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Slide 1: Transducers

Slide 2: 01. Introduction to Transducers
Welcome to the ultrasound transducers module. This module is one part of the US9069 Ultrasound Essentials course. This module describes transducers, the devices that generate and receive ultrasound. Transducers form the connecting link between the ultrasound-tissue interactions as described in previous module and the actual system.

When you have finished this module, you will be able to review the content and jump to different sections in any order you like.

Slide 3: 02. Objectives
After completing this module on ultrasound transducers, you will be able to describe the characteristics of an ultrasound transducer.

Specifically, given a representation of the elements used in ultrasound, you will be able to explain how the piezo electric effect is used in the transducers.
  Given an image of one ultrasound transducer, you will be able to identify and name the main exterior parts and components of it.
  Given a cross-section diagram of the transducer, you will be able to identify the main internal components and their functions.
  Given a beam shape of the ultrasound transducer, you will be able to identify the major zones and their corresponding names
  Given a diagram with an array of ultrasound elements, you will be able to describe how focusing and steering is performed.
  Given several variations, you will be able to identify the different types of transducers.
  Given an assortment of ultrasound transducers, you will be able to list at least one application where each would be useful.
  Given a diagram showing a body part, you will be able to identify one of the most suitable transducers to use for imaging that part.
  Given the model of a transducer, you will be able to identify the transducer type and the frequency or frequencies that it uses.
  Given a transducer datasheet, you will be able to identify the frequency range, resolution, and accuracy.

There is a quiz at the end of this module that will give you an opportunity to check your new knowledge.

Slide 4: 03. Imaging Transducer Basics
How would you describe a transducer?
A transducer converts one type of energy to another. Examples are: a light bulb, an LED, loudspeaker and microphones.

An ultrasound transducer converts electrical energy into ultrasound energy and vice versa. The electrical voltages applied to transducers are converted to ultrasound. Ultrasound echoes received on the transducers produce electric voltages.
Slide 5: 04. Using an ultrasound imaging transducer  
During an examination, the ultrasound transducer is held and positioned on the patient body by the sonographer.

Slide 6: 05. Transducer Overview  
An ultrasound transducer consists of following parts:  
The piezoelectric element converts electrical energy into sound and vice versa.  
Backings material damps the pulse and forces the wave into one direction.  
Matching layers are used to bridge the different acoustic impedances of the piezoelements and tissue.  
Lens is used to focus the beam and also as the footprint.  
Circuit boards contain electronics for various functions.  
A housing protects the inside.  
The strain relief is used to prevent the cable from pulling off the connector and transducer head.  
The cable contains a bundle of coaxial wires.  
The connector physical connects to the ultrasound system.

Other names for an ultrasound transducer are: a probe, or scanhead.

Slide 7: 06. Crystals/Piezoelectricity  
Let’s look at the piezo properties of ceramics in more detail.  
During the transmit stage, an electric voltage is applied to the face of the crystal and the crystal will deform. Depending on the polarity of the voltage, the thickness will increase or decrease.  
As a result of the deformity, the piezoelectric element will produce a sound wave.  
The terms transducer element, piezoelectric element, active element, crystal or ceramic all refer to the piece of piezoelectric material.  
Ultrasound transducers typically are driven by 1 cycle of voltage, which produces a 2- or 3-cycle ultrasound pulse.  
The frequency of the sound produced is equal to the frequency of the driving voltage, which must be near the operating frequency or so called resonance frequency.  
The operating frequency is determined by the following:  
The propagation speed of the element material; and  
The thickness of the transducer element.  
During the receive stage, the returning sound wave (the echo) will deform the piezoelectric element. As a result, the element will produce an electrical signal.  
In Ultrasound application, the driving transmit voltage is about 100V. The voltage produced by the element during receive is in the range of mV (millivolt) and µV (microvolt).

