

Regulations and Recommendations for Normal and High Level Control Fluoroscopy

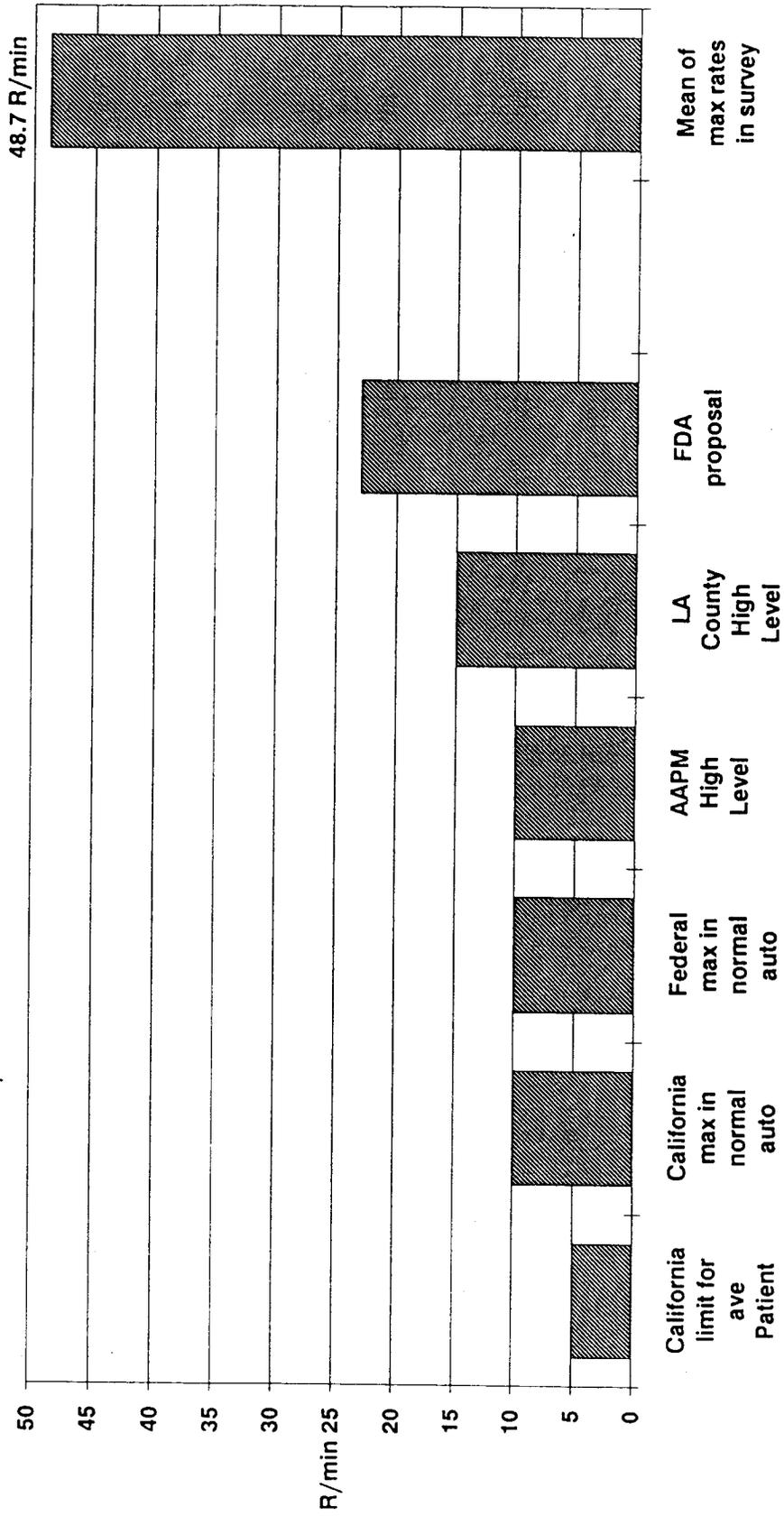


Figure 1

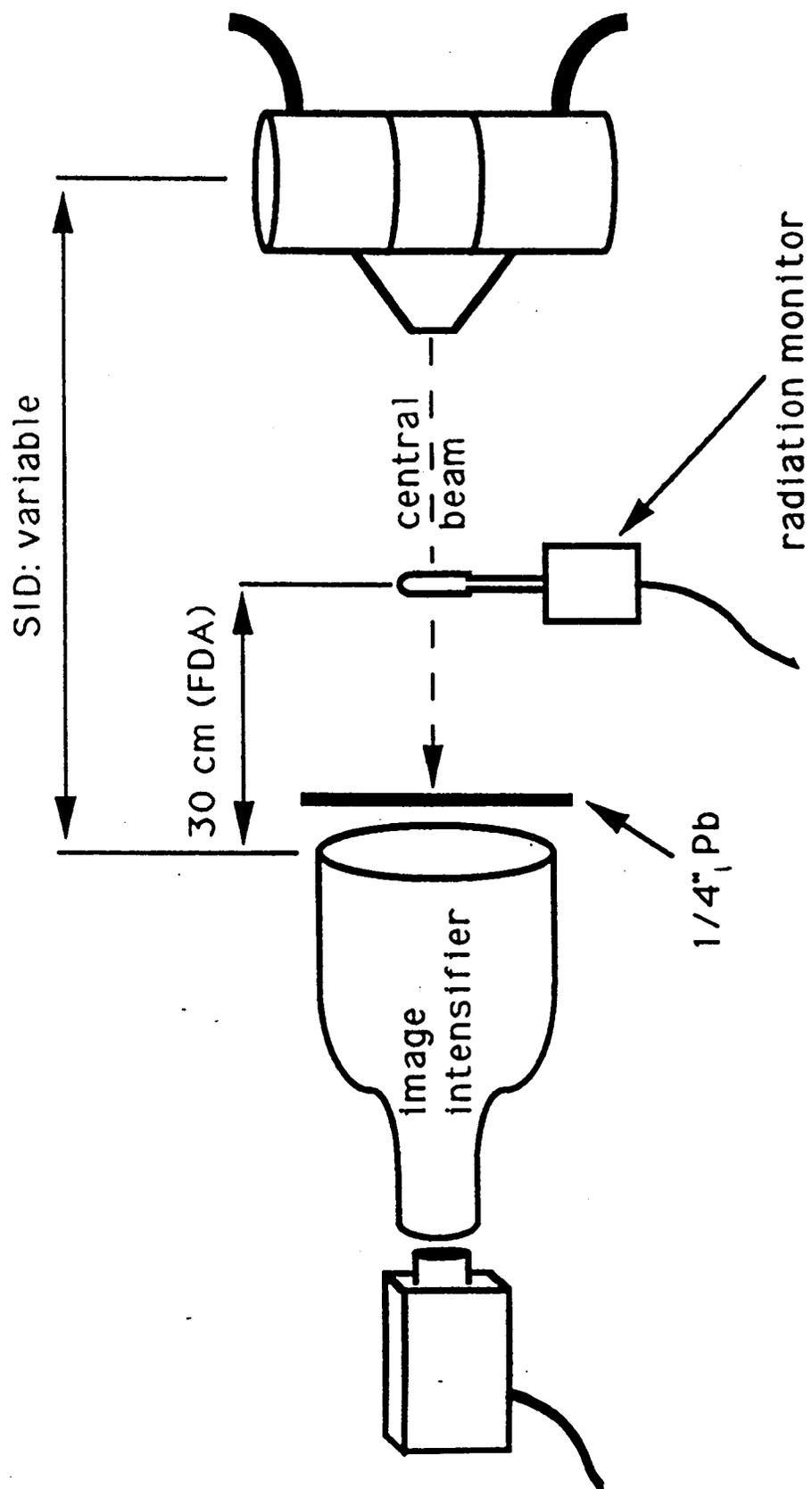


Figure 2

COMPARISON OF MAXIMUM HLC FLUOROSCOPY EXPOSURE RATES FOR
INVESTIGATED MACHINES

