Intravenous Angiography Using Digital Video Subtraction: X-ray Imaging System

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Intravenous Angiography Using Digital Video Subtraction: X-ray Imaging System

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An x-ray imaging system, using digital subtraction techniques, has been developed. The system requires: (1) high output generation equipment; (2) an image intensifier capable of receiving high output exposures, 1 mR (2.58×10^{-7} C/kg) at the face of the intensifier, without loss of either contrast or resolution; (3) a precision digital video camera; (4) processing computer with sufficient storage capacity; and (5) digital image storage. With this system it is possible to visualize the major arteries after intravenous contrast injection. The system, angiography technique, and early results are described.

Intravenous aortography was first introduced more than 20 years ago; however, it never gained wide popularity [1, 2]. Recently, the technique of intravenous angiography using video subtraction techniques has been explored at several institutions, all using the same general principle with some variations in equipment and techniques [3–7].

An x-ray system is being developed at the University of Arizona capable of imaging major arteries after the intravenous injection of contrast media. This image acquisition system consists of five major components: (1) high-flux x-ray generation equipment; (2) high quality x-ray image intensifier; (3) precision digital video camera; (4) processing computer with storage facilities; and (5) digital image store with mapping memory. Images obtained before intravenously injected contrast material are subtracted from subsequent images and then electronically contrast-enhanced to produce the final image of arterial structures which is viewed on the cathode ray tube display. Satisfactory images have been obtained in the experimental setting of dog carotid arteries, renal arteries, and heart.

Materials and Method

The system and image acquisition chain are shown in figure 1.

X-ray Tube

Preliminary calculations indicate that up to 1 mR (2.58×10^{-7} C/kg) per exposure at the intensifier face is needed to detect 2% contrast levels in 1 mm structures. Therefore, a high-flux x-ray source with high heat capacity is required, especially when multiple exposures are required. At present we use a CGR (Compagnie de Radiologie) RS772 tube with 1.8 million heat units storage at the anode and a 215 kW rating on the large focal spot (1.2 mm).

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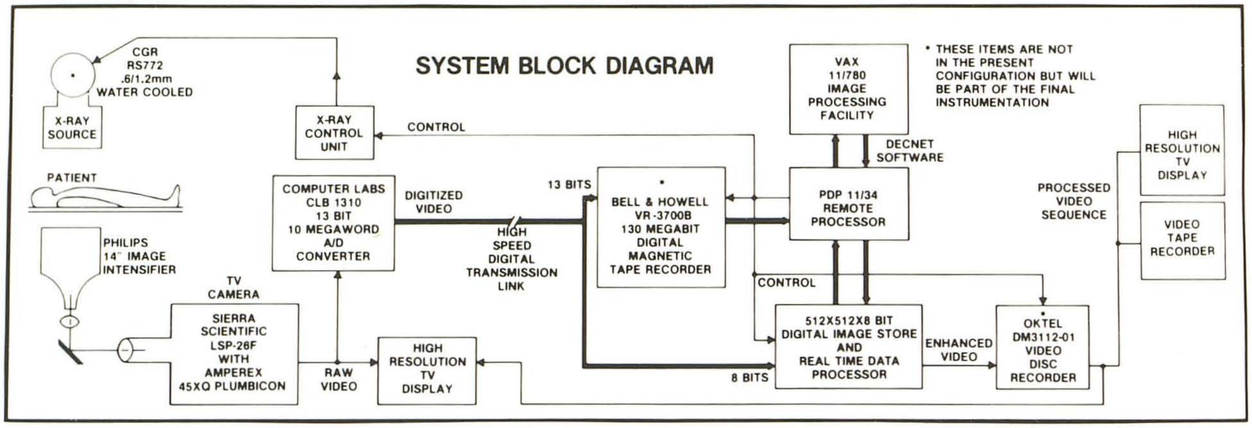
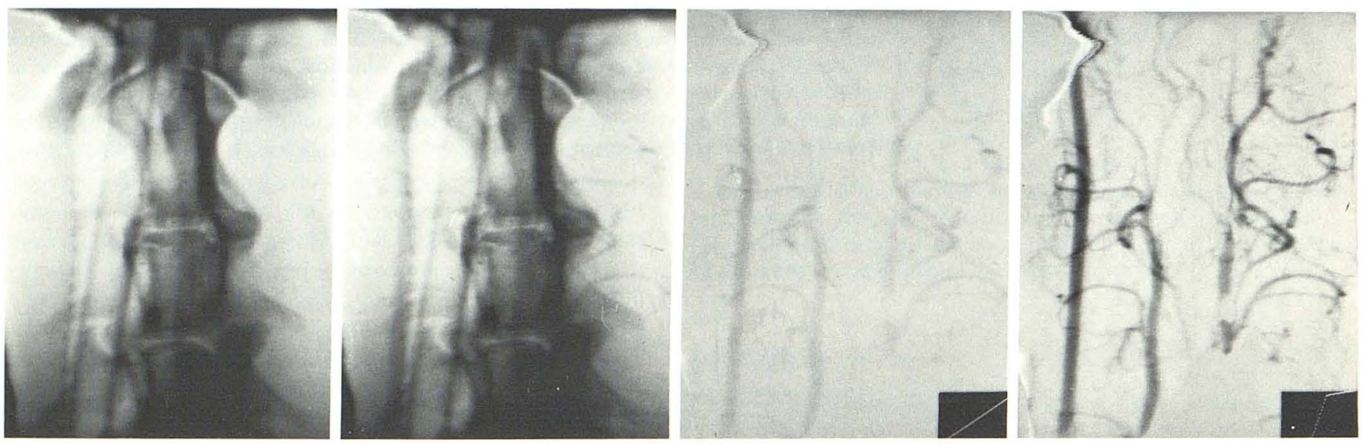


Fig. 1.—Block diagram of image acquisition, processing, and display system.



