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A Method of Endoscopic Investigation of Vascular Structures Directly Through Flowing Blood

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ABSTRACT

Background: Noninvasive cardiovascular diagnosis has improved immensely due to key technological refinements such as digital subtraction angiography, ultrasonography, Doppler flow analysis, and magnetic resonance imaging. Each of these methodologies provides a unique image of the cardiovascular system but will not permit surgical maneuvers or repairs during real time imaging. Our group has developed a new method of endoscopic visualization of the luminal surface of blood vessels directly through flowing blood without interference of the blood or vessel wall. This opens new possibilities in both diagnosis and surgical interventions.

Methods: Transluminal imaging through flowing blood was performed in normal animals using laser frequency light delivered and retrieved via conventional fiberoptic angioscopic instruments. The reflected light energy was reconstructed into a viewable image using a specialized method of optical data processing and filtering systems. Unlike conventional angioscopy, displacement of flowing blood was not needed as the images were obtained with higher frequency laser light.

Results: A total of 20 canine experiments were performed between 1996 and 1997 using our endoluminal imaging system. The images obtained revealed details of luminal surfaces, although primitive and low resolution with this first generation of technology. Images of the topography of the femoral, axillary, and subclavian arteries and veins, as well as several intracardiac structures (aorta and aortic valve) were successfully obtained without trauma or physiologic consequence to the animal.

Conclusions: Using conventional fiberoptic angioscopes coupled with laser light of differing wavelengths, it was possible to image the interior of vascular structures through flowing blood. This method visualizes the intraluminal surface in real time and is dependent only on the delivery and capacity of the endoscope. The implications for future cardiovascular diagnosis and corrective surgical procedures are widespread.

INTRODUCTION

The stethoscope, physical exam, and plain radiographs were once the foundations of physical diagnosis. Advances in computer processing power in conjunction with the application of physical principals have opened vast new frontiers of medical diagnosis. Ultrasonography, duplex scanning, echocardiography, magnetic resonance imaging, positron imaging, digital angiography, and intravascular ultrasound are now standard methods of investigating and defining cardiovascular pathology. These advances have revolutionized the practice of modern cardiovascular medicine and surgery, opening the doors for new therapies once thought to be impossible.

Each of these new technologies provides a new and unique window of observation into the cardiovascular anatomy and physiology. Computer reconstruction of the data creates vivid, anatomic images that can be displayed in multiple projections or sections. The advancing processing power of recent computer hardware now makes it simple to perform complex three-dimensional modeling of intricate intracorporeal structures such as the cardiac valves and intracranial anatomy. One promising frontier is the enticing possibility of imaging vascular and cardiac anatomy through flowing blood.

Since the mid 1980s, small-diameter fiberoptic endoscopes have been available to perform endovascular imaging. Angioscopy has found a role in the surgical arena as well as an experimental role during some forms of invasive cardiac procedures [Spears 1985, Thieme 1996]. During vascular reconstructive surgery, angioscopy can be used for diagnosis of intraluminal pathology, stenoses, intimal flaps, aneurysms, thrombosis, or suture anomalies [Iton 1983, Ahh 1988, White 1989 Buchmaster 1995]. Angioscopy is used as an adjunct to such operations as transluminal balloon angioplasty, catheter-based endarterectomy, thrombolytic therapy, placement of stents

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and endovascular grafts [Ahh 1988, White 1989, Buchmaster 1995]. Angioscopy is also being used in some centers to assess the completeness of an intervention or to demonstrate correct positioning of a transluminally inserted stent or graft [Buchmaster 1995].

Despite these important uses for angioscopy, there are distinct limitations. For example, current angioscopy requires displacement of the opaque flowing blood with an optically translucent fluid such as saline [Iton 1983]. This prohibits the surgeon from maintaining a stable image for a long time due to the interruption of blood flow [Serruys 1992, Thieme 1996]. This limitation renders angioscopy mainly an adjunct to another procedure or investigation.

Our group has been investigating the possibility of real-time imaging of intraluminal vascular anatomy without displacing the flowing blood [Sedov 1998]. We obtain a real time image from the border of the medium directly through the blood using high frequency laser energy and convert the image into the visible light spectrum with specialized filtration. The capacity of the method depends only on the capacity of the endoscopic instrument. Our technique is based on laser energy with the wavelength of 0.63 mk and capacity of 30–100 mV. In most respects, the images obtained correspond to those obtained via typical angioscopic studies. The image may be viewed immediately on a standard video display monitor. The data can also be used for further computer reconstruction.

In this report, we briefly describe our methods and the potential for future development of intravascular and cardiac diagnostics with this technology.

MATERIALS AND METHODS

The endoscopic portion of the system comprises commercial fiberscopes between 1.5 mm and 3.0 mm in diameter. The image acquisition system is separate and independent of the angioscope and currently will work with all commercial systems marketed by independent fiberoptic endoscopic vendors, such as Olympus and Baxter. Endoscope diameter is more dependent on the size of the channel being cannulated, and the imaging is not dependent on the endoscope diameter.

We utilized a commercial laser with an energy delivery of 30–100 mV at a wavelength of 0.63 mk. This yields a reflection of surface details about 3 to 4 cm from the endoscope tip. Data retrieved from the reflected light is filtered and converted to the “optical diapason” (i.e., visible range of the electromagnetic spectrum), reconstructed in several milliseconds and displayed on a conventional cathode ray display (CRT). A schematic diagram of the concept is presented in Figure 1 (◎).