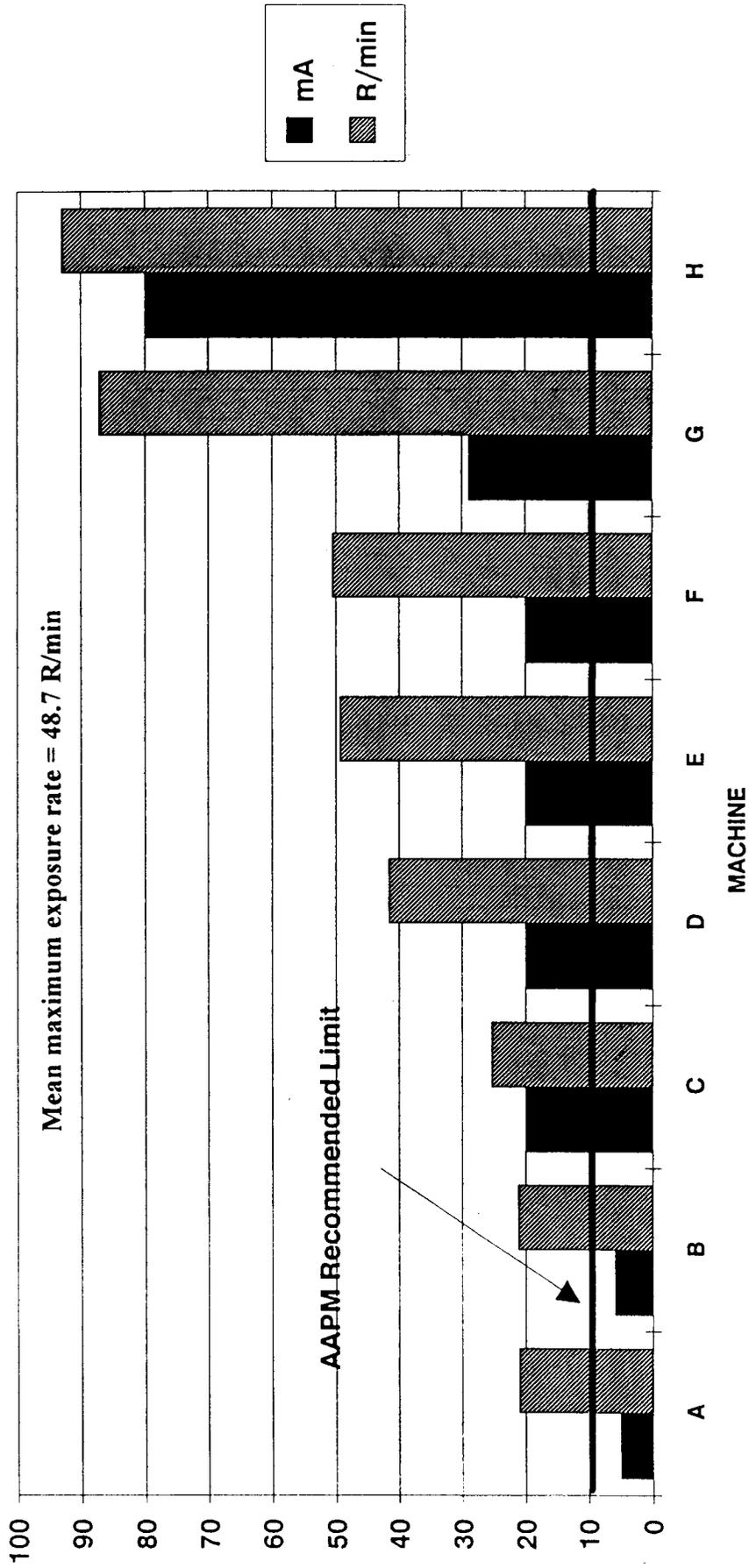


Figure 3

COMPARISON OF AVERAGE EXPOSURE RATES FOR STANDARD PHANTOM

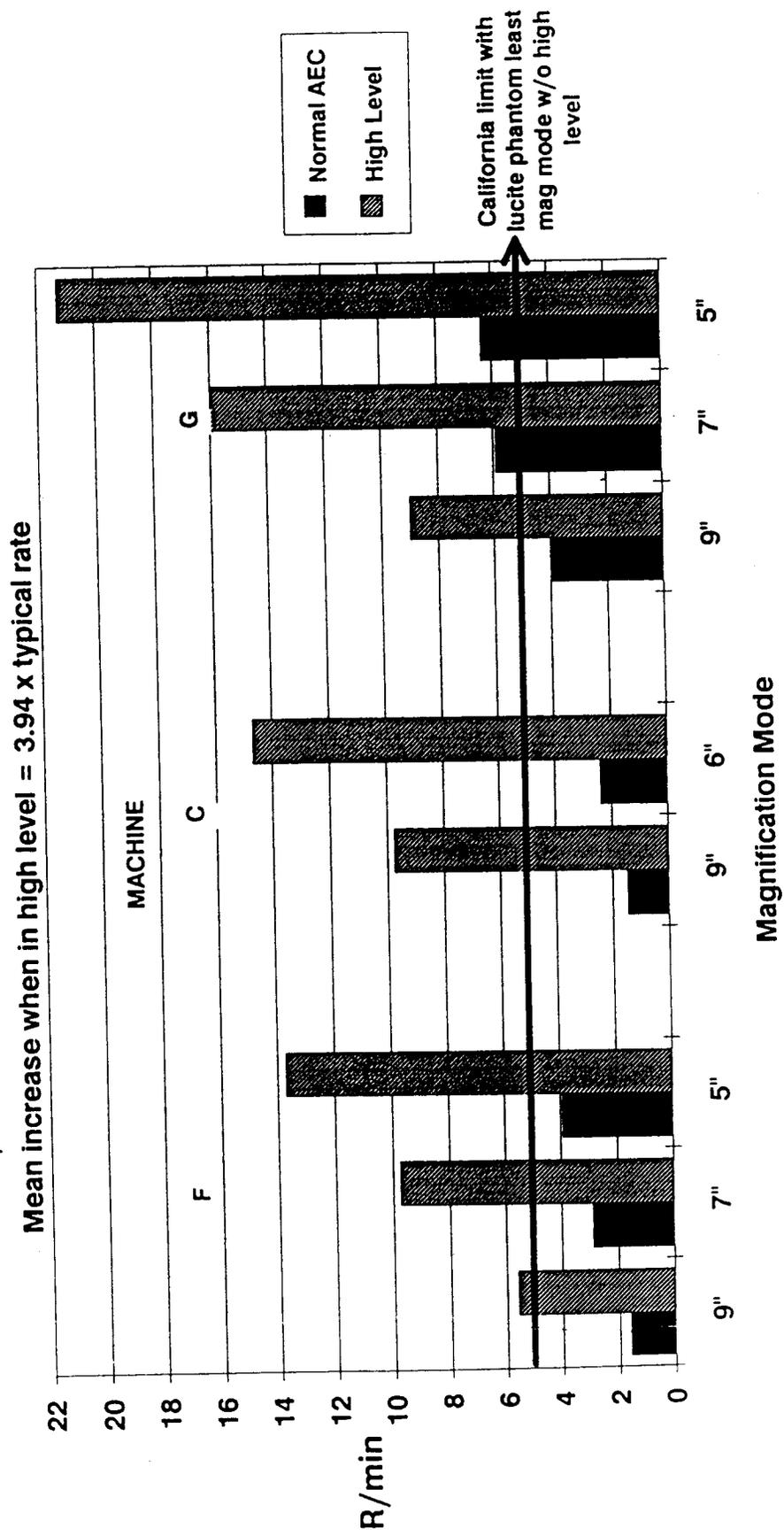


Figure 4

"HIGH CONTRAST" LINE PAIRS SEEN WITH BOTH EXPOSURE MODES

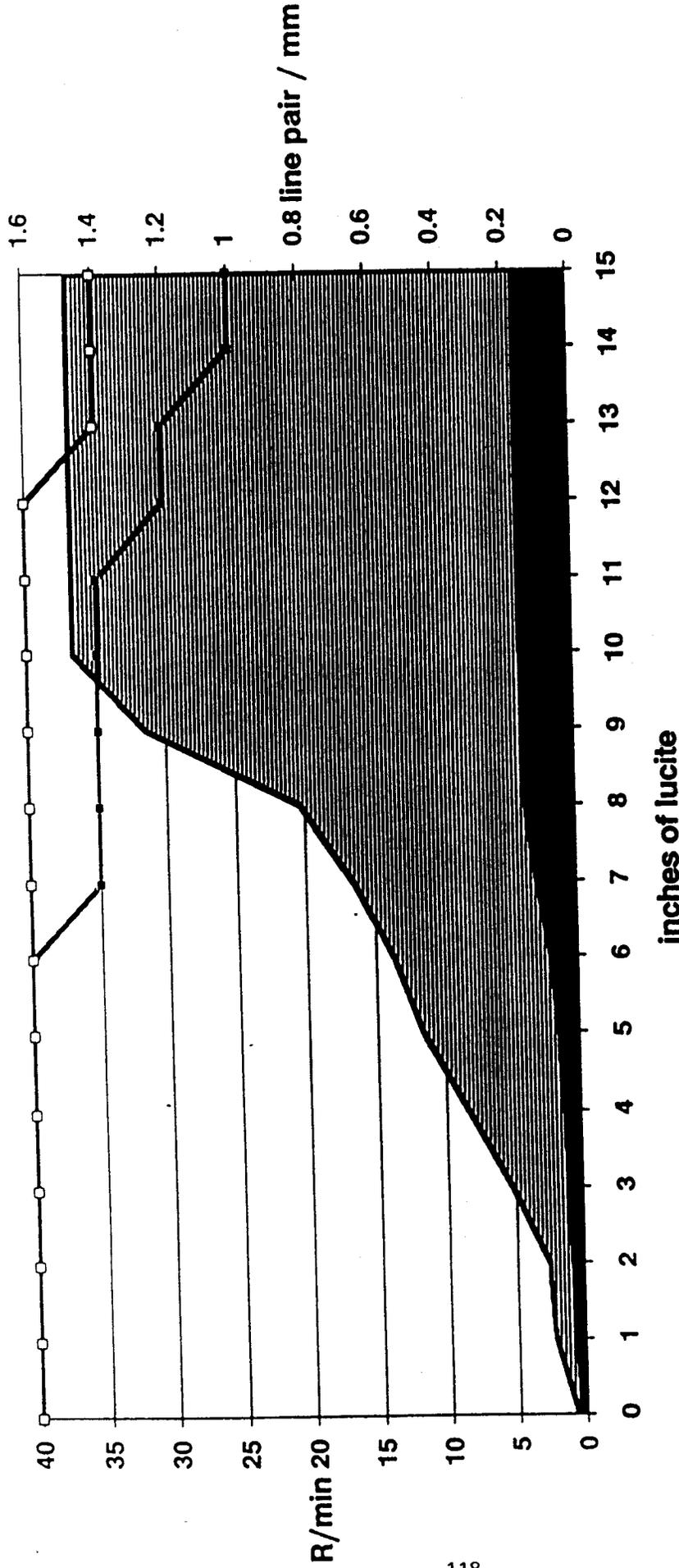
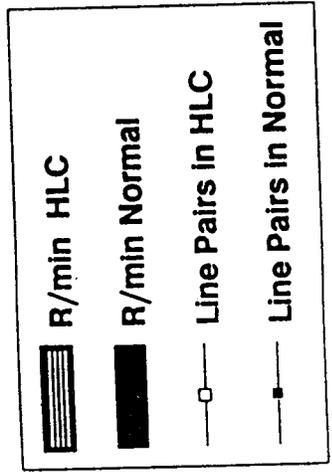


