Dynamic Process Captured on a Single Image: An Approach to Screening for Abnormal Superior Vena Caval Flow

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A strategy for displaying and archiving dynamic quantitative data from scintigraphic imaging is described and applied to diagnosing obstructed thoracic veins. A prospective series of 25 patients with concurrent radiographic contrast and tracer venograms along with 49 controls showed a 33% sensitivity, comparable to previously published data. The use of first harmonic Fourier analysis enhanced the screening value of the test by identifying all abnormals. Moreover, this format captured the dynamic physiologic data on a single photograph. This technique is readily available to nearly any nuclear imaging laboratory equipped with a gamma camera and a computer.

J Nucl Med 27:838–841, 1986

Widespread computer capabilities in diagnostic nuclear medicine have increased the need to depict and archive dynamic quantitative physiologic imaging data. Several approaches are presently in use, particularly magnetic media that utilize a computer or videotape display. Such techniques lack convenient accessibility and transportability. Moreover, they are unsuitable for inclusion in the patients' medical charts or letters to referrants.

The present report describes a simple mathematic modeling procedure, first harmonic Fourier analysis, that produces a single image that describes the dynamic relationship of physiologic processes. As an illustration of this approach, we have examined radiovenograms in patients at risk for superior vena caval obstruction.

MATERIALS AND METHODS

Clinical

The Radiation Therapy Section of our institution referred 119 patients for prospective analysis between September 1, 1982 and August 30, 1983. Patients were selected for referral on clinical grounds, usually stemming from clinically suspected superior vena caval obstruction (SVCO) or a need for scintigraphic evaluation of neoplastic dissemination. Of these patients, 25 had both thoracic tumors and concurrent radiographic contrast venograms; while 49 had no evidence of thoracic tumor or clinical evidence of an obstructive process involving the thoracic venous system. The latter was designated "controls" for the purposes of this study.

Received Sept. 17, 1984; revision accepted Jan. 22, 1986.

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Technique

Scintigrams of the venous flow were acquired on a large field-of-view Anger camera* through a general all-purpose, parallel hole, collimator. Since a bone scintigram was generally performed in conjunction with the radiovenogram, technetium-99m methylene diphosphonate ([^{99m}Tc]MDP) was the radiotracer of choice. Separate boluses of ~7.5 mCi (277.5 MBq) of [^{99m}Tc]MDP were injected into each antecubital vein. Anterior images of the chest were immediately obtained, at 1 frame/sec for analog photography and 2 frames/sec for digital analysis. An A-squared data processing system† was used to acquire the 64 × 64 digital matrices having a spatial resolution of ~0.4 cm^2.

First harmonic Fourier analysis was then applied to the digitized data. This procedure treats each of the 4,096 (64 × 64) pixels in the summed frame matrix as a separate temporal series of activity data. Each pixel was examined over the duration of the study to construct an activity versus time curve. Fourier analysis was then performed to extract a "best fit" cosine curve, the fundamental. Phase images were constructed in the following manner. The fundamental frequencies were assigned colors that code the angular sequence of cosine terms for each fundamental. The colors were then superimposed upon their corresponding pixels, to create the

"phase image." Thus, the phase image provides a spatial context for specifying temporal information regarding the passage of a tracer bolus. Since fitting a cosine function to the time-activity curves of each pixel distorts the bolus characteristics, a qualitative rather than quantitative interpretive strategy was adopted. The underlying assumption is that a bolus moves at a constant speed through veins that have an equal caliber. Therefore, fluctuations in speed are due to changes in venous diameter. If such changes cannot be anatomically explained, a partial obstruction could be indicated. These fluctuations appear on a phase image as a sequence of pixels whose color changes more abruptly than a corresponding sequence along a comparable venous path.

Thus, scintigraphic information was available in three formats: static–the analog and digital images; dynamic–the digital images displayed in cine mode; and phase–the first harmonic Fourier phase images. Each format was evaluated for (a) frank vascular obstruction or collateral vessel formation and (b) partial vascular narrowing or distortion of the venous channels. These criteria were analyzed with respect to concurrent contrast venograms.

Contrast venographic interpretations were based on frank SVCO, SVCO with collateralization, little or no visualization of the superior vena cava (SVC) with collateralization or marked narrowing of the SVC with collateralization.

Neither the radiographic nor the scintigraphic team was aware of the findings in the complementary procedure.

