Sononerds in the classroom

ARDMS Topic:
Ultrasound Physical Principles

Unit 13: Resolution #2 (Temporal)

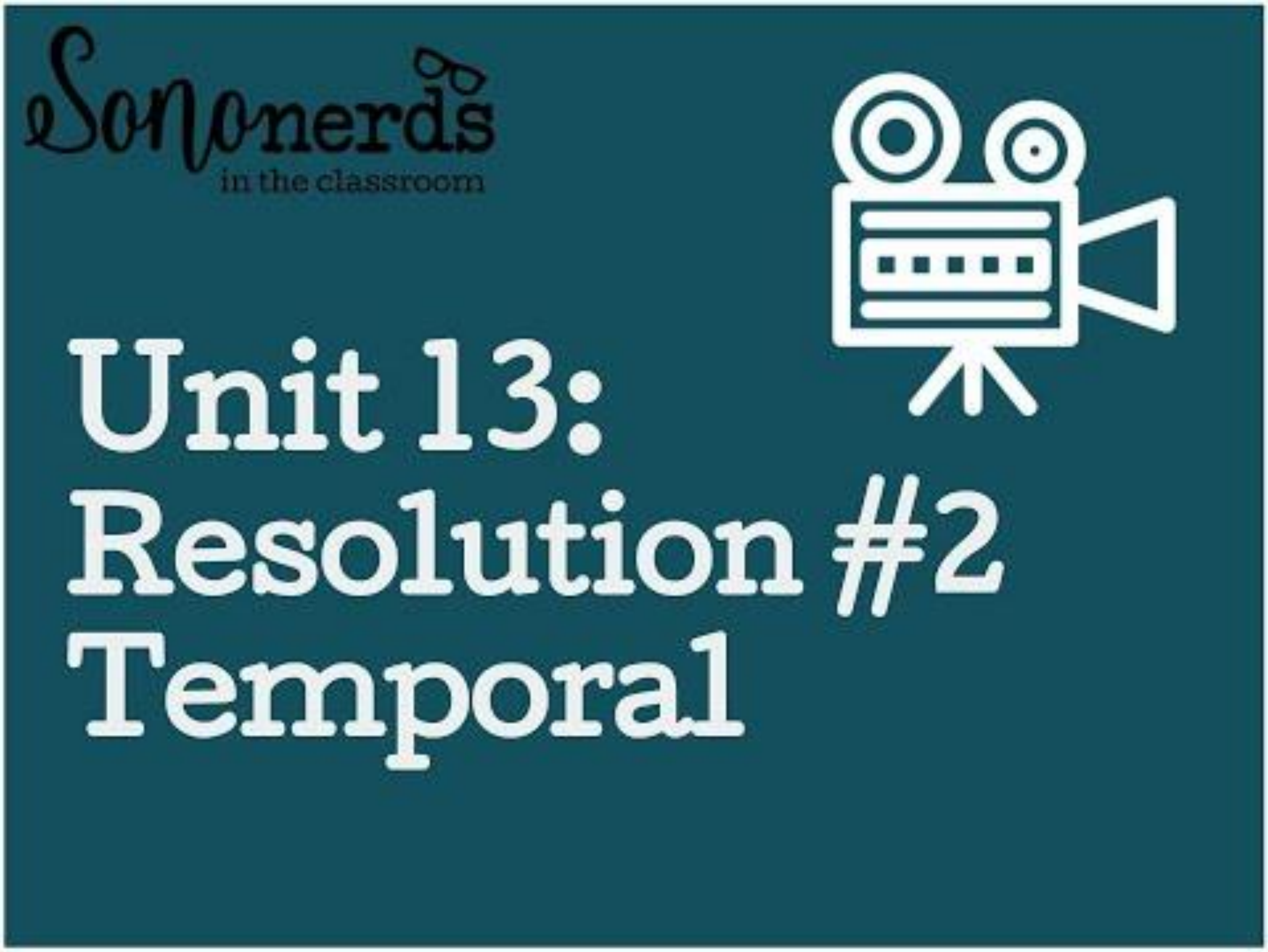
Sononerds Ultrasound Physics Workbook & Lectures

Unit 13: Resolution #2 (Temporal)

Table of Contents:

Unit 13: Resolution #2 (Temporal)

Entire Unit 13 Lecture:



Did you know you can time jump to each section by using the "chapters" in the YouTube video playbar OR timestamps in the video description?