Figure 5

Visualized line pairs on the right axis and the radiation exposure on the left axis. Each plot is presented as a function of increasing lucite thickness



LOW CONTRAST VESSELS VISUALIZED RELATIVE TO EXPOSURE RATE

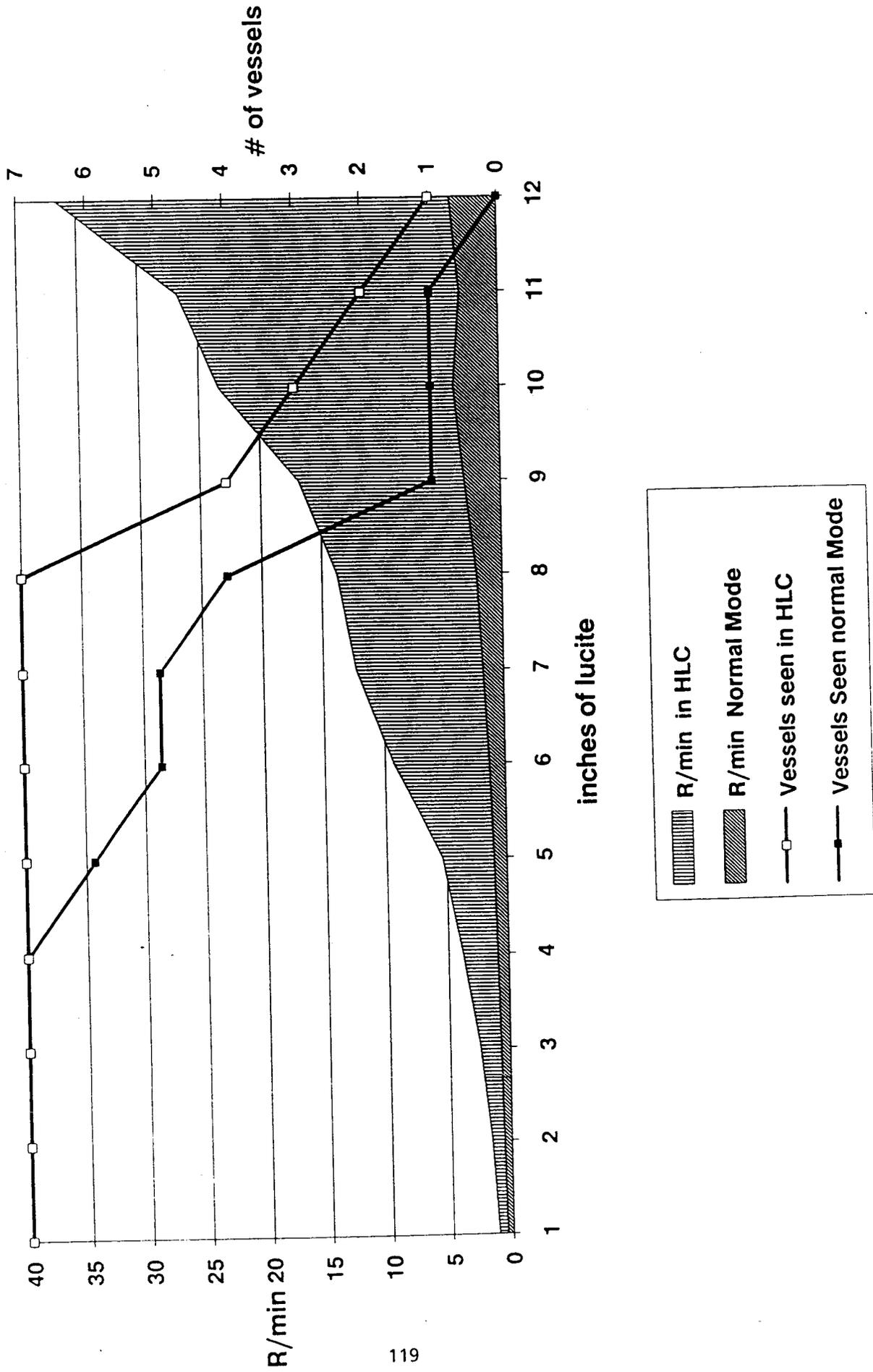


Figure 6

STEP WEDGE + 12 INCHES LUCITE (HLC exposure 8.14 times greater than normal mode)

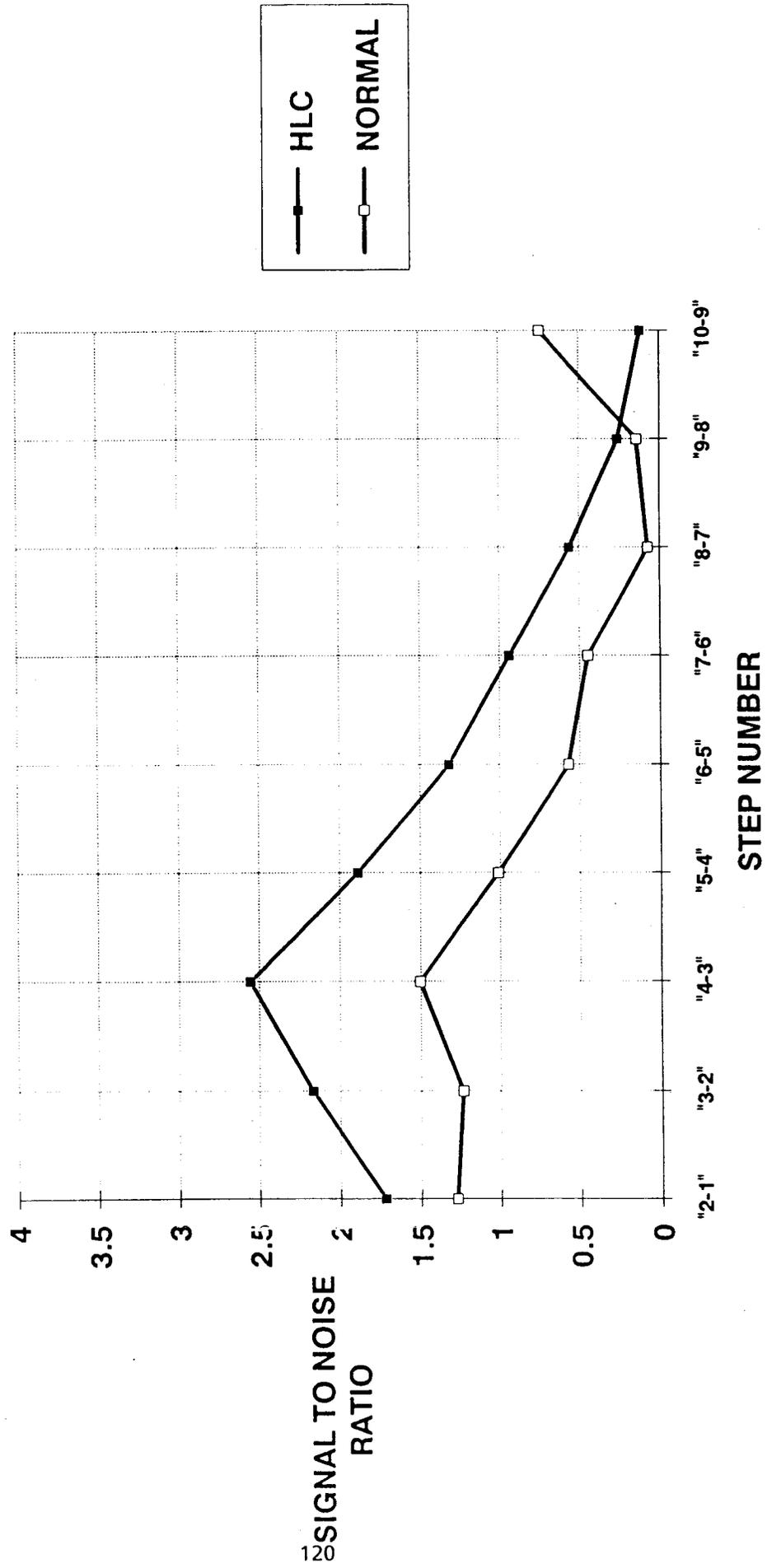


Figure 7

TABLE 1

Manufacturer Methods for Activating High Level Control

- OEC Diasonics DXR-10CP Mobile C-Arm ... *Two Position Footswitch*
- OEC Diasonics 9000 Mobile C-Arm ... *Boost Button & Two Position Footswitch*
- Philips Poly C/Lateral Arc ... *Constant Key, Button and Footswitch, Requires 2 People*
- Siemens Cardoskop U ... *Footswitch*
- Toshiba Angiorex ... *Separate Footpedal*

Assessment of Fluoroscopic System Performance

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Assessing Performance in Fluoroscopy

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Abstract

The assessment of fluoroscopy system performance involves the measurement of dose and image quality. Although the assessment of performance for conventional radiographic examinations is well understood, performing such evaluations for fluoroscopic equipment is much more difficult. One of the reasons is that fluoroscopy is not associated with a unique examination consisting of a single specific set of imaging tasks and an associated dose. What is traditionally referred to as a single examination actually consists of a set of many different images. These may be imaged dynamically or individually as static images. Assessing performance, whether it is dose or image quality, must address the differences between dynamic and static imaging.

