Delineation of Peripheral and Coronary Detail by Intraoperative Angioscopy

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In this study, the development of intraoperative angioscopy, the value of the information obtained, and the problems encountered with the procedure are reported. Eight angioscopes, 1.5 to 2.8 mm in diameter, with a line resolution of greater than 0.4 mm at 5 mm, were used. One-hundred ten angioscopic investigations were performed in 46 patients; 24 at peripheral bypass surgery and 22 at coronary artery bypass surgery. These included 68 arteries, 28 new anastomoses, six old grafts, five laser angioplasties, and three *in situ* vein grafts. The most important finding was that angioscopic data provide information not available from probes or angiography. Angioscopic findings were responsible for a change in surgical procedures in 12 patients (26%) including three anastomotic revisions, three alterations in graft site placement, and two repeat thrombectomies. The most significant technical problems were lack of steerability and insufficient irrigation, which resulted in poor angiographic images. Further technical development is necessary before routine intraoperative angioscopy is practical. Nevertheless, if these problems are resolved, angioscopy will provide unique, high-resolution information which can directly alter surgical therapy.

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THE INTRAOPERATIVE EVALUATION of blood vessels and anastomoses by probes and angiography is imprecise.[1,2] Although these procedures can determine vessel contour and diameter, important details concerning the endothelial surface, suture lines, and the effects of operative interventions remain hidden. In principle, ultrathin fiberoptic imaging systems of 1.5 to 2.8 mm diameter offer the prospect of visual inspection of anastomotic anatomy, thrombi, surface characteristics of atheroma, details of stenosis configuration, and the effects of embolectomy and balloon angioplasty.[3,4] The purpose of this report, therefore, is twofold: to describe the technique of intraoperative angioscopy which we have developed, and to analyze the role angioscopy has played in supporting critical intraoperative decisions.

Methods

Angioscopic Equipment

In these studies we used eight prototype devices. The 1.5-mm outer diameter angioscope (American Edwards, Santa Ana, California) is constructed of a shrinkable fluoride-based polymer jacket, housing an optical bundle constructed of 8000 fibers, each 10 microns in diameter with four to 12 concentrically arranged 0.1-mm illuminating fibers. Blood vessel irrigation with the 1.5-mm angioscope is performed through an external, coaxial, or concentric catheter. The 2.4- and 2.8-mm devices (Trimedyne, Inc., Santa Ana, California) are constructed of a flexible polyurethane elastomer and are contained in a four-lumen catheter. One lumen contains a removable 0.2- to 0.3-mm monofiber which transmits either white or laser light. The second lumen carries an optical bundle containing 6000 to 9000 12-micron fibers used to obtain the image.

The other two channels are used for flushing, for inflation of a 2.5- or 4.6-cc balloon, or for passage of a separate fiberoptic wave guide capable of transmitting laser energy. A 1.7-mm device (Trimedyne, Inc., Santa Anna, California) has a fixed illumination fiber and a similar optical

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bundle. Flushing of the vessel is performed through an external coaxial or concentric catheter. A 1.8-mm angioscope (Olympus, New York) consists of concentrically arranged illumination and imaging bundles. The jacket is constructed of polyvinyl chloride and the imaging bundle consist of 15,000 12-micron fibers. Irrigation is performed through an external coaxial catheter. After testing for water tightness, the angioscopes were sterilized with ethylene oxide at our institution prior to each use.

A 1000-watt xenon light source (Storz, Los Angeles) provides intravascular illumination for all angioscopic investigation. Images obtained were relayed from the fiberoptic bundles through a video endoscope coupler to a light-sensitive video camera (DXC 1850 Sony or Sharp professional model 3 tube camera). Permanent recordings were made using a ¾ inch video tape recorder (Sony 5800). In the operating room, images were viewed on-line on a high resolution video monitor (Sony PVM 1960).

To determine the image resolution and the minimum focus prior to use, a standard test pattern was photographed through each endoscope. The end of the instrument was mounted on an optical bench and a test pattern placed at a constant distance from the end of the instrument. The test pattern consisted of a series of parallel lines 200, 64, and 32 microns apart. Thus, a permanent record of the resolving power of each instrument was obtained.