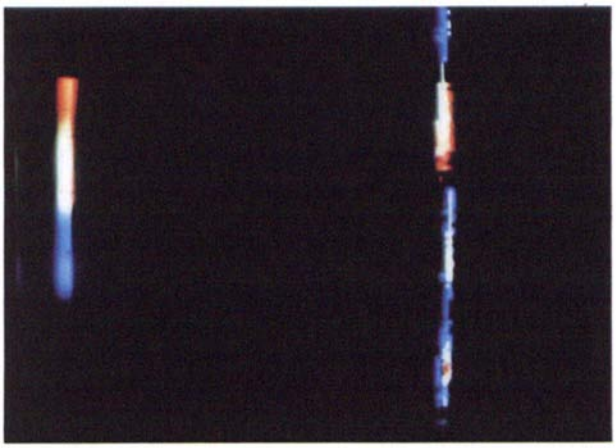

FIGURE 1
Figure contains three parts. On left is color bar showing coding for cosine of angles in Fourier transform. Blue pixels denote areas of early activity; red pixels, late activity. Above right, phase image shows early counts appearing at top. At level of 25% obstruction fashioned into connector between two test tubes, color abruptly turns green. Below obstruction, green gradually merges into red. Below right is "amplitude" image of total counts in each pixel over course of study where blue corresponds to fewest counts and red, most counts. Note thin area of blue, low counts in middle depicting region of obstruction

RESULTS

The approach of relating spatially abrupt changes in frequencies displayed by a phase image to changes in venous caliber was validated using a set of phantoms composed of two test tubes connected end-to-end by a constricting region simulating a 25, 50, and 75% obstruction. Technetium-99m pertechnetate was circulated through the phantom at rates from 4 to 16 cm/sec. The 25% obstruction was demonstrated using the Fourier technique utilized in this study (Fig. 1).

A concurrent contrast venogram was available in one of the 49 control patients; it was normal. The 24 patients with chest tumors included five with adenocarcinoma, five with oat cell, 11 with squamous cell and three with other neoplasms (Table 1). The classic criteria (*1–5*) of frank obstruction or collateralization yielded the highest accuracy (81%). The noninvasive feature of this test supports its use as a screening procedure before contrast venography. In this context, sensitivity becomes very important, since false-positive studies will be excluded in the definitive contrast venographic part of the workup. The addition of temporal information using the cine display substantially improved the sensitivity (33 to 93%). Phase imaging further improved the value of the test as a screening tool by identifying all the cases with abnormal

TABLE 1
Number of Abnormal Scintivenograms by Diagnostic Group and Contrast Venograms Results

Diagnostic group control	Frank obstruction or collateralization 3(49)*		Partial obstruction or narrowing 11(49)		Abrupt phase shifts 12(49)	
	+Venogram	−Venogram	+Venogram	−Venogram	+Venogram	−Venogram
Adenocarcinoma	2(4)	0(1)	4(4)	0(1)	4(4)	0(1)
Oat cell	0(2)	0(3)	2(2)	2(3)	2(2)	3(3)
Squamous cell	2(7)	0(4)	6(7)	4(4)	7(7)	4(4)
Other	1(2)	1(1)	2(2)	1(1)	2(2)	1(1)
All	5(15)	1(9)	14(15)	7(9)	15(15)	8(9)
Sensitivity†	33%		93%		100%	
Specificity‡	93%		69%		66%	
Accuracy§	81%		74%		73%	

* Number in parentheses is total in that group.
† True positives/(true positives + false negatives).
‡ True negatives/(true negatives + false positives).
§ (True positives + true negatives)/number of cases.