Results from the 1991 Nationwide Evaluation of X-ray Trends (NEXT) fluoroscopy survey show a wide range of imaging performance for both fluoroscopy and spot imaging. The design of the fluoroscopy phantom and imaging test object will be presented. How dose and image quality were evaluated, as well as a discussion of the results of this and other related studies will be presented.

Assessing Dose from Fluoroscopy

Assessing patient dose in fluoroscopy is difficult because the examination is dynamic in nature. What is often described as a single examination actually consists of many separate x-ray fields of different dimensions, positioned on different anatomy, and employing different x-ray energies and intensities. Differences in attenuation result from variations in anatomy and the presence of contrast agents. When barium sulfate is used as a contrast agent, attenuation effects are very significant. The dose an individual may receive is not only a function of the equipment but also very dependent on the length of the examination and the actual number of radiographic films made during the clinical examination (1).

Early efforts at assessing radiation risk from fluoroscopy involved determination of the exposure area product and the dose to the gonads. The 1964 and 1970 population exposure studies (2,3), reported the surface exposure integral, in Roentgens (R) x cm² at skin entrance for fluoroscopy, and the dose to the gonads as the genetically significant dose (GSD), which incorporated additional factors which affected risk, such as age and sex. The mean fluoroscopy exposure time for the upper GI fluoroscopic examination was reported as 180 seconds in 1970 with a standard error of 8.2 seconds (4). Other fluoroscopy studies have either measured the integral radiation exposure associated with an entire examination or calculated the radiation dose to a specific organ or organs (5,6,7,8,9,10,11,12,13). Taylor (10) reported skin exposures from fluoroscopy ranging from 1.6 to 90 R for barium meals. Servomaa identified the reasons for the lack of organ doses from fluoroscopy: "During the fluoroscopic examination many parameters (kV, mA, field size and size, number of exposures, fluoroscopic time) may vary, making it impossible to record all the data needed for organ dose calculation" (14).

The 1964 and 1970 x-ray exposure studies originally estimated the genetically significant dose to the U.S. population from all x-ray examinations. The final revised estimate included the doses from the fluoroscopic spot film exposures, but excluded contributions from the fluoroscopy scan component of the examination because analysis of the dose from the fluoroscopy scan proved difficult (15). Shleien, Tucker, and Johnson (16) estimated the mean active bone marrow dose per upper GI examination from the fluoroscopy scans and spot films to be 195 and 241 mrad for the 1964 and 1970 x-ray studies respectively. Eighty-nine percent of the 1964 dose, 174 mrad, and 69% of the 1970 dose, 166 mrad, was from the fluoroscopy scan portion of the examination.

Tissue Doses

In 1976 the Bureau of Radiological Health (BRH), now the Center for Devices and Radiological Health (CDRH) of the Food and Drug Administration (FDA), developed the methodology for estimating organ (tissue) doses from diagnostic x-ray sources (17). This method is based on the mathematical reference model originally developed by the Medical Internal Radiation Dosimetry Committee, MIRD (18), for the estimation of doses from nuclear medicine. In the early 1980's West Germany's Gesellschaft fur Strahlen-und Umweltforschung (GSF) (19,20), and then the British National Radiological Protection Board (21) further developed modified versions of the original MIRD phantom with which to calculate organ doses in diagnostic radiology. The development of these models continues today with the introduction of realistic adult human phantoms, phantoms reconstructed from clinical CT images (22,23,24).

Although integral exposures are useful for conventional radiographic examinations, primarily because tissue doses can be readily derived from them, integral exposures are not always representative of risk, especially for a dynamic examination such as fluoroscopy. Most recently a handbook for calculating tissue doses for the upper GI examination has been published (25).

Entrance Exposure Rate and Image Intensifier Exposure Rate

Another traditional measure of exposure or dose is the entrance exposure rate (EER) to the patient, or the image intensifier exposure rate (IIER). The former is a measure of patient exposure, the latter a measure of system performance.

The EER is a measure of radiation to the patient at the entrance skin plane. It incorporates the effect of the IIER, the grid, source-skin-image receptor geometries, the clinical beam quality, and patient attenuation. The EER is a direct measure of relative patient risk.

The inverse of the IIER, however, is a pure measure of the fluoroscopy system's speed, analogous to the speed of a screen-film system. Knowledge of it, along with the effect of any grid present, source-skin-image receptor geometries, clinical beam quality, and patient attenuation enables the derivation of the EER.

The IIER and EER are directly related and are described by the following formula:

$$\text{IIER} = D \times G \times u \times k \times \text{EER}$$

Where EER is the entrance exposure rate to the patient's skin,

D is the inverse square correction for the effect of distance from the tabletop or skin entrance plane to the II plane,

G is the factor accounting for the effect of the grid,

u is the attenuation of the patient or phantom for a specified beam quality,

and k is a unit conversion constant relating the EER to the IIER. When expressed in R/m (EER) and microR/second (IIER), this constant is 16,666.

Although related, the EER is a direct measure of risk, while the IIER is an independent measure of fluoroscopy performance. A more practical consideration is the fact that the measurement of the EER using a standard phantom is a non-invasive test measure, easily adopted as a quality control test. The measurement of the

IIER usually involves removal of a grid and the use of a low dose rate dosimeter. It should be performed by a qualified individual.

Divine (26) reported that the measured IIER ranged from 16 to 160 microR/second, with a mean value of 59 microR/second for a survey of 21 fluoroscopy systems in the Washington D.C., metropolitan area. He also evaluated low contrast detectability, and reported that most of the systems exhibited values in the range of 3.0% to 4.0%. A more recent survey by the American Association of Physicists in Medicine (AAPM) (27) of 62 fluoroscopy systems reports a median IIER of 64 microR/second, with values ranging from 20 microR/second to 1043 microR/second. Both of these studies measured the IIER using the 23 cm image intensifier (II) diameter.

It is interesting to note that when using the Leeds test objects (28), a set of threshold contrast-detail diameter test objects originally developed at the University of Leeds and introduced in the early 1960's, typical reported threshold contrast values are in the 1% to 3% range, using a standard image intensifier entrance air kerma rate of 0.26 microGy/s, which corresponds to an IIER of 30 microR/s.

Assessing Image Quality In Fluoroscopy

Although the assessment of dose and its relationship to risk, both conceptually and realistically, is understood much better today than several decades ago, such is not the case for the assessment of image quality. We understand how to calculate dose, we are capable of doing so for most diagnostic examinations, and we also know how to assess risk associated with specific tissue doses.

Although we conceptually understand image quality and the associated physical parameters such as spatial resolution, contrast, and noise, we have yet to demonstrate conclusively how these relate to clinical diagnostic accuracy. Doubling the dose to a patient is usually accepted as doubling the risk. Improving the spatial resolution by a factor of 2, however, or increasing the contrast by 25% or reducing the noise by a factor of 2, although improvements in the physical measures associated with image quality, cannot predict the improvement in diagnostic accuracy, even for the best understood diagnostic examinations.

When one considers that fluoroscopy adds a temporal dimension to image quality, one realizes why many individuals may not fundamentally understand the difference between fluoroscopy images, observed dynamically, and "static" images. The image quality, as measured using traditional measures, and associated doses, vary significantly, yet it is obvious that confusion may occur when we speak of dose per frame, dose per second, or dose per video frame.

Do we assess the image quality dynamically, or frame by frame?
Is the imaging task primarily dynamic in nature like the
collective images necessary to track the flow of barium sulfate
through the GI tract, or dynamic and static in nature like the
set of images necessary to view iodinated coronary arteries?

It is obvious that each examination has unique imaging tasks,
equipment requirements, and dose considerations. Indeed, we have
much to understand and agree upon when we discuss fluoroscopy.

Past History

A brief review of the literature shows that many of the problems
we face today have been identified previously and addressed. In
1984 Wesenberg and Amundson (29) demonstrated that they could
reduce the fluoroscopic dose by 20 - 50 times if a comprehensive
effort were made. This included a high quality image
intensifier, custom designed variable-dose rheostat, filtration,
and digital noise reduction. Gray and Swee (30) suggested
that grids could be eliminated with little or no degradation in
contrast and diagnostic image quality. Taylor (10) reported that
"high exposures can readily be reduced without any decrease in
diagnostic acceptability of the images."

The 1991 NEXT Fluoroscopy Survey

In the United States, the Conference of Radiation Control Program
Directors (CRCPD), the umbrella organization for state and local
radiation control agencies, along with the federal government's
Food and Drug Administration, conducts the Nationwide Evaluation
of X-ray Trends (NEXT) survey program. The examination selected
for the 1991 survey was the upper gastrointestinal fluoroscopy
examination. This examination was selected because it is the
most frequently conducted fluoroscopic procedure in the United
States. Forty-two percent of all fluoroscopic examinations
conducted in the United States in 1980, the most recent year for
which estimates were available, were of the upper
gastrointestinal (GI) tract (31). This was the first time a
fluoroscopy examination was selected as an examination for the
NEXT survey program.

For the NEXT survey it became obvious that a comprehensive
assessment of patient exposures associated with a dynamic
examination such as the upper gastrointestinal examination would
be extremely difficult to perform as a field survey procedure.
Consequently, the objectives of the 1991 fluoroscopy survey were
limited to the measurement of fluoroscopy EER, and entrance skin
exposure (ESE) measurements associated with the abdominal
portion of the examination. Image quality was evaluated using an
image quality test object.

