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Current Status of Electronic Portal Imaging

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An updated handout will be made available on the morning of the course

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Acknowledgments

James Balter, University of Michigan
Michael Herman, Mayo Clinic
David Jaffray, William Beaumont Hospital
Shlomo Shalev, Masthead Imaging Corporation
Marcel Van Herk, Netherlands Cancer Institute

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Estimates of Setup Error

Sites	No. of Studies	No of Patients	No. of Images	Sys. Error	Random Error
Head & Neck	8	6 – 95	120 – 380	3.4 1.0 – 5.0	1.9 1.0 – 3.2
Thorax	3	10 – 19	97 - 341	4.4 3.8 – 5.2	3.3 1.2 – 5.7
Breast	5	6 – 20	41 - 2120	3.9 2.8 – 4.7	2.7 2.0 – 4.4
Pelvis	8	9 – 62	105 - 288	2.9 1.7 – 6.0	2.5 1.2 – 6.0

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EPID : Outline of presentation

- **Physics Review**
- **Clinical Implementation**
  - **Setting up an EPID for clinical use**
  - **Tools to support EPID (software and QA)**
- **Clinical experience:**
  - **Strategies to improve patient setup using EPID**
- **Cost-effectiveness**
- **Ensuing new technology**

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EPID : Current status

- **Commercially available from accelerator companies and two 3rd party vendors (TheraView and PORTpro).**
- **Varian : scanning liquid ionization chambers on a robotic or manual arm.**
- **Others : fluoroscopic systems with 45º mirrors with retractable, dismountable, or portable assemblies.**
- **A compromise of several factors: convenience, field of view, rigidity, reproducibility, etc.**

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EPID : Current Status

- **Most produce 8-bit images; Varian ~ 10-bit images.**
- **Images are :**
  - **(256 x 256) to (512 x 512) pixels**
  - **acquire with dose ~ 2 to 8 MU**
  - **acquire in < 1 sec; display in < 3 sec.**
- **Image quality adequate, in comparison with film: 65% comparable, 30% inferior, 5% superior**
- **Purport to be more convenient;** *not true*

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Informal Survey (a) -- Interest group from TG58
No. of Institutions: 69

Portal Film Practice	Weekly	Bi-weekly	Once or twice
	66%	8%	26%

EPID utilization	Clinical use only	Research and clinical use	Not at all
	49%	28%	23%

Reviewer	RTT as first pass	RTT only	Physicist only	MD only
	58%	16%	4%	22%

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Informal Survey (b) -- Interest group from TG58
No. of Institutions: 69

Of the 69 institutions with EPIDs	75%-100% of patients	50%-74% of patients	25%-49% of patients	10%-24% of patients	<10% of patients
Imaged everyday	5 (7%)	5 (7%)	6 (9%)	8 (12%)	16 (23%)
Imaged once per week	9 (13%)	10 (14%)	12 (17%)	10 (14%)	14 (20%)
Once or twice only	9 (13%)	9 (13%)	11(16%)	10 (14%)	5 (7%)
Not at all	46 (67%)	45 (65%)	40 (58%)	41 (59%)	34 (49%)

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Informal Survey (c) -- Interest group from TG58
No. of Institutions: 69

Viewing	Primary Station only	Secondary EPID Station	In-house Review Station
	48%	38%	13%
On-line Evaluation	Visual only	Using EPID system	Using in-house system
88%	57%	20%	11%
Off-line Evaluation	Using EPID system	Using 3rd party (PIPS)	Using in- house tool
68%	38%	19%	11%

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Informal Survey (d) -- Interest group from TG58
No. of Institutions: 69

No QA	**Mechanical Only**	**Image Quality Only**	**Mechanical + Image Quality**
35%	**10%**	**16%**	**39%**
Daily QA	**Weekly QA**	**Monthly QA**	**Infrequent QA**
8%	**8%**	**39%**	**45%**
Port Film Superior to EPID		**EPID saves time**	
71%		**69%**	
Poor Image Quality	**Poor User Interface**	**Poor Archive /Network**	**Inconvenient to use**
45%	**27%**	**15%**	**13%**

