ECG-Synchronized DSA Exposure Control: Improved Cervicothoracic Image Quality

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An electrocardiogram (ECG)-synchronized x-ray exposure sequence was used to acquire digital subtraction angiographic (DSA) images during 13 arterial injection studies of the aortic arch or carotid bifurcations. These "gated" images were compared with matched "ungated" DSA images acquired using the same technical factors, contrast material volume, and patient positioning. Subjective assessments by five experienced observers of edge definition, vessel conspicuity, and overall diagnostic quality showed overall preference for one of the two acquisition methods in 69% of cases studied. Of these, the ECG-synchronized exposure series were rated superior in 76%. Linear intensity gradients across vessel margins generally showed improved or unchanged edge definition in the gated subtraction images as compared with their ungated pairs. These results, as well as the relatively simple and inexpensive modifications required, suggest that routine use of ECG exposure control can facilitate improved arterial DSA evaluations of suspected cervicothoracic vascular disease.

Although the appearance of digital subtraction angiography (DSA) equipment on the imaging scene several years ago was heralded with great enthusiasm [1-5], some of that initial excitement has been tempered with clinical experience. Early criticism focused on the inherently poor spatial resolution of first-generation DSA units as compared with direct film-screen radiography. Recent technologic advances such as improved image intensifier design, low-noise video cameras, expanded digital matrices, and more powerful computers have dramatically improved spatial detail and account, in part, for increasing displacement of conventional film-screen technique. The critical attention of users now has shifted to concerns of vessel conspicuity, edge definition, and reduction of motion artifact.

One approach has been the use of an assortment of postprocessing computer algorithms including remasking, reregistration, smoothing, edge enhancement, and histogram equalization. A complementary approach designed to reduce undesired motion effects is modification of the image acquisition such that image degradation secondary to cardiac motion is minimized. We undertook to evaluate the utility of electrocardiogram (ECG) gating of image acquisition. We expected that ECG gating would improve delineation of large central arteries most affected by pulsatile cardiac activity. Since the adverse effects of misregistration are most apparent at margins of inherently high contrast interface and most difficult to control in grossly pulsatile vessels, we confined our consideration to the aortic arch and carotid bifurcations.

Subjects and Methods

Equipment

The DSA unit was a prototype system (Picker International/ADAC Inc.). Images using a 0.6-mm nominal-focal-spot x-ray tube were generated at rates of up to 1.8/sec. The voltage signal output of a standard cardiac monitor, interfaced with the computer-controlled x-ray
Clinical Subjects/Technique

In 10 subjects referred for evaluation of suspected extracranial vascular disease, 26 arterial injection DSA "runs" were performed. The runs were paired, half being gated and half ungated. The radiographic projection was the same in each pair. Subjects were 44–76 years of age. Vascular access was by standard Seldinger puncture of the common femoral artery. Conray 60 (28 mg I/ml) diluted with saline to a 25% solution (12 mg I/ml) was used for both aortic arch and carotid studies. Five paired aortic arch studies were performed in five patients through a 5 French polyurethane pigtail catheter using an injection volume of 40 ml at a rate of 20 ml/sec. Eight paired carotid studies were obtained using a 7 French polyurethane catheter tapered to a 5 French distal limb. Injection volume was 10 ml at a rate of 6 ml/sec. The ungated (unsynchronized) exposure series at a fixed rate of 1.8/sec was followed by a repeat injection with ECG-synchronized exposures at rates varying from 0.8 to 1.8/sec, depending on the patient's heart rate. A preliminary 15-cycle computer analysis of the ECG signal is required for determination of the average R-R interval. X-ray exposures were triggered at 80% of the R-R interval (fig. 1). X-rays were thus triggered in late diastole, the period of least cardiac motion. Post-processing reregistration of subtraction images was performed on several acquisition sequences but was limited to compensation of artifact due to inadvertent patient motion occurring between the mask and contrast image.

TABLE 1: Acquisition Method of Preferred Image in Cumulative Evaluations (n = 65) of Five Observers

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Preference Indicated</th>
<th>Ungated Preferred</th>
<th>Gated Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall diagnostic quality</td>
<td>45 (69)</td>
<td>11 (24)</td>
<td>34 (76)</td>
</tr>
<tr>
<td>Edge definition</td>
<td>35 (54)</td>
<td>9 (26)</td>
<td>26 (74)</td>
</tr>
<tr>
<td>Vessel conspicuousness</td>
<td>34 (52)</td>
<td>9 (26)</td>
<td>25 (74)</td>
</tr>
</tbody>
</table>

Note.—Thirteen paired (ungated/gated) DSA studies were evaluated independently by five experienced observers.

Analytical Measurements

Edge definition was also analyzed objectively by means of a computer-generated graphic display of pixel values across a portion of image indicated by a line designated at the video display terminal. Edge definition was determined by the relative exposure (slope) gradient, displayed graphically. This method permitted direct objective comparison of the two acquisition techniques (fig. 2).

Results

The cumulative observer preferences for gated or ungated images are presented in table 1. When overall image quality was assessed, a preference was indicated in 45 (69%) of 65 comparisons, the gated image being preferred in 76% of these. When edge definition and vessel conspicuousness were judged, a preference was stated in slightly over 50% of comparisons, the gated image being preferred in 74% of these.

