Principi Fisici della formazione dell'imagine in Mammografia e Tomosintesi

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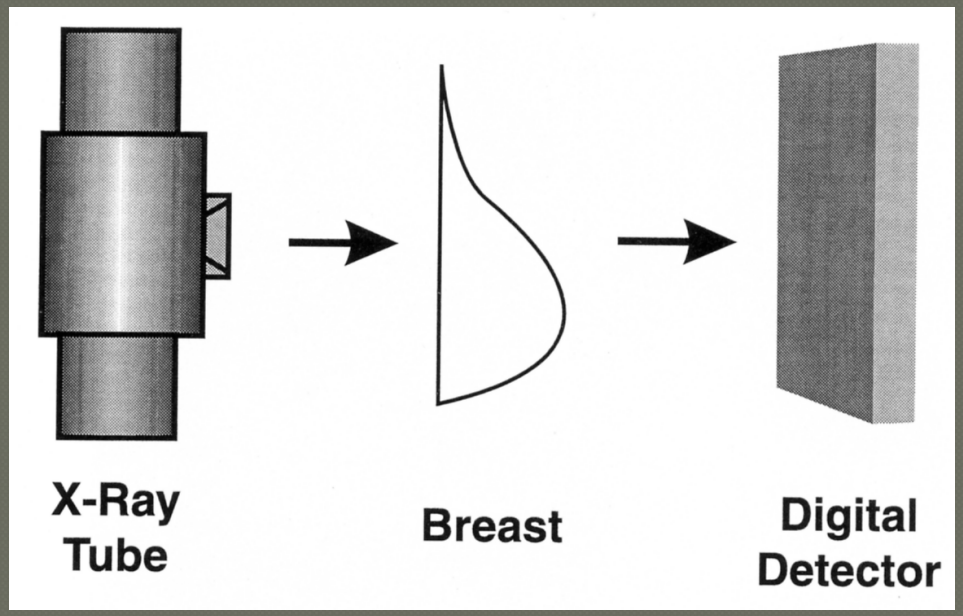
Convegno Nazionale GISMa, 14-16 Dicembre 2021

L'esame mammografico …



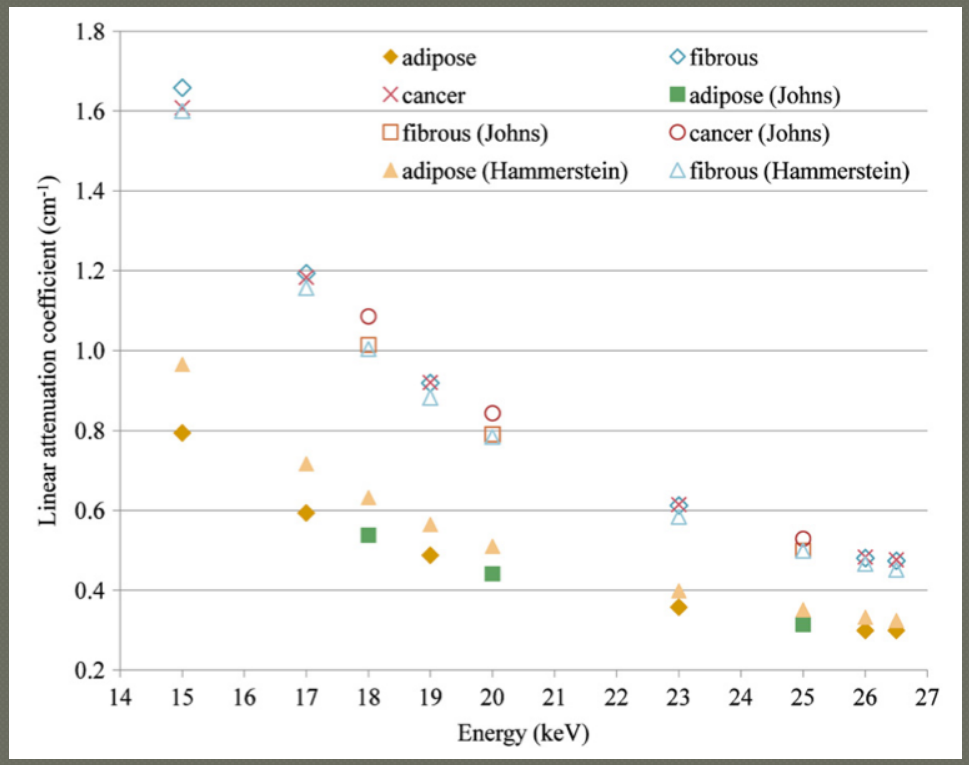
Esigenze dell'esame mammografico

ALTO CONTRASTO → **Visualizzazione di noduli**

ALTA RISOLUZIONE → **Visualizzazione di microcalcificazioni**

DOSE APPROPRIATA → **Minimizzazione del rischio**

Attenuazione dei raggi X



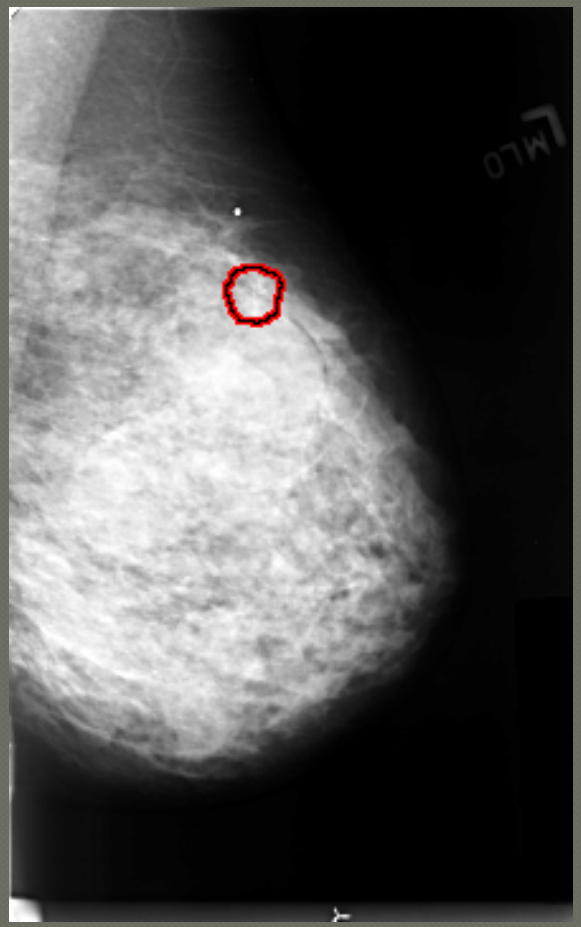
$$C \approx \Delta\mu \cdot x$$

R C Chen *et al*, Phys Med Biol 55, 2010
A Piai *et al*, Phys. Med. Biol. 64, 2019