Slide 8: 07. Piezoelectric Materials  
Ultrasound transducers operate according to the principle of piezoelectricity. Piezo is derived from the Greek word piezo which mean to press.  
The principle states that some materials like ceramics and quartz produce a voltage when deformed by an applied pressure. Conversely, piezoelectricity also results in production of a pressure when an applied voltage deforms these materials.

Today ceramics are used for piezoelectric materials in ultrasound transducers. These ceramics are not naturally piezoelectric, but made piezoelectric during manufacturing by placing in a strong electric field while at high temperature.

This is the reason why ultrasound transducers can not stand high temperatures after production. If a critical temperature is exceeded, the ceramics will lose its piezoelectric properties.
Slide 9: 08. Transducer Frequency

The Operating Frequency is such that the thickness corresponds to half of a wavelength in the element material. Thinner elements produce higher frequencies and thicker elements produce lower frequencies.

Slide 10: 09. Piezoelectric ceramic and PureWave crystal

A variety of ceramic/piezoelectric materials are used to create the ultrasound transducers. One of the most popular is PZT (lead-zirconate-titanate) ceramic, where the fine powders of the component metal oxides are mixed and then heated to form a uniform powder. The powder is mixed with an organic binder and baked into a dense polycrystalline structure. Notice that the texture is not perfect, even after sanding and other processes. New research has resulted in the development of other types of materials that also present good characteristics for ultrasound imaging. One example is the Philips’ PureWave.

Slide 11: 10. Matching Layer

Because the transducer element is a solid (having high density and sound speed), it has an impedance that is about 20 times that of tissues. Without compensation, 80% of the emitted intensity would be reflected at the skin boundary. Thus most of the sound energy would not enter the body. A returning echo also would have about 80% of its energy reflected. Only 4% of the initial energy would remain (0.2 * 0.2 = 0.04).

To solve this problem, a matching layer commonly is placed on the transducer face.

Its function is to:
- Improve sound transmission to the body
- Reduce the reflection of ultrasound at the element surface
  Allow most of the ultrasound energy to exit the front of the element.

The impedance (Z) of each matching layer is of intermediate values to compensate the Z of the elements.

Typically two layers are used, but one or three is also possible.

Next to the matching layers, the lens also acts as a matching layer.

Slide 12: 11. Array Stack Matching Layers

This is a real picture of the layers inside the transducer. You can see the backing material, the piezo element, the 3 matching layers and a ground foil. Depending on the operating frequency, the thickness of the piezo element is approximately between 0.1 and 1.0 mm.

In this picture you can see the size of the elements compared to a human hair.

During manufacturing, these layers are all glued to each other and to the backing, in large pieces.

Once they are glued, the stack is “diced” (or cut through), to create the acoustic elements. Every acoustic element is also diced, to create sub elements. The purpose of this sub-cutting is to improve the acoustic waves. Sub-elements of the same acoustic elements share the same electrical connection and therefore are “fired” at the same time and act together as a single element.
Slide 13: 12. Electrical connections
This is a picture taken from a transducer where you see the electrical connections to the elements.

Slide 14: 13. Propagation from an array stack
In this animation you can see how the ultrasound wave propagates from the array stack. In this example, voltage is applied to two elements which produce the ultrasound wave. Refer to the color bar, where you can see the compression and rarefaction of the sound wave. The sound wave moves to the right because behind the elements (at the left) the backing layer reflects the most energy.

Slide 15: 14. Backing Material
Click on the Backing Material to go to that section.

The Backing Material is a mixture of metal powder and a plastic or epoxy.

Without damping, a transducer element produces a long ultrasound pulse of many cycles. With damping on the rear of the face of the transducer element, a short ultrasound pulse of a few cycles is produced.

1) The shorter the pulse (the fewer the number of cycles), the more frequencies present in it (the broader the bandwidth).

2) A shorter pulse also improves resolution. This will be explained in more detail later during the Resolution section.

Typically, pulses of two to three cycles are generated with diagnostic ultrasound transducers.

