Fluoroscopy

Principles of Medical Imaging

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Abstract
Fluoroscope

Fluoroscopy is an imaging technique commonly used by physicians to obtain real-time images of the internal structures of a patient through the use of a fluoroscope. It is used to visualise:

- organ motion
- ingested or injected contrast agent
- catheterised interventions (inserting stents, RF ablation,...)

The first commercial fluoroscope was developed by Thomas Alva Edison in 1896.

Sample Applications

Fig 2.1: A modern Fluoroscope

Fig 2.2: Hand X-ray

Fig 2.3: Fluoroscopy of an RF ablation site

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Prof. Dr. Philippe Cattin: Fluoroscopy

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Introduction
Sample Applications (2) (6)

Sample applications with CT Fluoroscopy e.g. an IsoC3D Fluoroscope

Fig 2.4: A radiologist's hand accidentally slips into the primary beam during a fluoroscopy procedure

Fig 2.5: Cervical spine biopsy with CT Fluoroscopy

History

Early Fluoroscopes (8)

The earliest fluoroscopic systems used phosphor screens where the X-rays caused scintillations that were viewed directly by the radiologist.

In later versions the screen was backed by lead glass to reduce the radiation dose to the eyes.

The images were of poor quality, because

- Poor light output by the fluorescent screen for safe exposure rates
- Low efficiency of the light conversion mechanism of the screen
- Poor spatial resolution
Early Fluoroscopes (2)  (9)

Thomas Alva Edison wondered if it might be possible to find other chemicals that would fluoresce even more brightly when excited by the new rays.

Late March 1896, four men in Edison's laboratory had tried over 1,800 different salts and found that 72 fluoresced. Months later, some 8,000 substances had been tested, and the best found to be calcium tungstate.

Dark Rooms and Red Goggles  (10)

Due to the limited light produced from the fluorescent screens, early radiologists were required to sit in a darkened room thereby increasing their sensitivity to light.

Red adaption goggles were developed to shorten the 20 min dark adaption time of the eyes, see Fig 2.10.

The placement of the radiologists behind the screen resulted in significant radiation doses.
**Dark Rooms and Red Goggles**  (11)  
(2)

Fig 2.11: Protective cloths (1910)

Fig 2.12: Modern protective underwear

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**Fluoroscopy Sample Movies**  (12)

Fig 2.13: Fluoroscopy of the neck

Fig 2.14: US Army video (WW2)
The Shoe-Fitting Fluoroscope (13)

The shoe-fitting fluoroscope ([http://en.wikipedia.org/wiki/Shoe-Fitting_Fluoroscope](http://en.wikipedia.org/wiki/Shoe-Fitting_Fluoroscope)) (Pedoscope) is thought to have been invented around 1924 by Clarence Karrer while he worked with his father, selling surgical supplies and X-ray equipment. After building and selling several, he was asked by the Radiological Society of North America and some radiologists to stop because it lowered the dignity of the profession of radiology. Karrer complied, but one of his father’s employees quit the company and patented this device. For radioprotection reasons they stopped producing this system in the late 50’s.

The level of exposure ranged from 20 – 75 rem/min. The current maximum allowed exposure to workers in nuclear power stations in the USA is 5 rem/yr.

Image Intensifiers (15)

The development of X-ray image intensifiers (and the television camera) in the 1950s revolutionised fluoroscopy.

- The read adaption goggles often donned became obsolete,
- it enabled the viewing of the image on a monitor under normal lightning conditions, and
- away from the risk of radiation exposure.
Image Intensifiers (2)

The four main components of an image intensifier:

1. The vacuum tube
2. Input layer that converts the X-rays into electrons
3. Electronic lenses that focus the electrons
4. Output phosphor that converts the accelerated electrons into visible light

Input Window

The input screen is composed of four main components:

1. Aluminium (or Titanium) window (1 mm) that keeps the air out and is curved to withstand the air pressure (≈ 95% transmission efficiency for 60 kV X-rays)
2. The 0.5 mm curved aluminium support layer carries the input phosphor and focuses through its curvature
3. The input phosphor (CsI cesium iodide) absorbs X-rays and converts their energy into visible light (approx 3'000 photons with λ = 420 nm)
   - The long CsI crystals function as light pipes with minimal lateral spreading → keep focus
4. The photocathode (Antimon or Alkali metals) emits electrons (~300-600) when hit by visible light (10 – 20% conversion efficiency)
Output Window

The output window of the image intensifier is composed of:

1. The anode is very thin → each electron causes approx 1000 light photons
2. The output phosphor is made of Zinc cadmium sulfide (ZnCdS)
3. The reduction in image diameter (1 inch) leads to an intensity amplification → Minification Gain
4. Light bouncing around the output window is called Veiling glare and reduces image contrast

Fluoroscopic Imaging Chain

Fig. 2.19: Schematic diagram of the output window

Fig. 2.20: Components of the imaging chain
State-of-the-art Fluoroscope Setup

![Diagram of fluoroscope setup]

Fig 2.21: State-of-the-art fluoroscope setup

Fluoroscope with Brightness Control

![Diagram of fluoroscope with brightness control]

Fig 2.22: State-of-the-art fluoroscope with brightness (dosage) control
C-Arm

In 1955 Philips introduced the first mobile C-Arm system.

