitative measurements by the core laboratory. For the patients assigned to the IVUS group, IVUS was performed after a satisfactory angiographic result was achieved. A 3.2F Sonocath ultrasound catheter

Table I. Angiographic baseline characteristics

	Angioplasty group	IVUS group	*P* value
Treated vessel			
LAD	10 (50%)	7 (35%)	.34
RCA	6 (30%)	8 (40%)	.51
LCx	4 (20%)	3 (15%)	.68
SVG	0	2 (10%)	.15
Lesion length	10.2 ± 3.8	11.5 ± 4.6	.35
MLD pre	0.8 ± 0.3	0.8 ± 0.2	.63
MLD post	3.2 ± 0.5	3.3 ± 0.6	.63
Ref prox	3.2 ± 0.6	3.3 ± 0.5	.54
Ref distal	3.1 ± 0.5	3.1 ± 0.8	.84

LAD, Left anterior descending coronary artery; *RCA,* right coronary artery; *LCx,* left circumflex artery; *SVG,* saphenous vein graft; *pre,* before stenting; *post,* after stenting.

(Boston Scientific, Boston, Mass) with a 30-MHz transducer was advanced in a monorail fashion over the 0.014-inch guide wire several centimeters distal to the stent. The ultrasound images were transmitted in real time to the core laboratory as the operator manually withdrew the catheter during imaging. Frames from specific points of interest were digitized and stored for analysis. The core laboratory could direct the operators to interrogate specific areas of interest until a complete understanding of the anatomy was provided by the ultrasound exam. Images were obtained at reference positions within 1 cm distal and proximal to the stent as well as at the smallest luminal area within the stent. After the pullback was completed, the digitized ultrasound images were measured with NIH Image software.

Data analysis

After the catheterization procedure, the original videotape of the ultrasound images and the cineangiogram were mailed to the core laboratory. Selected frames from the cineangiogram that corresponded to the images before and after procedure chosen at the time of the telecommunication transmission were identified on a Vanguard cineprojector.

The cinefilm was sent to an outside commercial photography laboratory, where the selected frames were digitized on a Kodak Imaging Station and stored on a compact disk in a PICT format. These images were loaded on the core laboratory's computer, and quantitative measurements were made with the same technique and software as with the telecommunication images. The original IVUS videotapes were replayed through the videocassette recorder and digitized into the same computer system that was used to review and measure the telecommunication images. The measurements of the original cine and IVUS images were made independently of the telecommunication studies. The original cineangiograms and ultrasound images were then compared with their corresponding paired images, downloaded over the telecommunications system at the time of the initial procedure. The sets of paired images were compared by linear regres-

Table II. Cine versus telecommunication angiographic measurements (n = 39)

	Cine	Telecommunication	Paired *t* test	*P* value
Lesion length	10.8 ± 4.2	10.8 ± 4.2	0.92	.99
MLD pre	0.8 ± 0.3	0.7 ± 0.3	0.008	.67
MLD post	3.3 ± 0.6	3.2 ± 0.6	0.07	.77
Ref pre prox	3.3 ± 0.6	3.3 ± 0.6	0.56	.82
Ref post prox	3.5 ± 0.5	3.5 ± 0.5	0.20	.81
Ref pre dist	3.1 ± 0.7	3.1 ± 0.7	0.78	.87
Ref post dist	3.3 ± 0.6	3.2 ± 0.7	0.15	.83

Pre, before stenting; *post,* after stenting; *prox,* proximal; *ref,* reference.

Table III. VCR versus telecommunication IVUS measurements (n = 19)

	Tape	Telecommunication	Paired t test	P value
Prox ref maj	4.2 ± 0.9	4.2 ± 0.9	0.25	.98
Prox ref min	3.7 ± 0.9	3.6 ± 0.9	0.24	.99
Prox ref area	12.8 ± 6.0	12.8 ± 6.0	0.70	.99
Dist ref maj	3.6 ± 0.6	3.5 ± 0.7	0.11	.93
Dist ref min	3.1 ± 0.5	3.0 ± 0.6	0.20	.93
Dist ref area	9.5 ± 3.2	9.5 ± 3.2	0.31	.99
Stent maj	3.4 ± 0.5	3.4 ± 0.5	0.64	.96
Stent min	3.0 ± 0.4	2.9 ± 0.4	0.08	.94
Stent area	8.0 ± 2.0	8.1 ± 2.1	0.60	.98