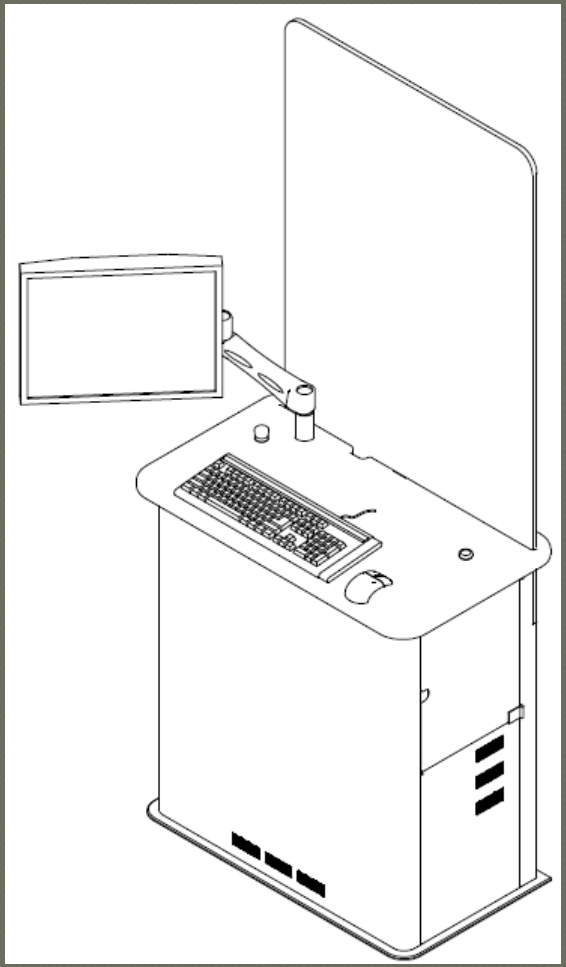
Lesion Conspicuity

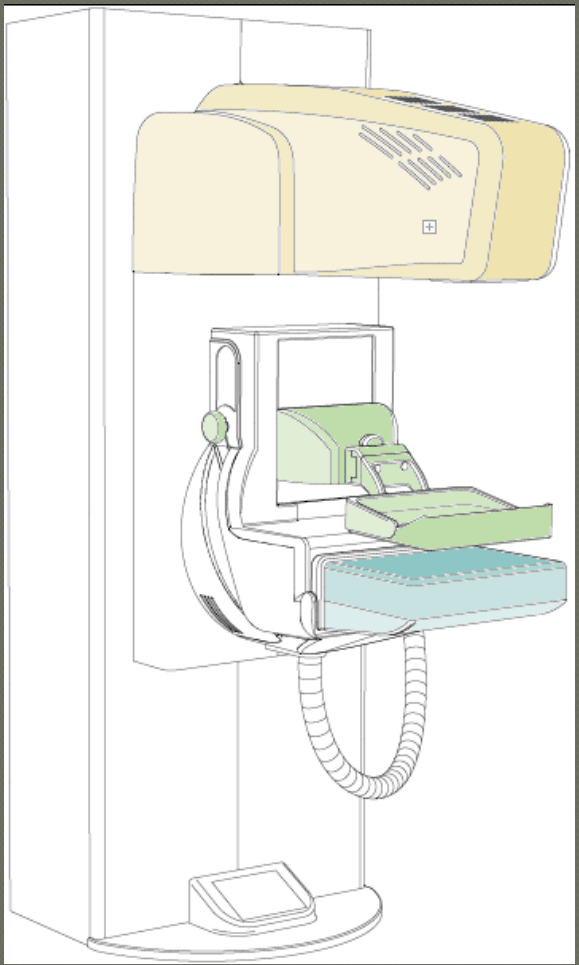
Seno Adiposo

Seno Denso



Il Mammografo





A Taibi and S Vecchio, *Breast Imaging*, 2014

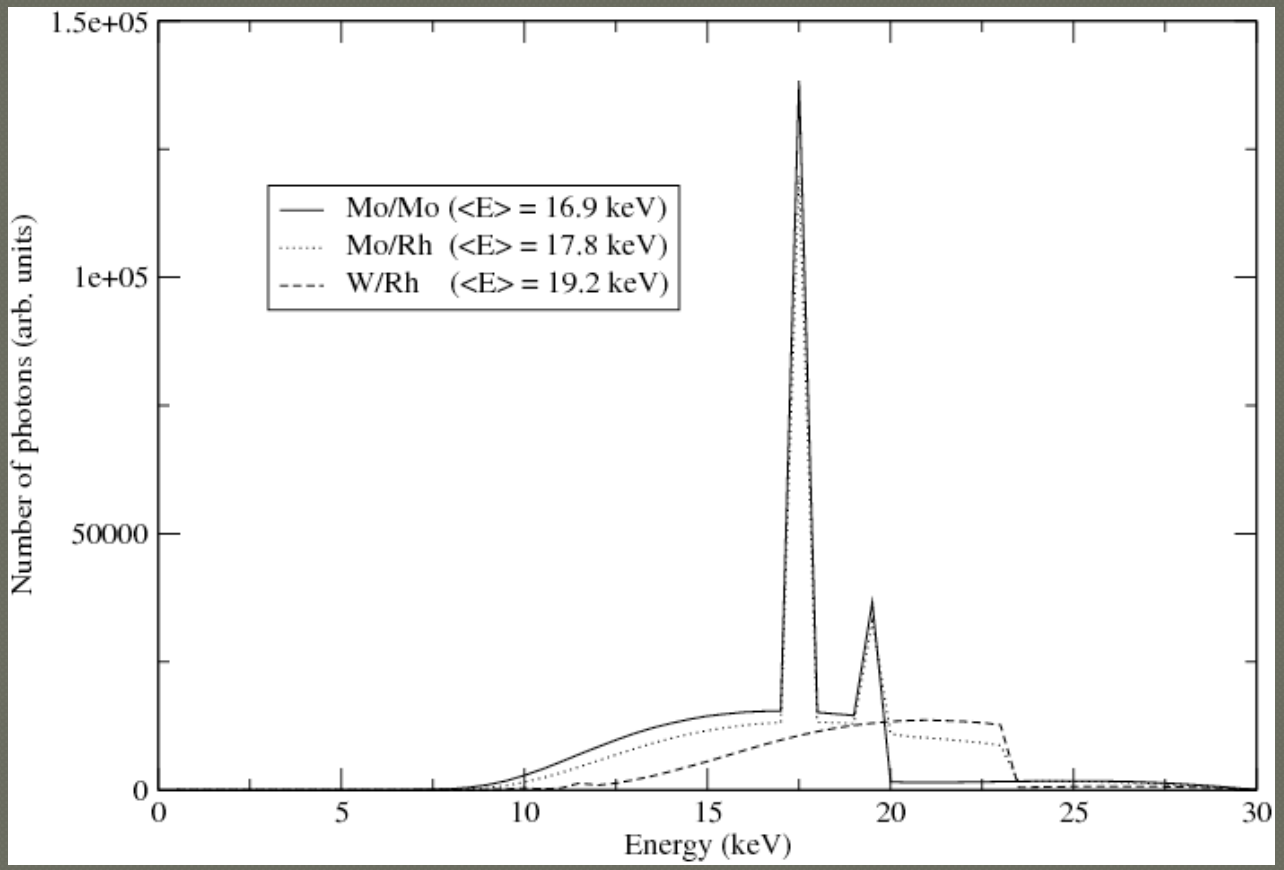
Sistema *quantum limited*

$$\frac{CNR^2}{MGD}$$

"For screen-film mammography, Mo/Mo is the spectrum of choice for all but the thickest or most glandular breasts. In digital mammography, an alternative spectrum is preferable for breasts thicker than 2 cm"

