# Video Presentation

## Optimising Ultrasound Images


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Professor Bamber provides a demonstration of the physics and optimization of ultrasound scanning. It is meant to complement other lectures presented during the School's course.

## Professor Bamber's Video Transcription

The demonstration is to provide illustrations of selected points from the lecture to optimise functions on the ultrasound scanner, and also, to give examples of how and when you change the controls for those functions that effect the image appearance.

By the end of watching this demonstration, you should be able to set up the ultrasound scanner to obtain the best images for the task that you have in front of you.

### 1. Acoustic Impedance

The first thing that you may remember from the physics lecture is that there is a strong acoustic impedance mismatch between and I'm holding an ultrasound probe in front of me between the material of the ultrasound probe the piezoelectric that emits the ultrasound and air and if we are holding a transducer in the air then what you're getting mostly on the image which I'm pointing to now is a reverberation of the sound within the piezoelectric and within the rubber lens on the end of the probe and very little sound is propagating out into the air

So, we see these reverberations because of that strong acoustic impedance mismatch we need to put ultrasound gel to couple the probe to the skin.

If I place the probe on my own skin, you can see on the scanner.

If I unfreeze, you can barely see any image at all. My skin is fairly dry and so therefore there's no way of coupling the sound into the tissue. We must put some coupling medium on the probe, and I'll do that by putting some gel straight on.

Immediately I do that, you can see the sound bouncing around between the probe surface, gel and air interface. You can see all these reverberations.

But as soon as I put probe on my neck, you can immediately see an image of my thyroid gland, jugular vein, carotid artery and neck muscles.

So that explains, related to the lecture, why we need the gel.

## 2. Selecting the Transducer

The next thing I want to remind you of is the need to select the appropriate transducer and although there are some different types of transducers (for example the linear array and the curvilinear array for breast imaging) you'll mostly be using linear arrays. This sort of array is useful for abdominal imaging, obstetrics and so on and is needed to obtain with the small aperture. That's the acoustic window on the body with a wide field of view at great depth. It's useful for that but not particularly useful for breast imaging.

So, putting that one aside, we have two different linear array probes here. This 9L and this ML 6-15. The 9L is a nominal nine megahertz fairly short linear array. This one is a little bit longer.

It gives you a slightly wider field view for breast imaging but also in the elevation direction.

This is a single row of elements whereas this is a 1.5 D array that has five rows of elements and will give you extra resolution in the elevation direction. In other words, a smaller slice effect thickness.

This would give you much better resolution but also better penetration and better, what shall I say, contrast, particularly with regard to discriminating whether they're echoes within (for example, cystic structures) where with this probe there would be more chance of echo filling and difficulty of discriminating whether something is a cyst or not.

So, this is a good probe to use for breast imaging. But, nevertheless, both probes could give good high-quality images.

## 3. Selecting the Frequency

The point that I want to demonstrate to you here, I'll use both probes to demonstrate the selection of the frequency with each probe. Each of these probes has very wide bandwidth and you can select the frequency that you want to use for that selection and frequency.

Also, if you had even higher frequency probes or lower frequency linear arrays, the selection of the probe or the frequency you're going to use in a particular probe, is based on that fundamental compromise that I explained in the lecture. That is, you choose a low frequency if you need to penetrate to deeper tissues and a higher frequency if you don't need to penetrate to deeper tissues. The reason for those selections is, if at all possible, you choose the highest frequency that you can so that you can get the best spatial resolution.

The reason is, as you heard in the physics lecture, the attenuation of sound increases with increased frequency.

We prefer to use the highest possible frequencies because they give us the smallest wavelengths and therefore the best resolution in the images. So always go for the highest frequency that you can find for the depth to which you wish to penetrate.

We'll put some gel on the probe and I'm going to image a phantom which actually is a physicist quality control phantom. But it works pretty well for illustrating this. You can see on the screen we're right now looking at some cylindrical insertions. They look a little bit like tumours of different contrast, brightness to background and, in here, are also some wire targets which in this plane look like points. The physicist measures the size of these for measuring the quality of the ultrasound scanner.

You'll be looking at the size of these points as they're displayed as a measure of spatial resolution and a measure of contrast discrimination provided by these targets. You don't need to know that but that's the sort of phantom that I'm working with.

Now I'll just go to a slightly larger depth setting so that we can see the full depth of the scan and show you what the effect of changing the frequency is. At the moment, I've set the scanner to a very low frequency of five megahertz. That's not typical of what you use for breast imaging. We would go for a higher frequency usually because we don't need this large penetration depth in general.

This is at the moment penetrating all the way down to 10 to 12 centimetres. It appears in this phantom which mimics tissue and attenuation properties. So, if I go to a high frequency and switch from five point five, you start to see the image changing. We're at six megahertz now.

At seven you can see the speckle. We'll talk about speckle in a moment. You can see these points of the targets are the wire targets. They are sharpening up as we go to nine megahertz, and that's the top frequency of this probe. You can see the effect of the improved resolution and the reduced depth of penetration.

Now we're only penetrating to about seven centimetres at nine megahertz. If I switch to the other transducer, you'll be able to see that I can exaggerate it even more. We'll take a moment for the scanner to bring in this other transducer and I'll need to increase the penetration depth on the display first. But what you can see immediately is the effect of the better transducer in these point targets. They are really beautifully displayed as very fine points now.

There's a very nice tissue contrast between these cylindrical inclusions in the background and a very sharp definition of the boundaries of these. So, you can see the superiority of this probe with these one and a half d (1.5 D) matrix arrays.

At the moment, this is automatically set to 15 megahertz. This is assuming that that's the frequency that we want to use because we switched to this transducer and you can see the consequence of that. The penetration depth is not much better - well it's about four centimetres. Very shallow.

As I decrease the frequency that's 12 and now 9 and that's the lowest frequency that this probe will go to at nine megahertz. That was in fact the top frequency of the previous probe of nine megahertz. We're now penetrating to about five centimetres.