Slide 16: 15. Bandwidth
Transducers resonate at a primary operating frequency but the pulses produced contain a range of frequencies called the bandwidth. A narrow bandwidth means that the transducer can only operate effectively over a narrow range of frequencies. For example, a 5 MHz transducer with a narrow bandwidth may not work well below 4 MHz or above 6 MHz.

The shorter the pulse (the fewer the number of cycles), the more frequencies are present in it (the broader the beam width).

Slide 17: 16. Lens or Footprint
Click on the Lens to go to that section.

The footprint is the part of the transducer that contacts the patient. The footprint functions as 1) a matching layer and 2) as a lens in the short axis. This will be explained later.

Slide 18: 17. Coupling medium
Because of its very low impedance, even a thin layer of air between the transducer and the skin surface reflects virtually all the sound, preventing any penetration into the tissue. For this reason gel is used as coupling medium. This eliminates the air layer and enables efficient passage of ultrasound into and out of the tissue.

Slide 19: 18. Ultrasound Beam Shape and Mechanical Focus
A continuous wave ultrasound beam is filled with ultrasound, similar the way to a flashlight beam filled with light. A pulsed beam is not.

An ultrasound beam consists of a beam width in two directions: short axis and long axis.

In the short axis view, we can separate different zones. The region from element to minimum beam width is called the near zone, near field or Fresnel zone. The near zone length is determined by the size and operating frequency of the element. The region beyond the minimum beam width is called the far zone, far field or Fraunhofer zone.

Even with a rectangular, unfocused element, there is some beam narrowing, called the natural focus. To improve resolution, transducers are designed to focus by using curved elements or by using a lens. Notice that, with focusing, the focal length and beam width in the focal zone become smaller and the beam width beyond the focal point becomes larger. You can practice this in the next simulation.

In the short axis view, of a transducer, the focus is mechanically fixed by the transducer design. In the long axis view, the beam can be focused and steered electronically. This will be discussed later.

**Slide 20: 19. Near-Length for unfocused elements**

With this exercise you can see which parameters affect the Near Zone Length. Use the sliders to change the frequency and/or element width and see how this results in a different Near Zone Length (NZL). Note that this exercise is valid for an unfocused single disk element.

**Slide 21: 20. Automatic scanning**

All elements of a linear transducer are not excited at the same time. The array is divided into subsets, or group of elements, called Aperture. Aperture is a group of elements, which are excited simultaneously; the echoes are then used to build up one line of image. This same principle is used on Curved transducers, as well.

A phased array transducer uses no aperture. All the elements are fired to form one line; however, they are not excited simultaneously. Slight delays are introduced with a given sequence. This sequence and the delays are arranged to move the beam through an arc-shaped pattern. With a small aperture: fewer elements used, and the focus is closer and more superficial. With a large aperture: More elements are used, and the focus is deeper.

**Slide 22: 21. Electronic Focusing and Steering**

We will now explain electronic control of the ultrasound beam.

The purpose of narrowing an ultrasound beam is to improve lateral resolution and image quality. It is most effective in the near zone and at the focus.

Focusing can be accomplished in four different (4) ways

As described in the previous slides, for conventional focusing:

By placing a lens on the transducer;
By cutting or curving the crystal; or
By using a focusing mirror

For non conventional focusing, by electronic (or “array”) beam forming
(which will be explained now)

**Slide 23: 22. Array beamforming**
By using phased array beamforming, the beam is controlled electronically.

Electronic steering:  
When voltage pulses are applied in rapid progression from left to right, one ultrasound pulse is produced that is directed to the right. A similar pulse can be produced and directed to the left. A wave always travels perpendicular to its wavefront.

Electronic focus:  
A curve in the phase delay pattern results in focusing the pulse. A greater curved delay pattern (with longer time delays between the elements) moves the focus closer to the transducer. Conversely, shorter delays move the focus deeper.