Dance *et al*, Br J Radiol 73, 2000

Molibdeno vs Tungsteno



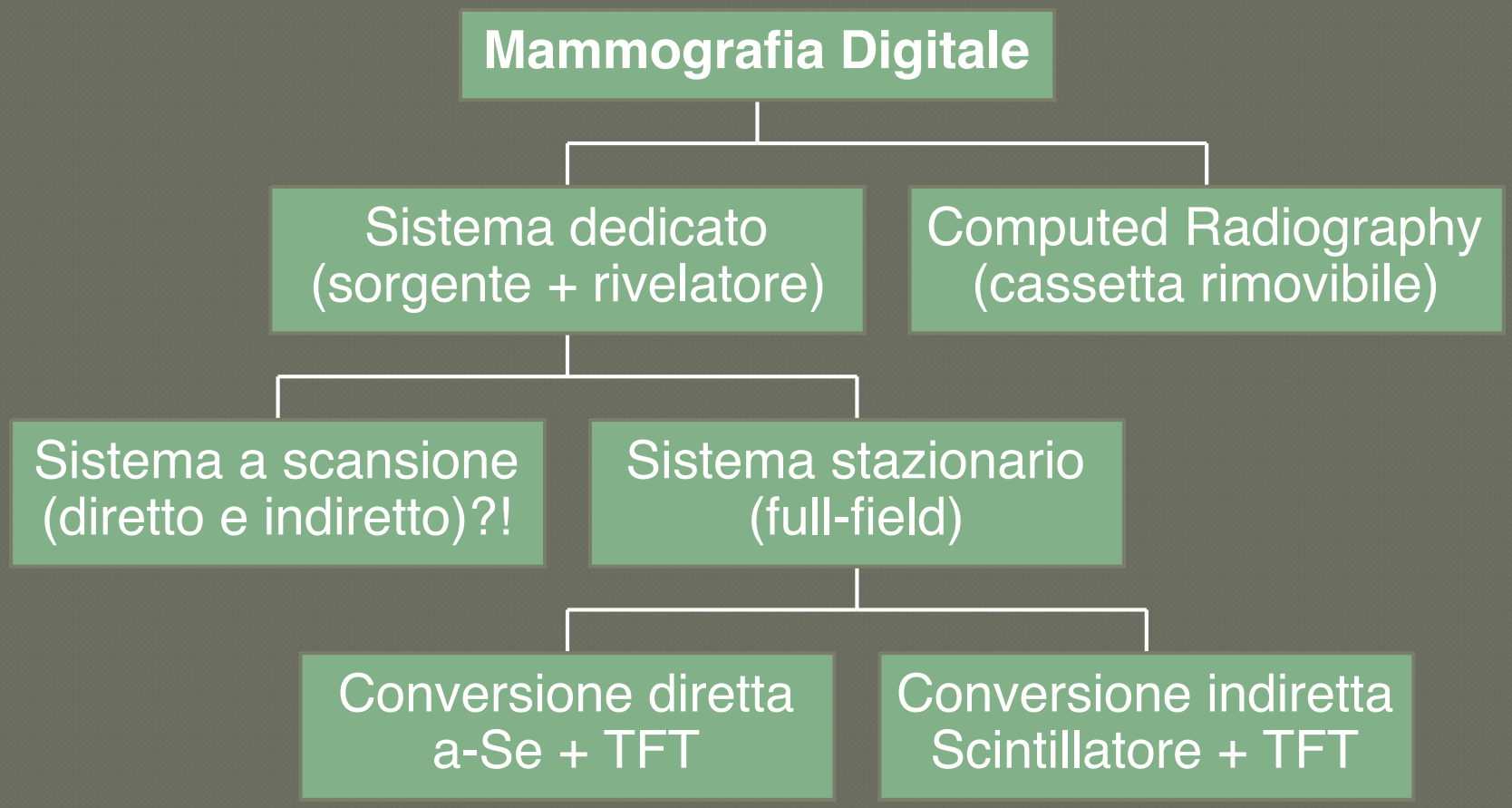
Anodo/Filtro vs Mammografo

- Mo, Rh (Mo, Rh): General Electric
- Mo (Mo, Rh), W (Mo, Rh, Al): Siemens
- W (Rh/Ag): IMS
- W (Al): Philips (Sectra)
- W (Rh/Ag): Hologic

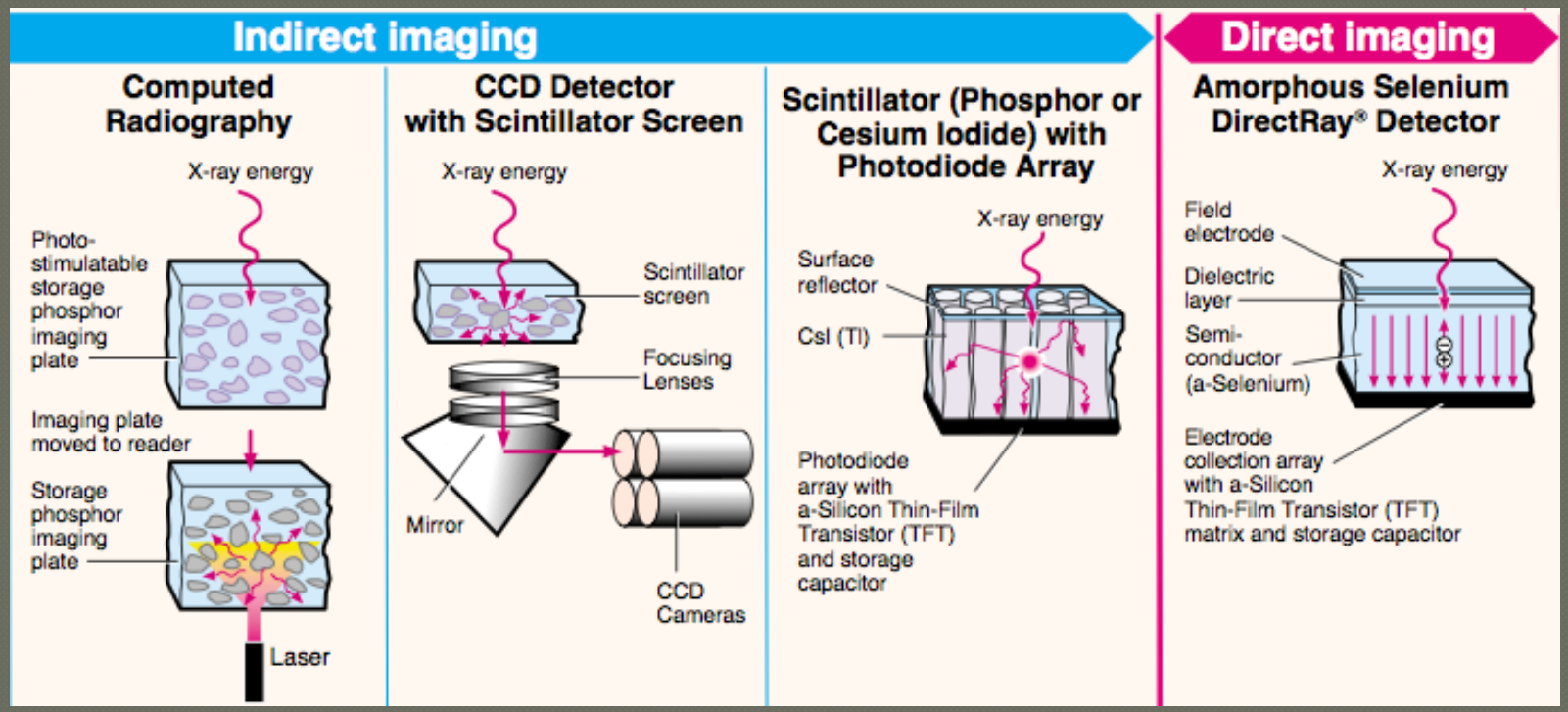
L'uso del compressore …

- Minore dose
- Minore sovrapposizione delle strutture anatomiche
- Minore dinamica (latitudine)
- Maggiore nitidezza (minor tempo di esposizione)
- Minore radiazione diffusa