Fluoroscopy Phantom

A phantom for the measurement of fluoroscopy ESE and EER (Figure 1) was developed. This phantom was derived from the lumbo-sacral spine phantom originally developed for the radiographic examination used in the 1987 and 1989 NEXT surveys (32). The phantom consists of 19.3 cm of acrylic and 4.6 mm aluminum. Technical modifications in the phantom were made because of differences between radiographic and fluoroscopic examinations.

The fluoroscopy phantom is smaller, and consequently lighter, than the LucAl lumbo-sacral spine phantom, primarily because fluoroscopy fields are smaller than conventional radiographic fields. This fact was also appealing to the field surveyor who would carry the equipment from one installation to another.

The fluoroscopy phantom is also uniform in thickness, lacking the separate "spine" associated with the radiographic lumbo-sacral spine phantom. The presence of the "spine" caused difficulty in precise positioning of the phantom within the small fluoroscopy field normally used. The inability to precisely reposition the phantom resulted in poor reproducibility of air kerma measurements, primarily because fluoroscopy systems employ automatic brightness control (ABC) circuitry to maintain constant brightness of the fluoroscopic image. To eliminate this problem the phantom was redesigned as a uniform phantom.

The fluoroscopy phantom's design also enabled exposure measurements at the tabletop position, along with the simulation of barium attenuation by using a copper filter.

In addition to exposure measurements imaging performance was assessed by means of an image quality test object, developed specifically for the fluoroscopy survey. The test object (Figure 2) employs low contrast test objects and wire mesh for the assessment of spatial resolution. The test object was evaluated with the television monitor during the fluoroscopic mode, and with medical x-ray film during the radiographic spot film or photospot mode of operation.

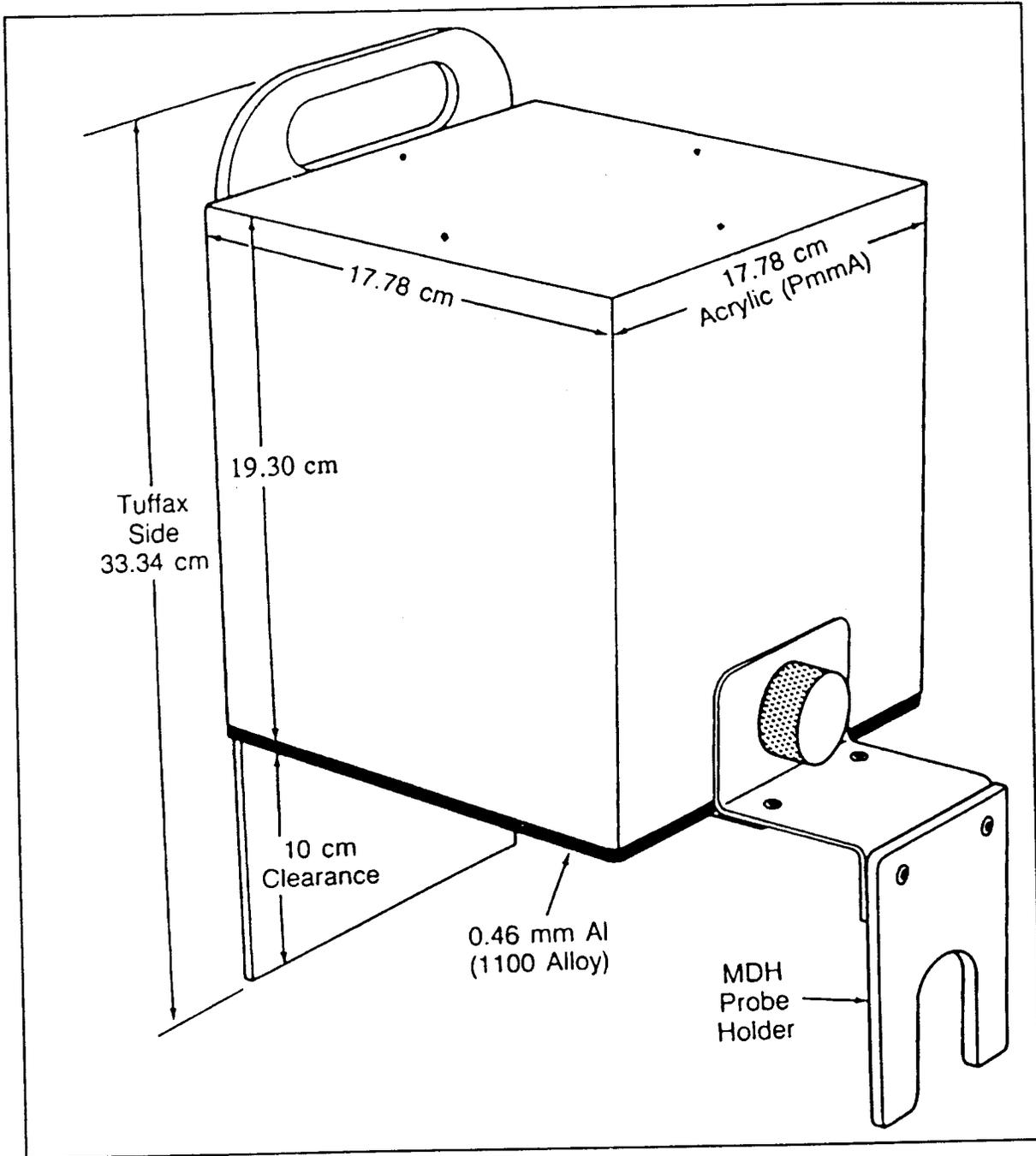


Figure 1 Fluoroscopy Phantom

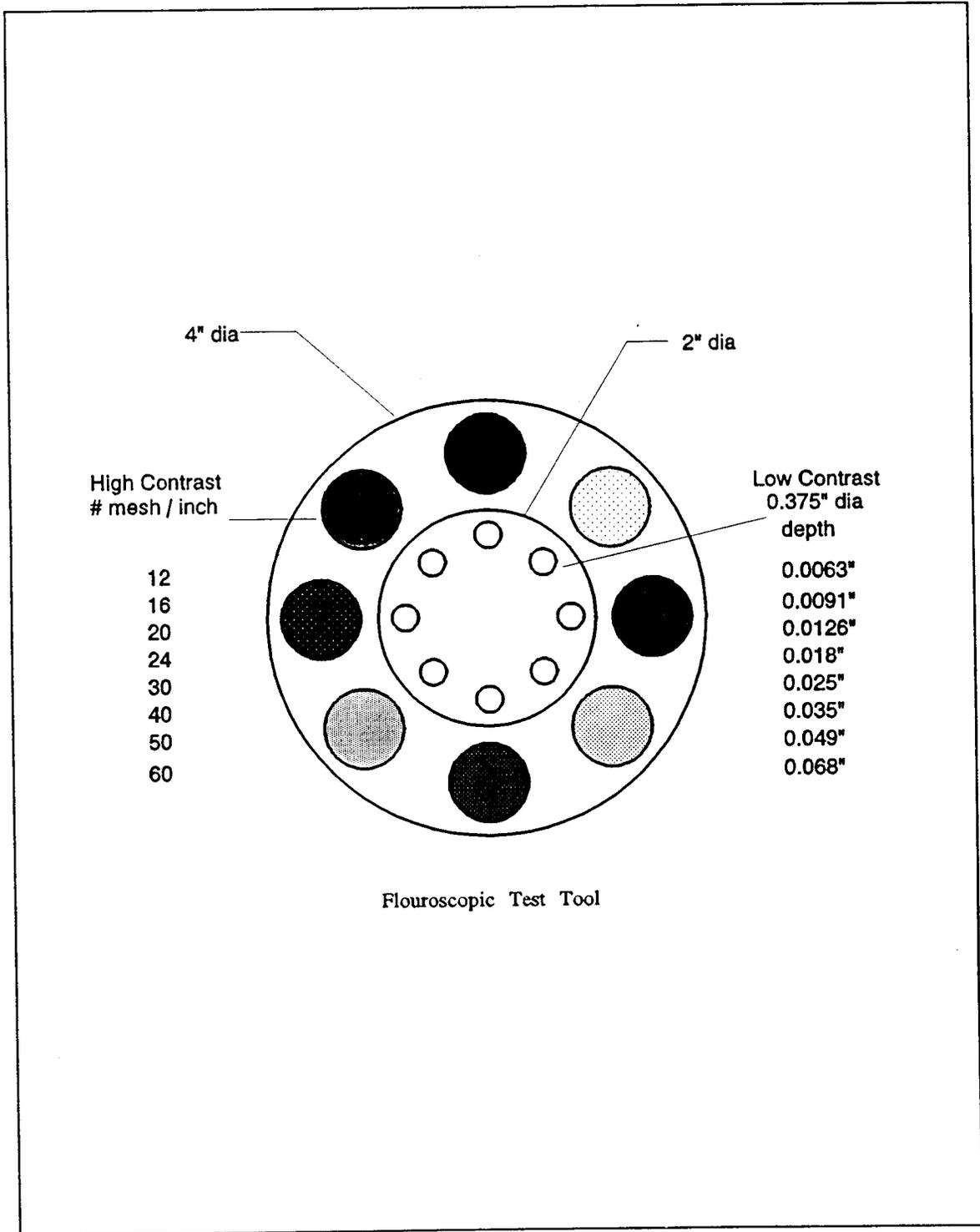


Figure 2
Fluoroscopy Image Test Object

Measurements

Radiation measurements performed with the phantom included:

the EER, free-in-air, at the tabletop for a typical fluoroscopy examination,

the EER with a 1.6 mm copper filter (simulating the presence of barium contrast agent),

maximum EER, by adding an additional 3.2 mm of lead to simulate maximum attenuation,

and exposures associated with the spot film or photospot mode, made with and without the copper filter.