Intraoperative Technique

Human angioscopic studies were approved by the Institutional Review Board of the Cedars-Sinai Medical Center. All studies were conducted in the operating room.

One hundred and ten angioscopic inspections were performed in 46 patients. Of these, 24 patients had peripheral bypass or dialysis shunt revision procedures, and 22 patients had coronary artery bypass grafting. The angioscope was inserted through an arteriotomy. For peripheral angioscopy, proximal control was achieved by vascular clamps, tapes, or balloon occlusion and a clear field was achieved with saline irrigation. Even with total proximal occlusion by vascular tapes or atherosclerotic disease, backflow sufficient to opacify the field of view occurs in both the peripheral and coronary circulations. Blood was displaced from the peripheral artery or vein by irrigation with either half normal or normal saline delivered through a pressurized bag inflated to 300 mmHg. The volume of infusion required for peripheral vessels varied with vessel size, patient blood pressure, and the degree of vessel occlusion. In a fully patent, proximally occluded iliofemoral system, 2 to 4 cc per second (total volume 200 to 400 cc) provided images for 1.5 to 2 minutes; in vessels with complete distal occlusion, 2 cc per 10 seconds (200 to 300 total volume) provided images for a 20-minute detailed assessment. During coronary artery bypass surgery, we obtained images in the arrested heart through crystalloid cardioplegic solution, either infused coaxially with the endoscope, or perfused retrograde through the coronaries *via* the aortic root. The total volume used was 50 to 500 cc in coronary studies. The time required for both peripheral and coronary angioscopy was 5 to 10 minutes for each graft or vessel inspected.

TABLE 1. *Angioscopic Procedures in Forty-Six Patients*

Twenty-four patients at peripheral vascular surgery	
Dialysis access fistula and old grafts	6
In situ saphenous vein bypass grafts	3
New grafts, patches, and anastomoses	11
Inspection of arterial endothelial surface	28
Laser angioplasties	5
Subtotal	53
Twenty-two patients at coronary artery bypass grafting	
Saphenous vein grafts and anastomoses	17
Inspection of arterial endothelial surface	40
Subtotal	57
Total number of inspections	110

Endoscopes were moved through the vessel by gentle rotation with forward motion, while viewing the vessel lumen. The key element in safe angioscopy was maintaining the angioscope in a centrally located position so that the vessel lumen was always visible. Obstructing lesions less than the diameter of the angioscope prevented passage of the device.

Of the 110 angioscopic investigations, there were 53 during peripheral bypass and 57 during open heart bypass procedures (Table 1). Five of the 24 patients undergoing peripheral vascular surgery were part of a Food and Drug Administration approved protocol for optically guided laser agron angioplasty. In these cases angioscopy was used to inspect the vessel, direct the placement of the argon laser fiberoptic wave guide, and assess the extent of atheroma ablation by the laser. Two patients also had aortic valve replacement. In these cases, the angioscope was passed through the coronary ostium as well as through the distal arteriotomy.

Results

Assessment of Spatial Resolution

Figure 1 is a photograph of a standard test pattern taken through the Olympus angioscope. The upper bars, 200 microns apart, are clearly resolved. The bottom pattern lines, 32 microns apart, cannot be separated. The middle panel, a series of parallel lines 64 microns apart, is imperfectly appreciated. The resolution of this device exceeds