The more elements are used, the bigger the aperture and the better the beam can be controlled

**Slide 24: 23. Multiple focus**
Multi-zone transmit was developed to get optimum focus over the entire depth of the field. Several transmit pulses are sent for each line, each focused at a different depth. Then the final image is formed out of the portions of those partial images that are most in focus. This has the disadvantage of reducing the frame rate.

**Slide 25: 24. Resolution**
Resolution is the ability to distinguish and display two objects as separate objects and is a measure of a system’s image quality.

Imaging resolution has three aspects:  
Detail;  
Contrast; and  
Temporal  
Contrast and temporal resolutions relate more directly to instruments. Detail resolution relates more directly to transducers and is thus discussed in this section.

If two reflectors are not sufficiently separated, they produce overlapping echoes that are not separated on the image display.  
In ultrasound imaging, the two aspects of detail resolution are axial and lateral.  
The smaller the axial and lateral resolution, the finer the detail that can be displayed and the closer two objects can be seperated.

**Slide 26: 25. Axial Resolution**
Do you remember what Spatial Pulse Length is?  
SPL is the length of a pulse from front to back.  
Spatial Pulse Length is measured in millimeters (mm). The length of each cycle is wavelength. Thus the spatial pulse length increases with the wavelength.  
Because wavelength decreases with increasing frequency, SPL decreases with increasing
frequency. Shorter pulse length improves resolution. Common pulses have 1 to 3 cycles.

Axial resolution is the minimum reflector separation required along the direction of sound travel to produce separate echoes. To improve axial resolution, spatial pulse length must be reduced by increasing the frequency. The Axial Resolution = ½ SPL With an increase of frequency comes a reduction in penetration (or image depth).

Other names for axial resolution are:
- Longitudinal Resolution;
- Axial Resolution;
- Radial or Range; and
- Depth resolution

This is an ultrasound Image Quality phantom. We can separate the dots in axial direction (from the top, down).

Animation A:
The separation of the reflectors is less than ½ SPL, so echo overlap occurs. Separate echoes are not produced.

Animation B:
The reflector separation is increased so that it is greater than ½ SPL. Echo overlap does not occur, separate echoes are produced.

Animation C:
The reflector separation is the same as in animation A, but better resolution is achieved by shortening the pulse so that separate echoes are produced.

**Slide 27: 26. Lateral Resolution**
Lateral resolution is the minimum object separation in the direction perpendicular to the beam direction (that is, across the scan line) that can produce two separate echoes. Lateral resolution is equal to the beam width in the scan plane.

Animation A:
The scanning is sequence results in continual reflection from one or both reflectors, separate echoes are not produced.

Animation B:
The beam fits between the two reflectors. Both reflectors produce separate echoes.

**Slide 28: 27. Temporal Resolution**
Temporal resolution is not related to the transducer, but to the system. However, as part of the “Resolution” overview, we will briefly discuss it here.

Temporal resolution is the ability to display reflectors with respect to time and motion.

Can you find the bird in the tree? Probably not, but when the bird flies, you can separate it from its surrounding and therefore notice its position and movement.
The faster an imaging system can produce an image, the better the temporal resolution will be.

Factors that affect the frame rate (in frames/second) are:
Line density;
Depth;
Sector width;
Number of foci; and
Mode / processing power

**Slide 29: 28. Transducer cable**
The transducer cable consists of multiple light-weight, very thin coax wires.
They are used to send and receive: the pulse to and from the crystals; power to the multiplexers; and for transducer ID.

The amount of wires inside the bundle are limited, otherwise it would be too heavy and not flexible enough for practical use and for the sonographer.
The cable must be light-weight and at the same time very flexible and strong.
In this first picture you can see the coax cable with its shielding, and compared to a human hair.
In the 2nd picture you see that even a single coax consists of several stranded wires.

The important properties of the cable are:
Strength
Flexibility
Light-weight
Low resistance, and
Low noise

If the number of elements inside the transducer exceeds the number of wires, multiplexing is used to route the signals.