Unit 13: Resolution #2 (Temporal)

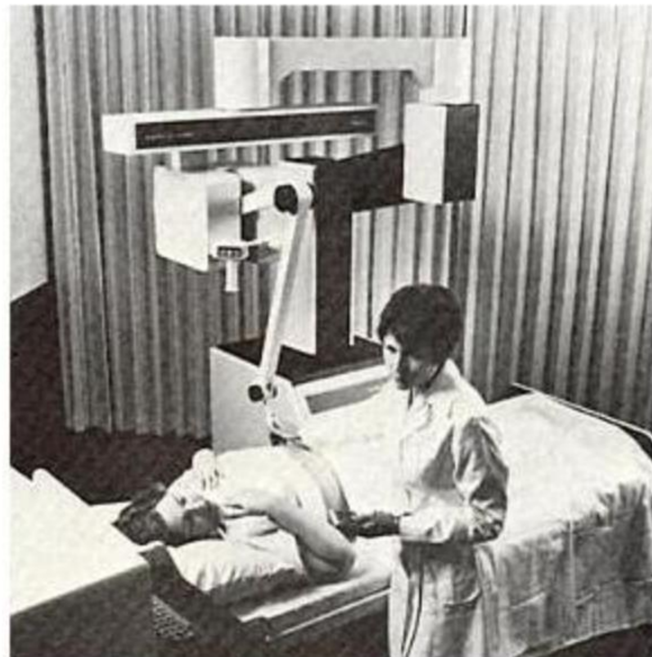
Recall that resolution is the machine's capability to display reflectors accurately. We already discussed axial and lateral resolution as they pertain to reflectors that are parallel and perpendicular with the sound beam, respectively.

This unit is going to add a third type of resolution: Temporal resolution.

Temporal resolution is the machine's capability to accurately display moving objects.

The moving objects could be those that are physically moving in the body like the heart or the machine keeping up with the sonographer moving the transducer, which is called real time imaging.

Section 13. 1 Real Time Imaging



Let's start with what real time imaging is, by learning how ultrasound started. Early sonographic images were created by the sonographer physically moving a transducer that was attached to an articulating arm. Each sweep created a scanline and the scanlines were added together to make one frame or picture.

Static scanning is the name given to the process of creating one frame and displaying it. Static scanning makes it impossible to see moving structures.

Current machines can create the illusion of real-time imaging because now the generation of each scan line is automated and occurs within a miniscule fraction of a second.

For this unit, remember that each scan line is created by at least one pulse. The machine waits for the echoes to return from a pulse and then sends out the second scan line. When all scan lines are created, the machine processes the information and displays it. That is one frame. When frames are created quickly enough, we cannot perceive the refresh of each image and it seems rather seamless.

Since the machine can quickly create and process scan lines and refresh the image, it appears that it is keeping up with any changes in transducer angulation that we make in real-time. This is because temporal resolution is improved or more "movie like."

Section 13. 2 Temporal Resolution

→ **Temporal resolution is the accuracy that moving objects are displayed in their correct position.**

When multiple frames are produced per second, the temporal resolution is good, we can see realistically how structures are moving.

When fewer frames are produced per second, the true motion of the objects are lost and we only see fragments of the reality.

The human eye needs a frame rate (the rate at which new images are created) to be about 30 frames per second to perceive the images occurring in real time.

Look at this image below - notice how the 10 frames per second seems to jump a little more where the 30 and 60 fps are more smooth or real time.

If our temporal resolution is poor, then we cannot truly evaluate anatomical motion or will feel like our machine is lagging behind our movements with the transducer.

Section 13.3 Frame Rate

Frame rate is the number of frames (or still pictures) that can be created per second. Since this is an "events per second," frame rate is measure in hertz. Frame rate is a true per second event, so frame rate is not reported in kilohertz or megahertz.

The higher the frame rate, the more "movie" like the images being displayed are. (Remember the gif with the 10, 30 and 60 fps?) The lower the frame rate, the jumpier or more lagging the pictures appear.

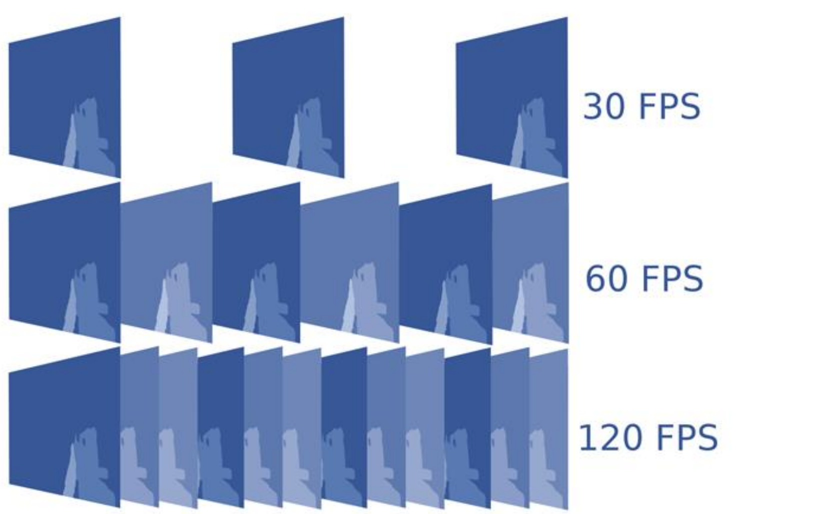
Frame rate is determined by three factors:

- ➔ **Sound's speed in the medium (fixed)**
- ➔ **The depth of imaging (sonographer controlled)**
- ➔ **The number of pulses per picture (sonographer controlled)**

Since speed of sound is a constant 1540 m/s in soft tissue, the two sonographer-controlled factors play a larger role in the frame rate.