So, a little bit of improvement in penetration depth but quite a loss of spatial resolution. If you check that, we can switch back to nine megahertz and look at the size of these points. In fact, I could zoom in.

Let's do that. Let's zoom into some of those points and you should be able to see the effect of improving the point target resolution there. As I increase the frequency to 15 megahertz, then that's the effect of it there. you can see the points are displayed very tiny.

## 4. Setting the Control Panel

The next thing I want to describe to you is, having chosen the probe that you're scanning with, you now understand selection of the frequency to use. You now need to think about how to set the scanner controls for getting the best image.

The easy way is to let the scanner do it for you. On some scanners, there's a thing called *auto optimize*. There are other names that different manufacturers provide for that control. You can just press that button and the scanner will set itself up for you to provide a pretty good image - equivalent to that you would select for the application (such as breast application).

Many scanners will have set the controls to be optimized for breast imaging. But of course, what is optimum for one breast is not necessarily optimum for another breast. Or for a pathology that you want to look for it's not necessarily optimum for another. For instance, cystic solid differentiation is not necessarily going to be done with the same settings as you would looking for some of the diagnostic criteria to distinguish benign and malignant solid masses.

So, understanding how to optimize the scanner is helpful. You can use the automatic optimization button but I think you'll always do a little bit better if you know how to do it yourself.

I will come back at the end of the video with a demonstration of the difference between setting things up yourself and setting it up with the auto optimize button.

For the moment, we're going to go through, if you like, the hard way and we're going to do it ourselves.

## 5. Gain, Time Gain Compensation and Dynamic Range

The first thing I want to talk about for scanner control setup is gain and time. Gain compensation is fairly straight forward. That controls the average brightness of the image and how much the scanner is going to amplify the strength of the echoes before displaying that echo strength as brightness on the screen.

### 5.1 Time Gain Compensation

The time gain compensation is sometimes called depth gain compensation or swept gain on some systems. It's set by these scanner sliders that you see here. The overall gain on this particular scanner is just a single knob. It's there to interact with something called the acoustic power output. That is over here on the scanner.

### 5.2 Dynamic Range

We'll come to that one in a moment. But first of all, the interaction between gain by time gain compensation (TGC) sliders and one other which control dynamic range. The dynamic range adjusts the relationship between small echoes and how much they're amplified before they're shown on the screen and how much strong echoes are amplified before they are put on the screen.

High dynamic range means that the low weak echoes are going to be amplified a lot, relative to the strong echoes. This allows a very wide range of echo strengths to be put on the screen at once. But because of that wide range put on the screen, in terms of echo strength, the ability to discriminate one brightness from another echo strength, is poor if you select a low dynamic range.

The ability to discriminate different echo strengths by looking at the brightness on the screen is much better. I showed in the lecture the logarithmic graph that describes input echo strength against brightness on the screen. From that graph you can sort of see what I'm trying to tell you.

Now we will show you that, in terms of contrast, it can be displayed on the screen. The reason for mentioning it now is because I'm talking about gain settings and time gain compensation settings. This is to mention that if you're trying to set the TGC, then don't do it with the dynamic range control set at the maximum because your vision is insensitive to small changes in image brightness. It does not give you a

good ability to discriminate between the different echo strengths and therefore, you would not be very sensitive to setting the TGC control.

So, let's have a look at an example of that. You can see that I've got the dynamic range set here to 96 decibels. That's the maximum on this particular scanner and that means everything looks really quite grey, a bit washed out and the brightness of the points is not very different from the brightness of the background

Everything looks fairly similar and if I change the brightness control, we see it does have an effect on the image brightness. But for the rate at which I'm changing this control, you'll see in a moment. When I set the dynamic range lower, the rate which the brightness changes here is not as rapid as it would be if the dynamic range were further down. In particular, if I change the TGC sliders, you can see how there is an effect on the image.

But it's not particularly dramatic. If the dynamic range is high and the brightness control is high, you can see almost no change in the image as I move these sliders around. So that would be absolutely useless for being able to adjust the time at the depth gain curve.

If I turn the brightness down, on the other hand, and I turn the dynamic range down, there is an interaction between these two controls.

I'll turn the dynamic range down to the minimum. It will go. This is an unreasonably low setting. You wouldn't normally use it this low. But the immediate impact on the image that you can see is it's very contrasty appearance and it's now saturating at the higher brightness levels.

So, we'll have to turn the brightness control down. One effect of having such a low dynamic range is that it's impossible to display all the information that you want to simultaneously appear on the image. You have to interact with the image changing the brightness to be able to see a nice background speckled contrast. Then you'd turn the image down to see this brightest lesion clearly and you turn it up a bit to see the lower-level lesion.

However, this sort of setting is really quite nice for getting the TGC just right because it makes you very sensitive to small echo strength changes. So now you can see that the TGC is not set very well. These sliders are all set to be giving us constant gain with depth. I can increase the gain at that particular depth, and you can see this bright band appearing across on the image there at that depth.

That's obviously overcooking it at that stage. But what we can do is now set the image up so that we're getting really quite a nice image. We need a bit more there. A bit down here and we can get a reasonably homogeneous brightness with depth. As you can see, I'm now comfortable with that TGC setting and with practice. My colleagues in the clinic do this in a fraction of a second by just sliding their fingers across these controls to set that up for a nice homogeneous image with depth which is what you're aiming for.

And then you can turn the gain up to the gain setting you desire and the dynamic range up to the region you want. Where to set the dynamic range depends on for what you're looking at the image and what you're trying to discriminate.

But a good typical sort of ballpark figure I would say, is in the region of 70 decibels. This scanner either flicks between 69 or 72 and it also depends on the ambient viewing conditions. For the purposes of making this video, we have a spotlight in the room and high brightness in the room. Of course, you wouldn't normally scan in those lighting conditions because it makes it more difficult to see very low contrast details on the screen.