Prox, Proximal; *ref,* reference; *maj,* major; *min,* minimum.

sion analysis and the differences in measurements in the paired images were assessed by the Bland-Altman analysis. A second independent observer who was not present during the telecommunication transmission made similar measurements from the angiogram and the ultrasound images at the core laboratory. Interobserver differences were compared by linear regression and Bland-Altman analysis. In addition, the original observer repeated the measurements of the paired cineangiograms and the telecommunication angiograms and of the paired original IVUS and telecommunication IVUS images. This intraobserver analysis was performed at least 2 months after the initial set of measurements.

Results

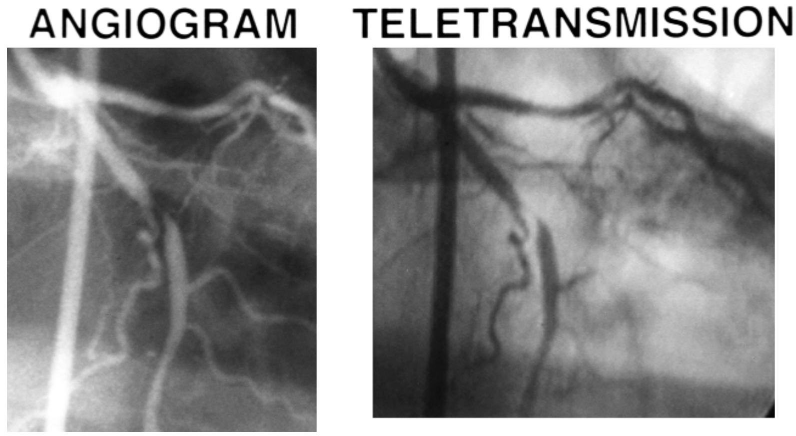
Forty patients were randomly assigned per protocol. There were no statistical differences in the clinical characteristics of the patients assigned to the angiographic versus IVUS groups. The mean age of the patients was 59.8 ± 8.9 years; 32 (80%) of the patients were men. There were 18 patients with unstable angina and 14 had diabetes mellitus. The American Heart Association/American College of Cardiology classification was type A in 22 cases, type B in 11, type B_2 in 6 and type C in 1. Five patients had restenosis lesions from prior balloon angioplasty. The lesions were divided into 17 left anterior descending, 14 right coronary, and 7 circumflex arteries as well as 2 saphenous vein grafts. A coronary artery stent (Johnson and Johnson, Inc, Warren, NJ) was successfully deployed in all 40 patients. There were 6 patients who received a second stent; in 5 patients this decision was made on the basis of the angiographic appearance, and 1 patient received a second stent on the basis of the IVUS findings.

The baseline angiographic mean lesion length, mean minimum lumen diameter (MLD) before and after stenting, and the mean reference lumen angiographic diameters are shown in Table I. There were no significant differences between the 2 groups for the baseline angiographic parameters. The final “punch-out” balloon mean diameter was larger in the IVUS arm (3.8 ± 0.4 mm) compared with the angiographic arm (3.5 ± 0.2 mm, P = .04). There was no difference in the maximum balloon pressure in the 2 groups, the mean final pressure was 17.4 ± 2.1 atm.

Telecommunications

The telecommunication network was successfully completed in 39 (98%) cases. The linkup was delayed in 3 (8%) cases because of routing problems within the phone company. The quality of the video images