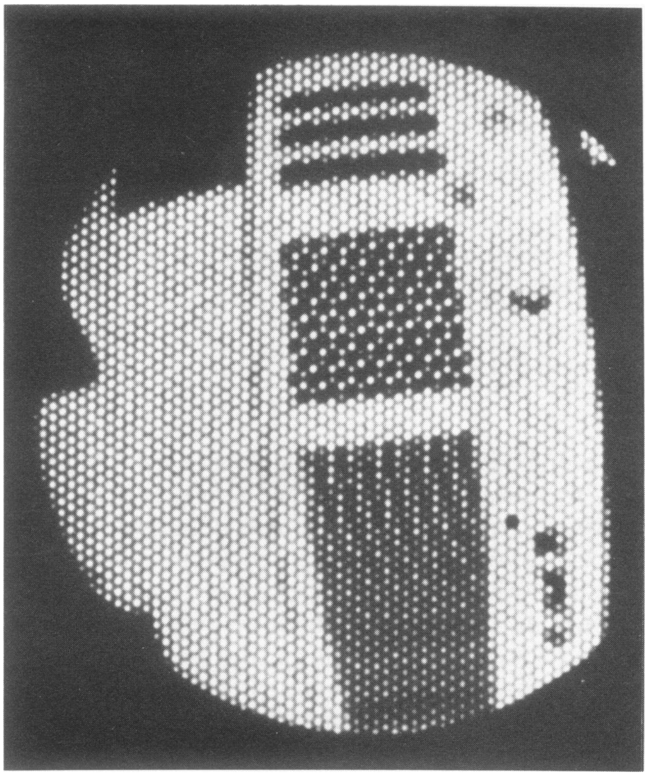


FIG. 1. This photograph shows our standard resolution test pattern as seen through a 1.8-mm endoscope. Curvature of the field or pin cushion distortion is due to the wide angle lens of the endoscope. The upper three bars are 200 microns apart. The middle bars are 64 microns apart and cannot be individually distinguished as separate lines. The bottom rectangle, lines 32 microns apart, are beyond the resolution of the angioscope. The limit of resolution of this device is between 200 and 64 microns at a distance of 5 mm. The black spots on the right hand side of the photograph are due to broken fibers.

200 microns and approaches 64 microns at a distance 5 mm from the object. All angioscopes were found to have spatial resolution of 0.4 mm or greater at 5 mm from the catheter tip. Pin cushion distortion, represented by curvature of the field as seen in Figure 1, was prominent in those devices which employed wide-angle objective lenses. The minimum focus distance was variable, but was most commonly 2.0 mm.

The uses of intraoperative angioscopy fall into three broad categories: the visualization of atherosclerotic disease, assessment of suture lines, and evaluation of therapy.

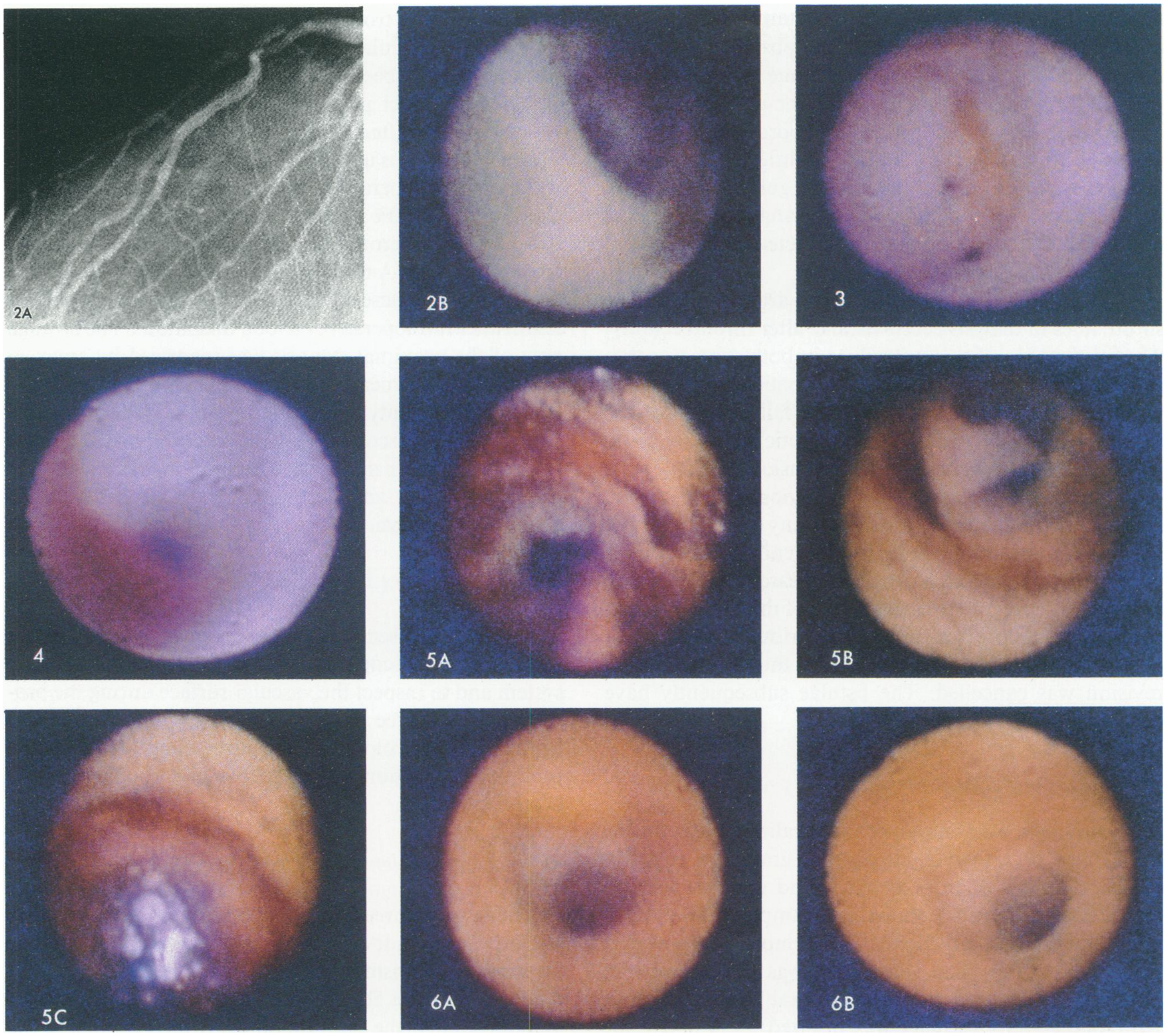
Visualization of Atherosclerotic Disease