**Slide 30: 29. Electronics inside the transducer**
The transducer also contains some electronics.
The transducer ID contains the identification of the transducer that is sent to the ultrasound system.
Multiplexing is the method used to reduce the number of channels used in the cable of the transducer. One wire is used for signals from different elements; they are timed, in the appropriate sequence, to send to the ultrasound system.
As an example, we use a multiplexer with 12 inputs (elements) and 6 outputs (channels) and scan with an aperture of 3 elements.
At first, elements 1-3 are routed to channels 1-3, elements 2-4 to channels 2-4, etc...
When element 7 is used, this signal is passed to channel 1, as you can see in the animation.

**Slide 31: 30. Basic Transducer types**
Here you see an overview of the basic transducers. We will go through them one by one.

**Slide 32: 31. Imaging Transducer Basics Linear Array**
The elements in a linear array transducer are rectangular in shape, and arranged side-by-side in a straight line. Applying voltage pulses to a group of elements produces each segment of the beam. In this illustration, a voltage pulse is applied to a group of elements at the same time. For example, elements 1-6 fire, then 2-7, 3-8 and so on, until the end of the array is reached.
In an actual transducer, this process repeats several times per second. The speed of the illustration is much slower by design, so you can see how the beam forms. Notice that the field of view is rectangular in shape, with a flat top. Applying voltage pulses to groups of elements in rapid succession is referred to as “electronic scanning”. When the process repeats rapidly enough, a real time presentation occurs. The number and size of the elements, in combination with how the groups of elements fire, impacts the number of scan lines (or line density) in the image. A 250-line density image has better image quality than a 128-line image. When we say a transducer supports multiple modalities, we are referring to Doppler, color, M-mode, etc.

**Slide 33: 32. Curved Linear or Convex Linear Array**
A curved array transducer works just like a linear array. The elements in a curved linear transducer are rectangular in shape and arranged side-by-side in an arc. The direction of the pulse changes due to the curved elements. In the linear array the pulses go straight down, while in the curved linear the pulses angle out to the side. Notice that the fan-shaped field of view, with a blunted top, becomes wider as it moves away from the scanning surface.

Usually, a curved array transducer is combined with lower transmit frequencies, as the application that is used requires deep penetration.

During manufacturing, the linear array stack is bent in the curved shape of the transducer.

**Slide 34: 33. Curved Linear or Convex Linear Array 2**
Some properties of the Curved Linear transducer are:
- a wide field of view; and
- difficult to use in small acoustic windows

**Slide 35: 34. Curved Transducers**
Here you see a curved probe on the left, and an endocavitary probe on the right. The curved probe has cut or curved crystals, so the beam spreads out as the crystals are fired in groups.

**Slide 36: 35. Mechanical Transducers**
Mechanical transducers are Linear or Curved transducers, where the array stack and lens can be moved by using a motor inside the transducer. The purpose is to produce 3D or 4D images.

The array stack is positioned in a fluid to allow the transmission of the ultrasound from the array to the outside of the transducer.

Between the array and the patient is a thin membrane known as a dome.

**Slide 37: 36. 3D6-2 Transducer – An Inside View**
Here you can see the array, dome and fluid chamber of a 3D6-2.

This is a 3D6-2 before the cable is attached and the housing is installed; and showing, among others components, the motor.

**Slide 38: 37. Sector transducer**
In a Sector transducer (also called a phased array), the elements are arranged in a straight line, as they are in a linear array. The difference is that the array is extremely small, and the voltage pulses are steered. The voltage pulse is applied to all elements at the same time, but with small
time delays (or “phasing”). These delays result in the beam going out in different directions. The firing sequence repeats with a different time delay thus changing the direction of the beam. Using time delays to sweep the beam from one side to the other results in a sector or pie shaped field of view.

A phased array is actually a linear phased array, but is commonly referred to as just a phased array or a sector transducer.

