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Comparison of digital subtraction video densitometry and area length method in the determination of left ventricular ejection fraction

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Abstract

Digital subtraction video densitometry is utilized in the determination of left ventricular ejection fraction. The mask mode subtracted video images obtained after a peripheral intravenous injection of a bolus of Renografin 76 are used in the derivation of a density-time curve. The left ventricular ejection fraction (LVEF) is computed by an algorithm described in this paper. Results for 15 patients are compared to the LVEF's obtained by applying the area-length method to the same patient data. The left ventricular ejection fractions computed by both methods had a good correlation ($r=0.96$) in fifteen patients.*

Introduction

At present the major quantitative imaging methods used in cardiology involve invasive techniques such as cineangiography. Other non-invasive techniques especially nuclear cardiology has also been providing clinically useful information.¹ With the availability of digital computers and faster gamma cameras nuclear medicine is now able to provide quantitative cardiophysiologic data with much less risk to the patient than cardioangiography. Nuclear cardiology has become one of the most rapidly developing fields in nuclear medicine. The dynamic nuclear studies are used to extract quantitative data which describes the function of the heart. These images in nuclear cardiology are obtained either during the first pass² of radionuclide through the heart or by EKG gating over many heart beats.³ The first pass studies represent the passage of the radioisotope fairly accurately but suffer from the lack of spatial resolution and/or poor count statistics in the images. Nuclear medicine scintigrams taken by EKG gating also suffer greatly from poor spatial resolution.

In this paper, we present first pass left ventricular ejection fraction results obtained using a digital fluoroscopy system. The first pass video images are acquired by employing the mask mode subtraction algorithm developed by Mistretta, Kruger et al.⁴ The subtracted video images are used in extracting density-time curves similar to the activity-time curves in nuclear medicine. A preliminary report on the evaluation of renal function by the same technique was reported by Nalcioğlu et al.⁵

Method

Prior to the intravenous administration of contrast agent, a mask image is taken and stored in the memory of a video image processor. The video images obtained after the injection of iodine contrast material are digitally subtracted from the mask image frame by frame at a rate of 30 frames/second and are stored on a video disk. According to work presented in reference 6, if one works in the linear response region of the image intensifier television system and logarithmically amplifies the video signals, the video amplitude (or gray levels) is proportional to the summation of materials traversed by x-rays.

$$V_1 \text{ (video amplitude)} \propto \sum_{j=1}^M \mu_j x_j \quad (1)$$

where μ_j , x_j are the linear attenuation coefficient and thickness respectively. The symbol $\propto$ stands for proportionality. The subtracted video signal eliminates all the other materials except iodine contrast agent, i.e.

$$\Delta V \propto \mu_I x_I \quad (2)$$

where I stands for iodine. If one sums the difference signals which are within a region, one obtains a number which is proportional to the volume which is projected onto that region under the assumption of homogeneous mixing of iodine within the volume. This can be expressed as,

$$\text{Volume} \propto \sum_{\text{region}} \Delta V \quad (3)$$

In equation 3, the summation is carried out over all the pixels within the chosen region.

The analysis of the subtracted first pass video images are done in the same way. After the clinical procedure is over, the physician views the study at a slower TV rate and visually

chooses an end diastolic (ED) video frame. Once this frame is selected, a region of interest is drawn around the boundaries of the left ventricle (LV) by employing a cursor. The integrated video signal within the ROI is proportional to the ED volume by equation (3). As the ventricle contracts from ED to ES the LV would remain within the ED-ROI, if the region was selected to be large enough. Thus the summation of the gray levels within the ROI chosen for ED is still proportional to the volume of LV at that instance whether the LV is at ED or ES. The summation process is repeated for each TV frame separately and a density (volume) - time curve is generated. A typical curve is shown in Figure 1.

Figure 1. Density-time curve

The maxima and minima in Figure 1 correspond to ED and ES respectively. It should be remembered that equation 3 holds under the assumption of homogeneous mixing of iodine with blood. In peripheral intravenous studies this assumption is valid. As the iodine bolus passes through the LV, the overall concentration changes but mixing remains. Using the curve given in Figure 1, the TV frame numbers corresponding to ED and ES are determined. The largest density ED frame is chosen and the subsequent ES frame is subtracted from it to give the stroke volume. Another ROI is drawn around the stroke volume for background correction (BG-ROI). If one examines the BG-ROI during an ES frame, ideally, there should not be any iodine within that area. Unfortunately, due to the length of bolus, 30-40 cc, while the iodine passes through the LV there remains some residual signals within the overlaying organs. The residual iodine contributes to a non-zero signal within the BG-ROI and BG-ROI is illustrated in Figure 2.