You will be scanning with dimmed lighting conditions. But that can, to some extent, be compensated for by changing the dynamic range and reducing the dynamic range slightly. These sort of lighting conditions gives us a more contrasty image and makes the image visually easy to see.

But the consequence of that is that I have to be careful that I'm not missing something. I would have to interact with the image by dynamically changing the brightness as I'm viewing it.

## 6. Depth Setting, Line Density, Transmit Focus Setting and Frame Rate

The next topic to briefly discuss is the interaction between depth setting and frame rate. Depending on the other settings of the scanner, this may or may not be particularly strong. But as you remember from the lecture (I hope you remember) is that the go and return time to the depth of interest and the maximum depth of interest for the ultrasound combined with the speed of sound is what determines the frame rate as well as the line density - the number of lines that one is reconstructing in the image

## 6.1 Line Density

The maximum line rate that the scanner can run at is still determined by the go and return time and therefore the speed of sound. So, the point that I'm making is that, if you insist on imaging to large depths, you will get a lower frame rate than if you image at shallower depths.

There's not a strong effect on this scanner because of compromises in other areas that are made. But you can see here the frame rate is 61 frames per second for this probe. The settings that I've set up on the scanner are for imaging to a depth of about 12 centimetres. If I reduce the depth, one can immediately see we've gone up to 76 frames per second illustrating the point I'm making. That's a very high frame rate. We don't need those frame rates for imaging the breast.

The reason we're getting those frame rates is because of the other settings that I've set in the scanner. That's because I wanted to illustrate what some of the functions do. This current image set up gives a fairly poor image. It's a sort of old-fashioned image. The sort of image that we would have been routinely observing if we were scanning with an ultrasound scanner built, say, in about 1985 or so.

When things like speckle reduction, angle compounding, tissue harmonic imaging and all sorts of other clever techniques had not yet been invented or if they had been invented, they would not have been incorporated into commercial ultrasound systems. Multiple focal zones are another feature.

All these things tend to slow the frame rate down a little bit which I will gradually switch in one at a time to show you what the effect is on the image appearance. So, let's start with image line density. I will use let's say a depth of penetration to about four centimetres. For this depth, you can see clearly this brightest inclusion. You can see the speckle in the background and at a frame rate of 76 frames per second.

This is running at a minimum line density. It doesn't tell us what the line density (lines per centimetre). But, if I gradually put it to the maximum line density, then hopefully the resolution on the video is good enough to be able to see on this image that the points have sharpened up. In particular, you can see the speckle in the background is now really sharp.

Probably the best way of showing that is, if I zoom in. I can do that on the ultrasound scanner. But what I want to just draw your attention to is what's happened to the frame rate? It's now dropped from 76 all the way down to 25 frames per second. So, there was a big penalty in improving the image in this way.

Again though, for breast imaging who's worried about 25 frame per second? It's perfectly adequate for surveying the breast. It's not like echo cardiology where we need really fast frame rates. So, I would always put in the line density if I was setting the system. I would set that to maximum.

Let's zoom in. As I said, I would illustrate that light effect for that line density by looking in detail at this speckle pattern. You can see here this fine speckle. We're going to (as I said earlier) talk about what speckle really is in a moment. Now I'll gradually put that line density down to zero. That's zero as a setting on the controls. It's not the zero-line density, obviously.

And for this line density, you can see that the image is being reconstructed to quite a coarse sampling. It's saving time but it has a severe penalty in terms of image quality. We're not really seeing the true physical speckle pattern there. It's under sampled. The scanner has done some nice smoothing to cosmetically improve that poor result. But it nevertheless still is a poor result.

As I just change the probe angle a little bit, you can see shimmering and artifactual black spots. Under sampling artifacts appear in the speckle pattern which indicate how bad an image, that is.

If I switch that up to the maximum line density again, you can now see the little wormy pattern of the speckle being clearly and faithfully reproduced. And even this point target is a little bit sharper with the light higher line density. It's interesting. It's not actually changing the spatial resolution of the ultrasound beam that still exists inside the medium we're imaging.

We're just displaying it in an under sampled way. If we use a low line density that's from now on. I'm going to leave that set at the maximum setting because in my opinion that's what we should be scanning with.

## 6.2 Transmit Focus Setting

Take the zoom control out and we'll do one next thing in getting from these images to a gradually better and better image. You can see on the right a single sort of carrot (as they call it) on graphical displays indicated a depth of two centimetres. This is telling us that there is, because there's only one of these carats, a single focal transmit zone receiver. All modern scanners have dynamic receive focusing which I explained in the lecture

That is not under user control. It's just running in the background automatically. But on transmit we have a choice of how many transmit focus zones are switched in. The reason we have a choice is that there's a penalty for that. Whereas with dynamic receive focusing, there is no penalty. The penalty for transmit focusing is that the more transmit focal zones are switched in, the slower the frame rate.

## 6.3 Frame Rate

In fact, we divide the frame rate by the factor of the number of focal zones. So, with one focal zone in that factor is one, this means that there is a slight degradation of system resolution outside of that focal depth. You can see that manifesting itself by the fact that, at this depth, these two point targets are well in focus. It's starting to get a little bit blurred as we go to these point targets that are nearer to the transducer.

Also, it’s a bit blurred as we get deeper. If I go to much deeper depths, you can see these point targets are very blurred by comparison. What happens if we switch in more focal zones?

We can do that. Here's two we've not changed things down here very much. We've helped a little bit up here. One nice thing is we can adjust the position of the focal zones. So, I can move those down to something deeper if I switch back to one.

You can now see if I change the depth setting, position and the focal zone deeper, then at least that focal zone is at the moment giving us optimum lateral resolution at that depth of five centimetres.

If I move that up to something much shallower, the best focal position is here. So, if you really were worried about frame rate, you can keep yourself to one focal zone and adjust the position. The depth of that focal zone is to be at the location of say the pathology that you want to image at the highest resolution to get the best detail for diagnosis.