The number of low contrast and high contrast image quality test objects observed by the surveyor were recorded.

All measurements were performed using the large image intensifier mode, usually 22.4 cm.

Technique information such as tube potential, tube current, the image intensifier field size, whether a grid was used, the type of screen and film used, was also collected.

Observations

Preliminary observations show that there was no correlation between age of equipment and EER ($r = 0.05$), and age of equipment and number of low contrast test objects observed ($r = 0.39$). There was also no correlation between the EER and number of low contrast test objects observed ($r = 0.12$).

Average EER was 4.9 R/minute, ($n=109$), which increased to 6.7 R/minute, when the 1.6 mm copper filter was added to simulate barium. When a lead filter was added to simulate maximum attenuation, the maximum EER only increased to 6.8 R/minute.

An average of 3.6 ($n=108$) low contrast test objects were visualized during the study from the fluoroscopic monitor. The number visualized ranged from 0 (none) to as many as 6, Figure 3. Since visualization of a test object depends upon its signal relative to its background, and the relative signal is highly dependent upon the x-ray beam quality, reporting the percent contrast associated with the smallest visualized test object is a more objective measure of low contrast detectability. Percent contrast values were calculated from knowledge of the beam quality and relative attenuation of the phantom and low contrast test objects, Figure 4 (33,34). Approximately half of the tested systems could image test objects corresponding to a four

Low Contrast Holes Observed

N = 351

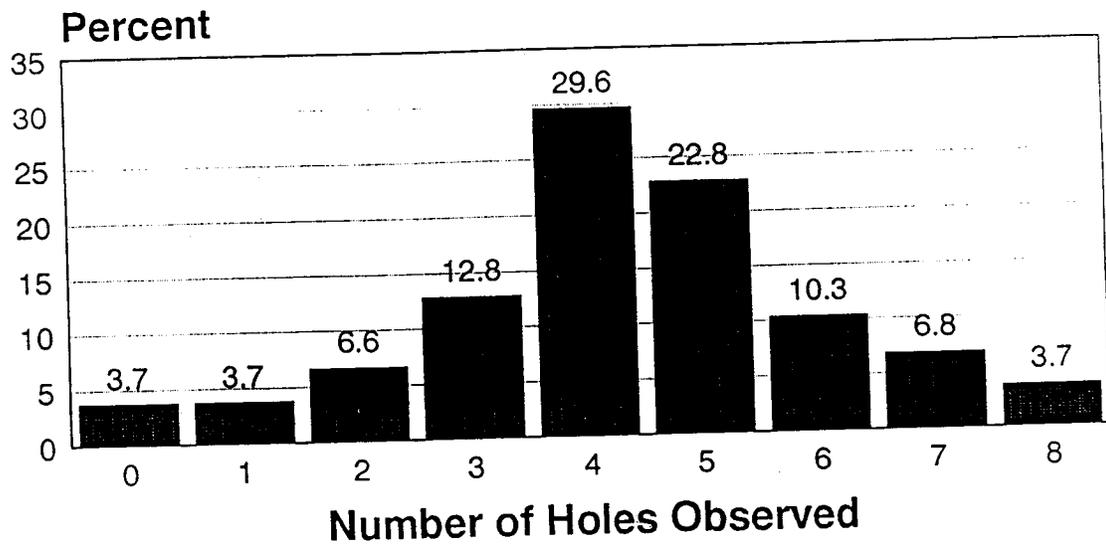


Figure 3

Minimum Detectable Signal Fluoro (N=351)

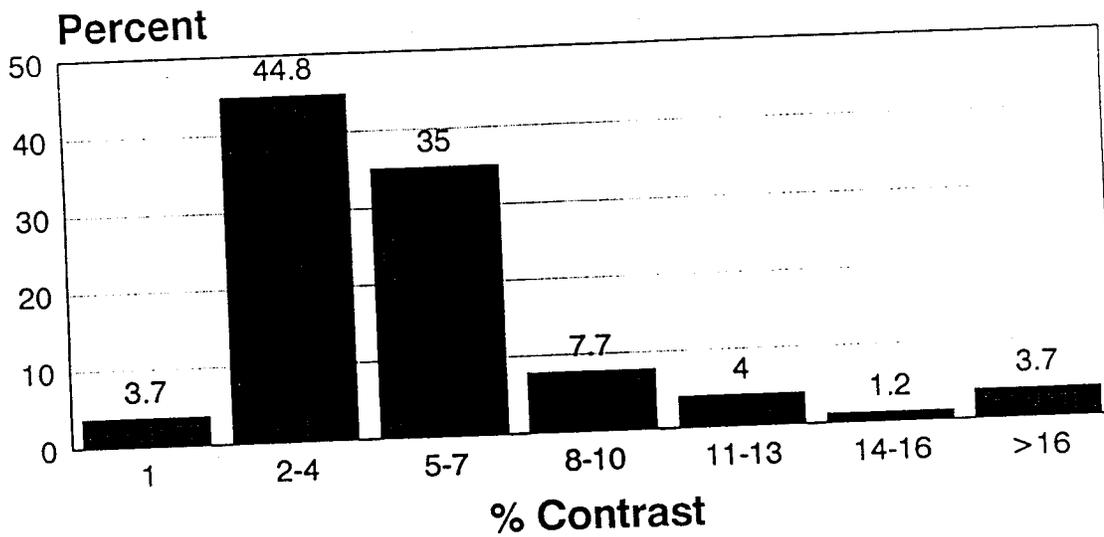


Figure 4

Meshes Observed

N = 351

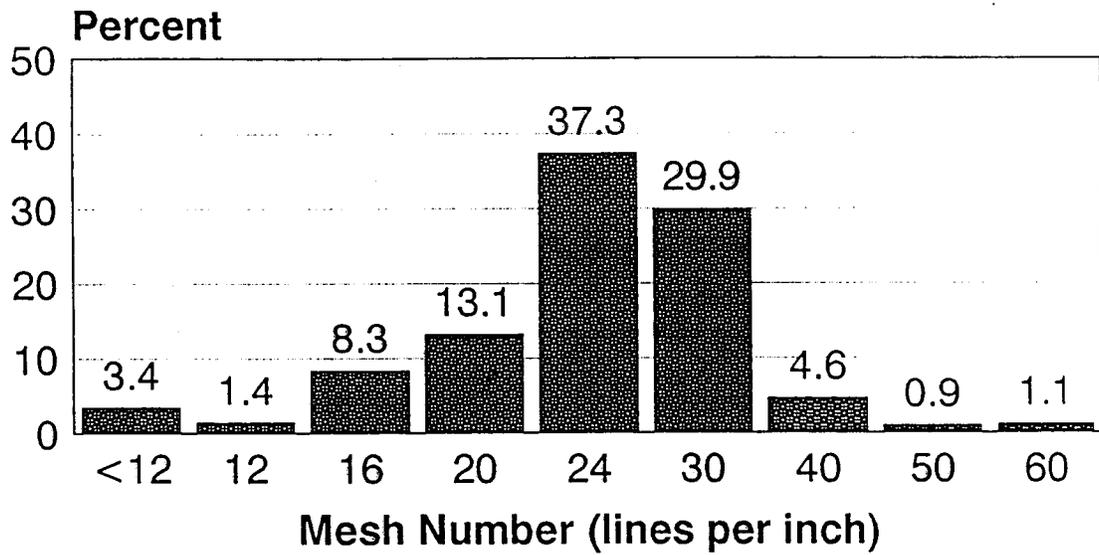


Figure 5

percent (4%) contrast or lower, although a significant number of fluoroscopy systems could not image even relatively large signals. Seventeen percent (17%) of observed fluoroscopy systems could not image an eight percent (8%) contrast signal.

The high contrast copper wire mesh ranged from 0 (none) test objects visible to as many as six (6) visible, with an average of 4.25 observed. Eighty-seven percent (87%) of all facilities could image 20 lines/inch wire mesh or better (Figure 5). This is considered to be acceptable for standard television systems (35).

Eighty-one percent (81%) of the systems employed the spot film grid during fluoroscopy, while 97% used the spot film grid for spot films. The average number of spot films routinely taken by the surveyed facilities was twelve (12).

Conclusion

The wide range of performance observed for fluoroscopy systems suggests that fluoroscopy exposure rates can be reduced and fluoroscopy image quality improved.

EER and IIER are directly related, the first is a direct measure of radiation to the patient, the second a measure of equipment performance. The EER incorporates the effect of clinical technique, including the kVp, geometry, grid, and patient attenuation. The inverse of the IIER is a measure of image intensifier speed.

Although the assessment of radiation dose from fluoroscopy is difficult because of the dynamic nature of fluoroscopy, measuring the fluoroscopy entrance exposure rate, and the spot film exposure, using a standard phantom, is useful.

Assessing imaging performance by using a standard imaging test object also provides a relative measure of imaging performance with which to compare different fluoroscopy systems.

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Interventional Radiology

John F. Cardella, M.D.

ABSTRACT

Clinical and Technical Parameters of Fluoroscopy Use by Interventional Radiologists

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Representing the Society of Cardiovascular/Interventional Radiology

Interventional Radiology is a relatively new subspecialty of Diagnostic Radiology, represented formally by the 1800-member Society of Cardiovascular/Interventional Radiology, which will hold its 18th Annual Scientific meeting in New Orleans in February, 1993. The Society's membership is composed of academic and private practice radiologists, who devote 50% or more of their time to the performance of innovative, fluoroscopically-controlled procedures throughout the body, which, in many instances, replace surgical procedures, and in most instances were not available 20 years ago.