An example of motion artifact reduction achieved by ECG gating in a carotid study is illustrated in figure 3. The ungated subtraction image shows blurring of a calcified plaque, due to

generator, permitted ECG-synchronized exposures in the "gated" series, triggered at a fixed time in the patient's R-R interval. The image intensifier was tritomodal (22.9 cm, 15.2 cm, and 11.4 cm diam). The exposure time for each image was 33 msec (one video frame) although the total exposure time per x-ray pulse was 133 msec (three video frames were used for system stabilization). Exposure factors were 65–80 kVp, and 100–400 mA. Subtraction images were recorded with a multifORMAT camera (Matrix Instruments, Inc.).

Subjective Assessments

Five experienced observers independently examined hard-copy images without knowledge of which images in a pair were gated or ungated. Each of the evaluators was requested to indicate a preference or lack of preference for one of the two acquisition methods for each of the 13 paired examinations. Evaluation criteria included comparisons of arterial edge definition, vessel conspicuousness, and overall diagnostic quality.

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misregistration from cardiovascular motion.

In three instances in which ungated DSA images were preferred more often than gated images, the gated study was most often degraded by artifact related to nonvascular motion such as swallowing, breathing, or rotational movement occurring between the mask and contrast image. Occasionally there was preference for the slightly misregistered (due to pulsatile motion) ungated subtraction image in which a calcific plaque could be visualized which was not appreciated on the gated image because of its better registration.

The computer-generated display of linear pixel-value gradients across vessel margins generally provided data showing improved or unchanged edge definition in the gated DSA series as compared with the ungated pair (fig. 2). Exceptions mirrored the corresponding subjective evaluations and again were usually attributable to gross nonvascular motion artifact.

**Discussion**

The theoretical advantage of ECG exposure control for improved registration of pulsatile vascular structures was confirmed in practice by the overall preference of the observers for ECG-gated images. However, those cases in which ECG gating did not result in significant increase in image quality deserve attention. Several factors may account for a lack of perceived improvement in image quality. Occasionally, an ungated subtraction image may be perfectly registered with respect to pulsatile vessel motion due to fortuitous timing of the mask and raw image exposures; that is, they may happen to occur in the same phase of the cardiac cycle. More rapid framing rates would increase the frequency of such an event but at the cost of extra radiation exposure. Also, effective use of postprocessing algorithms such as remasking...
or reregistration may occasionally salvage an otherwise un-
acceptable ungated subtraction image. However, it is not
unusual to find that ensemble pixel-shifting, used to com-
pen­
sate for plaque motion, may artifically introduce misregis-
tration at adjacent nonvascular high-contrast interfaces, such
as surgical spine, larynx, and hyoid bone, that did not par-
icipate in the pulsatile motion. Such a result is often counter-
productive and may in fact obscure vascular detail in other
regions of an image (fig. 3). The availability of region-of-
interest reregistration in the near future may help avoid this
problem.

With respect to carotid bifurcation imaging, the frequent
absence of calcium within plaques results in homogeneous
density of the unopacified vessels and bordering tissues
before the arrival of contrast material. Thus, the deleterious
effects of pulsatile motion often escape being encoded as
misregistration on a subtraction image. In the chest, however,
there is an intrinsic and constant density differential at the
interface of the aorta and adjacent aerated lung on masked
images. This interface undergoes oscillatory motion related
to both cardiac activity and respiration. Although breathing
can be interrupted temporarily with patient cooperation, the
effects of pulsatile vessel motion which sometimes detract
from pulsed DSA image quality can be minimized by the
gating technique used herein. The anatomic juxtaposition of
aerated lung against the mediastinal structures accounts for
the more consistently visible improvements in subtraction
image quality when ECG gating is used for arch studies. One
might extrapolate that similar results may be achieved with
pulmonary arteriography; encouraging results have been
achieved in a recent clinical trial [6].

The observation that extraneous motion artifact contributed
to suboptimal subtraction images in three of the ECG-syn-
chronized acquisitions serves to emphasize that the gating
method is not immune to the misregistration problems that
often compromise routine DSA studies. However, the sug-
gestion that misregistration of calcific plaques on ungated
subtraction images may be desirable or advantageous for
diagnostic purposes is untenable. Such lesions are clearly
visible on both the raw mask and the contrast-laden images
(fig. 3). In fact, our convention is to photograph hard copies
of selected raw images both for this reason as well as to
benefit the surgeon in terms of orientation and treatment
planning.

Technical modifications may be desirable for gated DSA
studies in patients with slow heart rates. For instance, at a
cardiac rate of 50 beats/min, gated exposures occur at 1.2
sec intervals. Such a slow imaging rate may be insufficiently
rapid to ensure capture of maximum contrast-material density
during bolus transit through the vessel lumen. This may
translate to diminished edge definition as compared with a
fortuitously timed and more rapid ungated acquisition. A more
prolonged injection of contrast material may be used as a
compensatory technique to obtain adequate gated images in
such patients. Alternatively—and preferably—a gating algo-
rithm that incorporates two or more exposures per cardiac
cycle might be devised.

Although the improvement in DSA image quality afforded
by ECG-synchronized exposure was often minor in this series,
we believe gated acquisition is a worthwhile technical adjunct.
The procedure entails no additional time, uses an ECG mon-
itor which is typically in use at most installations, and requires
only relatively minor software modifications. For cervicotho-
racic studies, this method offers improved visualization of
vessel margins and enables more accurate diagnosis of ath-
eromatous stenoses, particularly when accompanied by cal-
cification.

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