However, for breast imaging, the frame rate penalty you get (which, at the moment, we're running at 25 frames per second) for a single focal zone. If we switch in two, the frame rate drops to 13 frames per second and is still a reasonable frame rate for breast imaging.

So, let's go to three or even four. Now we're down at six frames per second. If you're rapidly surveying the breast, you're likely to see a little sort of jerky motion in the image. As I move the scanner probe around, you can see I'm moving around on the phantom. You can see the jerkiness in the image displayed on the screen.

It wouldn't bother me, but it might bother some people and you might say "well we don't need four or five focal zones". I can still reposition those. But you can see the benefit in the image quality that we're getting, particularly if I position them well.

We're getting good resolution at all the depths pretty much all the way down to about five centimetres and it's not too bad all the way down to six centimetres.

So, that's the advantage of it. But down to four frames per second, it's a very slow frame rate because of that. Some compromise is obviously necessary. I would have said, for scanning the breast, maybe three focal zones, eight frames per second is not bad. But you might feel that jerkiness in the image as you're moving around is a bit distracting.

So, two focal zones might be reasonable. We'll leave it at two focal zones for the moment and then we'll switch in the next image improvement property, speckle reduction.

## 7. Speckle Reduction, Including Image Persistence and Angle Compounding

Speckle reduction on this scanner is called high-definition imaging. Spectral reduction processing can occur in several different ways and you can use all of them. The simplest thing to use is persistence or frame averaging. You'll see it as different labels on different scanners.

What that does is provide in real time a dynamic averaging of the images over time and typically an exponential decay weighting function is used.

But you don't really need to know that. That's just saying that in the temporal average image displayed, the emphasis is on the current image and there's a gradual lesser weighting in the past images that are included in the temporal average.

The effect of that temporal averaging, or persistence as it's sometimes called, is to average speckle from one frame to the next If the probe is moving.

At this point, I really need to tell you what speckle is about. We did talk about it in the physics lecture. But it's that interference between the echoes that come from different parts of the tissue structure that happen to be close enough to be within the pulse length and within the beam width.

In other words, each point in the object has on the image a spread function. The physicists call this the point spread function. But if two tissue structures are closer together, then that point spread function from each of the tissue structures will overlap and those two overlapping point functions can interfere with each other.

The word interference is like code word for physicists. It means that positive parts of the wave can add up when they coincide. So, in that point spread function the ultrasound waves have both positive and negative components. And, if two-point spread functions overlap just right so that two positive going parts of the two different waves interact, they will constructively sum up and give us a large amplitude.

On the other hand, if a negative region sums up with a positive region, they could cancel and give a small amplitude or even zero. No signal at all and the speckle pattern is a result of all that interference of waves coming back from ultrasound scatterers that are very close to each other.

It's a unique phenomenon of coherent imaging system like radar or like underwater acoustics or laser speckle. It doesn't occur with other types of medical images in general.

Let's have a look at the speckle. I'm going to zoom in again to do that. You can see that speckle. It's interesting. It's almost like noise. It doesn't relate to the real structure of this phantom because it's coming from structures that are too small to be resolved. It's artifactual image detail and it's interfering with our ability to see the real image detail.

We would like to reduce it. Reduce low contrast discrimination, for example. To improve the image, we want to reduce the speckle. If I tap the phantom, you can see the speckled shimmery and that's the basis for reducing the speckle. Using persistence as I scan around, you can see the speckle pattern is changing.

## 7.1 Image Persistence

If we switch in persistence (and I'll do that now on this scanner) it's called frame averaging. I'll immediately switch it to maximum and you can immediately see the speckle is much reduced. But only so long as I'm moving the probe. Notice that if I'm holding the probe stationary (as I am now) the speckle is as clear as it ever was. But as long as I move the probe, then we see some speckle reduction.

If I go back out of the zoom mode and just look at that low contrast image, I will reduce the depth of penetration a little bit so we can see that inclusion. You can see how the contrast between the inclusion or lesion and the background improves as the speckle is reduced while I'm moving the probe.

Low contrast is probably easier to see if I go over to this part of the phantom. You can see these two low contrast lesions as one positive and one negative.

As I move the probe now, you can see discrimination between the brightness of these low contrast lesions and the brightness of the background more easily than if I hold it stationary.

Now the lesions start to sort of get a little bit more difficult to distinguish from the background. That's the first technique in image persistence for improving your low contrast discrimination.

It seems pretty crude but in the hands of a skilled person, you can adjust the trade-offs. The trade-offs of course are spectral reduction is being blurred and the speckle is being blurred (and therefore reduced) while the probe is in motion. But of course, so too are real tissue resolvable structures.

The detail and the information you want to pull out of the image is being blurred a little bit as well. But, if you're clever, you can use that interactively by scanning quickly, surveying and allowing your eye to be drawn to low contrast details that are made more visible by the speckle reduction due to the persistence.

And then, if you think you've spotted something, then hold the probe still and allow the probe to follow respiratory motion or ask the patient to hold their breath. Then start to see the finer detail which you might see for the resolvable structure that doesn't need the spectral reduction once.

You've found it with the persistence switched on and you can keep pausing and moving and pausing and moving as you're scanning around using that technique interactively. The next simplest type of spec reduction to use is something on this scanner. It is called speckle reduction.

That analyses each small region of the image's local texture pattern. It's analysing that pattern to

decide whether the pattern statistics are similar to speckle or not because speckle has very particular statistical properties.

Those statistical properties are characteristic of the scanner and not so much of the tissue of course. Each region, when we're imaging anatomy in this phantom, is almost all speckled because the phantom is not built with any resolvable structure - apart from these inclusions and the wire targets.

But in a real breast, you have a continuous mixture of partly resolvable structures fully resolvable and then there's a much finer detail right down to the cellular level.

Unresolvable structures provide the spec or component. Ideally, one would like to smooth out that part and leave only the resolve structure. That ideal is never achievable. But we can get some way towards it with a method called adapt this speckle reduction. And that is what's implemented here.