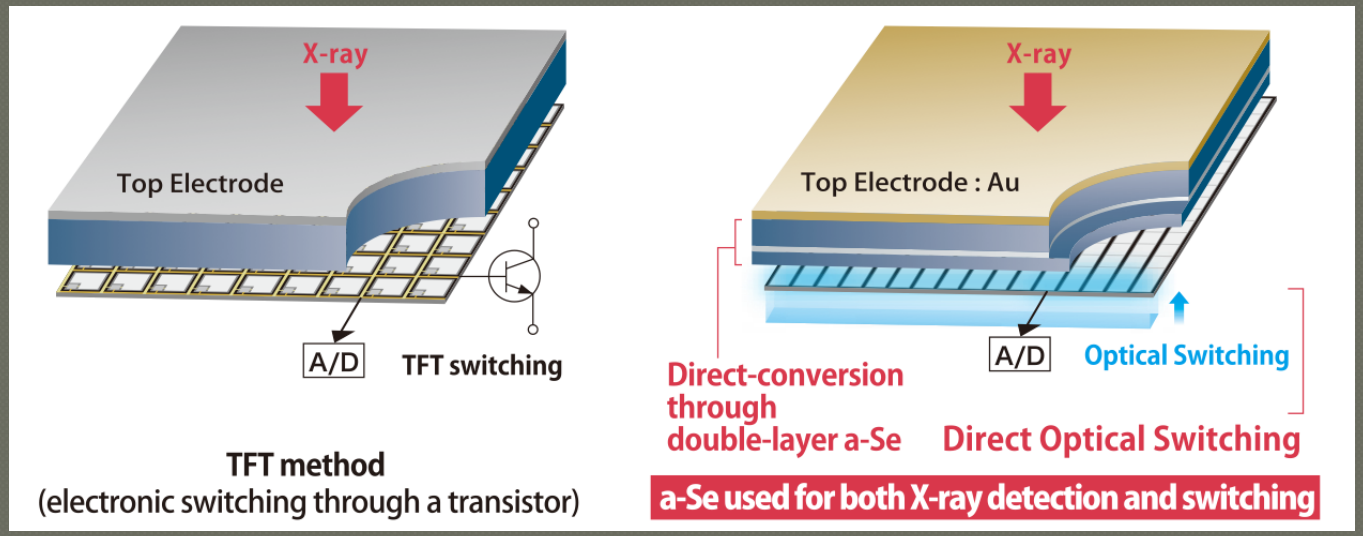
Rivelatori per Mammografia Digitale



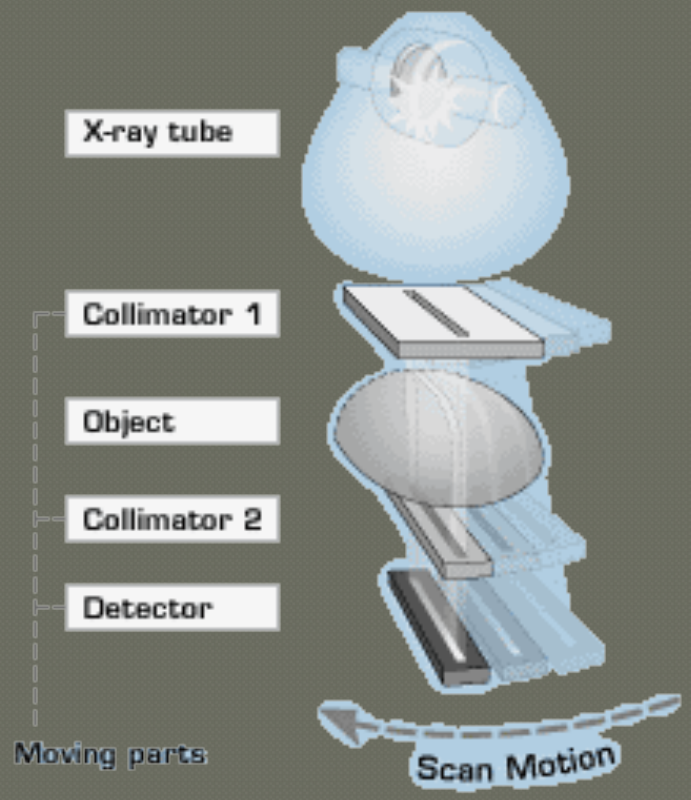
Rivelatori per Mammografia Digitale



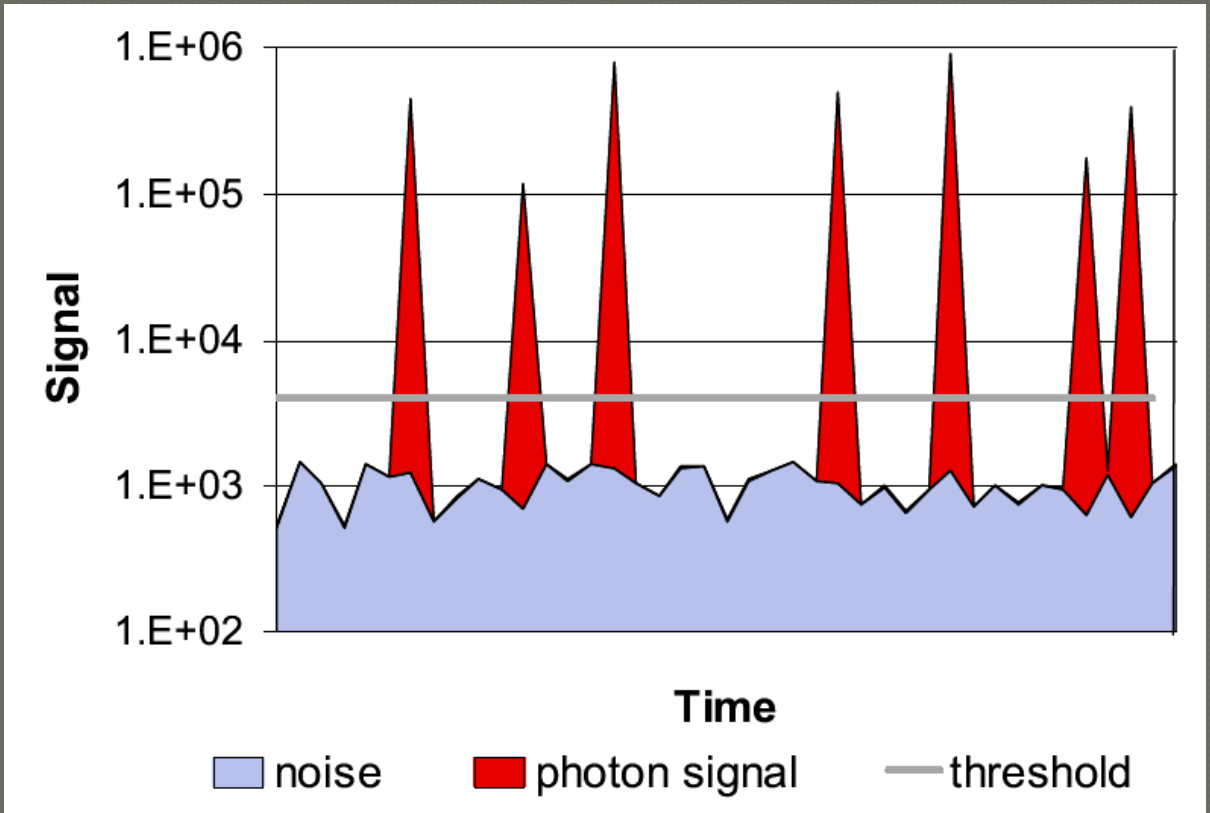
Altre strategie per rivelatori a-Se



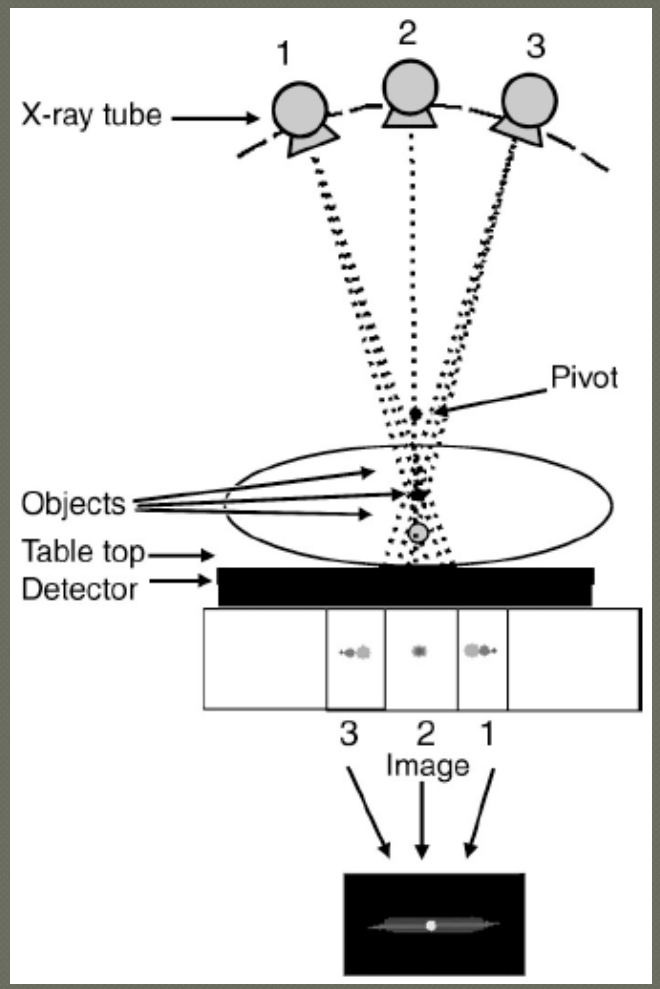
Rivelatore *photon counting*



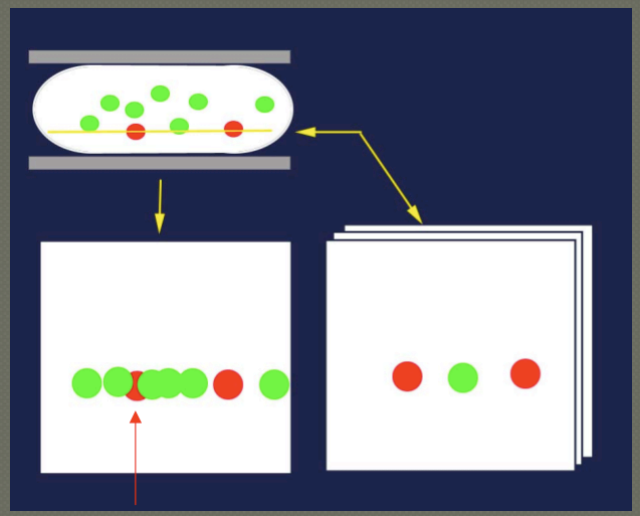
Discriminazione del segnale

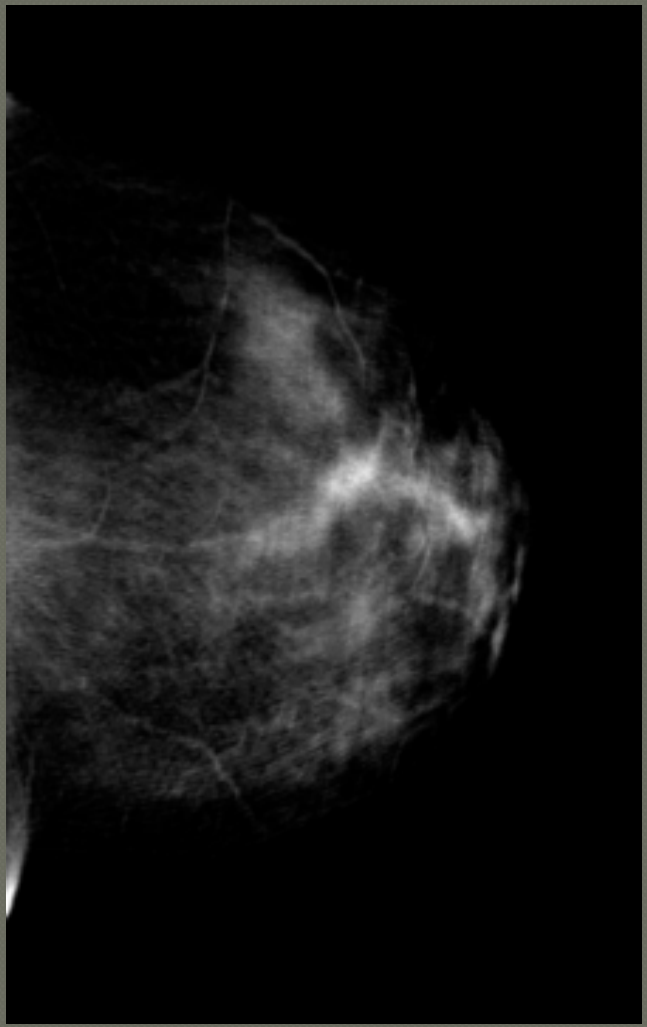


Tomosynthesis = limited-angle cone-beam Tomography



Attraverso una serie di radiografie (2D) del seno effettuate a bassa dose ruotando il tubo a raggi X, si ricostruiscono tomogrammi (3D) per ridurre le sovrapposizioni anatomiche





DBT System	*GE Healthcare SenoClaire*	*GE Healthcare Pristina*	*Hologic Selenia Dimensions*	*IMS Giotto TOMO*	*IMS Giotto Class*	*Philips Microdose*	*Planmed Clarity3D*	*Siemens Mammomat Inspiration*	*Fujifilm Amulet Innovality*