As catheter, guidewire, interventional device, and fluoroscopic image technology has improved, it has enabled performance of ever more and more complex procedures, most of which treat conditions formerly manageable only by open surgery. Examples include foreign body retrievals, TIPS procedures, central venous access, complex small vessel angioplasty, complex biliary drainages (with stent placement), complex genitourinary drainages (with stent placement), and complex biopsies/drainages.

Many of these procedures require exquisite fluoroscopic images (3-5 line pairs/mm resolution on the TV monitor) capable of resolving opacified anatomic structures from 2 mm size to several cm size, and devices from a .010 inch (.254 mm) guidewire to a 12 French (4 mm diameter) drainage catheter located deep within patients ranging in weight from 2 to 150 kg. The image must be capable of monitoring device motion/expansion, frequently in the setting of the device itself being moved about by pulsatile flow, patient respiration/cough, or operator maneuvers. The fluoroscopic image must be adequate in multiple angles of obliquity (including true lateral) and must be capable of magnification without significant degradation of image; biplane fluoroscopy is necessary in

some interventional applications.

Review of our own fluoroscopic practices by two fellowship trained full-time interventional radiologists in a tertiary care university teaching hospital over the most recent 60 day period revealed a mean fluoroscopic time of 8.013 mins per patient (range 0.7 min [PICC insert] - 63.7 mins [complex biliary drainage]). Both of our fluoroscopic units (Siemens Angioskop and Angioskop D) operate at a table-top dose rate of 8.33 R/min in standard nonmagnification mode. The latter unit has two levels of high-dose fluoroscopy capability (34.0 R/min. and 50.4 R/min table-top dose rates); when high dose fluoroscopy is activated, the standard dose rate drops to 4.83 R/min. The system requires a second person for activation: a continuous chime sounds, when the two-stage pedal is fully depressed to engage the high dose power. The high-dose feature is necessary to successfully complete cases 5 % of the time; the other 95% of the time, all of our complex full-spectrum interventional cases can be completed at the 8.33 R/min level. Our fluoroscopy units deliver resolution of 40 lp/inch (1.6 lp/mm) and 50 lp/inch (1.97 lp/mm) in the old and new rooms, respectively, measured by three observers from the live fluoro TV monitor image.

The two interventional radiologists are religious about film and ring badge use. Interventionalist A does clinical cases 3 days/week for 44 weeks/year, while interventionalist B does clinical cases 3.5 days/week for 44 weeks/year. At these duty levels, interventionalist A receives mean (range) film and ring badge readings of 560 mRem (230-1450 mRem) and 4500 mRem (2380-7250 mRem) per month, respectively, while interventionalist B receives film and ring badge readings of 865 mRem (680-1110 mRem) and 6000 mRem (2800-12000 mRem) per month, respectively. These readings are in the face of good radiation protection practices, and having radiology residents "share" the radiation exposure. We believe these exposures are typical for full-time interventionalists and would encourage all individuals using fluoroscopy to wear badges; this practice may not be universally adhered to. Not monitoring one's exposure is potentially hazardous, since exposure levels to personnel and patients are rising as fluoroscopy unit output and length of "on-time" increase.

Specific aspects of cases done in the CV/I Radiology section will be discussed, including some ways to limit exposure while still

accomplishing the interventional task at hand. Interventional radiologists are fully trained radiologists first and realize the hazards of extended radiation exposure to patients and to personnel; they are in a unique position to truly evaluate the risk-benefit ratio for patients undergoing these procedures. As technologies evolve, the day will come (or may already be here) when the risks of acute radiation exposure to the patient should be included in the informed consent discussion prior to the procedure, and the risks of chronic radiation exposure should be included in the career decision of the practitioner.

Cardiovascular-Interventional

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Use of Fluoroscopy in the Cardiac Catheterization Laboratory: Diagnostic and Interventional Procedures

The use of ionizing radiation in the form of fluoroscopy and cine angiography continues to play a major role in the diagnostic evaluation, treatment and follow-up of patients with heart disease -- especially those with coronary artery disease, valvular heart disease, and cardiomyopathies. In addition, newer therapeutic modalities such as radiofrequency catheter ablation for patients with certain cardiac arrhythmias require fluoroscopic imaging for the procedures to be performed. The aims of this discussion are: 1) discuss the current cardiac interventional procedures which are commonly performed -- emphasizing the fluoroscopic requirements and steps to be taken to reduce the amount of radiation exposure, 2) discuss in general terms the guidelines for reducing radiation exposure for all cardiac procedures, 3) address the issue of high level control fluoroscopy in terms of demands in the catheterization laboratory, and 4) briefly discuss future imaging developments and their potential impact on radiation exposure.

In adults, diagnostic coronary angiography is the most commonly performed procedure in the catheterization laboratory requiring the use of fluoroscopy and cine angiography. This is an invasive test and involves placement of catheters in the left and right heart chambers while measuring the pressures within those chambers, evaluating the function of the heart, and with selective angiography, identifying obstructions in coronary arteries. Although the average fluoroscopy time for such procedures is only about nine minutes, important demands are made on the imaging equipment. The most important one is that image quality must be optimal to visualize the vessels which may be as small as 1 or 2 mm in diameter and are of low contrast. In terms of imaging demands, the heart is unique in that it is constantly moving and so blurring of the vessels must be minimized. Finally, multiple angles of view, employing steep cranial and caudal angulations, are necessary to adequately visualize the entire coronary arterial tree. Until recently, the biggest concern for radiation exposure in the catheterization laboratory was for coronary angioplasty (PTCA) procedures. The technique involves the placement of a tiny balloon (1.5-3.5 mm in diameter) across a coronary narrowing and inflating the balloon to improve the arterial lumen. The balloon is positioned over a 0.010-0.018 inch guide wire which has been steered through tortuous and diseased vessels. PTCA demands the highest quality video x-ray imaging of any procedure performed in the laboratory. Average fluoroscopic exposure times have been reported to range from 20 to 47 minutes -- depending on the complexity of the procedure. Specific concerns about radiation exposure during PTCA procedures relate to the fact that repeat procedures are frequently necessary. There is also a rapidly increasing number of highly complex cases being attempted which often take considerably longer than simpler cases.

Very little has been documented about the exposure rates and potential risks to the pediatric population. The majority of pediatric patients have congenital heart malformations and can undergo diagnostic catheterization, angiography, and possible interventions that require fluoroscopic control. Many of these diagnostic and interventional procedures are very lengthy and often employ biplane fluoroscopy and angulated views. In recent years, there has been an increased number of interventional procedures, many of which require long procedural times. Specific concerns include the reported higher

sensitivity to induction of some tumors in children, the increased opportunity for delayed expression of radio-induced cancers and the necessity for multiple examinations. Preliminary data concerning pediatric radiation exposure from our institution will be presented.

Radiofrequency catheter ablation is a relatively new therapy designed to ablate abnormal electrical pathways within the heart which give rise to cardiac arrhythmias resulting in palpitations, blackouts, or even sudden death. Until now, these symptoms could only be treated with drugs which were often ineffective or potentially dangerous, or with open heart surgery. The technique is complex and requires the placement of many electrode catheters within the heart and may take many hours to completely and successfully ablate the abnormal pathways. Average fluoroscopic exposure times are in the range of 40-50 minutes but exposure times exceeding 100 or 150 minutes have been reported. Carefully performed studies documenting the amount of radiation exposure to both patients and physicians have recently been published. Excessive radiation exposure in this patient populations should not be easily dismissed, as these procedures are often performed on young adults or adolescents. High resolution fluoroscopy is generally not required for this procedure and cine angiography is only rarely used. Attention to shielding, field collimation and improving procedural efficiency will all contribute to lowering the radiation exposure in these cases. In addition, as only fluoroscopy is required, the antiscatter grid should be removed in those systems that allow this.

Is high level control fluoroscopy required in cardiac imaging? While high quality video images are necessary to visualize small low contrast arteries and avoiding motion blurring, high level control is probably only required during PTCA but not all PTCA procedures. Here, it can be used to help better visualize suspected complications of the procedure which are often difficult to see using conventional fluoroscopy or to assess whether the balloon is fully inflated. When used, it should only be used briefly (for a few seconds) and accompanied by strict field collimation. As x-ray imaging systems improve, its use should diminish. There appears little justification for its use during routine diagnostic coronary angiography and is almost certainly of no added benefit in pediatric catheterization procedures or during radiofrequency catheter ablation.

General guidelines to the cardiologist performing these procedures to help decrease the radiation exposure to the patient and attending personnel will be discussed. Regular (at least monthly) x-ray inspection and testing will help keep equipment functioning optimally. More attention to physician education, particularly among trainees, should heighten the awareness of the issues of radiation safety. Maintaining records of the cumulative radiation exposure for each patient should be a priority in every catheterization laboratory.

Finally, new image generation and acquisition techniques may play a role in reducing radiation exposure while maintaining optimal image quality. Such techniques include the use of pulsed progressive fluoroscopy which has been shown to reduce the radiation exposure by about 50% compared to conventional fluoroscopy. Digital imaging is beginning to play an increasing role in cardiac angiography and it is hoped once the transmission media and

archival systems have been standardized, that this will replace cine angiography and potentially result in a reduction in radiation exposure.

In summary, cardiac angiography, angiographic interventions as well as radiofrequency catheter ablation currently play an integral role in the management of hundreds of thousands of patients with cardiac disease in the USA. Although the benefits of these procedures almost certainly outweigh the risks that may potentially be associated with excessive radiation exposure, it is incumbent upon the physicians performing these procedures to minimize the amount of radiation exposure to patients, personnel, as well as themselves. Efficient and state-of-the-art x-ray imaging equipment should provide optimal imaging capability, while at the same time, reducing the amount of radiation produced.