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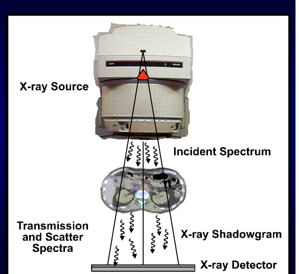
Portal Imaging: Elements



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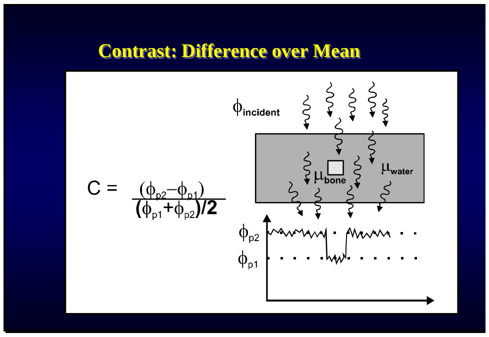

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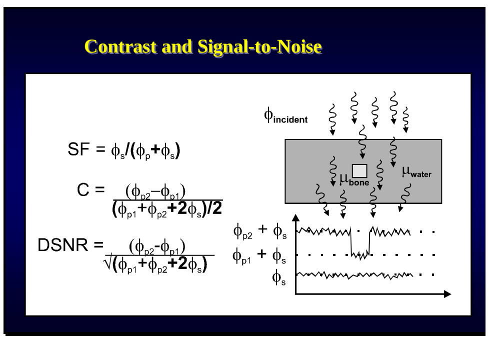

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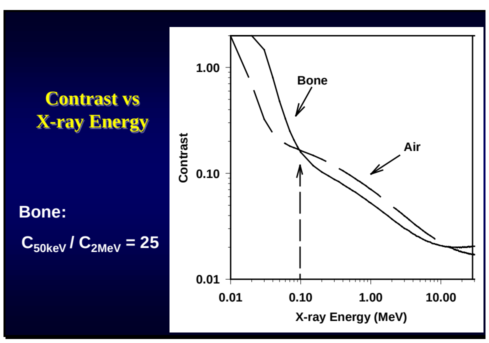

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Portal Imaging: X-ray Source Distribution

- **Focal region**
  - varies from accelerator-to-accelerator
  - determined by accelerator design
  - ~1mm for modern accelertors
  - should not significantly limit on-line
- **Extra-focal region**
  - large source, ~10% of apparent output
  - reduces contrast performance

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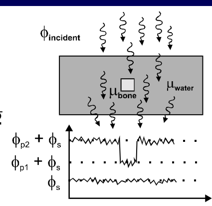
Portal Imaging: X-ray Scatter

- reduces the contrast of objects in the image
- introduces additional x-ray quantum noise

$$SF = \phi_s/(\phi_p+\phi_s)$$

$$C = \frac{(\phi_{p2}-\phi_{p1})}{(\phi_{p1}+\phi_{p2}+2\phi_s)/2}$$

$$DSNR = \frac{(\phi_{p2}-\phi_{p1})}{\sqrt{(\phi_{p1}+\phi_{p2}+2\phi_s)}}$$



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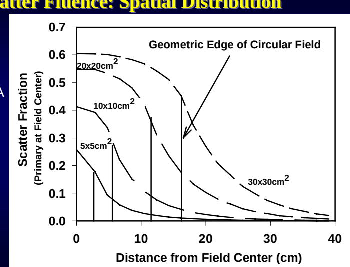
Scatter Fluence: Spatial Distribution

Ei: 6MV

Air Gap: 0cm

T: 17cm PMMA



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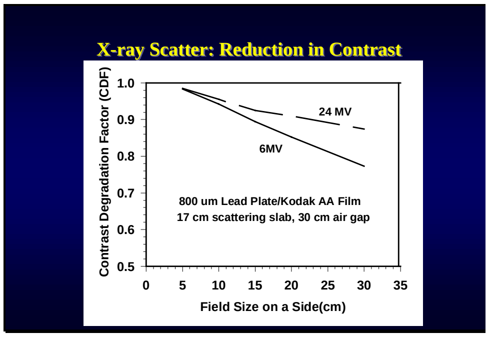