If I demonstrate that, it will show what the computer is doing in terms of manipulating the image. The computer uses the local statistical assessment of the texture of the image to make a judgment of whether that texture is probably speckled or probably real structure.

And, if it's probably speckle, it'll smooth in that region. If it's probably structure, it will leave the image alone and it grades the effect between those two extremes. But clearly, it's going to make the wrong decision some of the time and over smooth some real structure or under smooth some speckle.

Let's switch this into the maximum level to be able to demonstrate the effect. You immediately see the image has changed dramatically.

I'll just switch that out back into no speckle reduction and then what you see when we switch in the spec reduction is some of the detail in the background. Speckle gets preserved and the other is smoothed. This is overdoing it and the effect of overdoing it is to apparently create anatomical structure where there is not.

Now we have an image here. Let's see if I can zoom in to show you some of this. You can see a very different texture pattern to the background. This is very much artifactual as a result of the behaviour of this filter.

It’s not good in this phantom because it's a bit distracting. Although under the circumstances, I’m wondering whether I can demonstrate that with an image of my neck. Let's try it. Under some circumstances, it can produce an interesting result in that you know the brightness settings are not good for my thyroid. But let's zoom out.

It's not a nice image to look at. Let's switch out the spec reduction again and we'll turn the gain down because, for my thyroid, that's far too bright. We'll now turn the dynamic range up a bit. You can see the thyroid gland displayed with quite a bit of sparkle inside it and speckles dominating the appearance of a lot of the image.

I’ll switch the spec reduction back in and it's smoothing the thyroid gland but drawing our attention to the vascular structure present within the fine detail vasculature. So, even though the image is not one that I particularly like, it is drawing the eyes attention to some interesting detail and similarly in the muscles on the neck, it's doing the same.

So, you can see the effect of that. A better setting is a compromise. We can see that if I go back to this image, I need to reduce the dynamic range down to about 69 again and brightness down for this phantom. Maybe that's probably okay.

And let's tone the adaptive speckle reduction down to maybe two or something like that which is in combination with persistence. Once I start moving, we're now starting to see really quite a nice image.

But it's going to get better. You can see these boundaries nicely. The low contrast lesions can be seen quite nicely when we're moving.

## 7.2 Angle Compounding

Okay. The next type of spec reduction I want to switch in now is some angle compounding. What's that doing? It's taking the ultrasound beam that normally comes out straight ahead and, instead, it's steering it sideways.

First, it'll steer it that way and make an image and then straight ahead and then that way and then that way. I don't know how many images this scanner combines. But it could be anything up to maybe six and anything down to maybe three.

I think there's some control over how many different angles it will combine. It's not as steep an angle as I am showing you with my hand. It's only a small amount. But what happens is, as you steer the beam to look at a particular tissue volume from a different direction, that changes the speckle pattern. But hopefully does not change the tissue structure that you want to see.

So, the changed speckle pattern when you combine the two images by averaging, will tend to blur the speckle but keep the real structure. Life isn't quite that simple. It never is, is it?

But does it to a certain extent? There is a penalty, though. You do get a little bit of blurring. The effects of that can be due to things like speed of sound variation in different paths or maybe tissue motion because this has a frame rate penalty and other effects. But that blurring isn't very strong and it's often very worthwhile switching this technique of angle compounding.

Probably the place where you'll see the blurring most is in some of the diagnostic signs for breast tumours. For example, the edge shadow that you get on carcinomas. That might be just slightly less clear than it would be without the compounding.

Although with an aperture this size for this sort of narrow transducer, the amount of compounding that you can get is not that great. So, the penalties are not that great either. It's often worth using.

If you're really concerned, you can switch compounding on and off to see whether the diagnostic signs that you're looking for, are improved or made worse by having compounding on and off.

Let's have a look.

I might in a moment switch back to the matrix array probe. I was deliberately using this linear probe for the moment to illustrate the speckle because it has a nice sort of strong speckle display.

At the moment, we've got persistence switched in and we've got adaptive speckle reduction switched in at a moderate level. Let's switch in the angle compounding on this scanner. It's called cross beam.

So, here it is. That's set to a low value. I'll just switch that off again. You can see the speckle clearly. I'm holding the transducer still. In fact, what I will do is, I'll switch off the spectral reduction (so the speckle is even more obvious) and switch in compounding. You can see it has quite a big effect.

If I switch in the level 2 speckle reduction, you can see that the image is starting to get quite a nice image. Now with all the speckle reduction techniques in, that cross beam or angle compounding is set at a low level.

If I increase the level, there's a low, medium and a high. I presume that's the maximum on this scanner.

Nope.

There's another one that says maximum.

There's no supermax. So, we'll stay at max and you can see now how beautifully even the lowest contrast lesions are displayed. If I'm moving as well, they're very clear compared to what we started with. You can rewind the video yourself to make that comparison.

I'm not going to switch all the controls out all over again because that would take some time. So, the effect of that maximum angle compounding might be easier to see if I zoom in again. Let's have a look.

If I go to the low contrast lesion, there's two low contrast lesions there – a negative and a positive. We can see how clear they're displayed. Then I switch out the compounding and I'll switch it back. You can see the effect of that. You can also see one other effect. The boundaries are a little more clearly displayed.

We can switch out and have a look at that mimicked cyst there to see if that's also true. I'll switch out the compounding. No. It's not so obvious on the cyst but here I feel I definitely can see the edges of this lesion and probably that lesion better.

When I switched the compounding in, I hope you agree that (particularly when we're moving okay) all the speckle reduction and compounding types of things switched in, it's kind of running at maximum image quality.

## 8. Tissue Harmonic Imaging

There's one other image improvement function that I want to illustrate to you - tissue harmonic imaging on this scanner. It's called coded harmonic imaging.

Essentially, what that does is: it uses nonlinear propagation of ultrasound which generates harmonics of the sound wave as the sound wave propagates to improve the quality of the images - well I would say 'improve'.