Figure 2



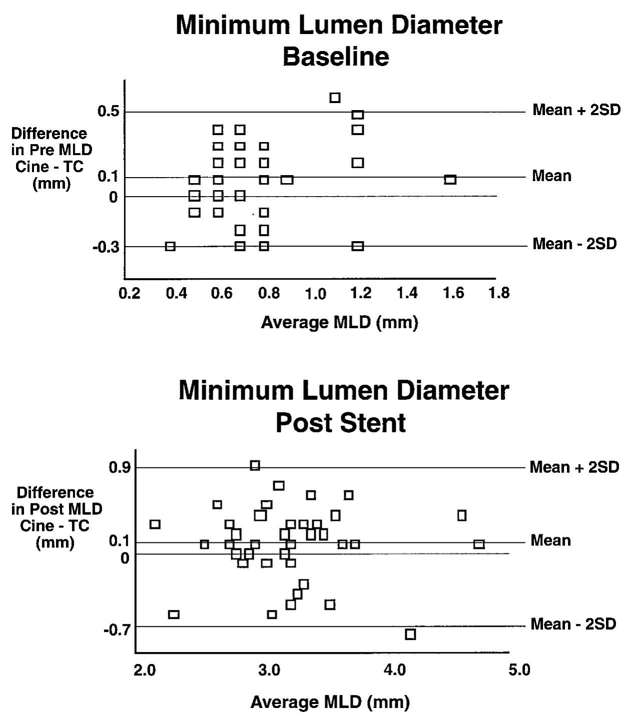
Comparison of original cineangiogram *(left)* and same image as viewed in core laboratory at time of video transmission *(right)*. Both images reveal comparable narrowing in left coronary artery system. Although edges are not as sharp in transmitted images, contour of lumen along length of vessel is similar in both pictures.

was impaired in 1 (3%) case because of "tiling" from inadequate speed of transmission when the T1 line was not used, and the quality of the audio was impaired in 1 (3%) case because of intermittent drop out of the voice channel from the catheterization lab.

The results of the quantitative comparison between the original cineangiograms and the angiographic images digitized over the telecommunications network are shown in Table II. There were no significant differences between the original cine and the telecommunications angiograms for the lesion length or the reference lumen diameter proximal or distal to the stent, both before and after stent insertion. The baseline MLD was 0.8 ± 0.3 mm for the original cine angiograms and was 0.7 ± 0.3 mm for the telecommunication group *(P* < .008). An example of a paired set of angiographic images is shown in Fig 2. The correlation of angiographic MLD measurements between cineangiograms and telecommunication images was very close (r = 0.99, Y = 0.97X – 0.04). The Bland-Altman analysis for MLD before and after stenting is shown in Fig 3. The average difference in measurements was 0.1 ± 0.2 mm before treatment and 0.1 ± 0.4 mm after stent insertion.

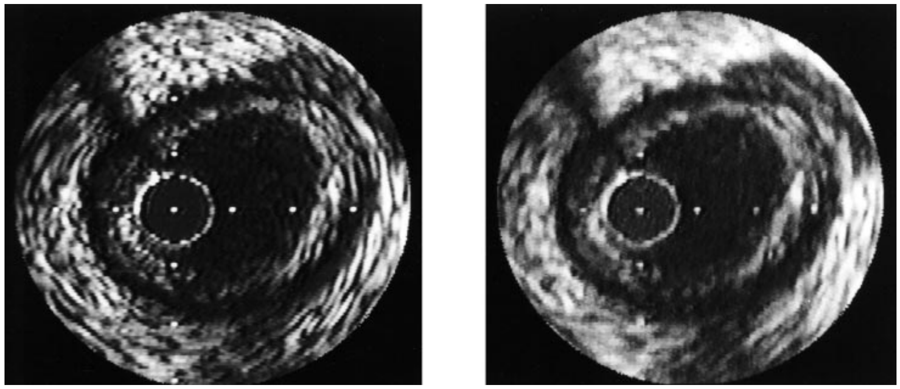
A standard radiographic phantom of line pairs demonstrated that the resolution of the cinefilm after passing through the video chain and digitization was 1.5 line pairs/mm. The phantom image was also transferred over the telecommunication system and digitized by the core laboratory. The transmitted line pair resolution was 1.3 line pairs/mm.

Figure 3



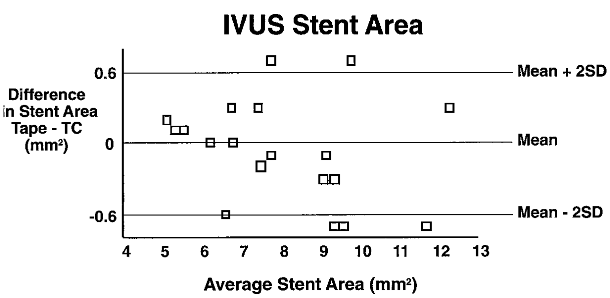
Bland-Altman analysis for MLD for studies performed before *(top)* and after *(bottom)* stenting. Average of each measurement between original cineangiogram and telecommunication (TC) paired images are plotted on *x*-axis vs difference between measurements on *y*-axis. Almost all measurements fall within 2 SD of mean of differences.