Figure 2A shows a preoperative coronary angiogram with a 95% stenosis in both the left anterior descending coronary artery and the first diagonal branch as seen in the 30° RAO projection. Similar estimates were obtained in two LAO projections. At angioscopy, these two lesions were approached from below. The precise angioscope position was determined both by palpation and by observation of the point of bright transillumination. The interior of the first diagonal coronary artery, the site of the 95% angiographic stenosis, as viewed through cardioplegic solution during coronary artery bypass, is shown in Figure 2B. There is an asymmetric smooth plaque producing a 60% diameter stenosis. This stenosis barely allowed passage of the 1.5 mm of the angioscope and was estimated to have a minimum inner diameter of 1.6 mm. Beyond this lesion, the left anterior descending obstruction was estimated to be 90% occlusive and would not allow passage of the angioscope. Small areas of intimal hemorrhage were seen in the ulcerated surface of this lesion. Discrepancies between angiogram and angioscopy were found in 12 of 46 cases.

Figure 3 shows the endothelial surface of the left anterior descending artery in a patient with a 4-day history of unstable angina, electrocardiographic evidence of recurrent anterior ischemia, and a 90% left anterior descending coronary stenosis on angiography. At angioscopy, a thrombus not visualized at angiography was found just distal to the LAD stenosis. The clot was firmly adherent to the endothelial surface as the angioscope was passed over it. During irrigation, undulation of clot surface was evident. In our 46 patients, fresh thrombus was found in eight cases. Two of these were pedunculated, mobile strands, and five were firmly adherent, glistening red, and undulating during irrigation. Persistent irrigation for 5 minutes removed two of these latter thrombi, revealing an ulcerated plaque on the underlying intimal surface. In addition to the eight fresh thrombi, four dull, dark red, fixed thrombi were found partially obstructing blood vessels: two in sites just distal to prior prosthetic bypass grafts, and two at the site of previous suture lines. Embolectomy removed the two distal lesions but graft revision was required in both cases where the thrombus was firmly adherent to old distorted suture lines. In these 12 cases angioscopy differentiated between fresh clot and organized thrombus, and provided insight into the cause of clot formation in the majority of cases.

