In the Name of God

A review of advancements in dedicated PET scanners

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Outline

- Why we need dedicated PET scanners?
- Dedicated PET scanners
  - Brain PET
  - Breast PET
  - Prostate PET
  - Cardiac PET
  - Multipurpose PET scanner
  - Small animal imaging
  - PET in operating room
- Challenges

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History

- ✓ First clinical positron imaging device developed in 1953 by Dr. Brownell (left) and Dr. Aronow (right): A pair of sodium iodide detectors

Why we need dedicated PET scanners?

- During the past 70 years, PET instrumentation has undergone significant advancements in its performance characteristics, application, and availability.
- It is evident that improving the performance of PET in terms of spatial resolution and sensitivity will lead to wider adoption of this imaging modality in the clinic.
- **Availability/Accessibility** depends mostly on fabrication cost.
- Based on a recent report by the IAEA, among 212 countries, only 109 have access to PET technology.
- The number of PET scanners in high-income countries is 3.52 per million population, while it falls to 0.004 per million in low-income countries.
- They estimated that approximately 229.3 M US$ are needed to equip these 96 countries with 16-slice PET/ CT scanners.

These statistics raise a few important questions:

I. Should the medical physics community (mainly instrumentation research groups) focus on improving PET scanners' performance or their accessibility?

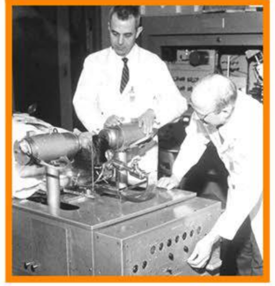
II. Is it really necessary to compete toward developing fancy detector modules or complex PET configurations to improve the spatial resolution by a few percent or compete on developing methods for reducing fabrication cost?

III. As a thought experiment, is it more beneficial for the society to have more PET scanners with low performance or fewer PET scanners with high performance?

✓ **Dedicated or organ-specific PET scanner**

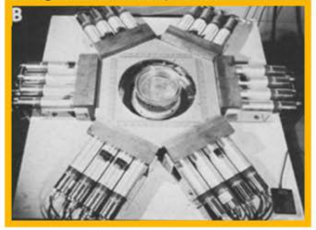
The History of Dedicated and Irregular PET Scanners

1953
Dr. Brownell and Dr. Aronow created the first clinical positron imaging device.



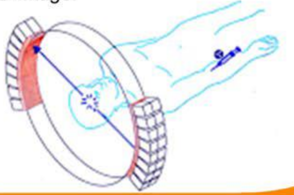
1969
First PET scanner with two planar arrays of crystals. The patient is positioned between the two detectors. Developed by Dr. Brownell

1974
Dr. Ter-Pogossian built the first positron emission transaxial tomography(**PETT**). A hexagonal array of NaI scintillation detectors was constructed surrounding a single transaxial plane.

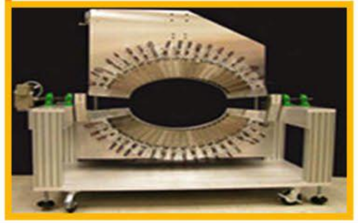


1979
First commercial emission computerized axial tomograph (**ECAT**), with hexagonal array of detectors.

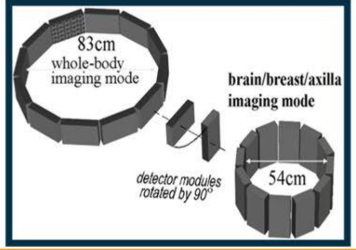
1990
A schematic of the **PRT-1**, a rotating PET scanner developed and fabricated at the University of Geneva, Switzerland. A low-cost design with reducing 40% of the detectors used in a full ring scanner. With two opposing BGO block detectors that rotated around the patient to acquire a full 3D image.



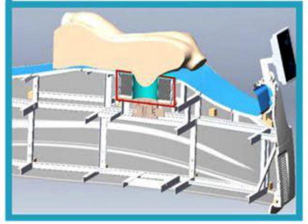
2006
Dedicated **prostate PET** with a pair of external curved detector modules. The distance between detector modules adjusts to position the detectors as closely as possible for maximum sensitivity with patients of various sizes.



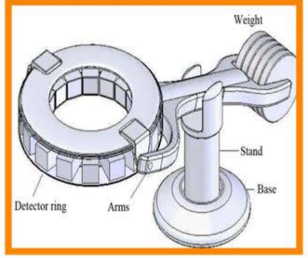
2007
HOTPET can change its AFOV and TFOV and transform from whole-body mode to brain/breast mode.



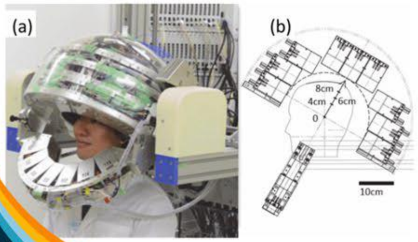
2009
PEMi is a dedicated breast PET scanner constructed in a polygon structure with LYSO crystal arrays mounted on a position sensitive photomultiplier.



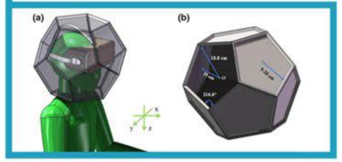
2011
PET-HAT is a low-cost wearable brain PET. By mechanical supports of the detector ring, it allows scanning of subject with freedom of motion.



2016
Helmet-chin PET geometry is consisting of a hemispheric-shaped detector and a chin detector to increase the sensitivity.



2018
Dedicated brain PET system with **dodecahedral** geometry with 11 regular pentagon detectors. The overall sensitivity by a factor of 4.91 increased in compare with the cylindrical brain PET system.

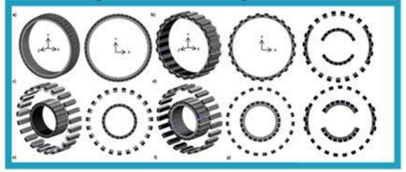


2018
Dr. Cherry and Dr. Badawi created the first clinical total body PET scanner.

2019
CareMiBrain dedicated cylindrical brain PET based on monolithic crystals.

2020
ProsPET is a prostate-dedicated PET scanner with monolithic LYSO and two movable parts that open and close.

2022
Active-PET is a multifunctional PET scanner with two different types of detector modules and mechanical jack to repositioning the detectors to allow the implementation of different geometries/configurations.



Dedicated PET scanners:

- Dedicated PET scanners optimized for scanning one specific organ offer both high performance and low manufacturing cost in comparison with general-purpose high-end whole-body PET scanners, which makes them more affordable and accessible.

- Their easier commissioning, maintenance, and training in addition to their smaller fingerprint or space consumption make them ideal for low-income and middle-income countries and small clinics in high-income countries.

Dedicated PET scanners:

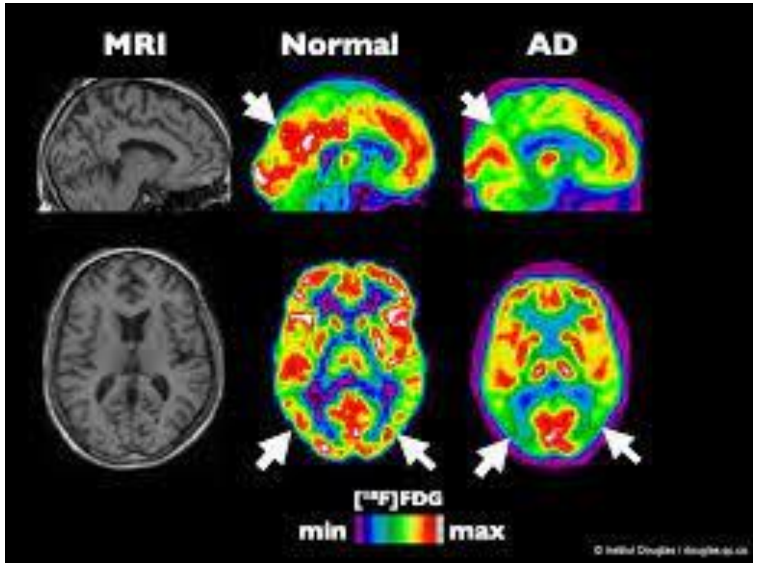
- **Better system sensitivity**
  - Reduce Injected Dose
  - Reduce Scan Time
  - Improve The Signal-to-noise Ratio
  - Improve temporal resolution for dynamic studies
- **Better spatial resolution**
  - A higher spatial resolution would be appreciated to register underlying signals from fine brain structures and neuro-connections.
- **Better image quality**

Organ-specific PET scanners:

- Brain
- Breast
- Prostate
- Cardiac
- Operating room
- PET scanners with cylindrical and non-cylindrical geometries (e.g., planar, partial-ring, oval shape, spherical/hat shape, etc.).
- Multi-purpose or conventional PET scanners
- In beam PET scanners: Dose verification in heavy-ion radiation therapy.

Brain PET imaging

- Cerebral blood flow evaluation
- Brain metabolism study
- Brain tumor screening
- Evaluation of vascular and neurological diseases
- Investigation of the localization of lesions associated with treatment-resistant epilepsy disorder

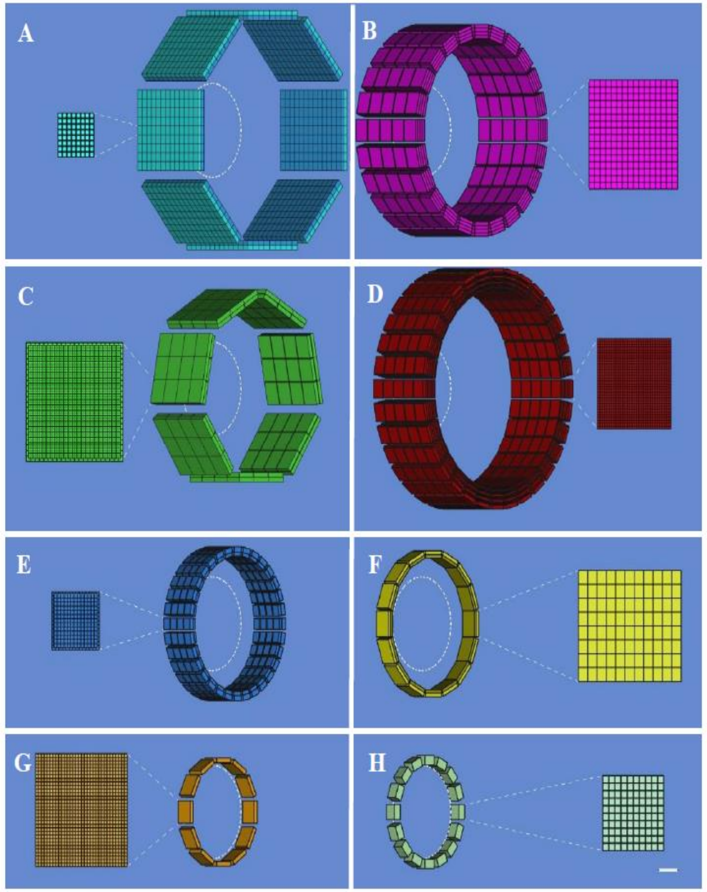


✓ With the developments of specific radiotracers, various applications of PET in neurology specially in in the diagnosis of neurodegenerative diseases have been found during the past two decades, such as:

- Dopamine neurotransmitter imaging in parkinson's disease
- Amyloid beta plaque and tau imaging in alzheimer's disease

Dedicated Brain PET … Conventional geometry

HRRT
CTI/Siemens
2 Layer LYSO (DOI)
2.5 mm Resolution



jPET-D4
Japan
4 Layer Gadolinium orthosilicate (DOI)
3 mm Resolution

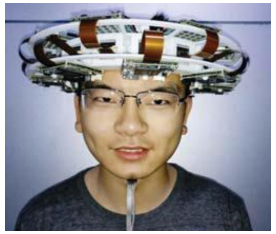
NeuroPET/CT
2 Layer LYSO (DOI)
3 mm Resolution

Hamamatsu
Japan
4 Layer LYSO (DOI)
2 mm Resolution

BBX
Brain, Breast, Extremities
Portable
2 Layer LYSO (DOI)
3 mm Resolution

PET-Hat
Freedom of movement
2 Layer Gadolinium orthosilicate (DOI)
<4.2 mm Resolution

