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Third Stage

Radiological Equipment techniques

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Linear probe

Linear arrays provide a rectangular field of view ideal for imaging regions close to the surface, such as the neck or limbs. Curvilinear arrays function similarly but have a curved shape, offering a wider field of view at greater depths—useful for abdominal and obstetric scans. However, because they require pressure for full contact, they are less suitable for sensitive or superficial structures. Trapezoidal (virtual curvilinear) arrays address this issue. Externally, linear-array transducers are hand-held blocks with a rubber lens that contacts the patient.

Linear-array transducers

typically have 128 elements, although some may have up to 256, chosen for convenience in digital control and processing. Each element is around 1.3 wavelengths wide, balancing a wide field of view with narrow enough elements to cover a broad range of angles. The elements are weakly focused to ensure consistent beam width across depths. High-frequency transducers are smaller, with dimensions proportional to the wavelength. Each element's front electrodes are connected to a common lead, while the rear electrodes are separately connected for individual signal processing. Additionally, elements are often mechanically subdivided to prevent unwanted vibrations, but this does not affect the number of electrically addressable elements.

Active Group of Elements in Ultrasound Imaging

1. **Active Group Definition**: A specific set of adjacent transducer elements, centered around a scan line, is used to interrogate that scan line. Other elements in the probe are idle during this process.

2. **Pulse Transmission**: A pulse is transmitted using a subset of the active group, typically the central 20 elements, along the transmit beam centered on the scan line.

3. **Receiving the Echoes**: After transmission, a different combination of elements (the same central group) acts as the receiving transducer, defining the receive beam. Initially, fewer elements are used for reception than for transmission, but this number increases progressively as echoes return from deeper targets.

4. **Dynamic Focusing**: Both transmit and receive beams can be focused or adjusted by controlling the signals of the active elements in the group.

5. **Advancing the Scan Line**: Once all echoes from one scan line are received, the active group shifts to the next scan line. This is done by removing an element from one end and adding a new one at the other end, effectively moving the scan line forward by the width of one element.

6. **Repetition**: The process repeats until all scan lines across the field of view are interrogated. After this, a new sweep across the entire array begins.

This method ensures focused and precise scanning of the target area.

Developments in Transducer Technology

1. **Importance of Transducer Performance**: The efficiency and bandwidth of a transducer are critical to the overall performance of an ultrasound system. Improvements in transducer technology have led to better system performance through new materials, fabrication techniques, and advanced technologies.

2. **Computer Modeling**: A key step in transducer development is creating a computer model that simulates its acoustical and electrical behavior. This model incorporates material properties and element dimensions, allowing designers to test and optimize design modifications before manufacturing.

3. **Traditional PZT Materials**:

   * **Definition**: PZT (lead zirconate titanate) is a piezoelectric ceramic material traditionally used in ultrasound transducers.
   * **Manufacturing**: PZT is made from small polycrystalline grains, molded, and fired at high temperatures. It is then polarized by heating and applying high voltage to activate its piezoelectric properties. However, the granular structure of PZT limits the alignment of piezoelectric domains, reducing efficiency.

4. **Single-Crystal Piezoelectric Materials**:

   * **Definition**: Single-crystal piezoelectric materials, such as lead titanate (PT) doped with other elements like magnesium and niobium (PMN–PT), offer improved performance over traditional PZT.
   * **Advantages**: The single-crystal structure allows complete polarization, leading to stronger responses (greater sensitivity and penetration) in transmission and reception. These materials enable wider bandwidth transducers without losing sensitivity, benefiting multi-frequency operation and harmonic imaging.
   * **Limitations**: These materials are more fragile both electrically and mechanically, limiting their use to lower frequencies where wider element widths and thicknesses are needed.

Capacitive Micro-Machined Silicon Transducers:

* **Definition**: These are small, hollow drums made from silicon, used as transducers by applying a voltage between two electrodes, causing electrostatic attraction that reduces the thickness of the drum and generates ultrasound waves.
* **Advantages**: These transducers are manufactured using silicon technology, allowing both the transducer and associated electronics to be fabricated on the same piece of silicon.
* **Applications**: Due to their small size (microns across), they need to be aggregated to form transducer elements for use at MHz frequencies.

Summary:

Transducer technology has advanced through better materials (single crystals vs. PZT), improved fabrication methods, and innovations like capacitive micro-machined silicon transducers. These developments enable transducers to achieve higher efficiency, wider bandwidth, and enhanced performance, although challenges like material fragility remain