Figure 2. Selection of ROI's

After the ROI's are chosen the determination of LVEF proceeds as follows. The ED volume is computed by summing the gray levels within ED-ROI during an ED TV frame, let us designate the ED volume by I_{ED} . The first ES frame following the ED frame is chosen. The gray levels within the ED-ROI are also summed and this number represents the ES volume plus the background. Let us call this number I_{ES} , i.e., ES volume and background. The background is measured from the same ES frame using the BG-ROI. Since the BG-ROI is smaller in area than the ED-ROI the measured number I_{BG} is scaled by a ratio of these two areas. Then the LVEF is computed by using the relation,

$$\% \text{ LVEF} = \left[\frac{I_{ED} - I_{ES}}{I_{ED} - (A_{ED}/A_{BG}) \times I_{BG}} \right] \times 100 \quad (4)$$

where A_{ED} , A_{BG} are the number of pixels within ED, BG regions of interest. The computation is repeated for 3-4 cardiac cycles and the results are averaged to give a mean LVEF. The computational algorithm is outlined in Figure 3.

EJECTION FRACTION ALGORITHM

Figure 3. EF computation algorithm

In our work, we keep the same ROI's for all the heart beats used in the computation. The drawing of the exact boundaries of the ventricle at ED for the ROI is not too crucial as long as other chambers are excluded.

Results

In this section, we present results from 15 patients obtained by applying the method described in the previous section. The digital mask mode subtraction and data analysis were done by using a digital video processor, CARDIAC 1000, manufactured by the American Edwards Laboratories. The CARDIAC 1000 system was interfaced to a Siemens Cardioscope c-arm which is located in the cardiac catheterization laboratory at the University of California-Irvine Medical Center. Some modifications in the Siemens system were made to optimize the imaging chain. The exposure factors for the studies were 75 kVp, 5 mm AL filtration and 8 mA. In 15 patients 30-40 ml Renografin 76 was injected intravenously via a femoral vein by using a 6 French catheter. The injection was done manually at an approximate rate of 10 cc/sec. For all the studies we used a RAO 30° view. Figure 4 shows a subtracted image of the LV for a patient.

Figure 4. Subtracted image of LV-RAO 30°

The ROI were selected as discussed in the previous section and these are shown in Figures 5 a-b.

Figure 5. (a) ED image and ED-ROI, (b) ES image and background ROI

Figure 5 is similar to the illustration in Figure 2. The computation of the LVEF was done using the algorithm described in Figure 3.

The same subtracted images were used in the determination of the LVEF using the standard area-length method.⁷ These results were also compared to the area-length results obtained by cine ventriculograms. The cine and peripheral images using the area-length method had a correlation of $r=0.94$ and the results will be published elsewhere.⁸

Figure 6 shows the comparison of the area-length and video densitometric determination of the LVEF for 15 patients using the same subtracted images obtained by peripheral IV injection.

Figure 6. Comparison of video densitometry and area-length for LVEF

The EF from the two techniques correlated closely ($r=0.96$). The relation between the percentage LFEV determined by both methods is shown in Figure 6 by a solid line and is given by,

$$\text{LVEF (video)} = 1.03 \times \text{LVEF (area)} - 4.25 \quad (5)$$

Summary

This paper has described our initial experience with using computerized fluoroscopy in the determination of left ventricular ejection fraction by digital subtraction video densitometry. The digital video images were obtained using a commercially available video image processor. In 15 patients Renografin 76 was injected intravenously through a femoral vein by hand. The amount of contrast agent used for each patient varied from 30 to 40 cc. Low x-ray tube currents (max 8mA) were used in our studies. The left ventricular ejection fraction was computed using a video densitometric algorithm described in this paper. The area-length method was applied to the same images to compute the LVEF independently. The correlation between the two methods was good ($r=0.96$).

We are in the process of clinically evaluating the system and the method described in this paper with a larger number of patients.

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