Helmet-PET
Wearable
2 Layer LYSO (DOI)

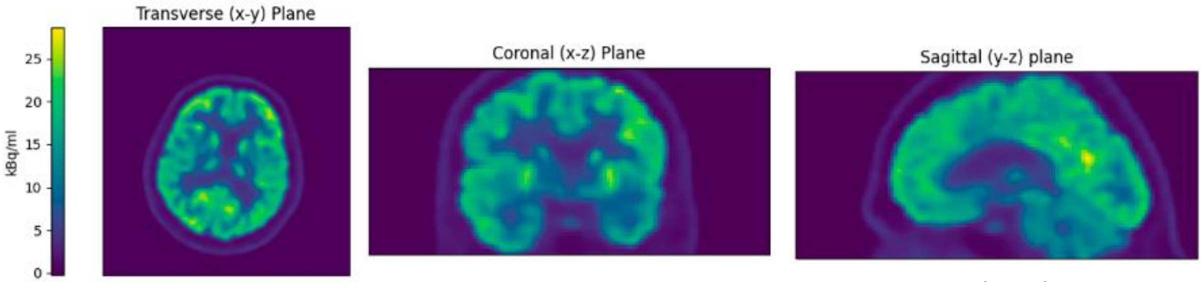


Mind-Tracker
Wearable
LYSO
3 kg
Imaging over a period of time

Dedicated Brain PET … Conventional geometry

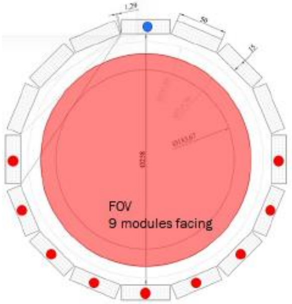
NeuroLF: FDA Approved

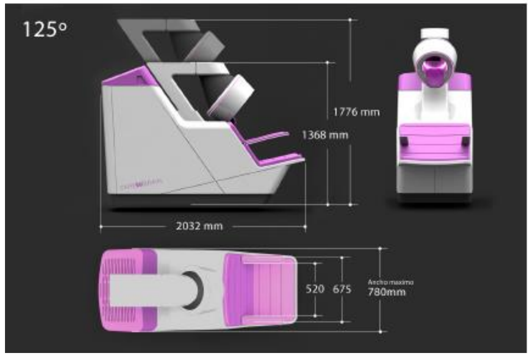
- Positrigo AG (Zurich, Switzerland)
- Ultracompact dedicated brain PET scanner
- LYSO, octagonal prism geometry

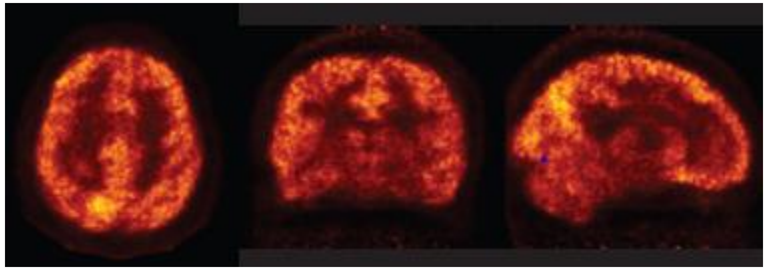


CareMiBrain

- Oncovision S.A. Spain
- Monolithic LYSO (50×50×15 mm3), 3 Detector ring







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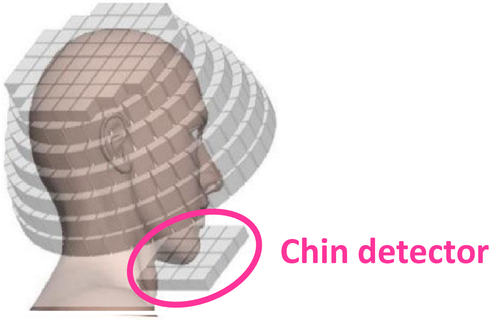
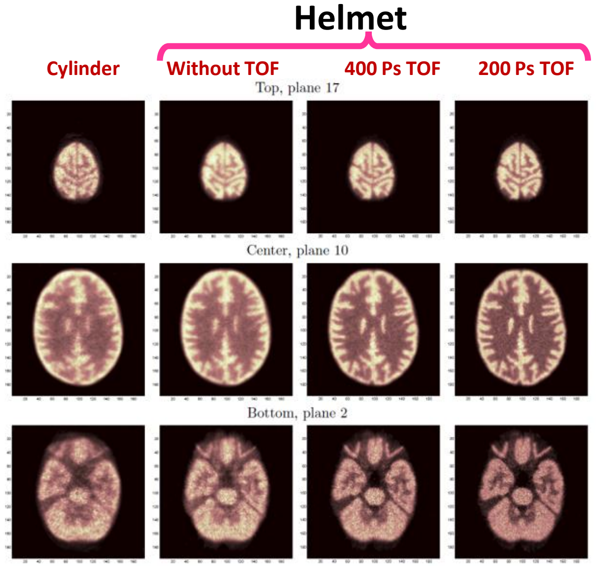
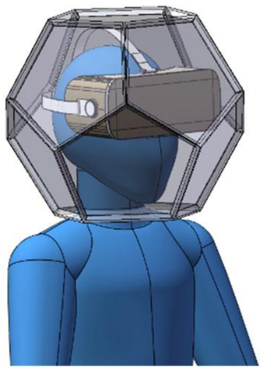
Dedicated Brain PET … Non-Conventional geometry

- Helmet
  - Add-on detectors were placed in various locations (i.e. chin, ear, neck)

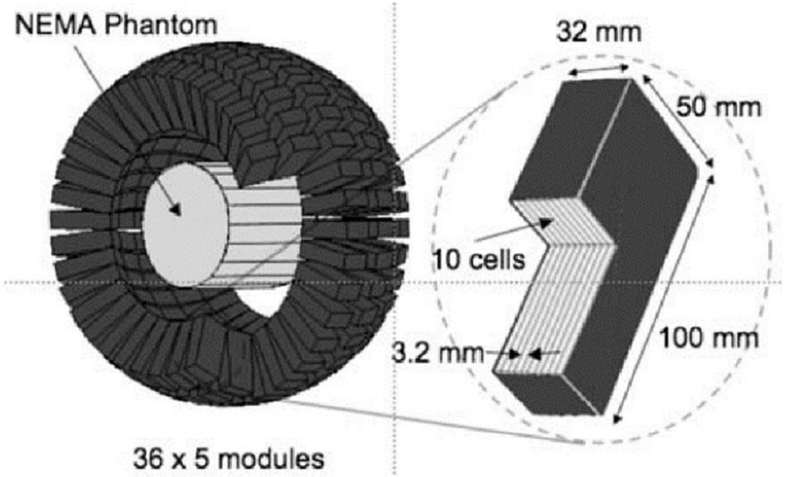


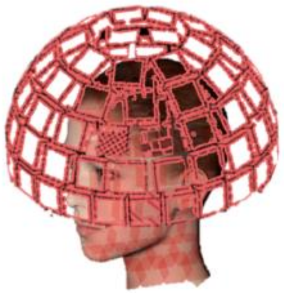


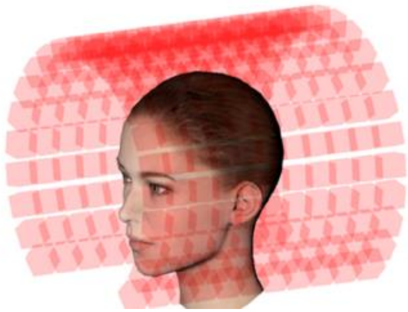
- Dodecahedral Geometry

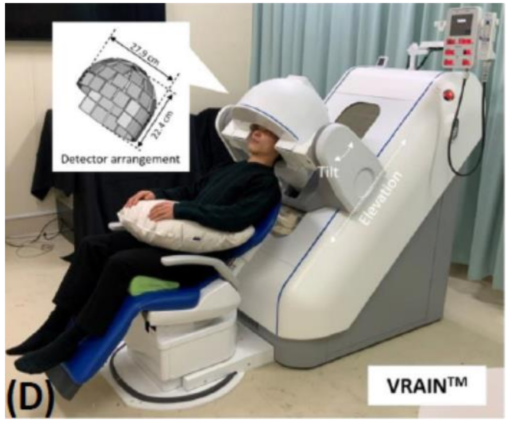


- Spherical Geometries



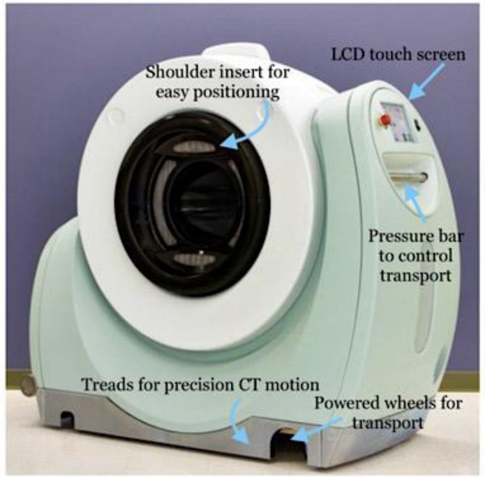




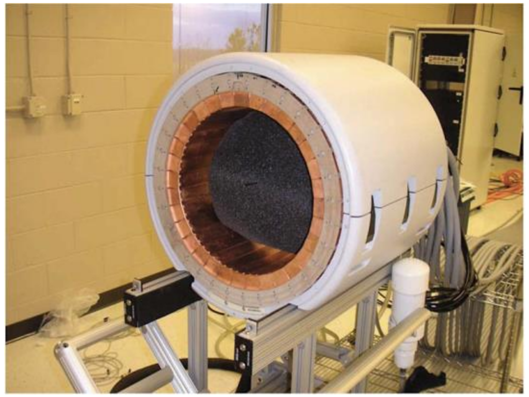


Multi Modality Brain PET

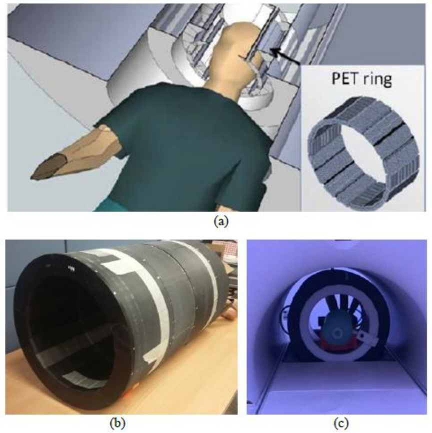
PET/CT
Neuro PET/CT



BrainPET was combined with the Siemens MAGNETOM Trio MRI

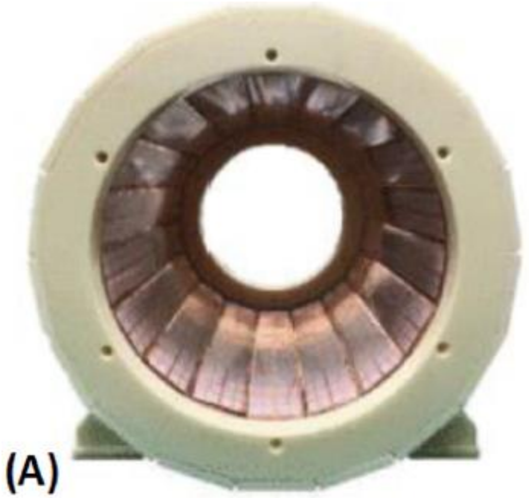


PET-MRI (1.5-T) electroencephalogram (EEG)