Figure 4



Comparison of original IVUS study replayed from S-VHS tape *(left)* and same image as viewed in core laboratory at time of transmission *(right)*. Video transmitted image is less sharp, which gives it appearance of smoother gray scale compared with higher contrast on original tape. However, boundary of lumen and plaque/media interface is distinct, so there is no difference in quantitative analysis.

Figure 5



Bland-Altman analysis of stented lumen area from IVUS images. Averages of paired measurements between original S-VHS tape and telecommunication *(TC)* images are plotted on *x*-axis vs difference in these values on *y*-axis.

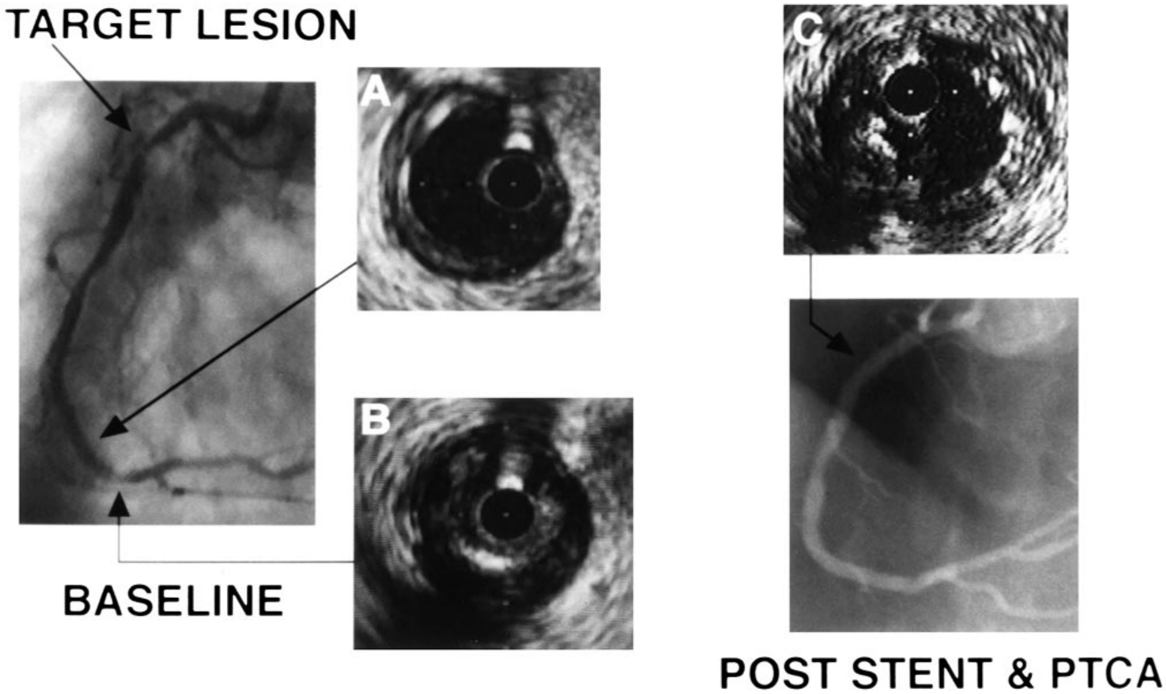
An example of a paired set of IVUS images is shown in Fig 4. The results of the IVUS measurements comparing the original S-VHS tapes and the images digitized during the telecommunication study are shown in Table III. There were no significant differences between these methods for assessment of lumen diameters or areas either within the stent or at the proximal or distal reference zones. The correlation coefficients between the original studies and the telecommunication system were between 0.93 and 0.99. The Bland-Altman analysis for stent area by IVUS showed only minor differences between the original ultrasound tape and the telecommunication images (average difference = 0.0 ± 0.3 mm^2, Fig 5).

The intraobserver variability study revealed that there was no significant difference between the first and second measurement for 14 angiographic variables or 18 IVUS variables. There was no difference in the measurements between the original cine or the transmitted angiogram or for the original ultrasound or the transmitted ultrasound images. There were also no significant differences in the interobserver variability study for the 7 angiographic or the 9 ultrasound variables that were measured.