Assessment of Suture Lines

In our initial angioscopic studies, we came to recognize the typical smooth, elogated, oval appearance of normal anastomoses. Thereafter, even minor anatomic variations were easily recognized. Figure 4 shows a saphenous vein graft anastomosis to a left anterior descending artery. Angioscopy revealed an unsuspected, partially obstructive intimal flap due to a misplaced suture. On the basis of the angioscopic information, the offending suture was removed but a portion of the intimal flap remained. The



FIGS. *2A.–6B. 2A,* This is a photograph taken from a frame of a coronary angiogram. It demonstrates a complex series of stenoses both 95% occlusive in the left anterior descending coronary artery and the first diagonal branch as seen in a 30 degree RAO projection. *2B,* This photograph is an angioscopic view of the angiographically determined 95% first diagonal stenosis as seen from within the first diagonal lumen. A crescent-shaped smooth atheroma producing a 60% area stenosis is visible. The more severe LAD stenosis is seen through the lumen of this lesion. The dark central patch is a thrombus on the surface of the LAD occlusion after partial removal by irrigation. The location of the angioscope was determined both by observation of the transilluminated light of the endoscope and by direct palpation. 3, This angioscopic photograph shows the lumen of the LAD with a crescent-shaped red thrombus. A 90% stenosis of the LAD is seen behind the clot. The walls of the atheroma are smooth and without surface irregularities. This thrombus could not be removed by irrigation. 4, This angioscopic view demonstrates an intimal flap and misplaced suture in a saphenous vein to left anterior descending arterial anastomosis. The flap is a wedge-shaped, yellow intrusion into the ellipsoid shape of the anastomosis. The black dots at 6 o'clock and in the center of the field are silk sutures. The lower dot marks the proximal end of the anastomosis. The center dot marks the offending suture which has pulled the intima across the anastomosis. Despite the intimal flap, a 1.5-mm probe was passed both proximally and distally into both limbs of the coronary artery. *5A,* This photograph was obtained through an angioscope placed into an occluded 4-month-old PTFE femoral to posterior tibial graft. The lumen is filled with organized irregular thrombus and neointimal proliferation. A red balloon embolectomy catheter is seen in the lumen at the 6 o'clock position. *5B,* This photograph was obtained from within the lumen of the PTFE graft pictured in Figure 5A after three balloon embolectomy attempts. A large rectangular flap is seen filling the graft lumen. *5C,* This angioscopically obtained photograph shows the balloon embolectomy catheter inflated as it is being withdrawn. The balloon is partly air-filled and appears as a shiny, translucent film in the graft lumen. Organized thrombus is overlying the superior aspect of the balloon. The red line denotes the point of separation of thrombus and neointima from the graft wall. *6A,* This angioscopic image shows two bulbous coronary atheroma, one from 5 o'clock to 10 o'clock, the other from 10 o'clock to 3 o'clock causing a 40 to 50% stenosis. Beyond this lesion there is a concentric 60 to 70% constriction of the vessel lumen. *6B,* This image was taken after three intraoperative balloon angioplasty attempts were performed on the lesions seen in Figure 6A. The lower bulbous atheroma has been rounded and more closely approximates the circular vessel contour. The superior lesion was minimally effected and is slightly flattened. The concentric lesion is more clearly seen after dilatation. The intimal surface of the artery remained smooth and appears undamaged.

flap was then sutured in place to obtain a near normal anastomosis. Misplaced sutures were observed in two additional cases; one at peripheral and one at coronary surgery. In both these cases the suture line revision resulted in a normal anastomosis with good approximation of the graft wall to native artery. In four additional cases, anastomoses were seen to have intimal irregularities that were left unrevised. All patients studied by angioscopy are part of a 1-year follow-up program conducted by the Cedars-Sinai Biometrics Section.

Angioscopy was used to analyze the arterial and venous suture lines in dialysis-access fistulae after thrombectomy. The importance of this procedure in both cases was that shunt replacement was avoided. Both patients had suffered hypotensive episodes prior to shunt failure, so that the angioscopically documented thrombotic occlusion could have been secondary to either the transient low flow state or suture line irregularities. Using angioscopy, the suture lines were examined after thrombectomy without opening the anastomosis. Both arterial and venous anastomoses were widely patent and normal in appearance, eliminating anastomotic irregularities as a cause of thrombotic occlusion. Shunt failure was therefore attributed to low flow due to the hypotensive episodes, and the scheduled graft revision was cancelled. The fistulae subsequently have been successfully used for dialysis.