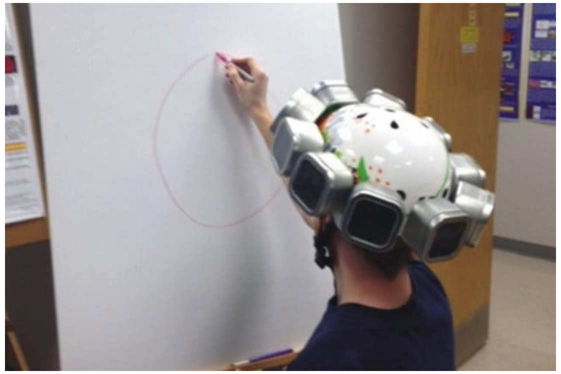


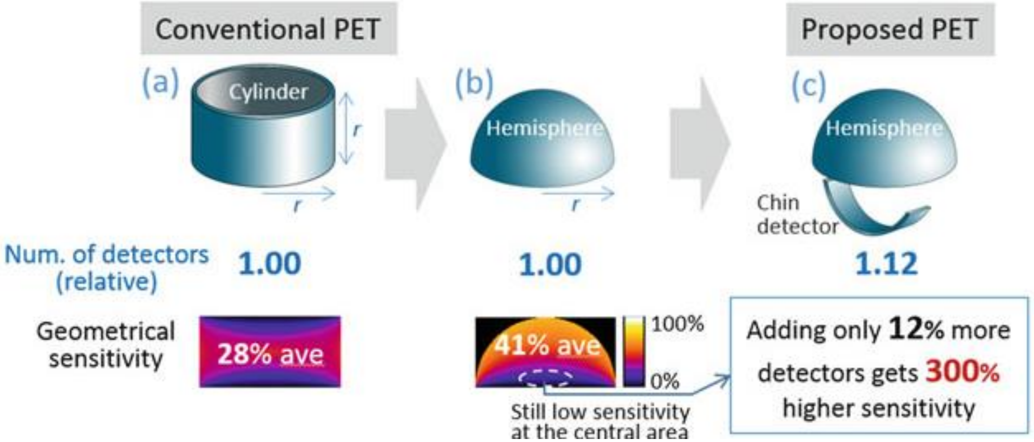
NeuroEXPLORER (NX)

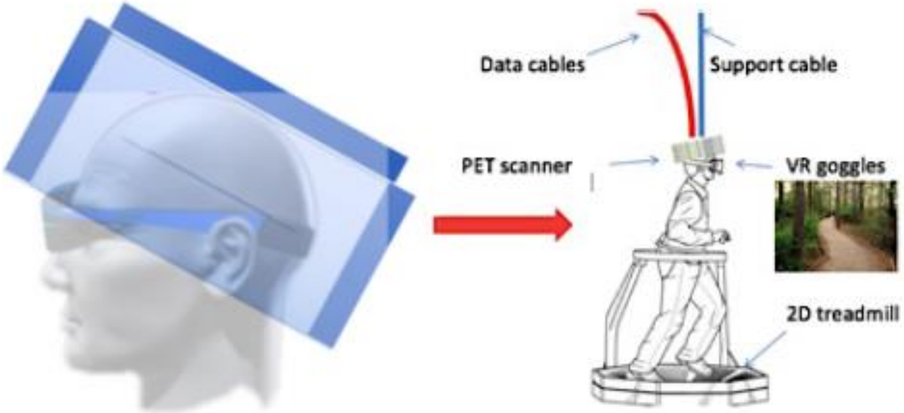
A brain PET insert was developed for integration with the Siemens 7T Magnetom MR scanner (Figure 6A).



Future Dedicated Brain PET Scanners







Prostate Cancer

- Prostate cancer (PCa) is a major worldwide health concern facing the male population. PCa is the most common type of cancer among men in Europe.
- PCa is currently the second most common cause of cancer death in men and is 3.8% of all deaths caused by cancer in men in 2018.
- The most frequently used method for imaging the prostate is **transrectal ultrasound (TRUS)**.
  - However, less than 60% of tumors—usually advanced tumors—are visible with TRUS.
- CT and MRI are not reliable enough in the assessment of local tumor invasion.
- Nevertheless, MRI has here several limitations that hamper its widespread application in PCa staging:
  - Difficulties in interpreting signal changes related to post-biopsy hemorrhage and inflammatory changes of the prostate

Prostate PET imaging

- PET with **FDG** has no role in early diagnosis of PCa because of **low and heterogeneous utilization of glucose by PCa**, and it has a limited role in **late-stage cancers**.
- A more advanced solution for diagnosing PCa is to search for PCa-specific antigenic targets and to generate agents that are able to specifically bind such as the prostate specific membrane antigen (**PSMA**), which is overexpressed in PCa tissue.
- PSMA targeting have the greatest potential to improve diagnostic sensitivity and specificity.
- State-of-the-art PET scanners present spatial resolutions of 3–5 mm, which is in a sharp mismatch with the sizes of the structures and cancerous lesions that need to be visualized in the prostate and, therefore, these scanners are not able to detect small tumoral lesions.

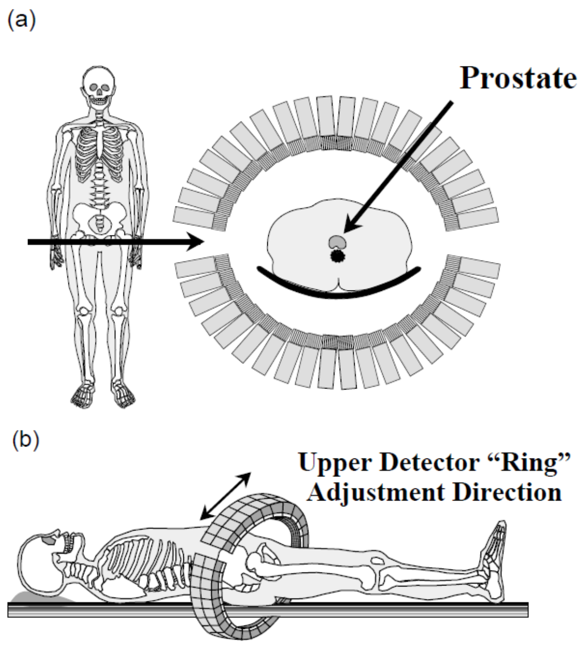


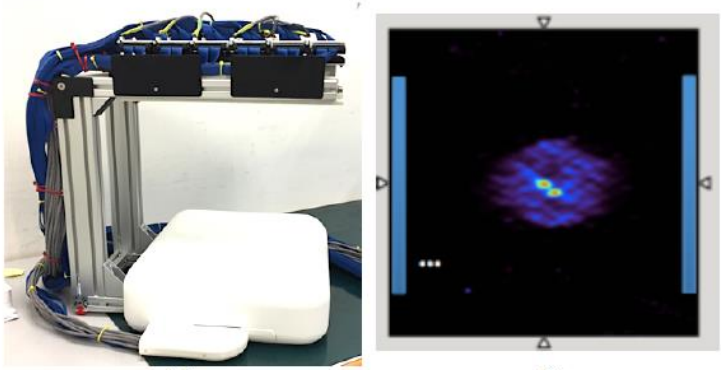
Fig. 2: Proposed positron tomograph for prostate imaging (shielding not shown). (a) Drawing of a transaxial view through prostate, showing the patient centered between two detector banks. The individual detector modules are angled to point towards the prostate. (b) Drawing of the sagittal view. The bottom arc is fixed below the patient bed, whereas the top arc adjusts vertically for patient access and compactness. Both detector banks are tilted and positioned as close as possible to the prostate, which improves sensitivity and minimizes attenuation.

Dedicated Prostate PET

Two panels dedicated prostate cancer

➢Two panels with an asymmetric design is currently under study at the Institute for Instrumentation in Molecular Imaging (i3M, Valencia, Spain).

➢Detector electronics with **TOF** capabilities will reduce the image deformation.



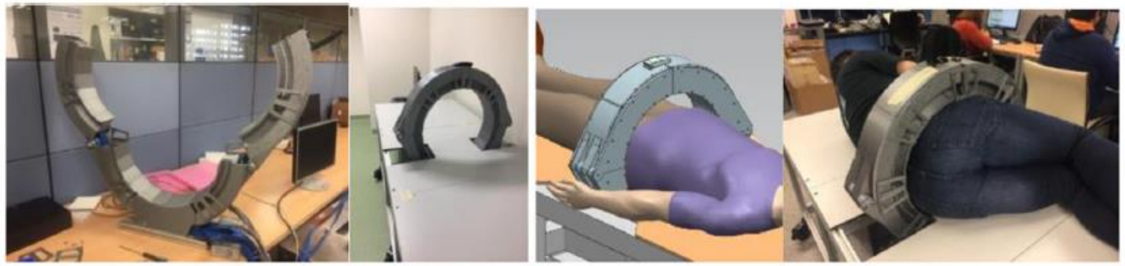
(a) (b)

Fig. 16. (a) Photograph of a dedicated two-panels PET for prostate cancer detection. (b) Simulated prostate and two lesion-sources (1 mm diameter size). The blue bars illustrate the detector panels, not in the exact position.

ProsPET

➢ Single monolithic LYSO scintillation crystal

➢ Cylindrical with **removed/ added detector modules**



(a) (b) (c) (d)

Fig. 2 Photographs of the scanner. **a** During assembly showing the movable sections. **b** Installed together with the bed. **c** System representation with a virtual patient. **d** During an ergonomic test showing the possibility for rectal biopsies

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Breast Cancer Imaging

- Breast cancer (BC) is the most prevalent form of cancer in women and approximately 12% of women globally are likely to develop some form of BC in the course of their lifetime.
- **Early diagnosis** increases the probability of treatment success.
- **Mammography** has very high sensitivity for detecting lesions and is the most commonly used imaging modality for BC screening.
- Despite several technical advances and the advent of Digital Breast Tomosynthesis (DBT), it however has lower specificity *i.e.*, the ability to differentiate between malignant and benign tumors.
- Mammographic sensitivity is also lower for women with <u>dense breasts</u>.
  - Ultrasound imaging has been approved as an adjunct imaging modality for such cases.

Breast PET Imaging

- However, the tumor biology information from PET is complementary to anatomical information obtained from other imaging modalities like mammography, computed tomography (CT), and magnetic resonance imaging (MRI).

- The biggest limitation of using WB-PET. however, is the **inability to visualize and accurately quantify small (5 mm or smaller in diameter) lesions that are prevalent in early stages of BC.**

- Current whole-body PET **is very sensitive to induced background** by the radiotracer decays originated in the rest of the body, thus reducing breast exploration sensitivity.

- Development of novel **breast-cancer-specific PET radiotracers (FES)** and **high-resolution scanner** which help in Extent of disease in the breast, biological characterization of breast tumor lesions, have unlocked several exciting applications including guiding and monitoring treatment and therapy response.

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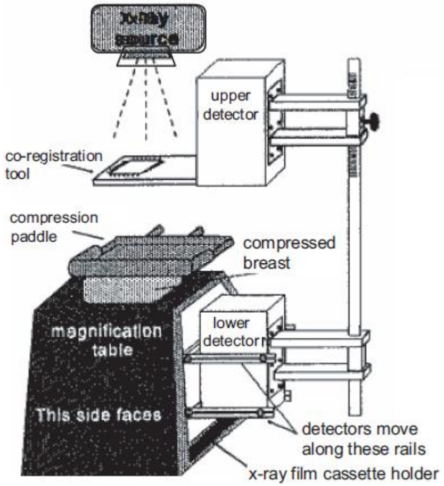
(a) Scanners imaging compressed breast with limited angular coverage (PEM)



PEM-I scanner

- The first generation of dbPET scanners were inspired by mammography and were designed primarily **for lesion detection.**
- PEM uses <u>limited-angle image reconstruction</u> for image generation.

Flex Solo II PEM scanner

- The detectors and compression paddle are mounted onto an upright gantry that has an articulating arm to help obtain Craniocaudal (CC) and Mediolateral (ML) views that are typically obtained with a compressed breast during a mammography exam.
- The PEM Flex, compresses the breast providing 2D images similarly to those provided by an X-ray mammography.

(b) Scanners with stationary or rotating detectors for imaging uncompressed breast with patient in the prone position

- Incomplete angular coverage in PET scanner design leads to non-optimal image quality.

- **Fully 3-D tomographic reconstruction** can provide the best image quality, and quantitative imaging capability.

- Newer design approaches acquired tomographic breast data by incorporating **detector panel rotation** or using the panels in a non-circular geometry that eliminated effects from limited angular coverage.