Type of geometry	Full-field	Full-field	Full-field	Full-field	Full-field	Scanning multislit	Full-field	Full-field	Full-field
Detector type	Energy integrating	Energy integrating	Energy integrating	Energy integrating	Energy integrating	Photon counting	Energy integrating	Energy integrating	Energy integrating
Detector material	CsI-Si	CsI-Si	a-Se	a-Se	a-Se	Si	CsI-a-Si	a-Se	a-Se
Detector element pitch (µm)	100	100	70	85	85	50	83	85	68[5]
Focal plane pixel size (µm)	100	100	95-117[1]	90	90	100	83/166	85	50-100/ 100-150
X-ray tube motion	Step-and shoot	Step-and shoot	Continuous	Step-and shoot	Step-and-shoot	Continuous	Continuous Sync-and-Shoot	Continuous	Continuous
Target	Mo/Rh	Mo/Rh	W	W	W	W	W	W	W
Filter	Mo: 30µm Rh: 25 µm	Mo: 30µm Ag: 30µm	Al: 700 µm	Rh: 50 µm Ag: 50 µm	Ag: 50 µm	Al: 500 µm	Rh: 75 µm Ag: 60 µm	Rh: 50 µm	Al: 700 µm
Angular range (°)	25	25	15	40[2]	30	N/A[6]	30	50	15/40
Number of projection images	9	9	15	13	11	21[3]	15	25	15