Assessment of Surgical Procedures

Angioscopy was employed to localize debris during valve extraction, to evaluate possible graft sites, to assess the effectiveness of embolectomy, and to assess balloon angioplasty. Figure 5A shows an example of analysis of embolectomy in a prosthetic PTFE femoral to a posterior tibial artery graft. The angioscope was passed from an incision placed 2 cm from the femoral end of the graft. An embolectomy catheter was inserted 2 cm above the distal anastomosis. The central red lines seen in the figure is the embolectomy catheter. The catheter is surrounded by organized thrombus. A thick neointima is seen clinging to the vessel wall. Large amounts of thrombus and neointima were extracted with the first two balloon passes. Very little material was obtained during the third extraction, suggesting that extraction was complete. Figure 5B shows the luminal anatomy after the third passage of the balloon catheter. An unsuspected large neointimal flap was seen obstructing the vessel lumen. Under direct vision, the balloon was passed a fourth time. Figure 5C shows the inflated balloon within the lumen of the vessel. Complete extraction of the debris was achieved with this passage.

We used angioscopy to assess the endothelial surface prior to graft placement in eight patients. In two patients, we found ulcerated atherosclerotic plaques at the planned site, one in the proximal common femoral artery and one in the infrageniculate popliteal artery. These ulcerated plaques had not been seen by angiography and were not detected by direct palpation. The site of graft insertion was therefore shifted distally to avoid these regions.

Angioscopy was used for direct visual assessment of the results of intraoperative balloon angioplasty. Figure 6A shows a 40 to 50% stenosis of the coronary artery with two bulbous atheroma protruding into the vessel lumen from either side. A 60 to 70% concentric obstruction can be seen beyond these atheroma. Figure 6B shows the same lesion after intraoperative balloon dilatations. The luminal area of the proximal stenosis was increased by approximately 25%, as measured by vascular probes, and confirmed by the ability to pass the 1.5-mm angioscope across the lesion. Angioscopy revealed a smooth, regular surface after dilatation. In addition to quantifying the increase in luminal diameter, angioscopy demonstrated that there was no intimal disruption caused by the balloon inflation.

Control of Laser Angioplasty

We used angioscopy to support laser angioplasty in five cases. The angioscope was used to aim the laser delivery system and to inspect the vascular surface during the procedure. The degree of intimal damage could be assessed by observing discoloration and carbonization as ablation proceeded. Ablation was halted when carbonization appeared extensive.

Procedural Problems and Complications

There were three important technical problems with these prototype devices. First, the angioscopes have no steering mechanism. This limitation of maneuverability frequently causes the device tip to impact on the vessel wall. Secondly, the illumination provided by smaller diameter angioscopes is insufficient to illuminate the lumen of large vessels. Vessel-angioscope mismatch occurs when a 1.5- or 1.8-mm angioscope is used to image a vessel lumen with a 3-mm or greater diameter. Because of these two limitations, clear images of a significant portion of the vascular anatomy were not obtained in six of the 46 cases. Thirdly, occasionally the irrigation system did not provide sufficient flush to permit visualization of the vessel lumen. Even a small amount of blood within the vessel lumen produced a hazy red image with poor resolution.

We had one probable complication in 46 cases. A thin, filamentous intimal flap was seen fluttering during irrigation after insertion of the angioscope. We believe this was created during angioscopy, because post-procedure inspection of the angioscope sheath revealed a small, spur-like projection at its tip. A second surgical complication of unknown cause occurred in a patient who had coronary angioscopy. This patient awoke from coronary artery bypass with cortical blindness, presumably secondary to an embolus. Since the patient had only distal coronary angioscopy with no angioscopic manipulation of the aorta, we attribute this complication to an embolism released during aortic cross-clamping.

Discussion

This study demonstrates that intravascular fiberoptic angioscopy provides clinically important information which cannot be obtained by either intravascular probes or angiography. Our data fall into three broad categories: native vascular pathology, vascular suture lines, and the effects of therapy.