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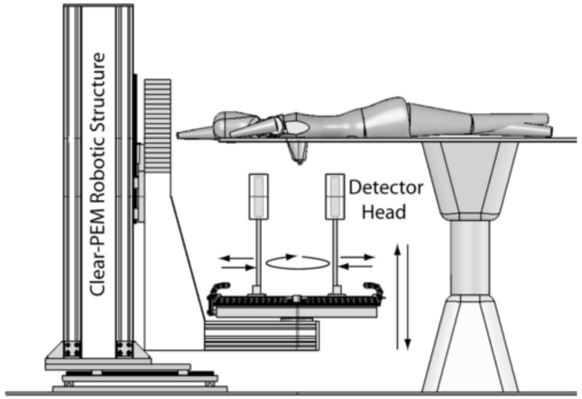
- **B-PET (University of Pennsylvania)**
  - curved plate, NaI(Tl) detectors are placed in a split-ring design on a flexible gantry and can be moved to provide variable detector separation.

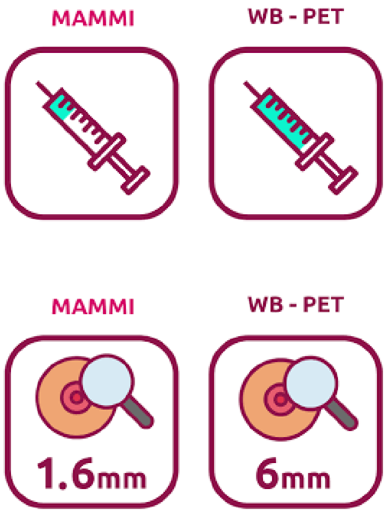
- **box-shaped PEM scanner (Lawrence Berkeley National Laboratory)**
  - rectangular FOV and thereby have complete angular coverage. The distance between the top and bottom detector panels was adjustable to accommodate different breast sizes.

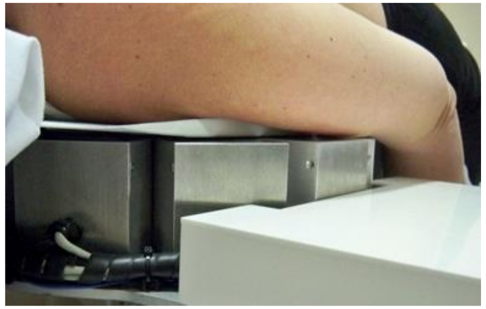
- **Clear-PEM scanner**
  - The two PET detector panels were rotated around the scanner axis to collect data at several angular positions necessary for tomographic reconstruction.
  - Instead of a compression-free hanging breast, the breast is encompassed by a cone applying minimal compression.

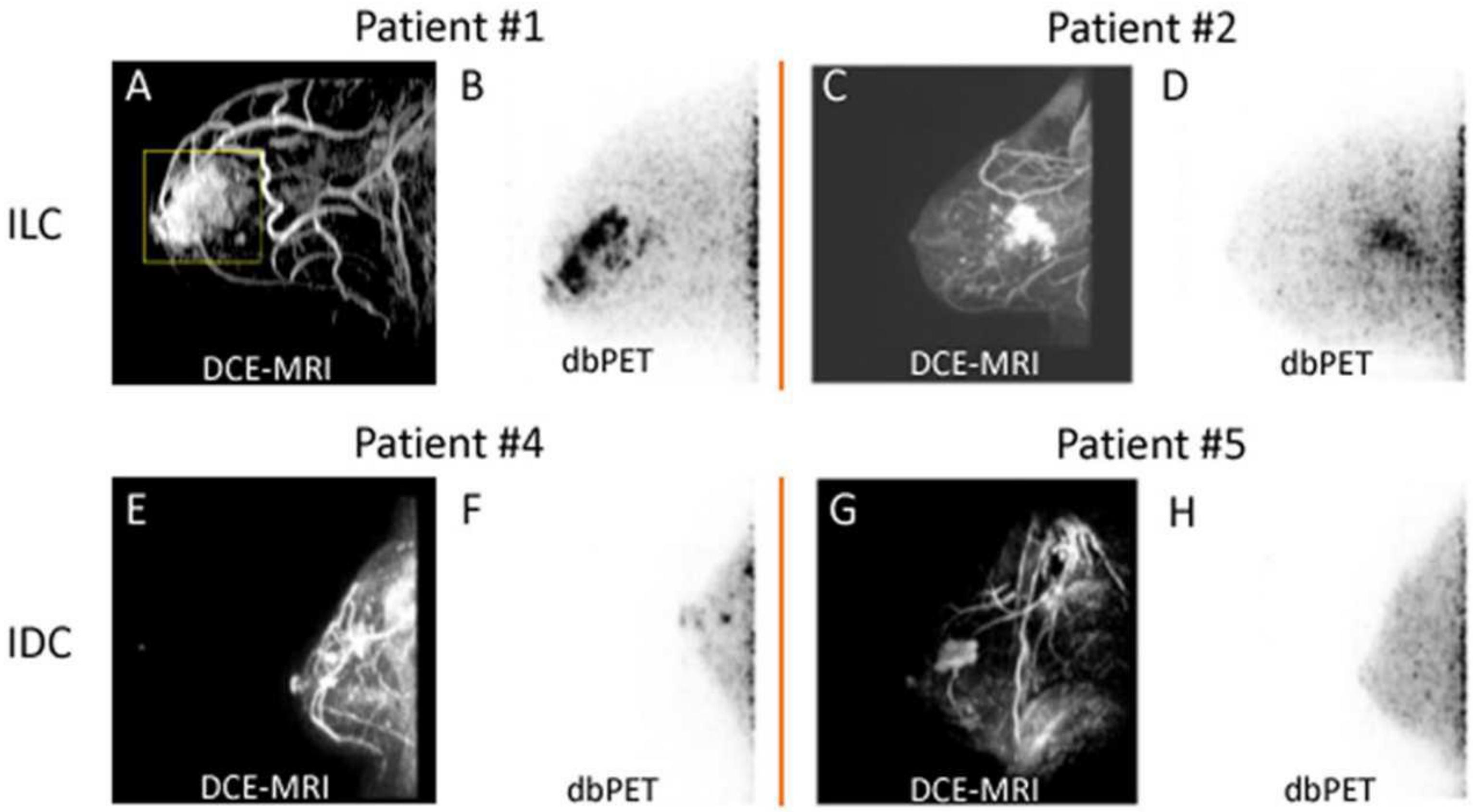


(c) Full ring dbPET scanners for imaging uncompressed breast in prone position

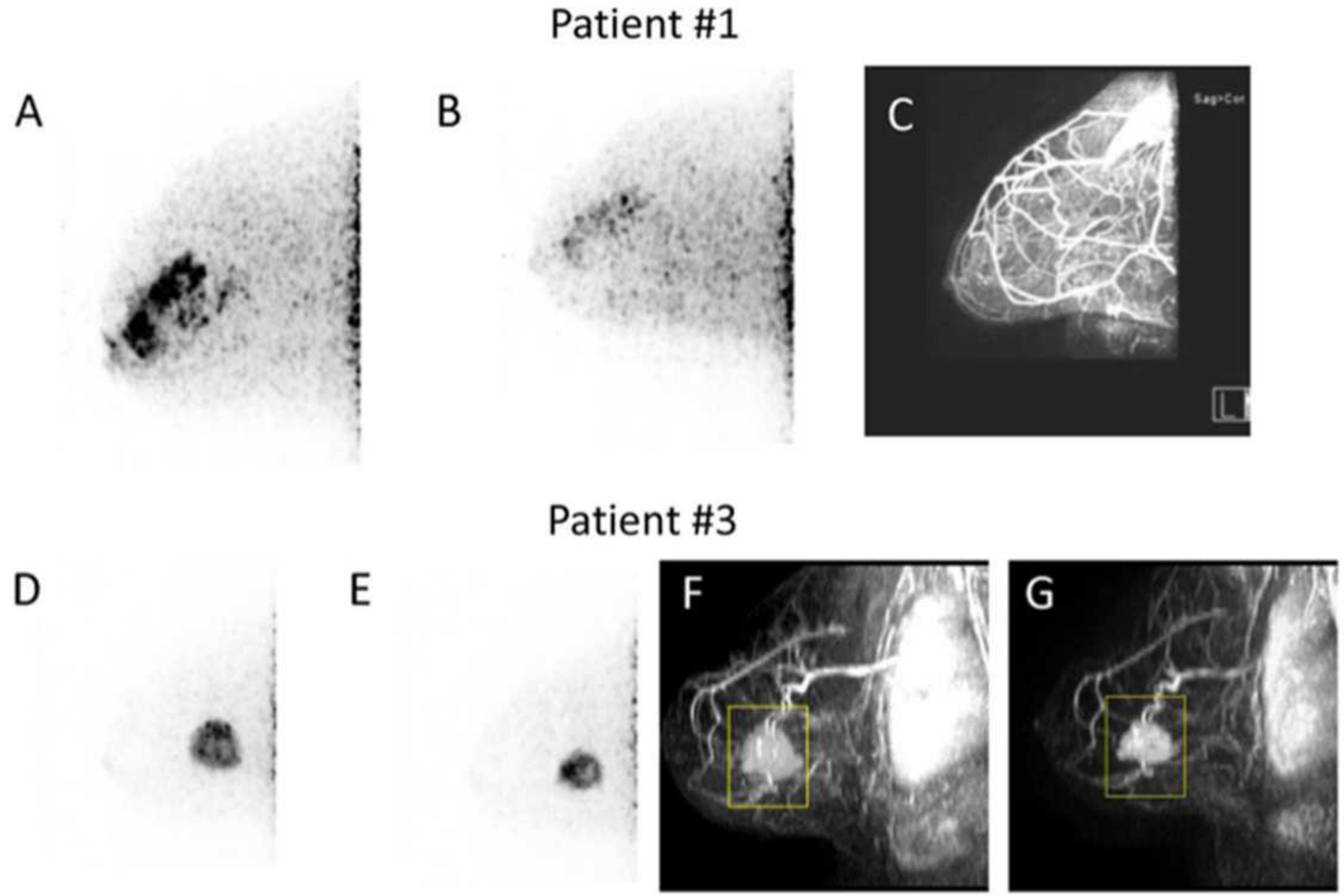
- **Full-ring PET insert**
- The MAMmography with Molecular Imaging (**MAMMI**) is a full-ring dbPET scanner currently commercialized by Oncovision (Valencia, Spain).
    - Spatial resolution of <2mm is measured in the central scanner FOV
    - Scan time for a single ring position takes up to 5 mins
    - The total scan time is dependent on the breast size.
- The patient is imaged in the prone position with the breast hanging through an opening in the bed.







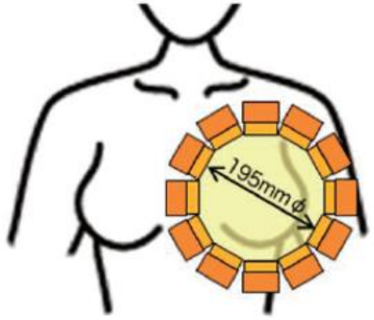
- An example of $_{18}$FES uptake from a pilot study using the MAMMI dbPET scanner for two categories of BC subjects – Invasive Lobular Carcinoma (ILC) on the top panel, and invasive ductal carcinoma (IDC, bottom panel). Dynamic contrast-enhanced MRI (DCE-MRI) and corresponding dbPET images for four patients are shown for each of the four subjects. All four subjects presented contrast enhancement in their MRI scan, and high SUV_{max} in their corresponding $_{18}$FES-dbPET scan. Patient #5 had a recent administration of Tamoxifen, which is an estrogen receptor blocker, and consequently shows no $_{18}$FES uptake. Image reprinted with permission from Jones *et al.,*

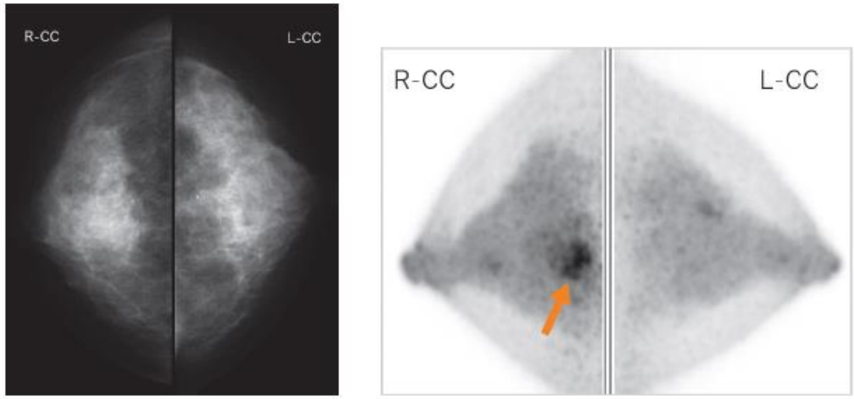


- An example of using the Mammi dbPET scanner for assessing treatment response with $_{18}$FES-dbPET. Top – reduction in SUV_{max} observed from dbPET scans in subject with ILC: at baseline (A), and two months after treatment (B). DCE-MRI confirming the favorable response with no residual disease, but significant background enhancement (C). Bottom – reduction in SUV_{max} and total uptake volume observed from dbPET scans in subject with IDC: $_{18}$FES dbPET scans at baseline (D) and post 3-week treatment (E). Corresponding DCE MRI (F), and (G) confirming the tumor size reduction. Image reprinted with permission from Jones *et al.,*

Elmammo dbPET

- ➢ This scanner has a spatial resolution of <2 mm.
- ➢ Prone position
- ➢ approval in Japan and China.