Again, there are trade-offs. You get some improvements but there may be penalties on some occasions. Whether there are substantial improvements depends on how much aberration there is. In a phantom like this, there's very little aberration from fat and non-fat layers, for example. You may not see very much change in the image properties when we switch from fundamental mode imaging to harmonic mode imaging.

But we'll try it. We'll illustrate some of the points with the phantom. This is the image still with our 9l probe. I might as well switch to the matrix one and a half d array probe to see what effect coded harmonic imaging has on the different probe.

In any case, it's been a while since we went back to that probe to have a look at the quality of the images from it. So, at the moment, we're still set with persistent switched in with speckle reduction switched in and with angle compounding switched in. For all the facilities to improve the image, the current frame averaging is not excessive. As we said, we had set it to about two. Oh! No, I've got it. All three. Okay for tissue harmonic imaging.

This is the fundamental mode image. I will now switch in harmonic imaging. The scanner resets itself and that's the sort of image that we get. It's different, that's certainly true.

It's doing something more than typical tissue harmonic imaging, I think. That's because the scanner uses what's called coded harmonic pulses. The coding technique is using coded ultrasound pulses that are sent out and can be decoded on the way back. As well as using the harmonics that might give us a bit of penetration artifact, it has advantage over what's normally termed simple tissue harmonic imaging which tends to suffer slightly worse penetration than fundamental mode imaging.

The reason for that is the harmonics, that the scanner is tuning into, doesn't penetrate the tissue so well. The coded harmonic images are here showing a different background texture to what we see with the fundamental B-mode. But I've noticed immediately that the point targets and the wire targets are sharpening up.

Let's switch that out again. You can see how blurred the deeper one is compared to these. Now I'll switch it back in. Yes, to my eyes anyway, they definitely are sharpening up - particularly at depth. So, we seem to be getting improved lateral resolution from the harmonic imaging.

It's a characteristic of harmonic imaging that you sometimes see a slightly worse resolution in the axial direction simply because, to tune into the harmonics, you need to generate them with slightly longer narrow bandwidth pulses.

But I don't see much evidence of a penalty here. Well maybe I do! If anything, I see an improvement in the axial resolution in the harmonic mode. So, this looks like a good mode to use on this scanner.

But beware. the changes in the image texture will change the anatomical detail that you can see in the image. So, as with angle compounding or speckle reduction, you may wish to switch it in and out at the beginning of an examination.

To decide which image is best for the breast or the pathology, it's hard to say for sure in advance that harmonic imaging should be used in this type of breast versus another type of breast. But you could argue that: images of breasts that contain a lot of fat and non-fat interfaces might suffer (particularly close to the probe aberration) and need harmonic imaging improvement more than others.

It's difficult to say.

Reverberation is another thing that harmonic imaging helps. I have no substantial reverberation in this phantom. Reverberation can occur between fat and muscle, for example. Reverberation gives the effect of echoes deeper to the structures that the reverberation is occurring in.

Reverberation is the sound bouncing backwards and forwards within a layer of fat and muscle for example, or other layers. Then it comes back at a time that makes that echo appear to be at a deeper structure than where it should be. It acts as what we call 'clutter'.

In interpreting the image of those deeper structures, that's probably best illustrated on my thyroid. I can show you some carotid artery. Well, it's not the thyroid but my neck. I can show you some carotid artery reverberation.

Maybe I'll switch out the frame averaging, and we'll go back to a single focus number (so that we're getting a reasonable frame rate) and put the focal zone at about the depth of my thyroid. By setting the depth so that we can see with a reasonable field of view and resolution, I'll just change the brightness setting and switch out the harmonic imaging. You will notice all the filling in the carotid artery here.

Now I switch in the harmonic imaging. If I do a Valsalva maneuver, you can see all the clutter inside my jugular vein as well.

When I switch in the harmonic imaging, it cleans it up quite a lot. It has substantially reduced the reverberation, cleaned up the muscle appearance and cleaned up the carotid artery and jugular vein appearance quite a lot. So, it's doing a lot of good things to this image.

But it has changed the nature of the image as well. So, it's worth making decisions whether you prefer it or not. Many scanners will switch on and they will just power up in harmonic mode because, in general, the images are better.

## 9. Rejection/Suppression Control

Okay. Let's just switch to the other transducer and see whether can see anything different about that one.

I have switched the scanner into running with the matrix one and a half d array and I'll scan that bit of my neck again. You can immediately see just how much better this probe is than the other one. There is beautiful detail in fundamental mode.

You can see we have again got some echo fill in both the carotid artery and the jugular vein. You can see pretty good fine detail in the muscle layer there and fine speckle pattern in the thyroid. It's an interesting bit of physics!

I can't resist pointing out why we got this image on the screen. It's the second thyroid here of course. That's just a mirror of this thyroid because all the sound is being reflected at the track here. So, we see this mirror artifact image there.

Let's go back to the point that I'm supposed to be illustrating. If we switch in the compound harmonic imaging again, see how it cleans up the image and makes a sort of much cleaner echo of structures – particularly in the two blood vessels where I can increase the gain. Sometimes when you switch harmonic imaging in, the gain does need to be adjusted a little bit and it's quite interesting to have a look at the anterior regions.

Look in the muscle structures to see how they change when we switch harmonic in and out. That's what it looks like with harmonic imaging and that's a fundamental imaging mode.

Oddly enough, I think for looking at the muscle structure, I have a feeling that there's things I can see there that may have been a bit more difficult to see. With the harmonic back on the phantom, let's have a look at the image.

It needs a bit more gel!

We really don't have a problem with filling in the cyst because there's almost no reverberation occurring in anterior structures here on the phantom. It just doesn't happen in these phantoms. So, it's difficult to illustrate the difference between the harmonic

Let's go to a slightly greater depth setting and see what we get there. These point targets are so beautifully displayed with this probe. Sorry. I was searching in the wrong place for the phantom for the moment and this is with contrast harmonics.