Native Vascular Pathology

Angioscopic images show the intimal surface with submillimeter resolution. We have encountered the full spectrum of atherosclerotic lesions from 0.2-mm fatty streaks through smooth, stable-appearing atheroma, to ulcerated obstructions with thrombus-lined surfaces. The new ability to analyze the surface characteristics of atherosclerotic lesions is important because these features probably correlate with the risk for subsequent cardiac events.[5] Our data imply that angioscopy can gauge the age of various lesions and the likelihood of progression. With our recently reported development of a percutaneous angioscopic technique in animals, angioscopy may find use outside the operating theater. If this occurs, the submillimeter intravascular detail would provide a mechanism for assessing interventions in hypercholesterolemic patients that might cause arrest of atherosclerosis development,[6,7] and for identifying those lesions most likely to progress.[8,9]

Suture Lines

Our studies demonstrate that rapid, yet detailed assessment of suture lines can be obtained during surgery. We are not able to state how frequently early graft closure is secondary to reversible technical factors we observed. Since the frequency of early graft closure is estimated at 10 to 16% at coronary bypass surgery,[10] it is likely that angioscopy will be used to define the frequency of unrecognized inadequacies and their importance. Our data suggests that these unrecognized technical problems occur in 25% of cases, substantially more than is generally recognized. Differentiation between major and minor technical imperfections will require correlation of angioscopic results with long-term follow-up of a large patient population.

TABLE 2. *Altered Management Based on Angioscopy in Twelve Patients*

Revise anastomosis	3
Secure intimal flap	3
Reexcise venous valves	3
Alter graft placement	3
Repeat thrombectomy/embolectomy	3
Total number of therapeutic changes	15

Results of Intravascular Therapy

In our hands, angioscopy led directly to 15 changes in the intraoperative procedure in 12 patients (Table 2). These changes covered a broad spectrum of intraoperative decisions. Graft placement sites were altered by angioscopic demonstration of unrecognized intimal ulcers at the proposed site. Unrecognized potential thrombotic debris after embolectomy and incompletely excised venous valves during *in situ* saphenous vein bypass grafting were removed because of angioscopic findings. Dialysis fistulae replacement post-thrombectomy was averted after angioscopic demonstration of normal anastomoses. Vascular suture lines were revised based on angioscopic data.

Implicit but unstated in our data base is the clinical importance of the majority of cases in which abnormalities were not found at surgery. These findings reduce the need for intraoperative angiography, increasing the certainty for good prognosis. Angioscopy has the potential to become a powerful teaching tool for vascular surgical trainees, as every detail of technique can be directly observed. Nevertheless, smaller diameter, more flexible angioscopes with better irrigation, illumination, and steerability are probably prerequisite to wide intraoperative application of this new technology. Given these currently feasible technical developments, our data suggest that vascular endoscopy will play a significant role in directing and modifying intraoperative cardiovascular surgical therapy.

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Discussion

DR. G. STIEGMANN (Denver, Colorado): I would like to compliment Dr. Grundfest and his colleagues on a very graphic presentation and emphasize a point that they have made. Frequently, there is disparity between what is seen on pre- or intraoperative arteriography when compared to what is seen endoscopically.

(Slide) At the University of Colorado, we are using miniaturized endoscopes and techniques similar to those described by Dr. Grundfest. Thus far, in 25 vessels and grafts examined during lower extremity reconstructive surgery, (Slide) we have noted in five of 19 patients endoscopic findings that differed significantly from what was seen on the arteriogram. In two of those five cases, or about 10% of the total, these findings significantly altered the operative strategy.

I have two questions for Dr. Grundfest. One, has he performed angioscopy in the setting of acute ischemia, either myocardial or of the lower extremity, and two, does he feel that special training is needed to perform vascular endoscopy and if so, how should it be obtained?

DR. WARREN S. GRUNDFEST (Closing discussion): (Slide) We have seen thrombi similar to this now in four patients. Angiography did not disclose thrombus in any of these patients.

In six peripheral vascular disease patients, we have seen evidence of thrombus in those with acute onset of rest pain, so we believe that angioscopy definitely will play a role in the delineation of acute ischemic syndromes and their pathophysiology.

With regard to the special training required, I must emphasize that these endoscopes are still technologically crude and difficult to use. They are not devices that can be placed easily into a vessel. Thirty to 40 minutes of setup time are required for each procedure, but only about 5 to 10 minutes of time during the procedure.

However, we have performed multiple experiments in cadavers and in animals prior to any human use, and it takes a great deal of experience just to learn the quirks and oddities of each individual device. Until further technologic advances occur allowing steerability and flexibility in these devices, I do not think they will become routine.