Mammographic Images　dbPET Images (CC)

Fig.7 Tumor Discovered in Patient with Dense Breast

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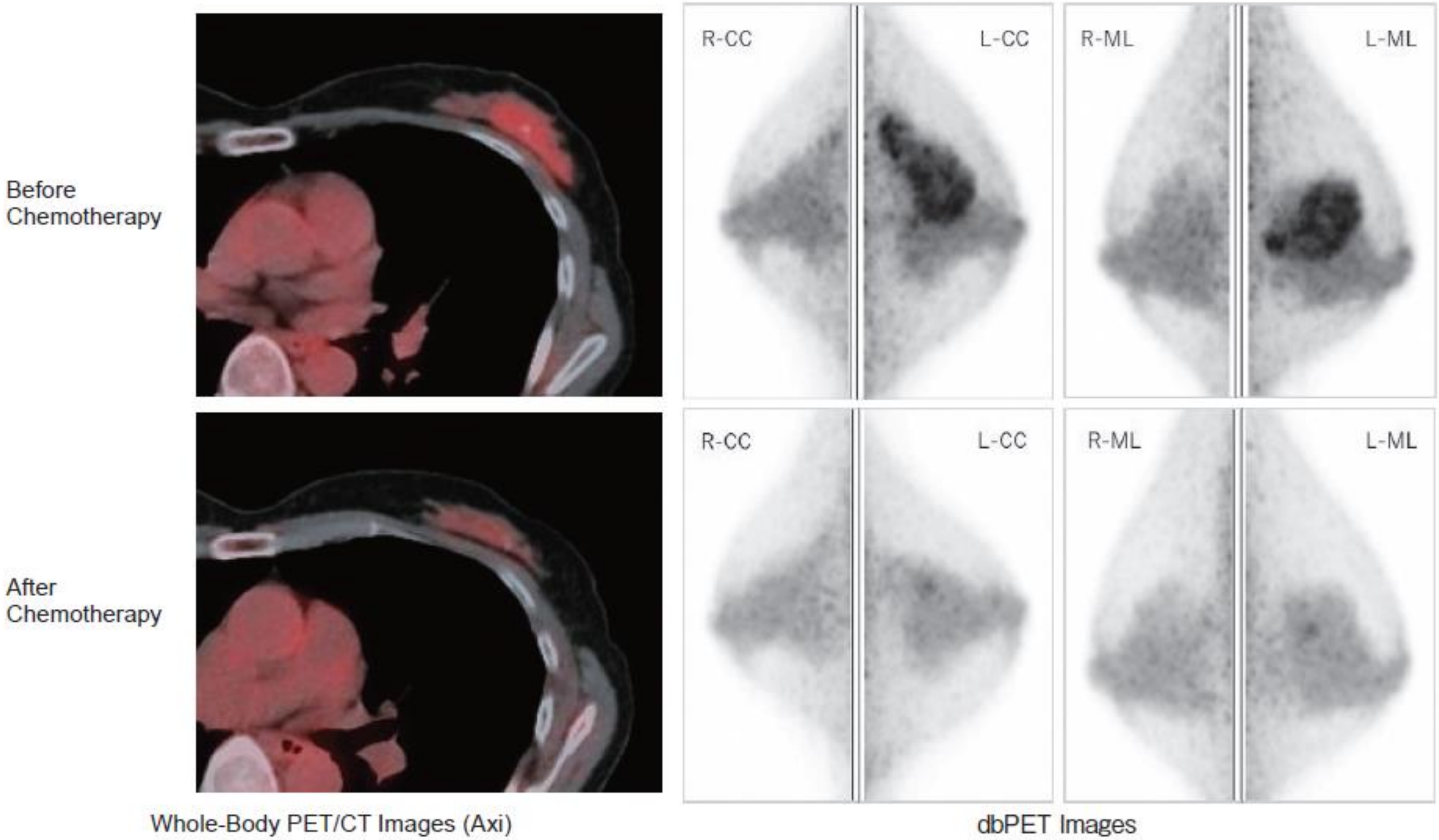
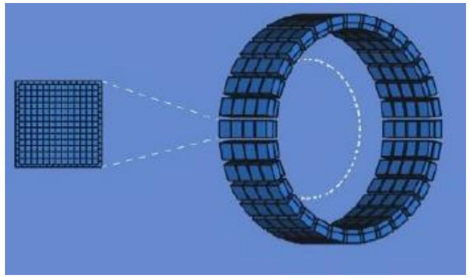


Fig.11 Before and after Neo-Adjuvant Chemotherapy

Brain, Breast, eXtremities (BBX) scanner



- Multi purpose dedicated PET scanner
- The detectors consisted of double-layer staggered lutetium fine silicate crystals
- Weights ~225 kg
- **Portability**
- Allows **brain** imaging in seated position, **breast** imaging in prone position and **extremities** imaging in other positions.
- Spatial resolution of **~2.6 mm**
- **2.59%** sensitivity at the center of the FOV

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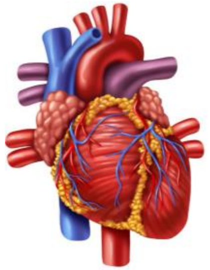
Cardiac Imaging



- Recent decades have seen large decline trend in cardiovascular disease (CVD), and coronary artery heart disease (CAD) mortality, with rates of CVD mortality falling by >30% in both sexes and CAD mortality falling by a third in men and over a quarter in women.

- CVD still remains the leading cause of mortality, premature death and morbidity in developed countries, causing almost 4.1 million deaths per year in the European Union alone.

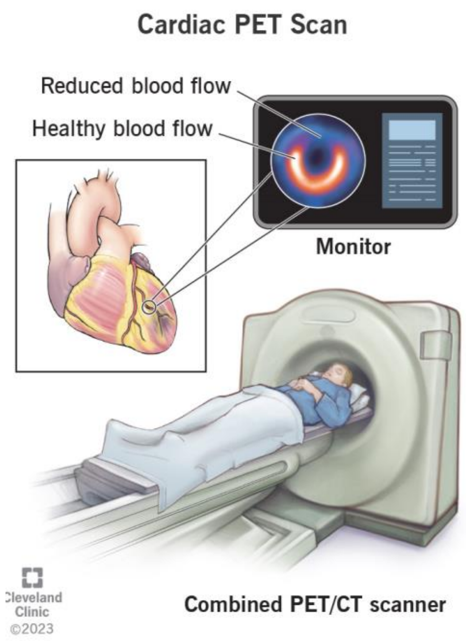
- Cardiac imaging has gained worldwide acceptance to detect and characterize extent and severity of cardiovascular diseases by non-invasive means.

- Currently, the **most robust technique to quantify perfusion noninvasively in human heart is PET.**

Dedicated cardiac PET Scanners

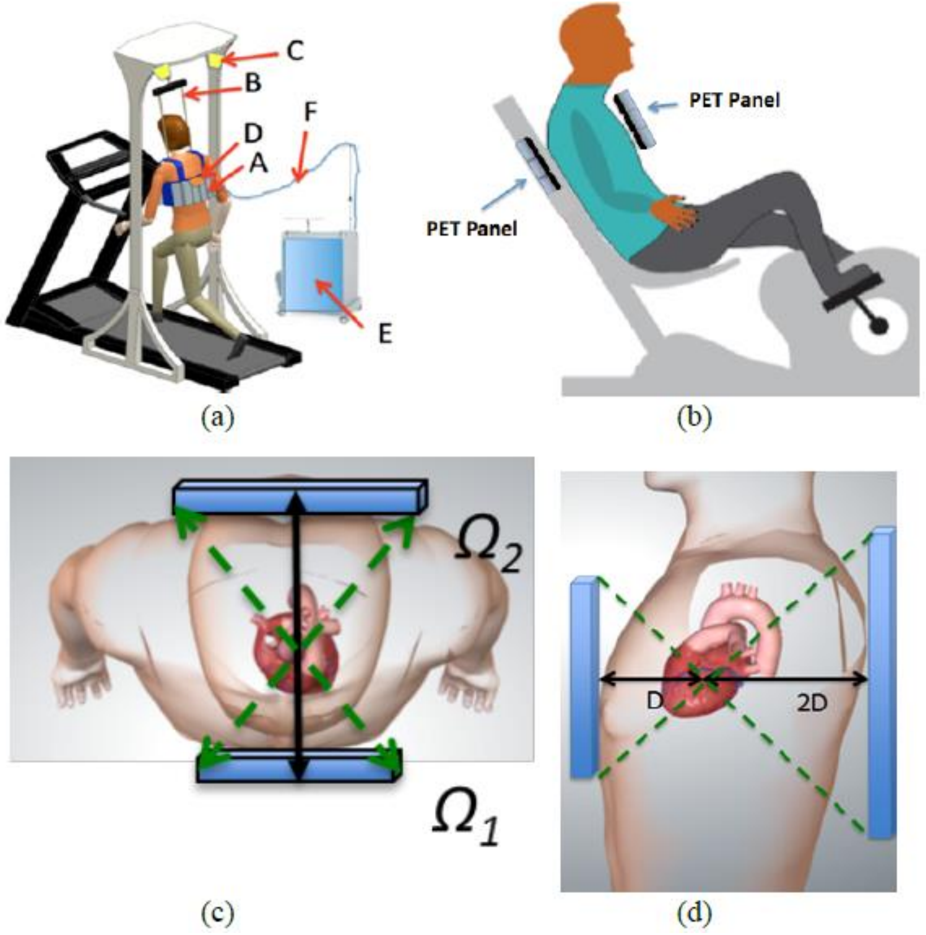
- Myocardium perfusion imaging and viability studies, the evaluation of the inferior myocardial wall is commonly degraded by the interferences from near by extra-cardiac structures such as the liver or stomach wall, due to both partial volume and spill over effects.
- Intense uptake in these organs can overlap with the adjacent heart wall and consequently reduce the ability to accurately assess the true myocardial uptake.

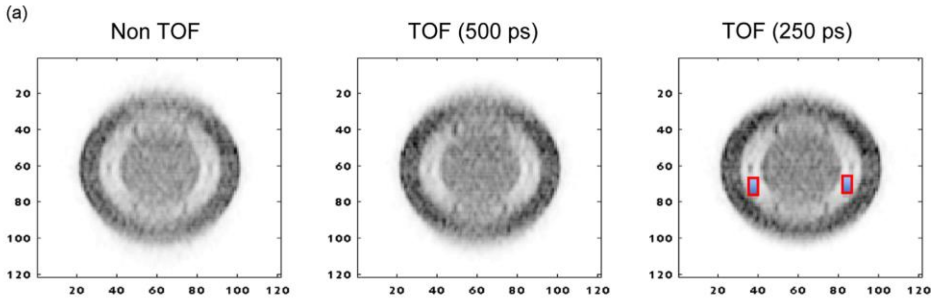
✓ A PET system with improved spatial resolution, photon sensitivity and contrast recovery has a great potential to address such a challenge.