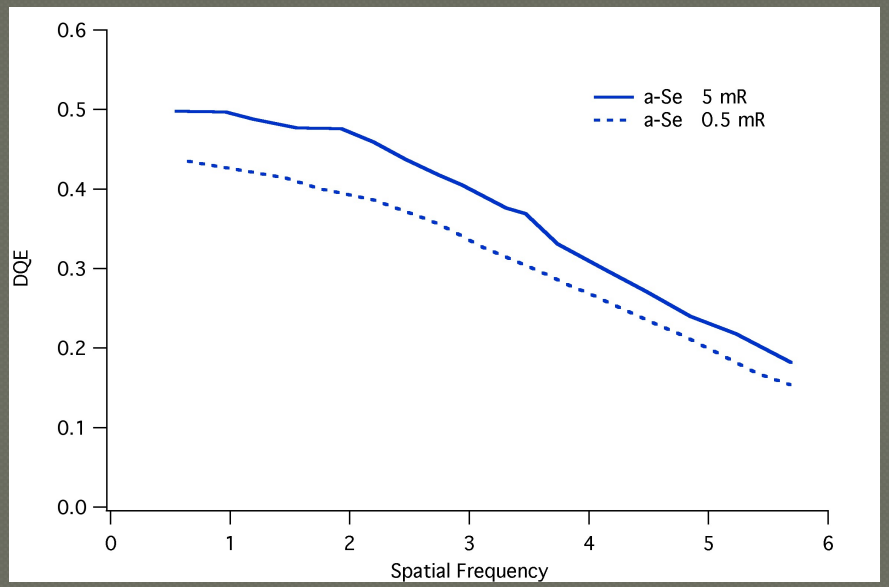
I Sechopoulos, Med Phys 40 (2013)

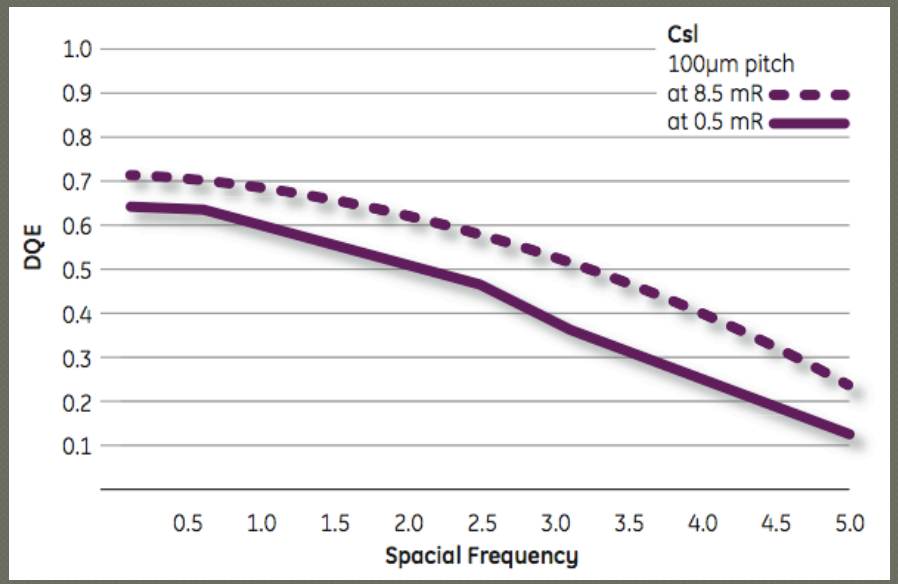
EUREF QC Protocol (ver. 1.0.3, 2018)

Confronto fra Sistemi Clinici

	GE Healthcare	Fujifilm	Hologic	IMS	Siemens
Pixel Size (µm)	100	68 (exagonal) 100/150	70/100	85	85
Detector	CsI	a-Se (HCP)	a-Se	a-Se (Anrad)	a-Se (Anrad)
Anode	Mo / Rh	Tungsten	Tungsten	Tungsten	Mo / Tungsten
Angular Range	25°	15° (ST) 40° (HR)	15°	30°	50°
Projections	9	15	15	11	25
Scan time	< 7 seconds	~ 4 seconds	< 4 seconds	< 10 seconds	15 ÷ 25 sec.
Scan mode	Step & Shoot	Continuous	Continuous	Step & Shoot	Continuous
Reconstruction	FBP/Iterative	Iterative	FBP	Iterative	Iterative
Functions	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)

Detector performance vs Dose





Uno spettro più energetico

- Penetrazione obliqua del fascio
- Tomosintesi: mammelle dense …
- Lunghi tempi di esposizione
- Rumore elettronico
- “Limiti” di dose

Confronto fra Sistemi Clinici

	GE Healthcare	Fujifilm	Hologic	IMS	Siemens
Pixel Size (µm)	100	68 (exagonal) 100/150	70/100	85	85
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Functions	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)

Parametri di acquisizione

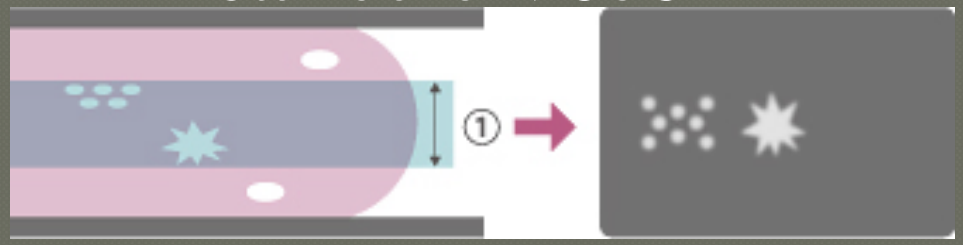
- Numero di proiezioni migliora la ricostruzione ma aumenta il tempo di acquisizione
  (e produce anche immagini a bassa statistica)
  10-25 proiezioni

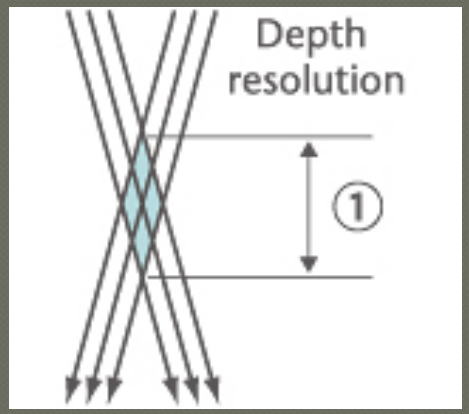
- Apertura angolare migliora la risoluzione in profondità ma riduce quella planare
  15-50 gradi

- Dose totale simile alla mammografia (CC+MLO)