Switched in, what we do see is a slightly different penetration effect. I'll switch it out again. We're penetrating to sort of in the background gel. We're running out of signal at about two and a half centimetres there.

In the fundamental mode, we're getting an extra centimetre or so of penetration. That's consistent with what was seen earlier. The harmonics tend to be absorbed more rapidly and, even the coding technique this scanner is using, doesn't really overcome that greatly.

That's a penalty.

So, it's a reason why you might want to try both modes and decide for a particular patient which mode is giving you the right information.

Okay. The closing part of this demonstration is to illustrate a few other functions on the scanner that are additional. One of those are what I would call post-processing functions - such as rejection controls or suppression controls.

These are sometimes included for cosmetic appearances to clean the images up. Rejection or suppression would have the effect of rejecting or suppressing the low-level echoes. Ideally, you would want it if you're suppressing the noise in the image and not displaying it.

I prefer to see the noise. It's visible in its twinkling and its characteristics as noise and, if I see the noise, I know that I'm not missing any information.

If I switch in some suppression or rejection, there's the potential to miss some information. It's perhaps partially illustrated on this phantom. Using one of these inclusions in the phantom with very low-level negative contrast regions having some weak echoes present, and if I switch in rejection for this image, you can see the effect of that on the image's appearance.

Two things happen: (i) It appeared to have not such good penetration and (ii) when it's switch back out again, we see that image but also see a suppression of the low-level echoes within this inclusion. These are real echoes. They're not noise and yet they're being suppressed now.

There's potential here that, if you use suppression or rejection, there's potential of not seeing low level echoes within a cyst (for example). Then making the mistake, if it were not a cyst, you might classify it as a cyst. That could be low level echoes in a solid lesion or elsewhere that you might misclassify.

If I switch that out, you can see it come back again. It's an illustration of potential for missing information. It may make the image look as if it's better but there's potential for losing information.

I would tend to <u>not</u> use controls like rejection or suppression.

## 10. Grey Map

Another post-processing function that can be adjusted is the grey map.

That's the function that controls the way in which the echo strength (echo amplitudes) is translated to greyscale values as a brightness on the display. It's similar to the dynamic range. But it acts independently of the dynamic range. You can set your dynamic range control. But you can independently set the grey map.

The grey map is post processing. It's taking the output of the non-linear amplifier that did the dynamic no range compression to the dynamic range level that you set previously. It further modifies the grey levels on the display.

It's best illustrated rather than me talking about it.

To illustrate the effect of it, I'll press the function that allows you to change the grey map. The default grey map that we're using here, you can see is grey map. They're all coded on the scanner by letters of the alphabet.

As I move from one map setting to the other, you can see a change in the image greyscale appearance and the corresponding greyscale wedge (as we call it) shown at the side of the image

In changing to greyscale, it has for some reason, jumped out of that mode and froze the image. So, I'll just go back and get into setting that again so you can see how greymap on this scanner is a sort of high dynamic range map. You can select one preferred.

I can't imagine you using this control very much. It's most likely the default setting
you want which on this scanner was greyscale mode. So, I'll cancel that and come out of it. I would use the default setting of the grey map and I would set the dynamic range to my preferred setting similar to that.

## 11.Colour Map

You can adjust a colour map on the scanner. It's called a tint map or colourise. What that is doing is taking the input echo amplitudes and assigning to each one a different colour - in the same way as the grey map assigns a different grey shade to the echo amplitude.

If I demonstrate it, you can see that here we've got a sort of sepia toned image and we can make that more blue-toned or another type of sepia tone like magenta, and so on. It's unlikely that you would find a lot of uses for this. One possible use for it is for showing the lowest level echoes.

If you have undesirable ambient lighting (as we have here) for filming this video, then the very smallest amplitude echoes might not be easily seen on the screen - particularly if you've missed the dynamic range and you've got the dynamic range set too low. Then the contrast on the display would be perhaps a bit excessive by using a colour tint map for the lowest level echoes and become a slightly different colour which can be discriminated more easily from the background black level.

It seems a dubious benefit. Just like the colour map, you're better off most times setting the room to the correct lighting conditions of subdued light and work with the standard color map in grey rather than using a tint.

So, that's all the main functions demonstrated. There are just two things to finish the demonstration.

12. Virtual Convex/Trapezoid Scanning

You will often find controls such as trapezoid scanning or (on this one) it's called virtual convex. It uses the steering capability that we mentioned earlier that provides angle compounding or cross beam. But now just uses it to steer sideways at the edge of the field of view to give you a kind of trapezoid scan (even from a linear array). This allows you to have a slightly wider field of view at depth.

I'll just switch that in. It takes a moment for the computer to reset itself and then you can see how we've got this wider field of view at depth. We're seeing much more of the phantom deep down and, if we had used the lower frequency probe, we would be able to see that having an effect (even at much greater depth settings).

## 13.Acoustic Power Output

The last thing I want to say - going back to the gain and acoustic power output, it's to remind you of the acoustic safety considerations.

Always check the mechanical index (MI) and the thermal index (TI). Mechanical index and thermal index are displayed at the top right-hand corner. Bear that in mind when using the ultrasound scanner. It's not tremendously important for the breast of course but, nevertheless, it's still a matter of policy. It's worth not using any more acoustic power output than you need to obtain the image for the diagnosis you need to make.

Most scanners will be set so when you power them up, they will switch on with a fairly high acoustic power output. If I show you the effect of reducing the acoustic power that's on this image at the moment, it's 90 percent.

I can increase it to a hundred percent and the image changes very little in its properties. I can bring that down around 30 to 40 percent is getting a little bit low, we're now down at 50 percent output and I can increase the gain to compensate slightly for that change.

At 60 percent output, the image isn't that much different from the 90 percent output. So, there's opportunity to achieve just the same sort of image quality you need to achieve and yet putting much less sound into the patient and giving a much lower exposure to ultrasound.