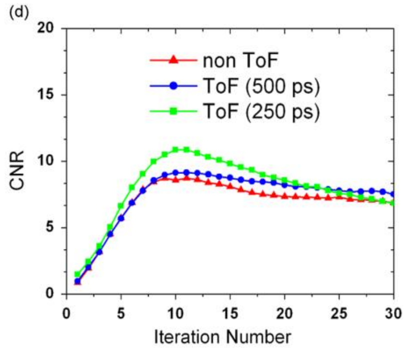


- The design of an ideal heart dedicated PET should consider the actual size and position of the human heart in the body, as well as to allow patient motion during scan, especially for tests under heart stress situation.

- At present, **there are no imaging techniques that are able to evaluate the functional operation of the heart while performing exercise** and that permit limited movement of the patient.



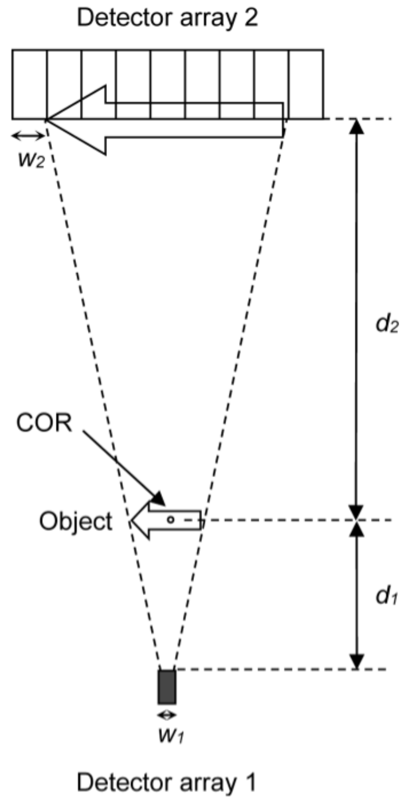




Virtual pinhole PET concept

- A PET insert panel that can be placed close to the breast while the patient is being imaged in a WB-PET scanner and lays in the supine position with an uncompressed breast.
- While the insert by itself does not collect PEM-like data, the insert is used to **augment the spatial resolution and sensitivity by collecting additional** data between the insert and WB-PET scanner.
- Couple of prototype inserts were developed to demonstrate local improvements in image resolution and contrast using phantom evaluations.

low-resolution



high-resolution

- A Siemens Biograph 40 PET/CT scanner with a prototype virtual-pinhole PET insert attached

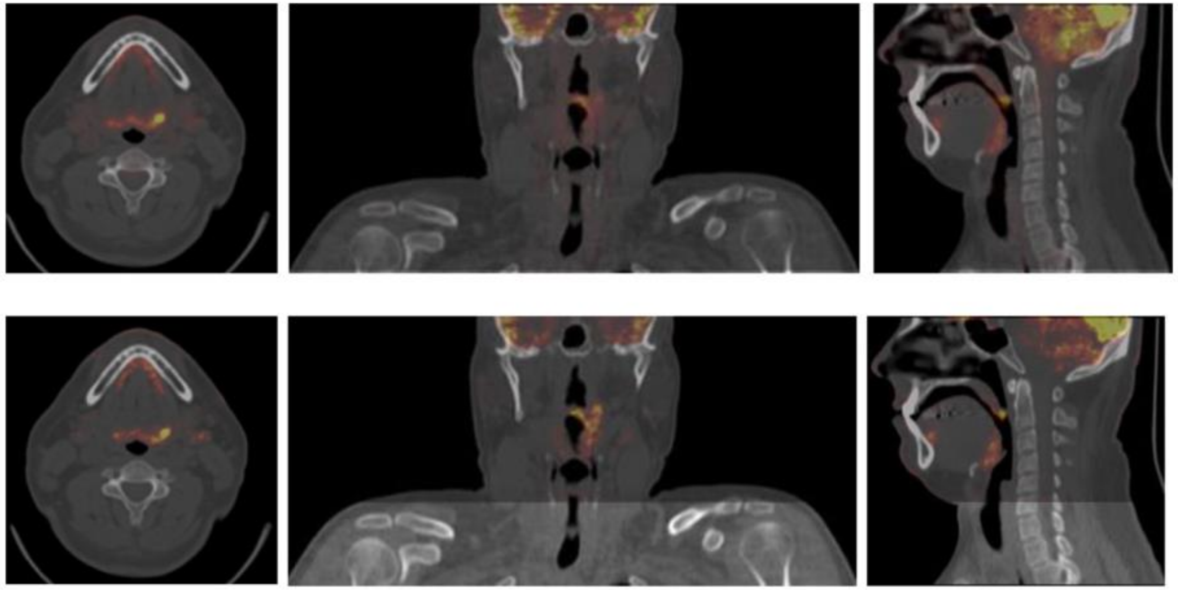
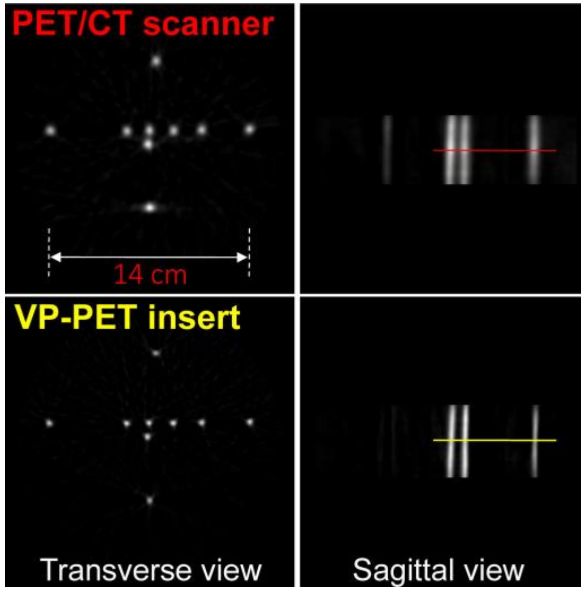
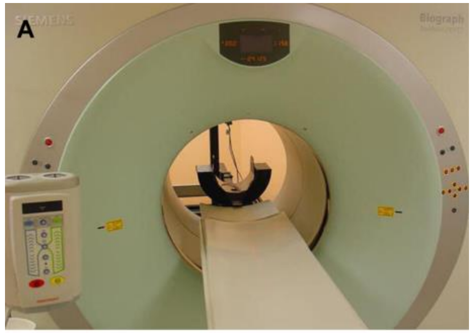


Figure 12.
(Top) PET/CT images of a head-and-neck cancer patient scanned by a Biograph 40 scanner.
(Bottom) The same patient imaged by the prototype virtual-pinhole PET insert device.





- **The virtual-pinhole PET insert system exhibits:** reduced system sensitivity, better image resolution and higher tumor-to-background contrast.

Dedicated PET: from operating room to specimen imaging

- **PET in operating room** allows for a detailed analysis of the specimen's molecular and histopathological characteristics, thus providing valuable information about tumor heterogeneity and aiding in surgical decision-making and treatment planning.

Applications:

- PET guided navigation survey systems
- PET gamma probe
- Laparoscopic and endoscopic PET imaging systems
- Open gantry (limited angle) intraoperative PET systems.

PET radio-guided surgery

✓Using PET to guide the surgeon

- **The benefits:**
  - It enhances the surgeon's ability to discern tumor margins in real-time, ensuring complete resection while minimizing damage to adjacent healthy tissues.
  - It can significantly **reduce operative times**, given the **real-time feedback**, and potentially **lower post-operative complications**.
  - **patients benefit (improving patient survival rates)** from more precise interventions, often translating to reduced hospital stays and improved overall outcomes.

- **The limitation:**
  - The absence of real-time or online PET data acquisition
    - restricts the surgeon's ability to adapt to dynamic changes during surgery, necessitating reliance on static preoperative imaging

PET imaging in endoscopy and laparoscopy

- The **integration of PET imaging in endoscopy and laparoscopy** could significantly **improve tumor detection and localization.**

✓ **EndoTOFPET-US project**

- The detection device is composed of two primary elements: a PET extension for a standard ultrasound endoscope, and an external PET plate which faces the inner probe.

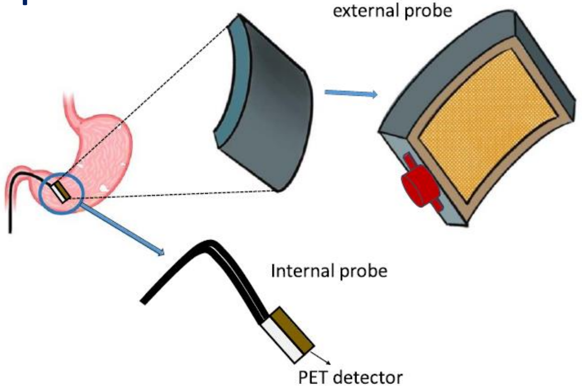


Figure 2. 3D drawing of the EndoTOFPET-US external plate, showing the crystal matrices arranged in a pointing geometry, the aluminium casing, and the attachment for a robotic arm. Sketch of the *in vivo* configuration for pancreatic clinical case. On the left is the endoscope PET extension for pancreatic clinical case, positioned under the bend of the duodenum opposite to the external plate, enclosing the pancreas in the field-of-view.

✓ **PET-laparoscope**

Designed to capture 3D PET imagery

- **Stationary external detector** array attached to the patient's surgical bed.
- **Dynamic detector probe**, carefully inserted into the patient's body

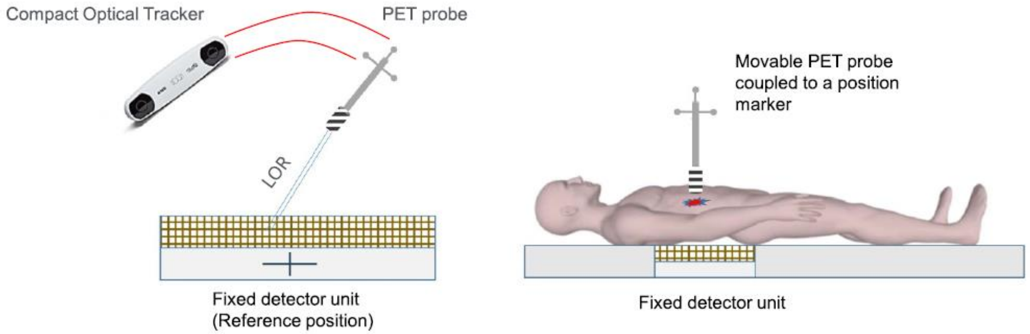


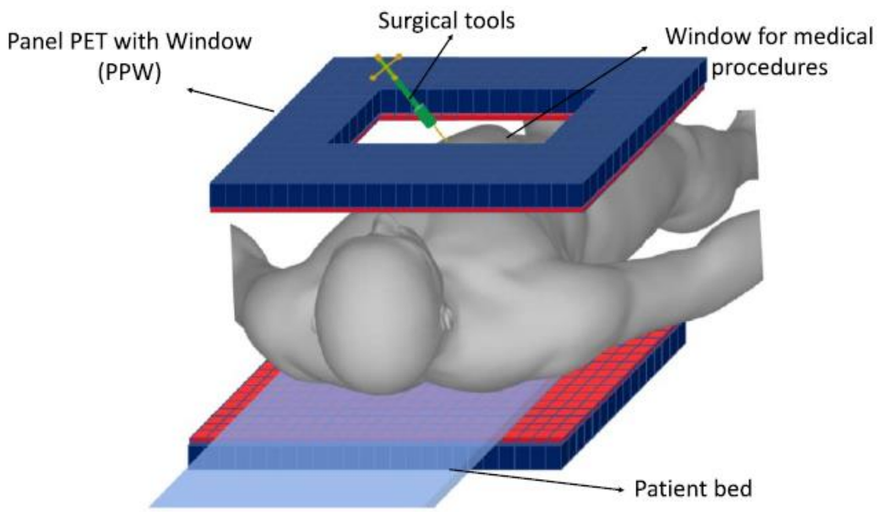
Figure 3. Schematic sketch of the PET-laparoscope system together with the tracking system.