Use of Fluoroscopy in the Cardiac Catheterization Laboratory

Interventional Procedures

ACR Fluoroscopy Workshop

Washington DC

October 1992

1992

Aims

1. Current cardiac interventional procedures
 - fluoroscopy use
 - emphasize special requirements
 - reduction in radiation exposure
2. General guidelines for reducing radiation exposure
3. High level control
4. Future imaging developments and impact on radiation exposure

Radiation Exposure in the Cardiac Catheterization Laboratory

- Adults**
- Diagnostic coronary angiography, catheterization
 - Interventions – Balloon angioplasty (PTCA), laser, etc.
 - Complex PTCA – e.g. chronic total occlusions
- Children**
- Catheterization and angiography
 - Interventions
- Both**
- Radiofrequency catheter ablation

Diagnostic Catheterization and Coronary Angiography

- Placement of catheters in the left and right heart chambers
- Measure pressures within heart chambers
- Evaluate function of the left ventricle with angiography (9 – 11° mode; mono or biplane)
- Identify obstructions in coronary arteries with selective angiography (0 – 7° mode; multiple views)

Percutaneous Transluminal Coronary Angioplasty (PTCA)

- > 400,000 performed in USA in 1992
- Technical issues include:
 - steering 0.010 to 0.016" wires through tortuous diseased vessels
 - multiple angles to ascertain correct balloon position and assess results and complications
- Demands high quality video x-ray imaging

PTCA and Other Coronary Interventions

Current Practice and Potential Benefits

- Relieve symptoms of angina
- Avoid costs and morbidity of coronary artery bypass surgery
- Treatment of acute heart attacks
- Simple or highly complex procedures; multiple lesions treated
- New devices – lasers, atherectomy, etc.

Radiation Exposures to Patients Undergoing PTCA

	Diagnostic Angiography	PTCA
Patients, no.	63	51
Fluoro, min	9 ± 6	47 ± 33
Cine, sec	70 ± 27	62 ± 29
Exposure, R	20 ± 16	69 ± 54

Circada PH, Am J Cardiol 59:1987

Radiation Exposure to Patients Undergoing PTCA

Importance of Multivessel PTCA

	1 Lesion	2 Lesions
Patients, no.	36	13
Fluoro, min	26	51
Exposure, R	47	100

Cascadia PH, Am J Cardiol 53:1987

Coronary Angioplasty Simple vs. Complex Cases

Radiation Exposure (min)

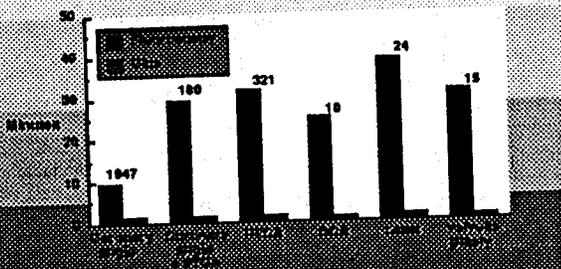
	Subtotal (n = 100)	Chronic total (n = 90)
Fluoroscopy	20 ± 11	31 ± 18
(range)	(3 - 53)	(8 - 62)
Exposure	6.5 ± 6.3	6.5 ± 6.3

Borik WH, Cathet CV Diagn 25:1992

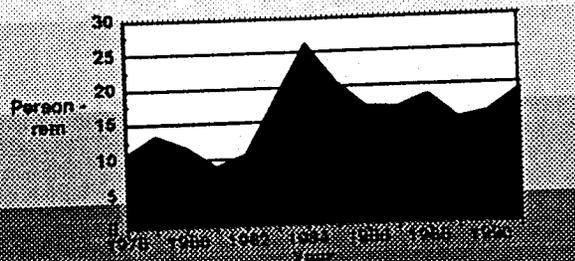
PTCA Radiation Issues

- Repeat procedures frequently necessary
- Increasing complexity of cases
- Often lengthy procedures
- Emergence of new devices -- longer procedures?
- High volume operators

Radiation Exposure Duration Mayo Clinic 1991



Radiation Exposure to Cardiologists Mayo Clinic 1978 to 1991



Cardiac Catheterization and Angiography Pediatric Population

- Diagnosis**
- Right and left heart catheterization
 - Angiography
 - cardiac chambers
 - great vessels
 - coronary arteries

Cardiac Catheterization and Angiography Pediatric Population

- Intervention**
- Pulmonary valvuloplasty
 - Rashkind balloon septostomy
 - Balloon angioplasty of recurrent aortic coarctation
 - Closure devices
 - Coil embolization

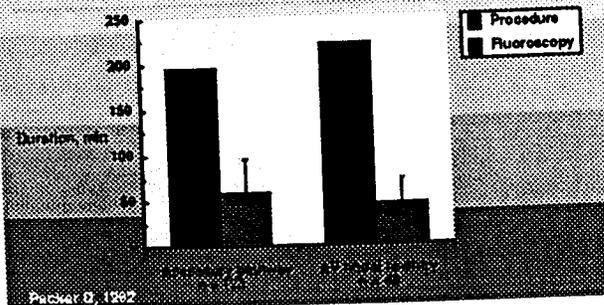
Radiation Exposure Considerations for Pediatric Cardiology

- Lengthy exam duration
 - Biplane fluoroscopy, angulated views
 - Increasing numbers of interventional procedures
- Concerns:**
- Higher sensitivity to induction of some tumors
 - Opportunity for delayed expression
 - Possibility for multiple exams

Radiofrequency Catheter Ablation Therapy Aims of Therapy

- Relieve symptoms
 - palpitations
 - syncope
 - sudden death
- Avoid open heart surgery
- Avoid life-long drug therapy
 - side effects, proarrhythmia
 - convenience
 - cost

Radiofrequency Catheter Ablation Mayo Clinic Experience



Radiofrequency Catheter Ablation Radiation Exposure

- Long procedures - "learning curve"
- Young adults and adolescents
- Fluoroscopy only
- High resolution fluoroscopy *not* required
- Remove anti-scatter grid
- Operator position
- End point - radiation exposure vs procedural outcome

Radiofrequency Catheter Ablation Radiation Exposure to Patient

Fluoro 50 ± 31 min (n = 108)



Limsey BD, Am J Cardiol 70: 1992

Radiofrequency Catheter Ablation Radiation Exposure to Personnel

Predicted Exposures

Personnel	Task	mrem/case	mrem/yr*
Physician	- femoral	1.8	450
	- neck	3.6	900
Monitoring technicians		0.6	162
Nurses		0.2	54

*250 cases

Limsey BD, Am J Cardiol 70: 1992

Radiofrequency Catheter Ablation Measured Radiation Exposure to Patients

Fluoro 44 ± 40 min (5 - 150 min)

Organ	Median (rem)	Range (rem)	mrem/min
9th vertebral body	7.26	0.31 - 135.7	447
Thyroid	0.46	0.06 - 7.26	36
Posterior iliac crest	2.43	0.01 - 8.3	64

Cookson H, CMA 64: 1991

Approaches to Decreasing Radiation Exposure

- Shielding; increasing distance
- Field collimation - manual
- Light foot
- Improve procedural efficiency
- Avoid magnification
- Reduce frame rate if practical
- Increasing X-ray tube filtration

Approaches to Decreasing Radiation Exposure

continued

- Remove antiscatter grid whenever practical
- X-ray inspection and testing
- Physician education
- Display/record cumulative fluoro time
- Image generation and acquisition techniques
- Estimate H.I.D. or change ceiling exposure

Fluoroscopy: High Level Control

- AKA: Fluoro boost, high contrast fluoro, high resolution, turbo fluoro
- Upper limit - 10R / min? or more?
 - No limit on X-ray exposure
 - Heat load capacity of tube
 - (is it needed?)

Fluoroscopy: High Level Control Need and Utility in Cardiac Imaging

- Why?** • Small arteries, motion blurring, low contrast
- When?** • PTCA only: visualize inflated balloon or complications
- How often?** • Uncommonly if good imaging equipment
- How long?** • Brief - seconds
- How high?** • 10 - 20 R / min maximum??

High Level Control Fluoroscopy

	Entrance, R / min	Exit, μ R / frame
Low	~ 6	3.4
High	~ 27	15

General Electric 31C

New Image Generation and Acquisition Techniques

Issue: Reducing radiation exposure vs. optimizing image quality

- Pulsed progressive fluoroscopy
- Digital manipulation and abandonment of cine

Radiation Dose Reduction with Pulsed Progressive Fluoroscopy

Fluoroscopy	PTCA	
	Subtotal	Chronic total
Conventional (3.7 R / min)	74 R	115 R
PPF (2.7 R/min)	54 R	65 R

Bell MR, Cahill CV, Dagnan 1992

Digital Imaging

Applications in Cardiac Angiography

- Image enhancement
- Image storage
- Image transmission
- Image analysis - interactive, quantitative
- Reduction in radiation

Digital Imaging Comparison of Radiation Exposure

	Exit Dose μ R / frame
Fluoroscopy	1 - 3
High resolution fluoro	14 - 15
Cine	20 - 30
Digital	14 - 15 (?)

High Level Control Fluoroscopy Guidelines for Use During PTCA

- Use sparingly – “seconds”
 - balloon inflation
 - assessment of complications and result
- Avoid magnification if possible
- Strict collimation of field – manual control
- Do not use for catheter placement
- Apprehension of level of radiation exposure

High Level Control Fluoroscopy Summary

- Only for PTCA – minority of imaging tasks
- Set maximum level
- Education