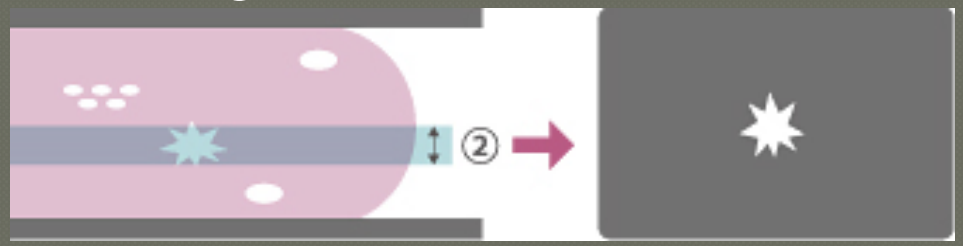
Doppia modalità di acquisizione

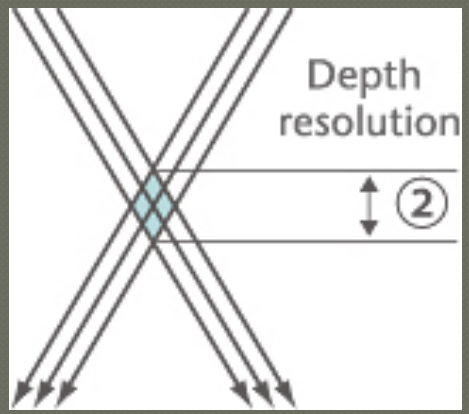
Standard Mode





High Resolution Mode





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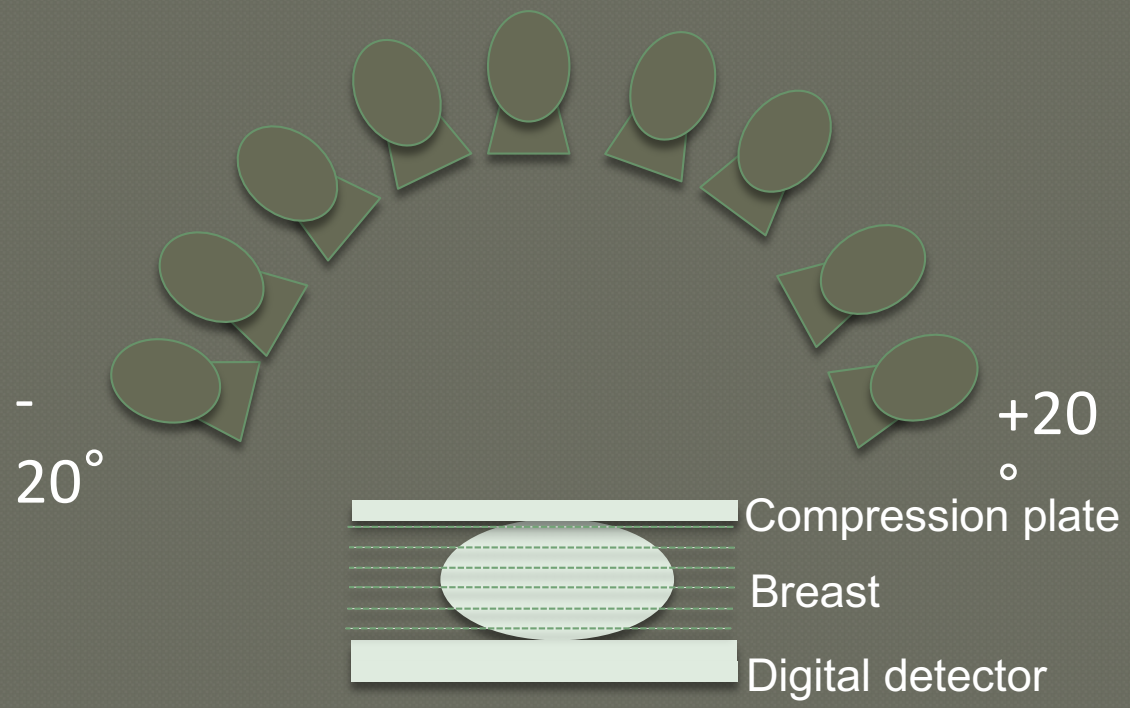
Step & Shoot vs Continuous

Il tubo RX si muove rapidamente lungo un arco fermandosi ad ogni esposizione per una frazione di secondo



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Functions	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)	Mammo/Tomo (Sintetica)

Algoritmi di Ricostruzione

- Mathematic method of geometric transformation
  - SAA (Shift-And-Add)
  - BP (Back-Projection)
- Mathematic method of Fourier Transformation
  - FBP: Filtered Back-Projection
- Statistical reconstruction algorithms
  - MLEM: Maximum-Likelihood Expectation-Maximization
- Algebraic reconstruction algorithms:
  - SART: Simultaneous Algebraic Reconstruction Tech.

Algoritmi di Ricostruzione

A review of breast tomosynthesis. Part II. Image reconstruction, processing and analysis, and advanced applications

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(Received 13 June 2012; revised 16 November 2012; accepted for publication 16 November 2012; published 4 January 2013)

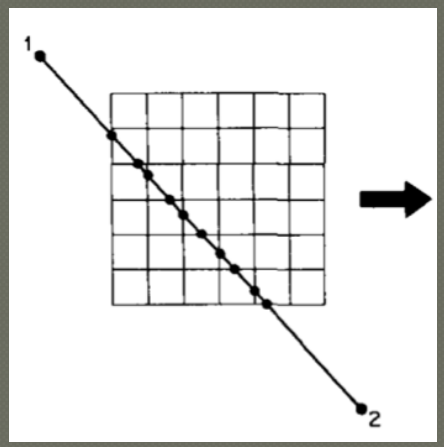
Many important post-acquisition aspects of breast tomosynthesis imaging can impact its clinical performance. Chief among them is the reconstruction algorithm that generates the representation of the three-dimensional breast volume from the acquired projections. But even after reconstruction, additional processes, such as artifact reduction algorithms, computer aided detection and diagnosis, among others, can also impact the performance of breast tomosynthesis in the clinical realm. In this two part paper, a review of breast tomosynthesis research is performed, with an emphasis on its medical physics aspects. In the companion paper, the first part of this review, the research performed relevant to the image acquisition process is examined. This second part will review the research on the post-acquisition aspects, including reconstruction, image processing, and analysis, as well as the advanced applications being investigated for breast tomosynthesis. [http://dx.doi.org/10.1118/1.4770281]

Immagine Sintetica in DBT

- Tomosynthesis plus 2D significantly increase the cancer detection rate as compared with FFDM alone*
- Tomosynthesis with synthetic 2D images makes combined 2D and 3D possible with the same radiation dose as conventional FFDM
- The additional interpretation time for 3D + 2D as compared to 2D alone is acceptable for implementation in organized breast cancer screening

*Skaane et al, Radiology 267, 2013

Riproiezione 2D del Volume DBT



… Re-projection methods are well known in the field of image processing. A source point and image plane is chosen, on opposite sides of the image volume. Pixels are obtained by projecting the source point though the slice set to an image plane point. The pixel value is summed at each slice location by interpolating values in the original slices …

System and method for generating a 2D image from a tomosynthesis data set

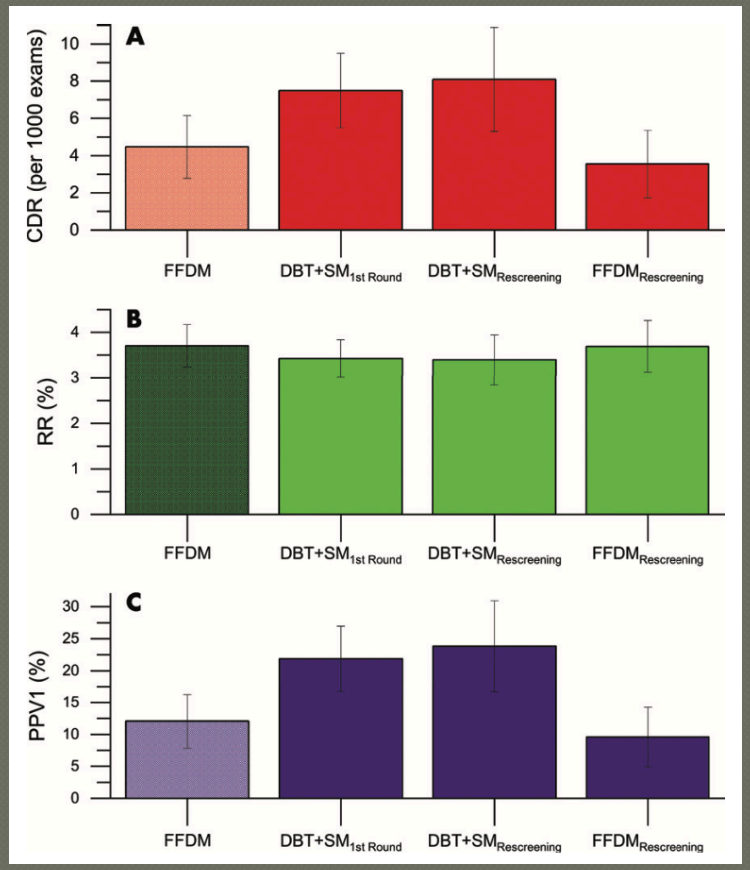
US patent no. 7,760,924 B2, 2010

Differenze nel Cancer Detection Rate?