Dedicated intraoperative surgical PET

whole-body PET scanners:

- Reliable image quality
- × Their considerable size
- × Restricted patient accessibility (for the purpose of surgery)
- × Significant cost

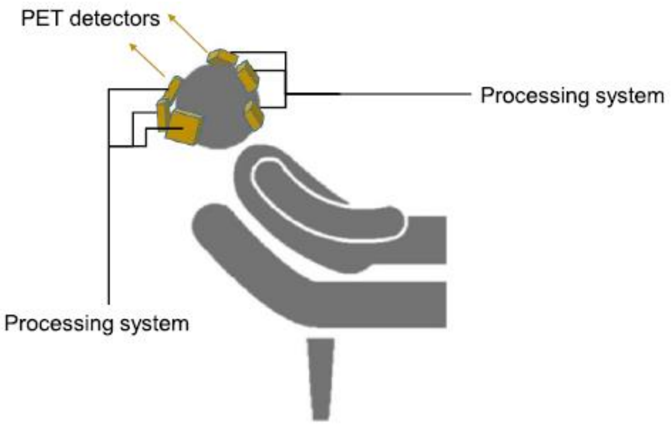
➢ **Panel PET with Window (PPW)**



- ✓ Precise localization and recognition of tumors during surgery
- ✓ **Real-time 3D reconstructed PET imagery throughout surgical procedures**.

Surgical brain PET

- This arrangement not only permits unobstructed access to the patient but also allows for surgical instruments to be maneuvered through the gaps between detectors.
- Furthermore, to optimize imaging capabilities, these detectors are affixed to robotic arms.
  - This enables precise positioning of the detectors, ensuring that critical images can be acquired during the surgical intervention.



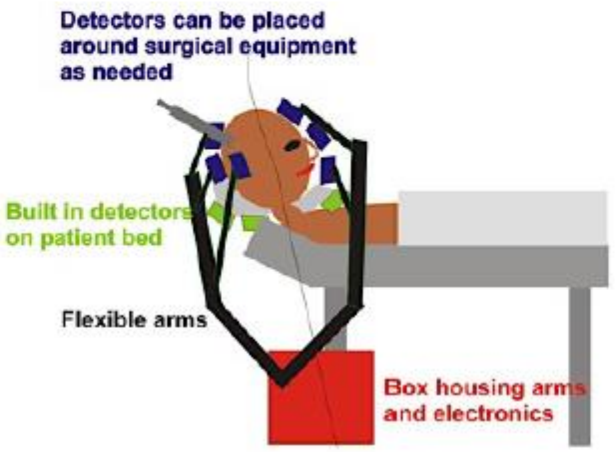


Figure 7. Illustration of a surgical brain PET with various modules adaptably positioned around the head.

Biopsy

- Biopsy done by an automated robotic arm.

- The system's biopsy feature comprises a device capable of **moving in all three dimensions** and **rotating a full 360 degrees** around the scanner's imaging axis.

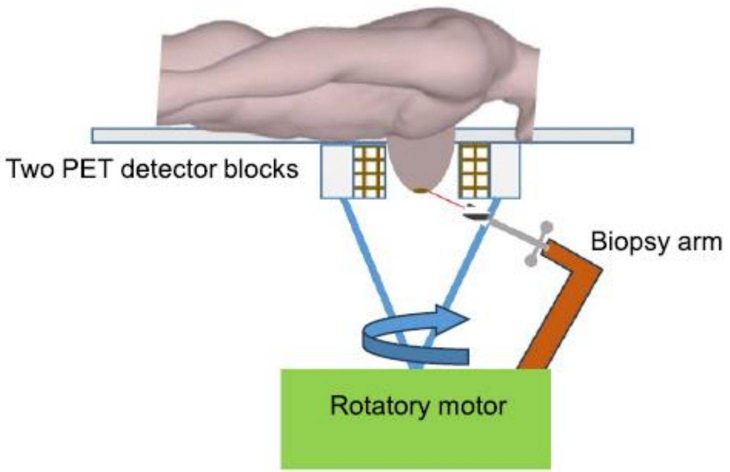
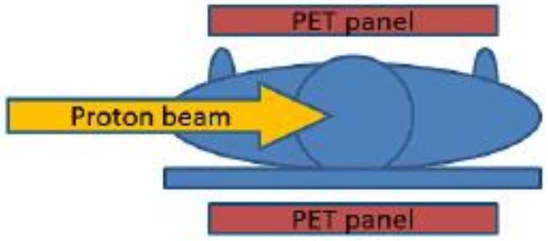


Figure 1. Schematic sketch of the PEM-PET designed by (Raylman 2009).

- It would allow real-time visualization and 3D image reconstruction of tumors, monitoring the path of the needle inside the patient.

In-beam PET scanners

- We approach treatment planning and monitoring. These innovative scanners allow for **real-time imaging** and **analysis of the dose deposition** during radiation treatment, providing valuable information about the effectiveness and accuracy of the delivered therapy.
- In-beam PET scanners have been shown to be particularly useful in **particle therapy**, such as proton therapy and carbon ion therapy



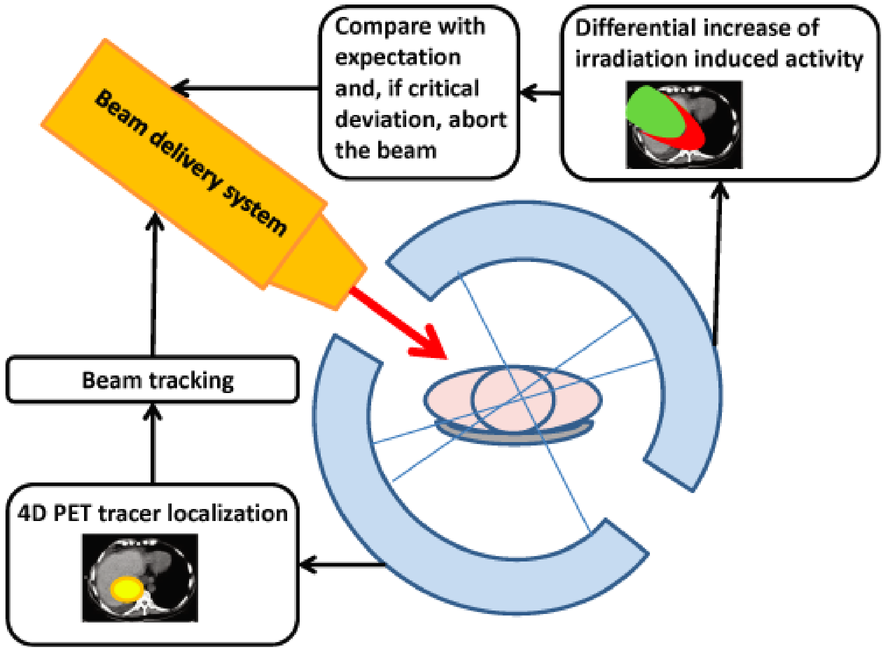


FIG. 7. Schematic illustration of possible future strategies of in-beam PET-based image guidance of ion (or energetic photon) treatment, combining information from injected isotopes for biologically based beam tracking with differential information on the build-up of the irradiation-induced activity for confirmation of the beam delivery and, in case of critical deviation, interruption of the treatment.

In-beam PET scanners

- ✓ The unique configuration of in-beam PET scanners, rooted in the principles of partial coverage or limited angle PET imaging, is primarily driven by the need to **maintain patient accessibility** during the delivery of the prescribed radiation dose, such as carbon or proton beams.

- × Due to the fact that the **rate/ probability** of positron emission **is not very high**, these PET scanners should be equipped with **high-sensitivity** detectors to achieve acceptable SNR.

- ➢ **Sensitivity has higher priority than spatial resolution in this case.**

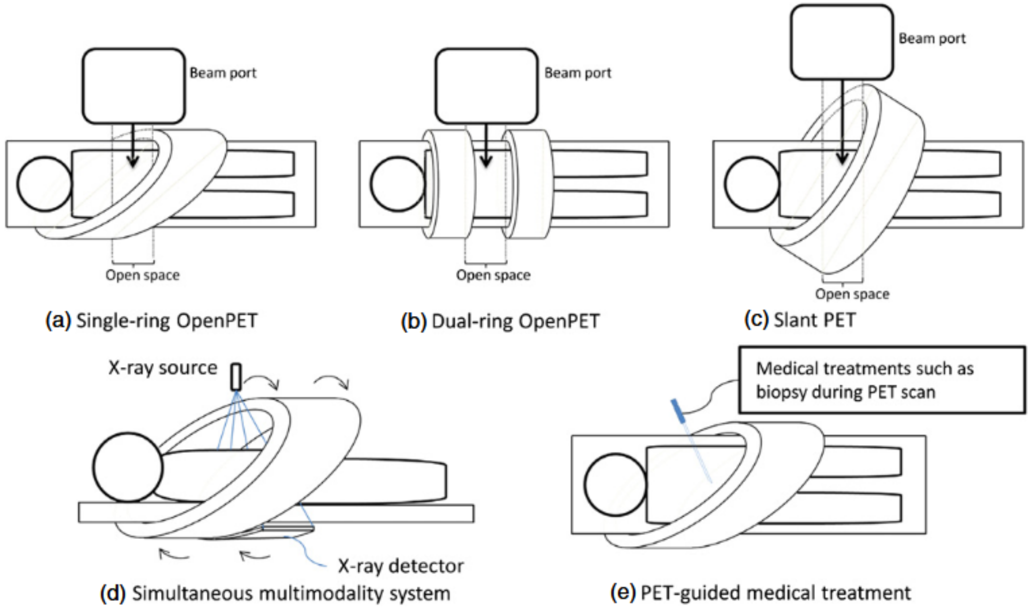
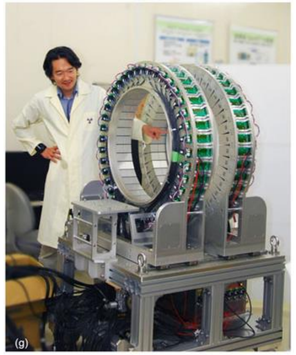
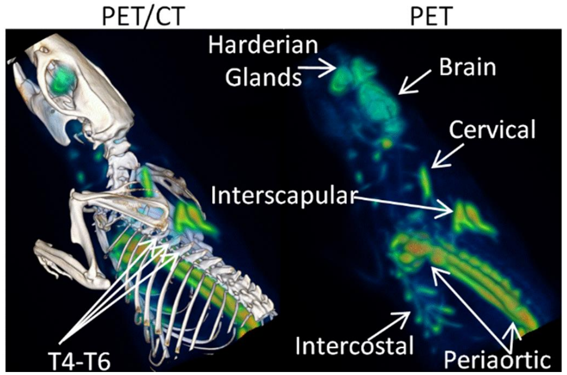


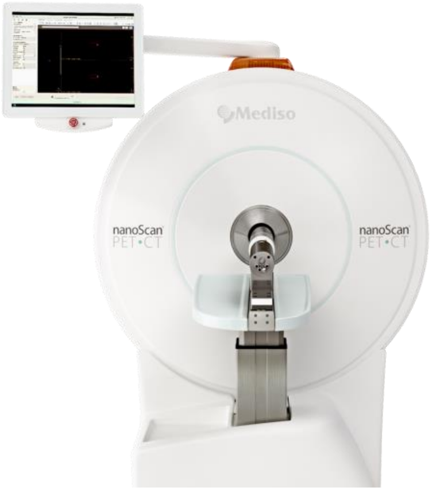
Figure 1. Conceptual illustrations of PET geometries with an accessible open space to the patient. The proposed single-ring OpenPET (a) has the shape of a cylinder cut at a slant angle and the beam port can be placed near the patient bed, the same as in dual-ring OpenPET (b). Conventional cylinder PET can also provide an open space by placing it at a slant angle against the patient bed (c). Applications are shown as well for the single-ring OpenPET for PET-CT as a simultaneous multimodality system (d) and for PET-guided biopsy as a PET-guided medical treatment (e).