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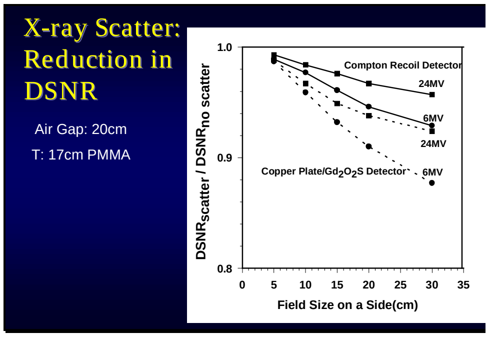

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Setting up a EPID

- Installation : System calibration
  - lens focus and aperture; flood field images, synchronize scan rate, etc.
- Acceptance : use simple contrast-detail phantoms;
- Additional checks : baseline phantom images, gantry stability, image quality with different phantom thicknesses.
- Establish a QA program :
  - QA frequency, integrity of mechanical assembly, image quality (and image transfer)

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EPID : Starting out

- Establish imaging protocols :
  - provide prescription images on the EPI system,
  - sites requirement, e.g. optimal imaging dose
  - verification frequency,
  - archive: save every image? hardcopy?
- Correction strategies
  - decision criteria
  - on-line, off-line, or combinational
- Install a secondary review station.

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EPID : Need of a QA program

- Factors leading to sub-optimal performance:
  - non-rigid detector housing
  - sub-optimal maintenance
  - improper system settings
  - optical components out of alignment/focus
- Consequences:
  - poor image quality and increased imaging dose
  - wasted efforts leading to rejection of the device.
- Physics involvement imperative.

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A QC test system for EPID (Shalev)

- A set of test phantoms and procedures for acceptance and routine quality control
- Develop quantitative and objective tests for analyzing image quality.
- Derive accept / reject action levels for maintenance.
- Adapting a common test system allows:
  - inter- and intra- comparison of EPID systems
  - a baseline for future improvements.

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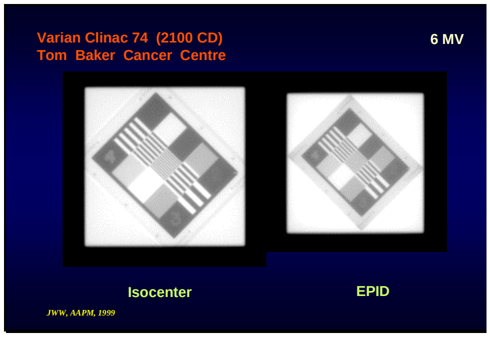

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The phantom contains five sets of high contrast rectangular bars with spatial frequencies :

- A - 0.75 lp / mm
- B - 0.4 lp / mm
- C - 0.25 lp / mm
- D - 0.2 lp / mm
- E - 0.1 lp / mm

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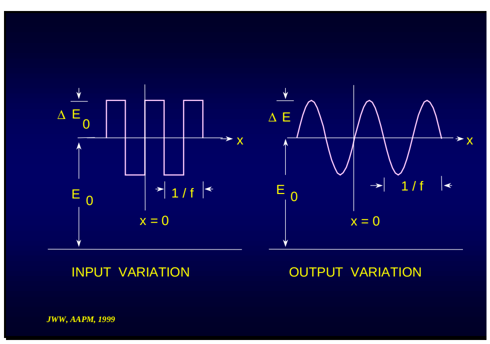

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Determining the SWMTF

(Square Wave Modulation Transfer Function)

---- from Shalev

- **SWMTF is defined as :**

$$SWMTF(f) = \frac{\Delta E(f)}{\Delta E_0} \qquad (1)$$

where ΔE_0 is the input modulation
and $\Delta E(f)$ is the output modulation

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A relative measure of SWMTF can be obtained by defining

$$RMTF(f) = \frac{\Delta E(f)}{\Delta E(f_l)} \qquad (2)$$

where $\Delta E(f_l)$ is the output modulation for the lowest frequency

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For sinusoidal output, $(\Delta E)^2$ is proportional to the variance (M^2)

$$\therefore \quad RMTF(f) = \frac{M(f)}{M(f_l)} \qquad (3)$$

In the presence of random image noise, M (f) can be obtained by

$$M^2(f) = \sigma_m^2(f) - \sigma^2(f) \qquad (4)$$

where $\sigma_m^2(f)$ is the total variance
and $\sigma^2(f)$ is the variance due to random noise