RESULTS

Between 1996 and 1997, we tested our apparatus in a total of 20 canine experiments [Sedov 1998]. To insert the fiberscope into the vessels, we used several different approaches. We have successfully examined the venous and arterial aspects of the femoral, axillary, and subclavian systems. We observed the interior of vessels with different diameters and speeds of circulation [Sedov 1998]. We also moved the endoscope directly into the heart and observed movements of intracardiac structures such as heart valves.

We were able to obtain images of the blood vessel walls directly and without any additional processing of the vessels or blood. The image is analogous in appearance to those obtained with a standard angioscope in translucent medium. There was no difference in observation of the vessels with large or small diameter, nor was there a difference in observation of arteries and veins. Stable images can be obtained for a long time. We have been able to perform laser imaging for up to 1.5 hours without harm. All.of the dogs survived the experiments and a number of them were used several times in different experiments.

Figure 2 (◎) illustrates a sample image obtained from the canine femoral artery. Although the first-generation images are suitable for gross assessment of vessel character, there is room for refinement in resolution and detail with further development of the equipment.

DISCUSSION

Diagnostic imaging has undergone a revolution in the past few decades. Most of this growth has been due to computer enhancement and the ability of computers to reconstruct and display images obtained with different forms of energy. The impact on medicine and surgery has been profound. It is now possible to examine internal body structures with great detail and little harm or invasiveness using one of many newly developed technological advances in diagnostic equipment.

Cardiovascular therapeutics has also leapt forward with the invention of angioplasty and intraluminal therapies. Less invasive procedures of all kinds are being developed with the goal of reducing trauma and morbidity. Cardiac surgery has undergone a recent upheaval with the introduction of limited-access incisions and procedures performed entirely by endoscopic and port-access approaches [Stephens 1996]. At present, what is needed is a new method of viewing the internal structures of the circula tory system without invasiveness, trauma, or the need to displace flowing blood. Angioscopy has been able to provide images of this type for peripheral vascular surgery and some limited applications, but requires displacement of flowing blood with an optically translucent medium.

Our work has shown that the opacity of the blood can be overcome by using analogous methods of light information processing (optical filtration). Our studies have shown that laser light energy of the wavelength of 0.63 mk will provide images of the intraluminal structures. The resolution of the images obtained is still crude but does confirm the possibility of endovascular imaging through flowing blood.

Although we obtained very encouraging preliminary results, we understand that it is only the beginning of this work. During these studies we did not have the opportunity to observe key vessels with small diameters, such as coronary arteries. As expected, using normal animals, we did not observe atheromatous plaques. Hopefully, technical refinements will provide greater image quality and versatility in future versions.

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REVIEW AND COMMENTARY

Commentary from Mark Levinson, MD:

This paper by Grif Alexey Vadimovich and colleagues from St. Petersburg Russia reporting visualization of vascular structures through flowing blood offers some rather unique potentials. Until now, the only way to examine the interior of vascular structures has been with ultrasound or angioscopy. The main drawback of angioscopy has been the need to displace flowing blood with a visually translucent fluid, such as saline. Thus, angioscopy is not practical on the beating heart or in the proximal aorta. Intravascular ultrasound offers a coronal reconstruction of reflections from the vascular layers, but cannot reconstruct the surfaces in a manner representative of the view seen by the surgeon during open cases.

The possibility of real-time visualization of intravascular and intracardiac structures through flowing blood is a potentially important, if not monumental breakthrough. Consider the possible applications of this concept. Would it be possible to introduce the laser endoscope through a small peripheral vessel (like the radial artery) and examine the interior of the aorta, aortic valve, and the left ventricular chamber? Smaller versions could even be used to examine the coronary anatomy. What tremendous possibilities must exist for diagnosis and clarification of complex congenital heart disease. Transeptal puncture could allow direct visualization of the mitral apparatus in real time with a detail that even transesophageal echo could not provide. The performance of native heart valves or prosthetic devices, the presence of intracardiac septal defects, and the examination for the site of dissection tears are other examples of potential uses.

Breakthrough technology occurs only rarely. Computerized tomography and magnetic resonance imaging were breakthroughs in diagnostic technology. Both of these have lead to dramatic improvements in anatomical diagnosis, which then spawned refinements in surgical procedures and the development of entirely new procedures. How will intravascular laser endoscopy through flowing blood affect our future as cardiovascular surgeons? It is too early to tell, but there are so many possibilities. The first advance that comes to mind is the potential for reparative operations on the beating heart. Such lesions as mitral regurgitation, ASD, and simple VSD may be amenable to direct surgical repair in the closed chest beating heart using intraluminal tools and laser endoscopic visualization. The frontiers are limitless.

This report by Vadimovich is preliminary and lacks details regarding the instrumentation and technology. In my correspondence with Dr. Vadimovich, he indicated, the instrumentation is being patented and thus specifics could not be made public at this time. Thus, it is difficult to judge if the technology will actually provide images of sufficient quality to be useful for diagnostics or endoluminal surgery. However, these early images stimulate the creative mind to project what may be possible in the future if refinements are achieved. All of us in cardiovascular surgery are clearly in need of this advance and await further and more detailed scientific reports of visualization through flowing blood. This advance alone may open the door to endoluminal surgical repairs that will mark the next major era of cardio-vascular surgery.