Screening with DBT + synthetic 2D vs. DBT + conventional mammography			
	DBT + synthetic 2D mammography	DBT + conventional mammography	p-value
Cancers detected per 1,000 screened	5.03	5.45	0.723
Clinical recall rate	7.1%	8.8%	< 0.001
Technical recall rate	0.1%	0.2%	0.03
Biopsy rate	1.3%	2.0%	0.001
Invasive cancers vs. ductal carcinomas in situ per 1,000 screened	4.10	3.85	0.301
Radiation dose	4.88 mGy	7.97 mGy	< 0.001

Zuckerman et al, Radiology 281, 2016

DBT+SM vs FFDM



F Caumo *et al*, Radiology 298, 2021

Sintetica & Microcalcificazioni: studio su fantocci

Phys. Med. Biol. **63** (2018) 165020 (19pp) https://doi.org/10.1088/1361-6560/aad106

Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

PAPER

A comparative study of physical image quality in digital and synthetic mammography from commercially available mammography systems

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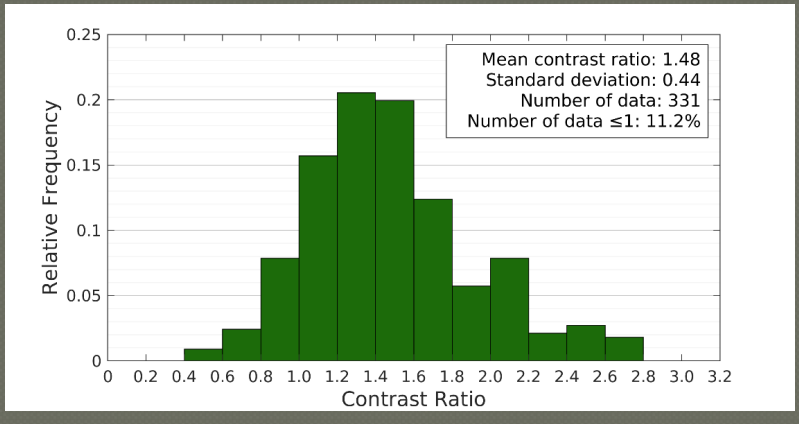
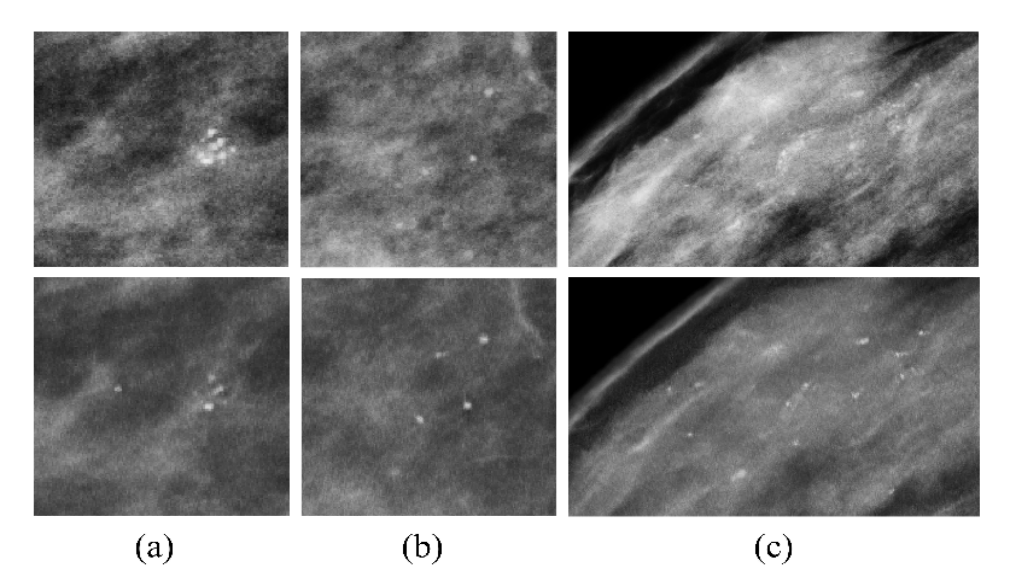
Keywords: digital breast tomosynthesis, mammography phantom, volume reprojection

Sintetica & Microcalcificazioni: immagini cliniche

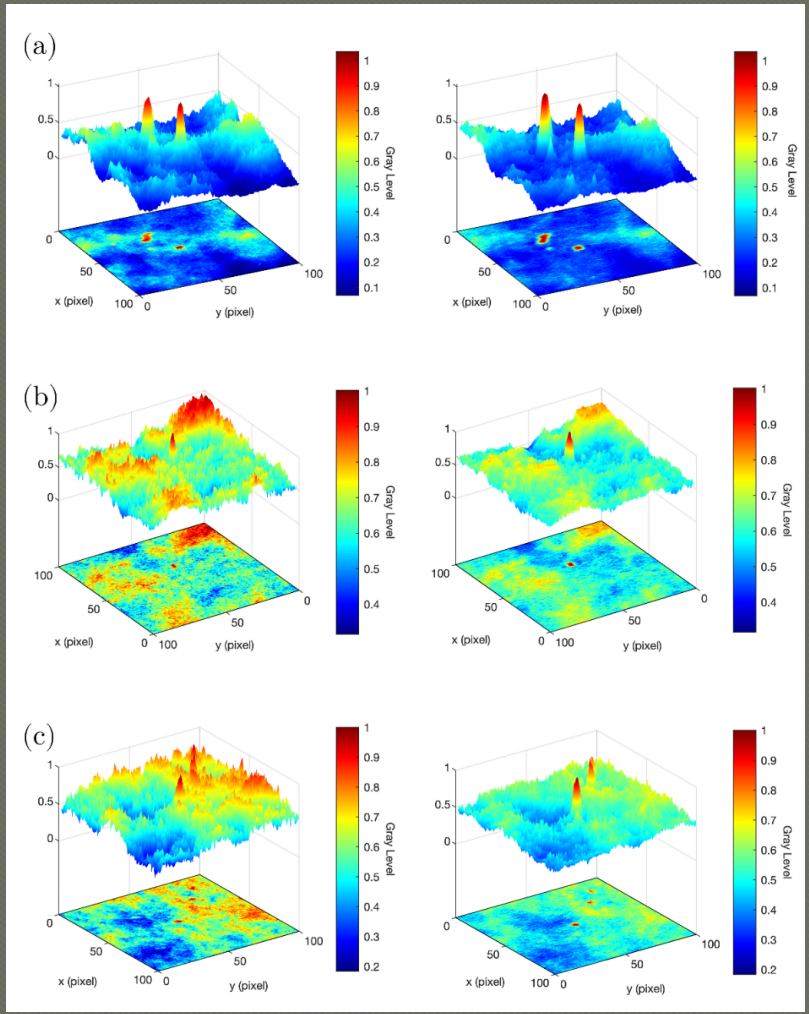




P Baldelli *et al*, EJR 140, 2021

Sintetica & Microcalcificazioni: immagini cliniche

DM images



SM images

Considerazioni finali

- I limiti della mammografia sono ben noti …
- La DBT è ormai una tecnica matura (screening?)
- Altre applicazioni avanzate (CESM, BCT) sono state proposte per migliorare il potenziale diagnostico