A phased array transducer uses no aperture. All the elements are fired to form one line; however, they are not excited simultaneously. Slight delays are introduced with a given sequence. This sequence and the delays are arranged to move the beam through an arc-shaped pattern.

The main application for Sector transducers is cardiac imaging, because of the small footprint in combination with higher frame rate.

**Slide 39: 38. Sector transducer 2**
Some properties of a Sector transducer are:
- Small footprint for tight acoustic windows between ribs and lung
- High frame rate, and
- Small field of view, compared to a curved array

**Slide 40: 39. xMatrix Transducer**
Unlike other imaging transducers, xMATRIX transducers have square elements instead of rectangular.
Show image] This image is a magnified xMATRIX array showing individual elements and a human hair for scale reference.
Depending on application and design it contains up to 9200 elements.
Matrix transducers have technically the same principle as Sector transducers.
But a matrix transducers consists of much more elements and have elements in two directions in a matrix pattern, while other transducers use an array.

With the xMATRIX transducers you can control the beam in any direction, using xPlane. Initially these transducers were developed for Echocardiagraphy, nowadays they can be used for General Imaging also.

**Slide 41: 40. xMatrix Transducer 2**
Depending on the type of xMATRIX, you can use all the modes with one transducer – 2D, 3D/4D, Live xPlane, Live MPR, MPR, Doppler, color Doppler, CPA

**Slide 42: 41. Pixels and Voxels**
Pixels are stored in a 2D format on 2D machines, but three dimensional images or full volumes have an additional dimension of information to store, and display. They are stored in Voxels.

A voxel (volumetric pixel or Volumetric Picture Element) is a volume element, representing a value in three dimensional space.
It visually represents and measures a full volume capture
A Voxel of information can displayed and rotated on the screen.

**Slide 43: 42. Non-Imaging transducers**
Continuous wave (CW) transducers emit sound continuously. There are two elements within the housing: one that continuously emits sound and one that receives. CW capability can be combined within an imaging probe; however continuous sound can not be used for imaging.

Pulse Wave (PW) non-imaging transducers are used when the correct location of the vessel must be identified. PW transducers are low frequency Doppler probes that emit several pulses along the scan line. They provide range detection, allowing clinicians to choose a specific area of flow to analyze.
Note: other names for these probes are pedoff, pencil or static transducers. PW and CW are explained in more detail in the Imaging Module of this eLearning.

**Slide 44: 43. Imaging Transducer Basics Naming Transducers**
Different manufacturers have different methods for naming transducers. Some manufacturers include the arrangement of the crystals, and the frequency range in the name of their transducers. The next few slides show examples of different naming conventions.

For instance, within Philips, a “C6-3” is a Curved Array transducer using a frequency range from 6 to 3 MHz.

L stands for Linear Array
S for Sector or Phased Array
X for xMatrix transducers
V for Volume used for 3D/4D transducers, and
D for Doppler

**Slide 45: 44. Transducer Selection**
The type of transducer required depends on the application, the acoustic window, field of view, scan mode, etc

**Slide 46: 45. Care & Handling Overview**
When using the transducer, it is important to:

Handle with care;
Use the cable management system;
Follow the cleaning procedure;
Check the user manual for approved disinfecting solutions;
Use the mounted transducer holders;
Visually inspect the transducer, prior to use;
Carefully align the connector before locking into system; and
Clean the gel from the transducers after each use

Use the link to visit the Philips Healthcare Transducer Care and Cleaning site. Please give this link to your customers as well, and instruct each customer on how to use and clean the transducers.
Slide 47: 46. Care & Handling Overview 2
Do not:

- drop or bump the transducer face
- let the transducer cables dangle loosely while moving system.
- drop the transducers into a cleaning solution
- immerse the connector
- use solvents or abrasive cleaners on the transducer
- excessively twist or pull cable, or
- use ink on the cable

Slide 48: End
You have now finished the Ultrasound Transducer module of the Ultrasound Essentials eLearning