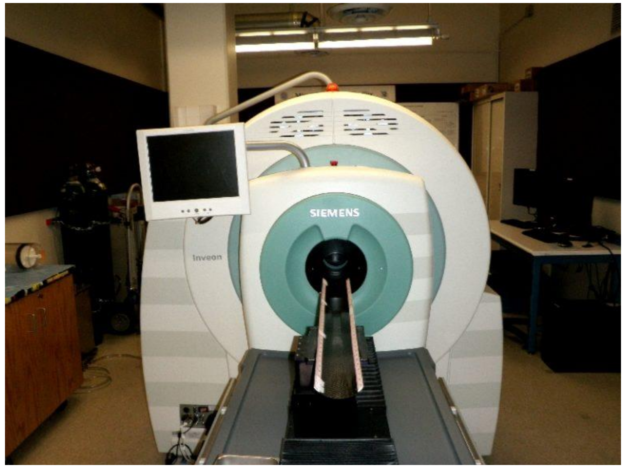


Dedicated Small Animal PET scanners

- Studying the disease process over time
- Biologic research
- The screening of novel diagnostic/theragnostic PET probes
- Specimen imaging

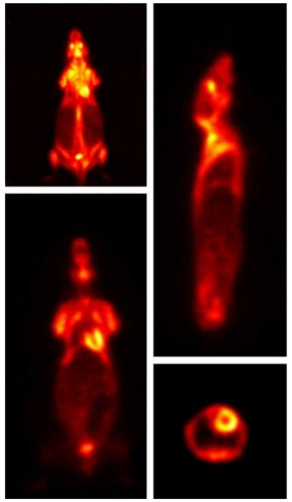




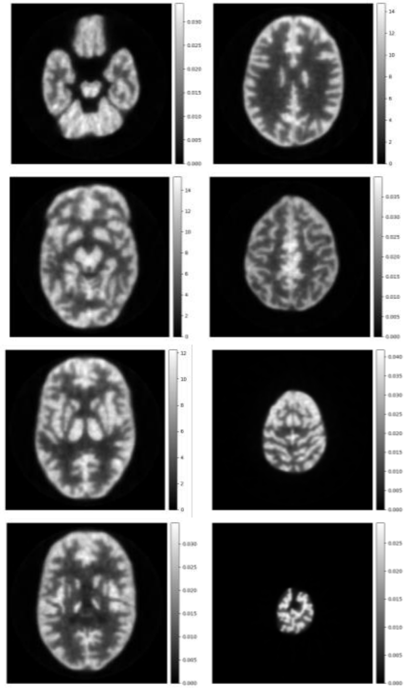


Dedicated PET Scanners in Iran

- **Xtrim PET:** Dedicated small animal PET scanner
  - 10 detector blocks that arranged in polygonal full-ring structure with a ring diameter of 162.6 mm.
  - Each detector block consists pixelated LYSO scintillators



- **Dedicated Brain PET**
  - LYSO array with size 23 x 23 pixels
  - Pixels size: 2mm x 2mm x 15mm
  - Ring diameter = 389 mm
  - AFOV = 202 mm
  - SiPM
    - MRI compatible
    - TOF



Reconstruction Challenges: Attenuation & Scatter correction

- The **absence of an anatomical imaging modality** on most organ-dedicated scanners brings new challenges to PET attenuation and scatter correction which might consequently compromise PET's quantitative accuracy.

- Therefore, attenuation and scatter corrections are sometimes ignored on such scanners or alternative innovative approaches are sought.

✓ In the case of brain imaging, atlas-based u-maps generation was extensively studied.

✓ A prostate PET scanner was designed with the unique feature that it can be tilted to minimize photon attenuation effects.

✓ Existing CT images from a separate scan can be co-registered to PET images to perform attenuation correction on dedicated prostate PET scanners.

Reconstruction Challenges: Detector Gaps

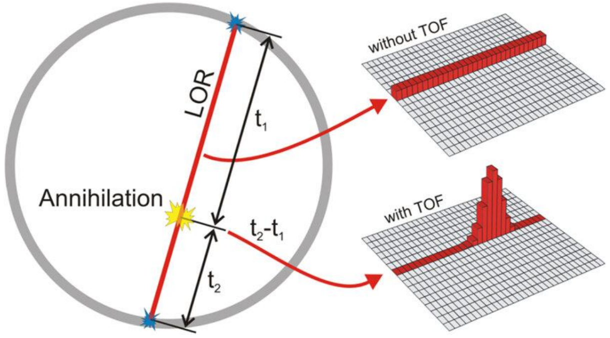
- Another challenge in the reconstruction of organ-specific scanners is that often a large part of the data might be missing due to the inevitable **detector gaps**.

- **Detector gaps** in PET scanners cause regions of **reduced sensitivity**, leading to **underestimation of activity concentration** in areas adjacent to the gap and potentially reduce image quality and spatial resolution, and also leads to streak artifacts.

- These can be handled through interpolation, forward projection of an initial image estimate, or directly in the projection domain using Gap filling or deep learning (DL)-based approaches.

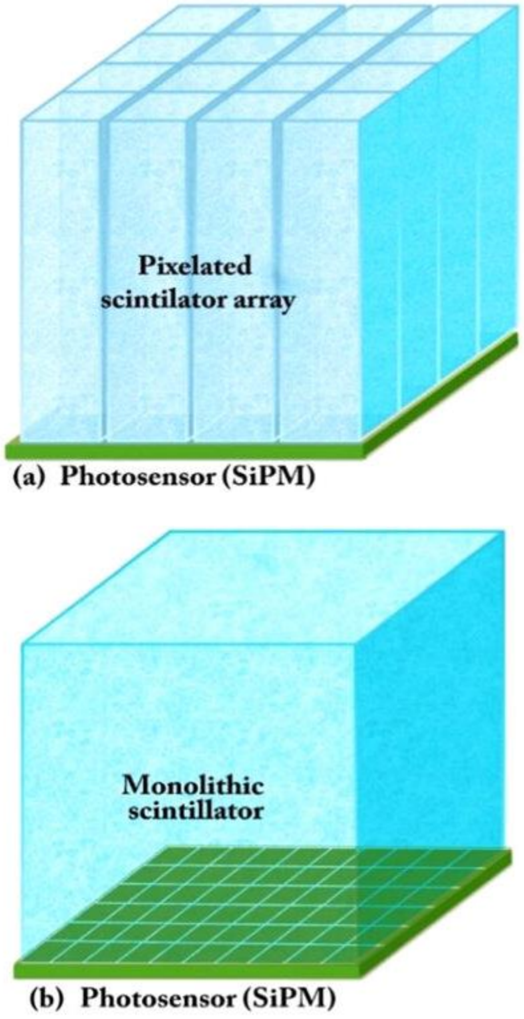
Reconstruction Challenges: DOI & TOF

- Achieving better spatial resolution improves image quality and quantitative accuracy. Using thicker crystals allows higher sensitivity at the cost of reduced DOI localization accuracy, which leads to parallax errors and deteriorated spatial resolution.
- The solution to this **trade-off between sensitivity and resolution** is substantiated in two key technologies, namely, DOI determination and TOF capability.
- The **DOI information** minimizes the parallax error and allows providing a **more uniform spatial resolution**.
- **TOF information** has the potential to significantly **increase the SNR** of PET images by limiting the location of the positron annihilation point along the LOR to a smaller segment.
- Excellent determination of the photons TOF can overcome the problem generated by the limited angle geometry and improve the quantification accuracy (**the ultimate goal is 10 ps).**



Monolithic Crystals

- Detector modules based on monolithic crystals have a number of advantages, such as **higher sensitivity**, **the ability to extract DOI**, **no zero detection regions**, **decent performance in spatial resolution**, and **less manufacturing cost**.
- However, these detectors commonly **require complex calibration procedures**, and **complicated algorithms for the location, energy, and timing assignation** of photon interactions.
- Moreover, **the spatial resolution deteriorates around the edges**, although multiple studies attempted to confront this issue by calibrating the detector using analytical, simulation-based, and experimental approaches.



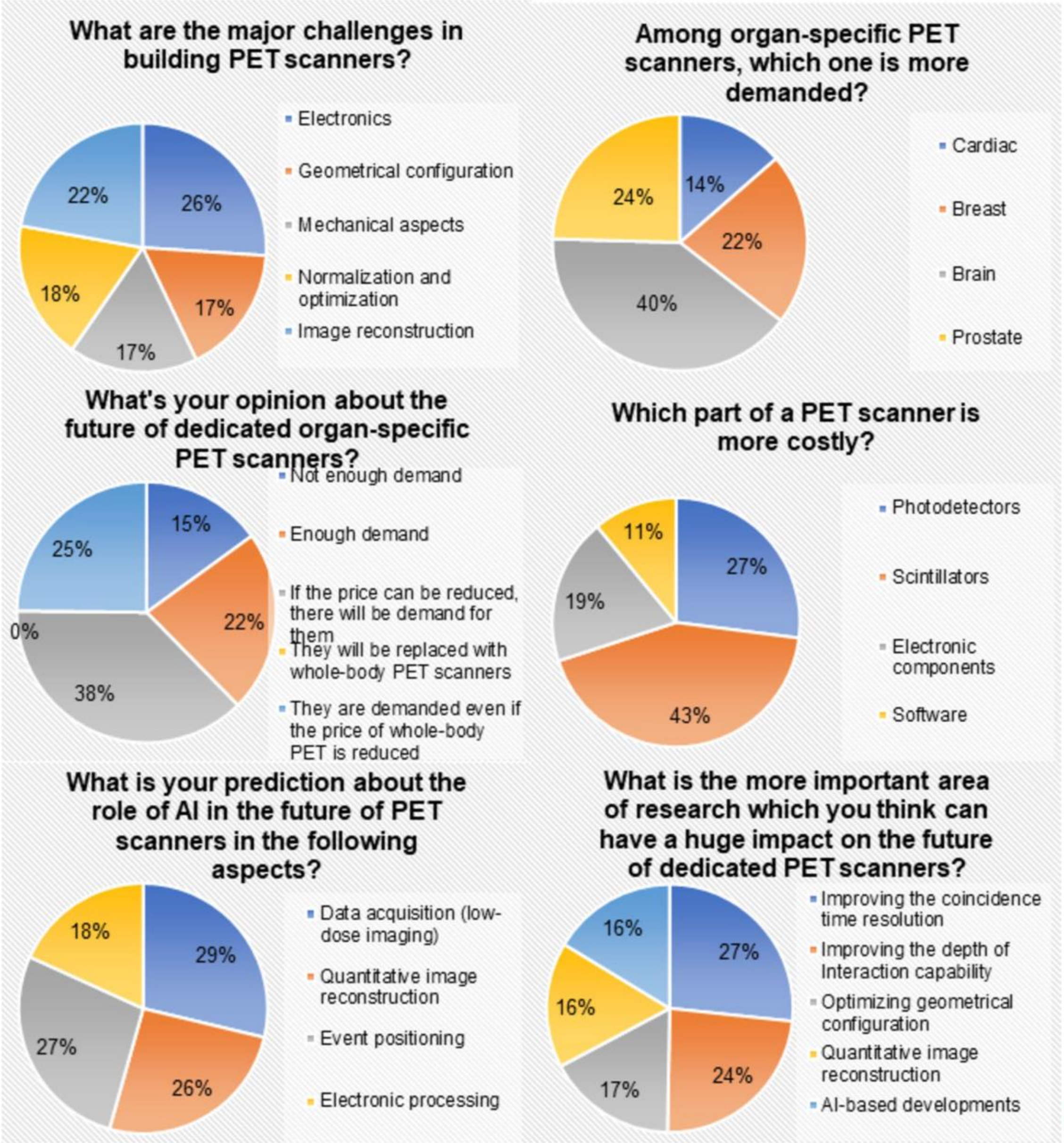
AI in dedicated PET scanners

- Attenuation and scatter correction (ASC) on PET:
  - Attenuation correction factor estimation in the sinogram domain
  - Attenuation map estimation from non-ASC PET images.
- Moreover, deep learning algorithms are employed for:
  - Accurate event positioning
  - Calibration
  - Post reconstruction processing
  - Image quality enhancement

✓These techniques not only boost the overall quantitative accuracy and image quality of PET scans, but could also reduce manufacturing costs.

Future Trends

✓ **The aim of dedicated scanners is not to replace existing clinical whole-body PET systems.**



Thanks for your attention