Clinical results

The video telecommunication interaction had a significant impact on the procedure in 23 (58%) of 40 cases. A "significant impact" was defined as an input from the core laboratory that resulted in an alteration in technique or clinical decision. This instance occurred when the core laboratory's measurement or interpretation of the angiogram affected the area to be treated (5 cases), the size of the inflation balloon (5 cases), the diagnosis of a different lesion that required treatment (2 cases), or suggestions of different equipment or technique that lead to a successful result (4 cases). In addition, the core laboratory's measurement or interpretation of the IVUS study altered the procedure in 11 (58%) of 19 cases. This occurred because of recognition that the stent was underdeployed (6 cases), deployed at the wrong location (1 case, Fig 7), that significant disease was present at the entrance or exit of the stent (2 cases), or that other lesions were present but their severity

Figure 6



Left, Right coronary angiogram as viewed by core laboratory over telecommunication system. Targeted lesion was in proximal segment *(top arrow)*. Core laboratory noted stenosis in distal RCA *(bottom arrow),* which was felt to be significant and could affect outflow after stent insertion in proximal segment. At request of core laboratory, IVUS was performed at distal site. This revealed severe stenosis 1.2 × 1.0 mm that hugged IVUS catheter **(B)**. On the basis of this observation, operators agreed that distal lesion should be dilated. **C,** IVUS image of proximal stent and cineangiogram after stenting proximal stenosis and balloon dilatation of distal lesion.

was underappreciated by angiography, which lead to a further intervention (2 cases). Examples of this immediate influence of the core laboratory on the procedure are provided in Figs 6 and 7.

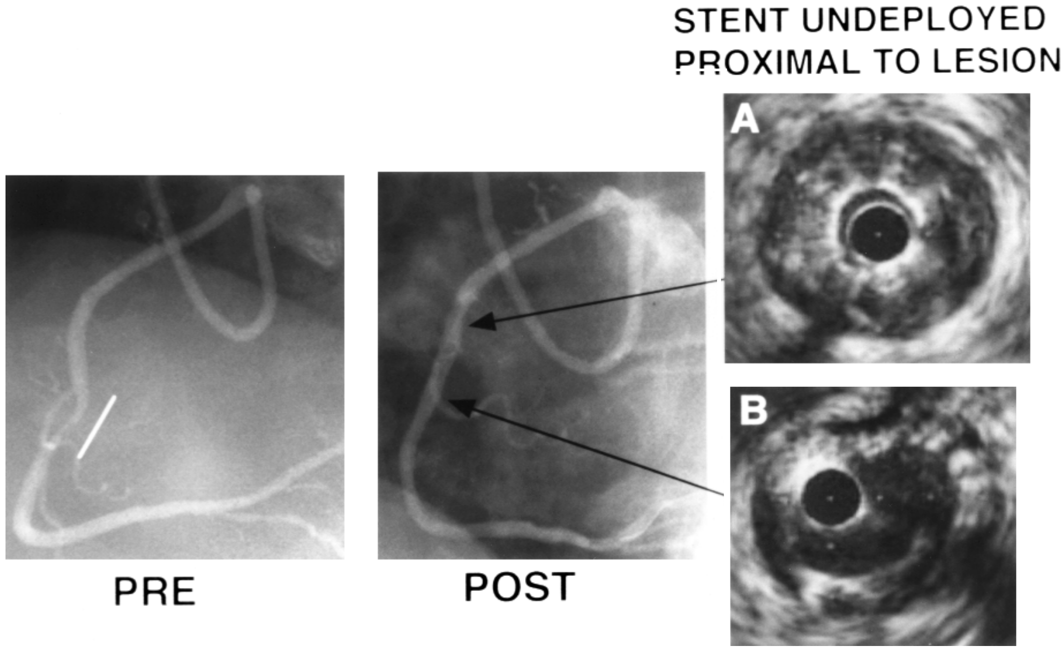
Effects on patients and catheterization laboratory personnel

The presence of the large television monitors from the telecommunication system and audible discussions had some minor intrusive impact on the catheterization laboratory personnel and patients. For the physician, this setup was similar to having an outside visitor in the lab. For the catheterization laboratory personnel, there was some initial concern that "external doctors" might conflict with the opinions of the catheterization laboratory operators. Three (8%) of the patients expressed concerns that the discussions on technique or diagnosis increased their anxiety. As the experience with the system increased, the personnel became more comfortable with the televised procedures. The patients were told before they signed informed consent that the procedures would be televised and discussion would take place about their case, but their physicians performing the procedure would make the final decisions. In 5 patients, music was played on a cassette recorder with headphones to block out the audible communication; however, most patients did not feel this was necessary.

