Digital Subtraction Angiography*
Eric Castleman, M.D.; and Jonathan Tobis, M.D.

NOTE: The communication which follows is another in a series of communications from the ACCP Section on Cardiologic Diagnostic Techniques. The format of these contributions will vary. Some reports will consist of editorial comments on current medical literature, while others will represent brief narrative summaries or "state-of-the-art" papers. The officers and members of the American College of Chest Physicians are indebted to the members of the ACCP Section on Cardiologic Diagnostic Techniques for providing these clinical communications.

Editor


Summary

This report describes the application of computer technology to enhance angiographic imaging. Digital processing methods, including digitized image subtraction, integration, and non-linear representation techniques, are described. Examples from animal experiments are presented. These investigators describe a combined method for recording and storing radiographic images using digitally formatted videotape for recording and conventional digital storage of selected image data.

Commentary

This review article describes pioneering work from West Germany using a new system that simplified angiographic video image acquisition and allowed processing of images by combining analog and digital computer techniques. The foundation for future systems were laid in the authors' detailed description of the components of this newly developed image processing computer. The processing techniques of mask mode subtraction, integration, and non-linear representation are well detailed. Pilot studies of this new radiographic system in the animal model are described. A significant clinical application of this technique was the reduction of the amount of contrast material injected during studies. This technically sophisticated article describing, in computer engineering terms, the conversion of analog data acquisition and storage to a digital format, has played a major role in demonstrating the potential benefits and wide applicability of digital processing to angiographic data.


Summary

A computerized fluoroscopy system developed by the authors allowed image contrast enhancement of 8 to 16 times compared with conventional image intensifier fluoroscopy and permitted assessment of canine and human ventricular wall motion using peripheral intravenous injections. The time dependent image subtraction algorithms, mask mode fluoroscopy and time interval difference imaging were assessed using artificially infarcted dog hearts. The first algorithm produced a display similar to direct ventriculography, while the second displayed regions of dyskinetic motion as anomalous gray shades.

Commentary

This article discusses in detail the limitations and physical considerations of two computerized fluoroscopic techniques, i.e., mask mode fluoroscopy and time interval difference imaging, as they apply to cardiac wall motion assessment. Mask mode fluoroscopy involves subtracting all the digitized contrast ventricular images from a contrast-free reference image to eliminate irrelevant background and enhance

*From the Division of Cardiology, University of California Irvine Medical Center, Orange, California.
only the object containing the contrast material in the image. Patient motion and respiration during the imaging are the major limitations of the mask mode technique. Time interval difference imaging, on the other hand, is relatively insensitive to both patient motion and respiration. This technique involves changes in opacification levels which occur over short time intervals. The difference between adjacent integrated image pairs is displayed as white (increased opacification/chamber expansion) or black (decreased opacification/chamber contraction). These preliminary experiments demonstrated that normal, as well as abnormal heart wall motion can be adequately visualized with an intravenous technique using either of the computerized algorithms. The two techniques are not only complementary, but time interval difference images can be derived from a series of mask mode images. This group of researchers has had a significant impact in applying computerized acquisition and processing to cardiovascular imaging.


Summary

In this study, small dose left ventriculography, using only 5 ml of contrast media, was performed with the aid of a computer image processing system. Digital subtraction was used to enhance the ventricular images. The boundary of the left ventricular cavity was automatically determined to calculate the instantaneous volume change throughout the cardiac cycle. Results of end-diastolic volume, end-systolic volume and ejection fraction calculated from the 5 ml digital angiograms and the standard film-based cineangiograms were similar in 16 patients. The small dose of contrast medium did not elevate the left ventricular end-diastolic pressure, whereas conventional doses of 40 ml of contrast medium used during film-based angiography consistently raised left ventricular end-diastolic pressure.

Commentary

This report explored some of the many uses of a computer-aided image processing system. Minimal doses of contrast medium processed using the digital subtraction format permitted accurate measurement of left ventricular dimension and function without significant hemodynamic effects. The on-line computerized method for ventricular edge detection was similar to those obtained by the conventional manual method, thus bringing uniformity to the calculation of ventricular volumes. Small dose ventriculography has the added benefit of allowing serial angiographic studies with interventions to be performed without adding significant risk.