Fig 2.23: Philips C-Arm

Fig 2.24: Cervical dorsal root radiofrequency lesion performed in a patient with chronic cervical headache

Iso-C 3D

The SIREMOBIL Iso-C 3D introduced by Siemens tries to bridge the gap between fluoroscopes and CT. The iso-centric mechanical setup allows to capture 3D images intra-operatively.

The images are, however, of inferior quality compared to CT having a much lower contrast.

The Iso-C 3D is very helpful for patient referencing.
Flat Panel Digital Fluoroscopy

Flat Panel Digital Fluoroscopy  (26)

- Flat panels are X-ray detectors based on TFT (thin film transistor) technology
- The visible light from the scintillator (CsI) is converted to an electrical signal by a photodiode
- Flat panel detectors replace the image intensifier and video camera

→ Less geometrical distortions → easier more accurate calibration

→ Better for navigation e.g. in Image-Guided Therapy (IGT)

Fig. 2.26: Flat panel vs Image intensifier
Continuous Fluoroscopy (28)

- X-ray beam continuously on (Tube current 0.5 – 4 mA or higher)
- Display at 30 frames/s → 33 ms per frame
- Blurring due to patient motion is acceptable
- A special high X-ray dose protocol exists for obese patients → audio warning

Fig 2.27: Angiography with a conventional Image intensifier

Fig 2.28: Angiography with a flatpanel fluoroscope
Pulsed Fluoroscopy (29)

Pulsed Fluoroscopy is used when the high temporal resolution is not required:

- Series of short X-ray pulses at e.g. 10 ms per pulse and a frame rate of 30 frames/s
- The shorter exposure time reduces motion artifacts
- Other frame rates also available: 15 frames/s, 7.5 frames/s

→ allows to spare X-ray dosage.

Frame Averaging (30)

- Fluoroscopes have good temporal resolution
- Fluoroscopic images are quite noisy

→ Image averaging reduces noise but increases lag

- Does not work well on moving organs (motion blur)
- Gating, e.g. cardiac gating, can help in some cases

![Frame Averaging Diagram](image)

Fig. 2.29: The more images are averaged, the lower the noise level but the larger the lag
Digital Subtraction Arteriography

In Digital Subtraction Arteriography (DSA) the computer subtracts the (previously acquired) background from the current image. It is often used to

- display coronary trees with contrast enhancement, and to
- visualise the catheter.

Fig. 2.30: Principle of DSA imaging

Fig. 2.31: (a) Unsubtracted original digital fluoroscopic image obtained midway through the contrast material injection, (b-d) subtracted DSA images obtained at three time points during contrast material injection

Last-frame Hold

- When the radiologist takes his/her foot of the foot-switch the last frame is continuously displayed and the X-ray source switched off
- No unnecessary radiation exposure
Road Mapping

Road mapping is a software enhanced variant of the last-frame hold and is used for the placement of catheters and wires in complex and small vasculature.

- A DSA sequence is performed, the post-contrast frame with the highest vessel opacification is identified → roadmap mask
- The roadmap mask is then subtracted from all subsequent non-enhanced fluo images

Road Mapping Example

Fig. 2.32: Principle of road mapping

Fig. 2.33: Example of road mapping (a) DSA image, (b) road map image with the dark catheter
Application of the Fluoroscope (35) on TEVAR

Fluoroscopy is an essential tool for Thoracic endovascular aortic repair (TEVAR), where aortic stents are placed in stenotic coronary arteries.

In TEVAR interventions, the Fluoroscope is used in several different operation modes:

1. The passage of guidewires, catheters, and sheaths are performed under pulsed fluoroscopy
2. Continuous fluoroscopy is used to shoot a arteriogram
3. Digital subtraction arteriography (DSA) allows to display the contrast enhanced vasculature without the background
4. Road mapping is used for real-time catheter guidance with a contrast background acquired previously

Fluoroscopy Conclusion

Fluoroscopes are most often used for

- Intra-operative navigation
- Intra-operative referencing
- Target location

Problems

- Very low contrast
- Image noise