A B C D

Fig. 2.—Intravenous carotid angiogram in a dog's neck. **A**, At start of contrast injection in right external jugular vein. **B**, 8 sec after injection (1 cc/kg). **C**, Subtracted image without processing, and, **D**, with electronic contrast enhancement. **D**, demonstrates right carotid artery, portions of left carotid artery (it had been previously surgically ligated) and cervical arteries.

Image Intensifier

Three image intensifiers have been incorporated, at one time or another, in the system. For the past year we have used a Thompson CSF 9-6 intensifier. The intensifier must be able to accept a 1 mR (2.58×10^{-7} C/kg) exposure without loss of either resolution or contrast. While this exposure is excessive for most intensifiers designed for fluoroscopy, newly evolving intensifiers such as the Phillips 35.6 cm are designed to meet this exposure requirement. In addition, large field intensifiers will be needed, especially in the clinical setting, so that examinations are not compromised by limited intensifier field size.

Video Tube and Camera

We use a newly developed Amperex 45XQ frog's head plumbicon video tube incorporated into a Sierra Camera. This tube has a linear response which is desirable for subtraction techniques. Its most important feature is a high signal output of up to 3 μA with only 1–2 nA preamplifier noise, so that a high signal-to-noise ratio, in excess of 800:1 at 5 mHz, is achieved. At present, it is operated in a 545 line interlaced mode, which limits resolution to 2.2 line pairs/mm. It may be modified to produce noninterlaced scans up to 2,048 TV lines, and to run at a 20 mHz bandwidth, for use with large field intensifiers and large displays. This will also allow study of smaller vessels.

Analog-Digital Converter

The analog-digital converter is a high speed converter capable of 10 megawords/sec with 13 bit accuracy. This allows digitation 512×512 rasters at 30 frames/sec, and a tradeoff of improved resolution for slower raster rates as needed. At present we use only 8 bits because of the temporary limitations of the digital image store.

Digital Image Store

The digital image store is a $512 \times 512 \times 8$ bit memory charge coupled device built in our laboratory. (This will be expanded soon to a 2048×2048 display.) The device accepts the TV image in real time and transfers it to the computer at a rate limited by computer capability. In addition, it has a mapping memory so that in the display mode any portion of the 256 gray levels can be expanded or compressed on the cathode ray tube display. This allows for considerable contrast enhancement of the displayed image.

Computer

The computer in use is a VAX 11/780, chosen for its high speed processing and its large memory addressing capabilities. Digitized images can be obtained at 1 frame/sec and stored within the computer system. Any image can be subtracted from any other image and redisplayed on the cathode ray tube within several seconds. Both binary and logarithmic subtractions are conventionally performed.

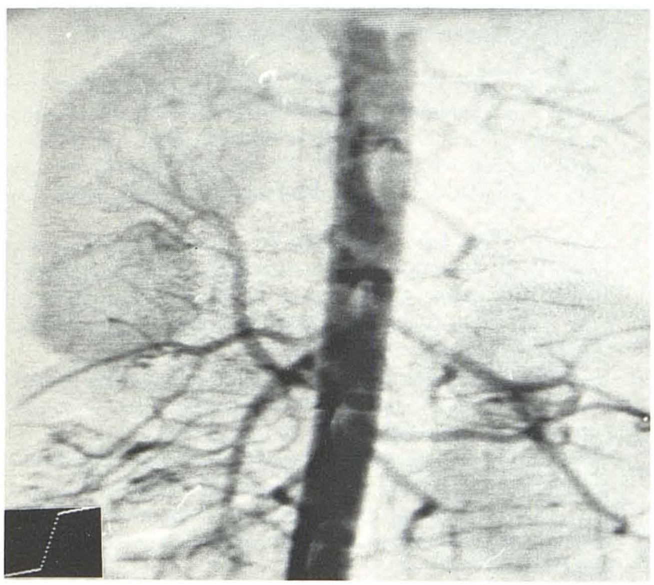


Fig. 3.—Renal artery imaging in a dog.

A Bell & Howell digital magnetic tape recorder is being interfaced into the system. When completed, raw data at 512 × 512 × 13 bits at 30 frames/sec or 1,024 × 1,024 × 13 bits at 7½ frames/sec will be immediately acquired and stored. This will allow complete postprocessing of the data.