DIGITAL ANGIOGRAPHY IN ASSESSMENT OF VENTRICULAR FUNCTION AND WALL MOTION DURING PACING IN PATIENTS WITH CORONARY ARTERY DISEASE. Tobis J, Nalcioglu O, Johnston WD, Seibert A, Iseri LT, Roeck W, Henry WL. Am J Cardiol 1983; 51:668-75

Summary

This study describes the combined application of digital subtraction angiography and atrial pacing to assess the functional significance of coronary stenoses. Left ventriculograms were obtained with 10 ml of iodinated contrast material in 21 patients both at rest and during atrial pacing. Coronary artery disease with greater than 50 percent diameter narrowing in at least one major artery documented by angiography was present in 15 patients, and six patients had angiographically normal coronary arteries. During pacing, five of the six patients without coronary disease had mild increases in ejection fraction, whereas 14 of the 15 patients with coronary disease demonstrated a fall in ejection fraction and developed wall motion abnormalities corresponding to the myocardial areas supplied by specific stenotic arteries.

Commentary

This study demonstrated the clinical benefits of using low contrast dose ventriculograms processed by digital subtraction combined with atrial pacing to determine the functional significance of coronary disease as defined by changes in ejection fraction and development of wall motion abnormalities. Although coronary anatomy is well detailed during catheterization, there is often disagreement in the interpretation of the severity of a specific lesion. A functional assessment of the hemodynamic effect of a coronary stenosis provides an independent measure of its severity and the effect that the lesion has on reserve ventricular performance. During atrial pacing studies, digital acquisition of left ventriculograms are advantageous because the low doses of contrast used for each injection allow multiple ventriculograms to be obtained.

Summary

This study describes a new technique using selective coronary angiography to assess the hemodynamic significance of coronary stenosis by measuring relative arrival time of the contrast bolus. The technique involved obtaining coronary angiograms at end-diastole and then subtracting sequential images from each other to derive a composite image of the time of arrival of the contrast bolus at each diastolic frame over 6 cycles. The spatial distribution and timing of contrast medium appearance through its arterial, myocardial and venous phases are depicted in functional images with the use of simultaneous modulation of color and intensity. Myocardial contrast appearance time was found to correlate inversely with coronary blood flow as measured by the coronary sinus thermodilution technique. A source of coronary flow reserve was derived by obtaining coronary artery appearance time images before and after contrast media-induced hyperemia. Hemodynamically significant obstructions do not permit increased arterial flow as demonstrated by the lack of change in appearance time.

Commentary

This study applied digital techniques to selective coronary arteriography in an attempt to provide useful clinical information on relative coronary blood flow and regional coronary flow reserve. Color mapping studies performed at rest and within 10 seconds after hyperemic stimulation of iodine contrast allowed assessment of coronary flow reserve. An increase in blood flow corresponded to a more rapid rate of arrival compared to rest and this was demonstrated in normal arteries. Coronary arteries with significant stenoses had less of an increase in flow following the hyperemic stimulus and thus did not demonstrate the same degree of change in the arrival time image. This study demonstrated the type of contributions that can be made with digital processing of angiographic images. Using this technique, a functional assessment of the hemodynamic effect of coronary stenosis can be obtained and thus provide an independent measure of the severity of the lesion.


Summary

Digital subtraction coronary angiograms were compared to 35mm cine film angiograms by a panel of four observers. Both cine and digital angiograms were obtained sequentially in 19 patients using selective intracoronary artery injection of contrast medium. Digital images were obtained at 8 frames/second with a 512 x 512 x 8 bit pixel matrix. There was no significant difference in the mean percentage of stenosis of 32 lesions between the digital angiograms (53 ± 31 percent) and the cineangiograms (52 ± 31 percent). A two-way analysis of variance demonstrated no significant difference between the amount of variability in the measurements between the cine film and digital technique.

Commentary

This study demonstrated that digital image processing during selective coronary angiography is feasible and produces coronary images that are comparable in overall quality and clinical usefulness to film-based angiograms. The digitally acquired angiograms compared favorably in terms of interobserver variability with cineangiography with respect to stenosis identification and quantitation of diameter narrowing. Advantages of digital acquisition include immediate playback, image enhancement, and an accessible format for quantitative analysis of coronary stenoses using an edge detection method or a videodensitometric method. In addition, because of the storage capabilities of digital memory, these coronary angiograms can be interleaved with the live fluoroscopic video image to provide a “roadmap” during coronary angioplasty. Disadvantages include misregistration artifact, television camera over-saturation, and limited computer disk storage. In response to their experience with digital acquisition of radiographic images, this group of researchers has transformed their clinical cardiac catheterization laboratory from a primary film-based system to a laboratory in which all coronary and ventricular angiograms are acquired and processed digitally.