## 14. Auto-optimise Function and Speed of Sound Optimisation

There are two further points that I've not been able to demonstrate easily with this scanner.

a) the auto optimize that I mentioned right at the beginning of the demonstration; and

b) speed of sound optimization

For those two points, I would need to switch to a different scanner to show you those affects.

To finish off the demonstration, we have moved to a different scanner and a different room. That's because I would like to complete the process by showing the auto optimize function that I mentioned to you earlier.

As well as speed of sound optimization, both were mentioned in the physics lecture. It's good to show you with the 'hands-on' demonstration as well. This scanner has both functions allowing me to show how they operate.

I'm using here for completeness, a 15L4 probe. It's very wideband and allows frequencies between 4 and 15 megahertz to be used. It's a breast imaging probe offered by this manufacturer. We can see the images using the same phantom as I had for the other scanner.

The image isn't too bad as it is currently. If I switch into measure time gain control, then I can deliberately miss and set the TGC. I'm going to give it some crazy settings that you can see with a dark band in the middle and then exit that.

Then I'm going to press what is the automatic optimize button and the scanner analyses the image data and automatically sets the TGC to provide a reasonably homogeneous image with depth. But, as you can see, it's not perfect. We can probably do a slightly better job ourselves.

To do that, I do what I recommended earlier. I will turn the dynamic range down and I will turn the B-mode gain down so that it emphasizes the small brightness variations going back into TGC.

I should be able to improve those dark patches and bright patches a little bit so that it is set slightly better and that's probably as much as I would want to do.

As you can see, that's a better job than the auto-optimise did. I can now turn the dynamic range back up and the B-mode brightness back up. Now we have a very uniform image with depth.

Another thing the auto optimize button will often do on many scanners, is adjust the dynamic range. It adjusts the grey level map for the sort of pre-set the breast imaging or other imaging pre-set that you've chosen.

As I said earlier, that won't necessarily know the lighting conditions that you work in or the diagnostic information that you want to extract and the part of the body you're scanning. It's a good starting point though and, if you're in a busy clinic, then, by all means, rely on it.

It will produce a reasonable image for scanning.

The very last thing to demonstrate which I am able to do on this scanner is the speed of sound optimisation. The reason that is important is that it affects resolution and speed of sound varies in different tissues.

If you get the speed of sound wrong, the scanner assuming the wrong speed of sound will upset focusing. It will upset beam steering that influences compounding because beam steering relies on the correct knowledge of speed of sound to be able to adjust the delay profile across the array elements.

If the steering is not correct, then the registration between different compounded components will be wrong. So, the effect of compounding will be to degrade spatial resolution quite a lot. Focusing also requires that the scanner knows that the speed of sound is what it is in the material. Otherwise, it can't adjust the delay profile for making the transmit focus or even the dynamic receive focus correctly.

For this scanner, I've set up a very large depth of field. It should be in focus over the whole range of depth that I'm indicating from shallow depths down to beyond three centimetres. We can see in this phantom that down here the point targets are displayed with a very poor point spread function. Very wide laterally, the focus is not too bad up here.

Part of this is because I have missed set the speed of sound. It's set to 1420 metres per second in this phantom. It's almost certain that the phantom's been set up to mimic tissues and to have a speed of sound around 1560 to 1580 metres per second. But that's not necessarily breast tissue. So, let's change the speed of sound. It's currently 1420 meters per second. You won't be able to see that on the display.

It's on part of the scanner's knobs (which the video camera can't show you). It's now set to 1480 metres per second. Already you can see the effect on the image.

I will change the depth setting so that we can see a bit deeper and switch back to 1420. You can see how wide the lateral point response function is here very poor. 1420 to 1480 already sharpened the image up a lot. This is now set to 1540 and suddenly very sharp. Now set to 1600 and getting blurred again. 1660 is very blurred.

Another thing you'll notice is that the vertical scale of the image changes. This is because all our vertical scaling and axis scaling in the image is dependent on speed of sound. It's the return time that tells us where an echo structure is positioned along the beam axis. We need to know the speed of sound for that as well.

So, if I do that again (it's currently set on 1660) I'll reduce it to 1600. You can see the position of these targets moving closer to the transducer. There's 1540 that's the point of which we felt we had the maximum lateral resolution and now 1480 and 1420. This is probably the most blurred result of the lot.

Also, it's the one where these targets are closest to the transducer so that's the other thing that it influences. If you're measuring dimensions of structures, then having an accurate knowledge of the speed of sound helps measurement accuracy with the ultrasound callipers in the axial direction.

In summary, speed of sound is important for lots of things – such as calliper measurement accuracy, image scaling, focusing, beam steering, compounding - and getting it right.

For this phantom, it looks as if the speed of sound is what I expected to be - in the mid 1500s - and that gives us the best quality image that you can see here. Different tissues have different sound speeds but the tissue that has the biggest difference in sound speed from all other tissues is fat and it has a very low sound speed.

So, it's likely that if you're looking at a breast that is very parenchymal, very glandular, then you might want to use a slightly higher sound speed of 1540 maybe. But if it's a very fatty breast, then you might want to use a lower sound speed.

The nice thing is that if your scanner allows you to adjust the sound speed, then you can simply use the image quality and the image sharpness to judge what it should be because adjusting the sound speed on the scanner to find the one that gives you the best image quality is the way to do it.

Some scanners have different types of controls. I believe one scanner has a thing called ‘fat imaging’ and a switch for imaging fatty breasts. I know of another scanner that has a sound speed optimize button which works much the same way as the automatic TGC. Optimise does this on this scanner. The optimise button has that function. It can go through all its possible sound speed settings and, just like an autofocus camera, will judge the image quality and choose the sound speed where the image quality is best and sharpest.

That can be particularly convenient to use either way. Even if it's manual, it doesn't take very long to do it - even if you're in a busy clinic it's probably worth doing.

Thank you for listening

I hope that demonstration was useful, even though there was the switch between scanners, and complemented the physics basic principles lecture as I hope it would be.

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