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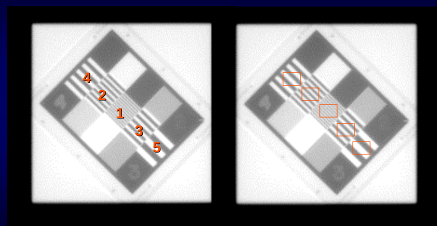
ROIs for Spatial Resolution



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Determining the CNR

(Contrast to noise ratio) --- Shalev

- **CNR is defined as:**

$$CNR = \frac{I_6 - I_{11}}{\sigma}$$

where σ is the random image noise

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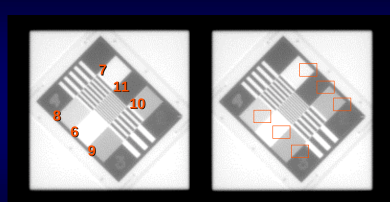
ROIs for Noise Measurements



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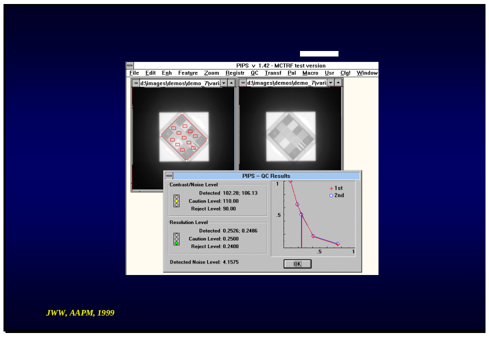

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Summary of Results for f_{50}

(Spatial Resolution lp/mm)

EPID	6 MV	10 - 25 MV	All Energies
Philips	0.180 ± 0.016	0.179 ± 0.014	0.180 ± 0.014
Siemens	0.214 ± 0.027	0.192 ± 0.005	0.204 ± 0.023
Infimed/GE	0.231 ± 0.011	0.218 ± 0.011	0.223 ± 0.012
Varian	0.258 ± 0.008	0.251 ± 0.007	0.258 ± 0.009
ELIAV	0.352	0.255	0.180 ± 0.016

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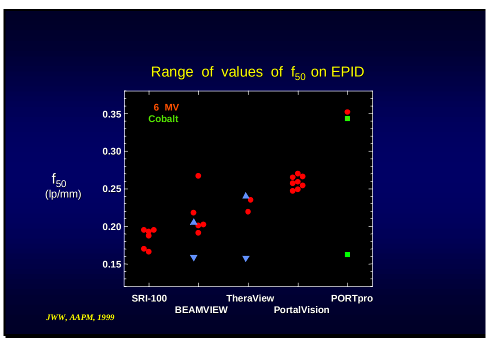

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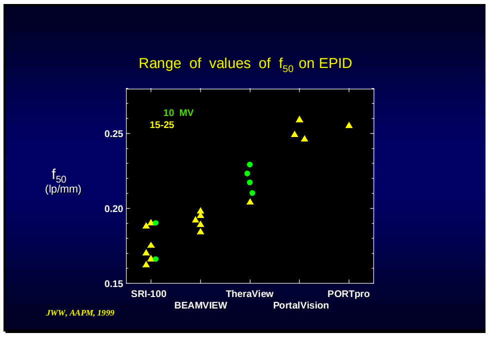

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EPID : Clinical Application
Verification of treatment setup

- Treatment verification with portal images involves the comparison of a reference image (simulation, DRR, a reference portal image) with a treatment portal image.
- Field placement error (FTE) is determined by identifying the patient setup with respect to the proper field shape
  - often involves double-exposed image, particularly for small fields.

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EPID : Software tools

- The advent of EPIDs leads to the development of many image handling tools.
- Three main types of software tools:
  - image processing
  - field shape or edge detection
  - patient setup measurement
    - snap shot analysis vs time-sequence studies
- These tools need to be integrated
  - NKI, PIPS, electronic view box, etc.