Discussion

In the field of medicine, video telecommunication systems have been used over the past 5 years to provide diagnostic consultation in rural regions that do not have easy access to physician specialists, such as in western Kansas.[2,3] The Mayo Clinic has used telemedicine to provide wide access to their medical experts to discuss unusual cases.[4] In addition, this technology is ideally suited to transmit static images such as electrocardiograms, radiographs, computed tomographic, or magnetic resonance images. This is the first time, to our knowledge, that a telecommunication network has

Figure 7



Angiogram before and after stent deployment in anomalous right coronary artery. Cannulation of ostium of vessel was difficult. There was some adjustment of balloon position for precise placement of stent after sheath was withdrawn. Despite excellent angiographic appearance, IVUS (**A**) revealed that most of stent was proximal to original stenosis and was not expanded, demonstrating that stent had been stripped off balloon during final positioning.

been used to transmit interventional procedures from a catheterization laboratory to a core laboratory.

This study demonstrates that a video telecommunication network with commercially available equipment provides satisfactory image quality with accurate representation of angiographic anatomy and lesion severity. In addition, IVUS lumen and plaque geometry also closely correlated with the original images directly observed in the catheterization lab. The image quality was such that the core laboratory personnel could clearly visualize 0.014-inch guide wires, stenoses, and dissections and even identified some lesions that were not immediately appreciated by the operators in the catheterization lab. The lumen edges on the telecommunication images were not as sharp as the original studies. Although this did not interfere with the diagnosis of lesions, there was some difficulty in identifying the edge of the guiding catheter, which is necessary for scaling the images to obtain accurate measurements. The telecommunication images minimally underestimated the diameter of the stenoses compared with the original angiograms (0.7 ± 0.3 mm vs 0.8 ± 0.3 mm), but this was not clinically significant. There were no statistical differences in any of the other parameters measured from the original or transmitted angiograms.

The correlation of measurements between the original and the telecommunication IVUS images were much closer than that for the angiograms. Although the edges in the original IVUS image were more distinct, it did not affect the accuracy of measurement or the ability to interpret the teletransmitted images. The IVUS images have an internal scale across the entire height and width of the image, which is derived from the speed of sound in blood at 37° C (1540 m/s); therefore this technique does not depend on identifying the edges of a relatively small calibration catheter as is done during quantitative coronary angiography. In addition, the IVUS images are at a much greater magnification than angiograms, so the percent error is less compared with the use of a 2.7-mm catheter to provide the scaling factor. On a digital angiogram, 2.7 mm is represented by approximately 10 pixels, or only 2% of a 640 × 480 matrix. With digital angiography, the edges become significantly less sharp as the magnification increases.

The video telecommunication network had a significant impact on the performance of 23 (58%) cases in this small clinical trial. The causes of this influence were (1) the presence of another reviewer for discussions of image interpretation or recommendations of technique on-line during the intervention, (2) the ability to have lumen measurements of coronary angiograms by digital calipers performed by an independent observer at the time of the procedure, and (3) the presence of an experienced reviewer of IVUS images both for diagnosis and measurement at the core laboratory. There was some initial concern that the telecommunication system might interfere with the physician's performance of the case. It was important for the core laboratory to be sensitive to the communication and to convey concern or varying options in a way that did not alienate the catheterization laboratory staff or increase the patient's anxiety. The implications of this initial study for the use of telecommunications in interventional procedures are significant. Telecommunication networks could be used to link community hospitals to universities or other high-quality centers to facilitate physician training and improve technical skills and judgement during interventional cases. This link could also assist managed care networking to a tertiary center for review of cases for clinical conferences. Finally, this project demonstrates a paradigm of how future multicenter clinical trials could be operated through video telecommunication networks so that the procedures could be reviewed on-line for appropriate inclusion criteria, correct adherence to the protocol, and immediate assessment of the adequacy of the results. In addition, the cost of telecommunication systems is likely to decrease as technology improves and the accessibility to these systems increases.

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