Video Disc Recorder

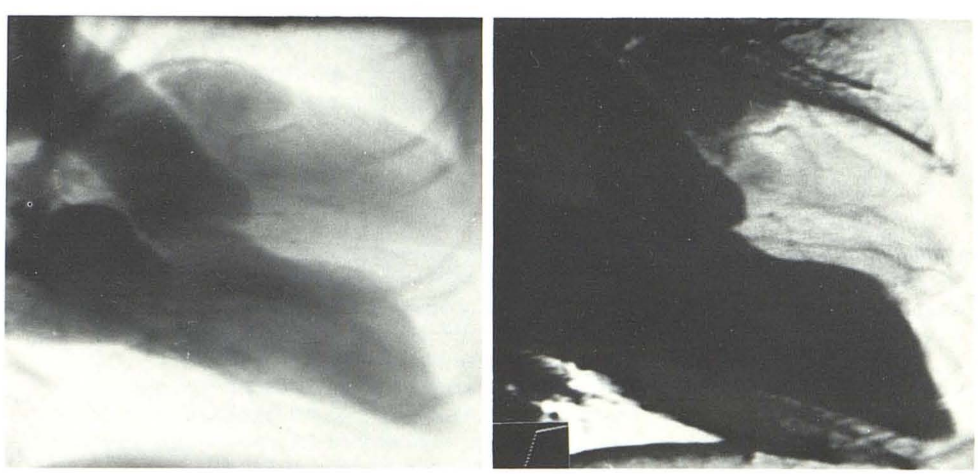
An Oktel video disc recorder is incorporated in the system for display purposes. This allows dynamic display as well as freeze frame capabilities. This recorder has a signal-to-noise ratio of 55 dB allowing the display of images without significant degradation.

Technique

Adult greyhound dogs weighing 30–35 kg were lightly anesthetized with sodium pentobarbital and endotracheal tubes were placed. X-ray technique was at 5 msecond exposures, 400 mA, and kV was varied between 70 and 90 so that a dose of 0.4–0.5 mR (1.0–1.3 × 10^{-7} C/kg) was obtained at the intensifier face. The dogs were then placed on a mechanical ventilator and hyperventilated so that spontaneous breathing ceased for a 10–15 sec period. Renografin 76 (1 ml/kg) was then forcefully injected by hand, through a 16 gauge angiocatheter in either an external jugular vein or a foreleg vein. Exposures were obtained at a rate of 1/sec. Carotid, renal, and coronary arteries were studied using the 22.9 cm mode of the intensifier. Figure 2 is an example of a sequence. The first image (fig. 2A), which does not contain iodine, was subtracted from those obtained thereafter (fig. 2B) in a sequential manner, until the image (fig. 2C) with the most iodine content in the arterial structures was identified. The latter (fig. 2D) was then contrast enhanced using the mapping memory, displayed, and photographed. Studies of the renal arteries (fig. 3), left ventricle (fig. 4A), and coronary arteries (fig. 4B) have also been performed.

Discussion

The success of intravenous angiography depends on three factors: (1) it is imperative that the subject be effectively motionless so that completely subtracted images can



A B

Fig. 4.—**A**, Intravenous angiogram left ventricle of canine. Left ventricle enables excellent angiograms because of its relatively large volume. **B**, Further contrast enhancement of fig. 4 brings out parts of coronary arteries not superimposed over left ventricle.

be obtained when using the simple subtraction methods described; (2) a sufficient bolus of contrast must be delivered so that the iodine content on the arterial side is at least 2 mg/cm^3; (3) the x-ray system must be capable of delivering a dose of 0.5–1.0 mR (1.3–2.58 $\times 10^{-7}$ C/kg) to the intensifier face to provide sufficient flux for detection and characterization of these low contrast arterial images.

Results in animal experiments show that these conditions can be met in the experimental situation. Patient studies are in progress to further evaluate system performance.

The impetus for developing such a system is to provide a means for detecting and quantifying atherosclerotic lesions in asymptomatic but high risk patients. At this time it is difficult to quantitate atherosclerotic lesions in the human arterial system unless angiography is performed, or the lesions are so severe that secondary effects are produced, such as decreased blood pressure in an extremity, angina pectoris, stroke, or myocardial infarction. It would be desirable to identify significant atherosclerotic lesions before they cause symptoms. Because direct angiography is an invasive procedure and requires hospitalization, it is not appropriate for identifying atherosclerotic lesions in the asymptomatic patient. The intravenous procedure has been developed, therefore, as a screening method to identify clinically important but latent disease, to follow patients serially, and to determine the effects of treatment on demonstrated atherosclerotic lesions.

Left ventricular function and wall motion kinetics are also expected to be easily studied with this technique. This application must await the incorporation of our high speed digital magnetic tape that will allow image acquisition rates up to 60 images (fields)/sec. The ultimate goal is to visualize the coronary arteries in detail so that the presence or absence of coronary disease may be identified. This instrumentation has been designed to achieve a resolution and contrast capable of identifying a 50% stenosis in a 2 mm artery at a 2% contrast level so that coronary arteries can be studied. However, because of contrast within cardiac chambers, the visualization of coronary arteries will be difficult and will require additional image processing techniques combined with optimum vessel projection using a flexible biplane angiographic facility.

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