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EPID : Methods of analysis

- Requirements :
  - objective, accurate, fast and automatic

Visual → Interactive → Automatic

- Interactive
  - Pro : applicable to a wide range of treatment sites
  - Con : subjective, labor intensive
- Automatic
  - Pro : objective, fast, reduce workload
  - Con : mostly optimized for few specific sites

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EPID : Image processing

- Simplest manual approaches are to adjust display "window and level", and to use measure distance.
- Image processing tools:
  - improve visualization, at least subjectively
  - pre-process for measuring field placement error
- Many software tools (e.g. in PIPS):
  - smoothing to suppress noise (e.g. Gaussian)
  - sharpening for edge detection (e.g. highpass)
  - contrast enhancement: histogram equalizations

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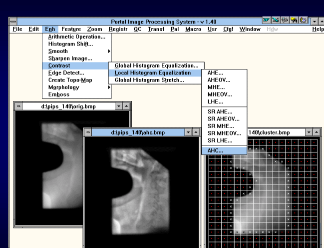
Image Processing by Adaptive Histogram Clip from PIPs



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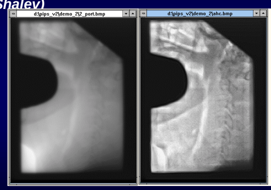
•An example of contrast enhancement by AHC --- *(courtesy of Shlomo Shalev)*



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EPID : Field edge detection

- Automatic algorithms available for quantitative description of shapes and alignment errors
  - few, if any, are implemented on the commercial systems and/or used clinically
- Interactive block template
  - define template once, and overlaid on subsequent Fx
  - require user examination; subjective
- Computer controlled MLC and accurate repositioning of EPID likely to change the use of field edge detection tools.

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EPID : Measurement of setup error

- Most tools to determine setup error assume 2D in-plane rigid body variation.
- Basic approach:
  - Identify homologous anatomical features on the reference image and the treatment portal image.
- Selected features
  - Point : Meertens, Balter
  - Gray scale regions: Munro, Dong and Boyer
  - Curves : Gilhuijs and van Herk, Fritsch
  - Interactive template: van Herk, Wong

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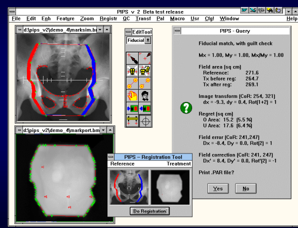
Image Registration - point based

(courtesy of Shlomo Shalev)



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General comment on EPID software tools

- Comprehensive software tools to analyze portal images are typically not available from the EPID vendors
  - e.g. secondary review stations are general not available
- Software suites are available from 3rd party:
  - PIPS, Electronic view-box from the NCI CWG
  - mostly snap-shot tools
- The general lack of tools and infra-structure precipitates how EPIDs are used currently.

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Setup error detection : Reality check

- Patient setup is a 3D problem
- Simple patient shifts, even if only translational, may lead features changes; caution when choosing anatomical points.
- Out-of-plane rotation
  - cannot be quantified
  - may lead to interpretation of in-plane translation/rotation
- Oblique beams
  - images are difficult to interpret

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- Laura Pisani slides 1 and 2

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Setup error detection : 3D models

- Takes advantage of the anatomical information from 3D CT dataset for treatment planning.
- Assume rigid body variation.
- Approaches to match portal image with CT data:
  - interactive or automatic adjustment of CT to align DRRs with portal images (Gilhuis)
  - registration of features on pre-calculated DRRs (Lujan)
  - registration of 3D homologous features with their 2D projections (Pisani)

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Gilhuis

- 3D CT alignment
- pisani CT alignment

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EPID : 3D setup error

- Presently a research topic, methods not quite ready for clinical use.
- Need to establish the clinical frequency of 3D setup error.
- Rigid models do not account for deformable rigid elements : joint flexing, or non-rigid organ motion
- Rule of thumb :
  - small setup errors == small out-of-plane components
  - large setup errors == potentially a 3D problem.

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EPID : Current status of clinical use

- At present, there is no standard recommendation on the clinical use of EPID for the community at large.
- EPIDs are used to acquire more images than with film (sometimes, in those clinics that use EPIDs)
- Analysis of the images are mostly still based on the model of weekly port film
- Cost-effectiveness is of major concern

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