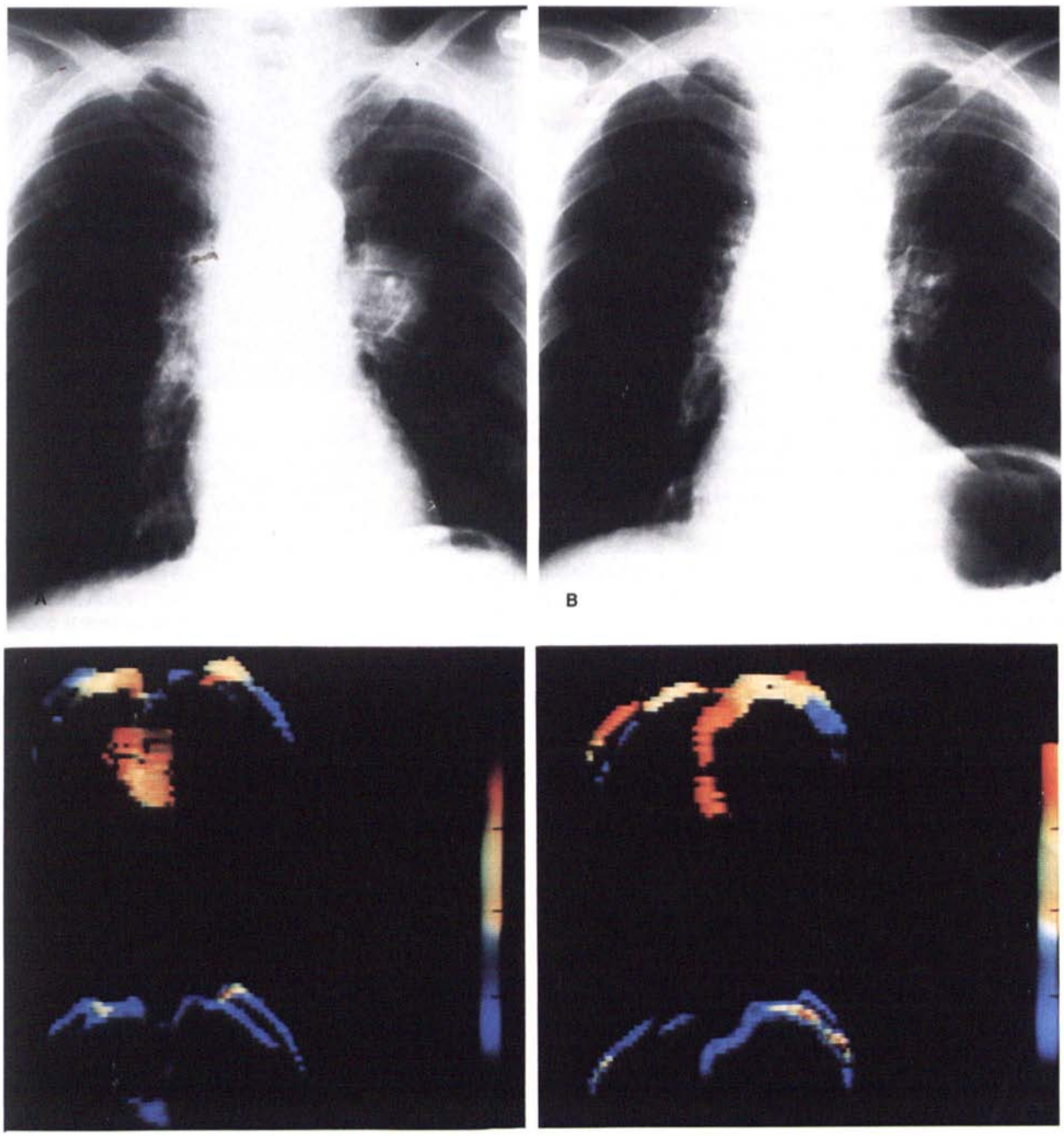

FIGURE 2
Case illustrates patient who had normal radiographic contrast venogram. PA chest radiograph (A) was obtained before radiation therapy; (B) after. Note that phase (above and amplitude (below) images obtained prior to therapy (C) differ markedly from corresponding images (D) obtained after therapy. In this study, simultaneous left and right injections were performed. In image (C), note that transition in left subclavian vein is extreme, pixels progress from blue to red in very short distance. Compare this appearance to "D" where transition occurs over almost entire left subclavian vein. Right subclavian vein showed narrowing in both (C) and (D). Patient developed clinical evidence of superior vena caval obstruction and died shortly thereafter

venograms. The phase image offers the further advantage of yielding a single, easily archived image rather than requiring that a cine display system be available whenever one reviews the test results.

The reliability of contrast venography as the diagnostic standard may not be absolute. Two cases (Fig. 2) were normal by contrast rates from 4 to 16 cm/sec. An obstruction as small as 25% was demonstrated using the Fourier technique utilized in this study (Fig. 1).

The establishment of contrast venography as a diagnostic standard has not been accomplished. Figure 2 illustrates one of the cases that was considered normal by contrast venog-

raphy, but abnormal by tracer techniques. Although considered false positives for the purpose of statistical analysis, the test reverted to normal when repeated after radiation therapy.

DISCUSSION

Using conventional criteria, Kehr (6) identified four of ten (40%) cases of SVCO. These data were supported by our identification of five of 15 (33%) cases. Improved sensitivity, so essential in a screening maneuver, was gained by emphasizing temporal information through cine display or phase imaging.

Phase imaging is not a quantitatively perfect technique for this application. Since first harmonic Fourier analysis generates a cosine function, a perfect fit to the noncyclical, irregular characteristics of the bolus through a point of the frame matrix will not be achieved. The difference compromises the absolute quantitative accuracy of data, but does not invalidate the relative temporal information. It is this relative temporal information, encoded in the phase image, that conveniently portrays the relative speed of bolus transit and, hence, the likelihood of venous obstruction.

The software to create the phase image is readily available on many nuclear medicine computer systems and requires only minimal operator intervention. The software does not rely upon subjective judgments and thus produces an image free of operator bias. The image is easily photographed, obviating special instrumentation to review and permitting copies for archiving in the patients' chart. The phase image technique could be applied to any nuclear medicine procedure where the primary information sought is temporal rather than spatial. Other curve modeling techniques could, of course, be developed to achieve this purpose. Such an effort might yield significant quantitative improvements if the curve fitting were more faithful than this technique, but dissemination would still be a problem. Fourier analysis can be adapted to the "turnkey" software available in many nuclear medicine laboratories.

FOOTNOTES

* Technicare, Solon, OH (Technicare Sigma 410).
† Medical Data Systems.

ACKNOWLEDGMENTS

The authors thank Luta Roberts, MD for independently interpreting the chest radiographs and Eugene P. Frenkel, MD for reviewing the manuscript. The authors also thank Christine Lieurance for typing the manuscript and Sharon Matthiesen for assembling the phase images.

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