Just like frequency is an events per second and period is the time it takes to make one event, frame rate the time to create one frame are related the same way as reciprocals.

- ➔ **If frame rate increases, then the time to create one frame must decrease.**
- ➔ **If the frame rate decreases, that is because the time to make one frame has increased.**



13.3.1 T Frame

- **T Frame is the time is takes to make one frame**

We just learned that T Frame and Frame rate are inversely related and reciprocals of one another, which gives us our first formula related to T Frame:

$$T_{frame} \times frame\ rate = 1$$

This first formula shows us that frame rate and T Frame are inversely related. If a system can refresh the image at a rate of 20 Hz (this is the frame rate) then it takes 1/20th of second to make one frame.

If it takes 1/50th of a second to make one frame, then the system has a frame rate of 50 Hertz.

Another formula related to T frame gives us more detail on what factors into the time it takes to make one image.

$$T_{frame} = \# \ of\ pulses \times PRP$$

The second formula shows us how the time it takes to make one frame is directly related to the time is takes for one pulse to travel to maximum depth and back (remember this is the pulse repetition period) AND directly related to the # of pulses it takes to make one frame.

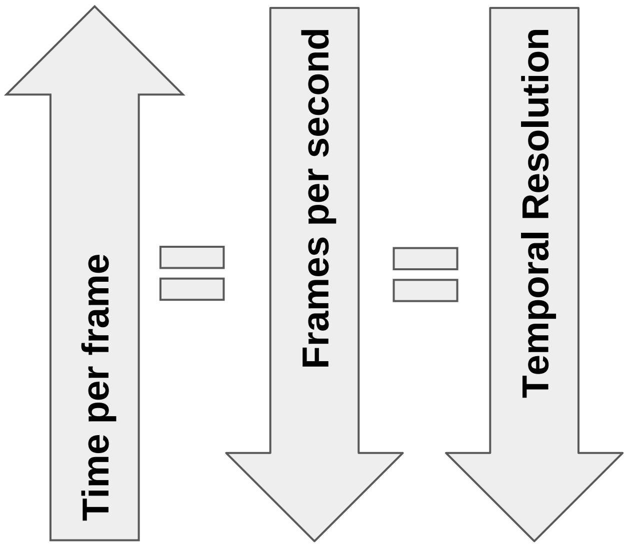
If a machine is set to 10 cm of depth, the PRP is 130 microseconds (Remember the 13-microsecond rule…10 x 13 = 130). If it takes this system 100 pulses to make a frame, it will take 13,000 microseconds to create one frame.

Let's first increase the depth (which increases the PRP) to 20 cm. Now the PRP is 260 microseconds. Using the same 100 pulses, the T frame is now 26,000 microseconds.

Let's try increasing the pulses now. Returning to our 10 cm depth and PRP of 130 microseconds, let's increase the number of pulses to 200 to create one frame. Now the T frame has increased to 26,000 microseconds.

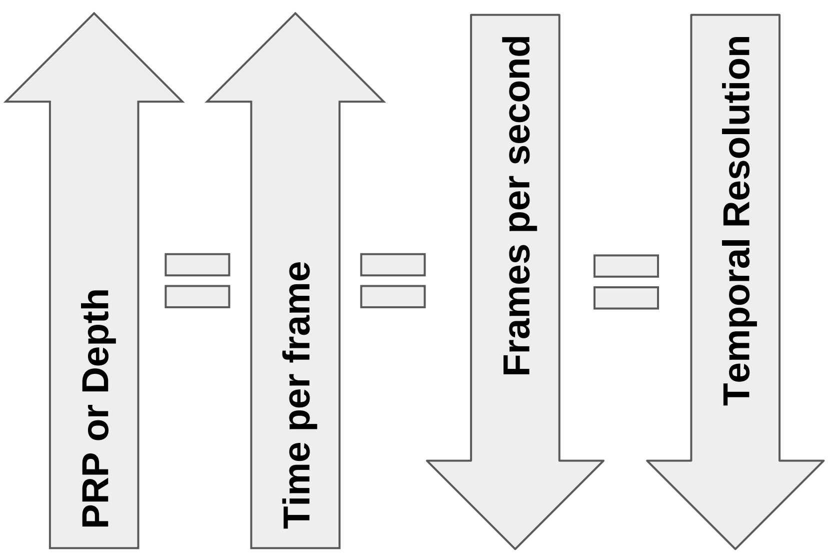
These two examples show us that by increasing the PRP (which increases with more depth) OR increasing the number of pulses per frame increases the T-frame.

When T-frame increases, less frames can be made per second, therefore the frame rate decreases. When frame rate decreases, temporal resolution worsens.



13.3.2 PRP (Depth) & Frame Rate

PRP (and therefore depth) is directly related to T-frame and T-frame is inversely related to frame rate. This makes PRP inversely related to frame rate too.



So because of this:

- ➔ **Short PRP = shallow imaging = improved frame rate**
- ➔ **Long PRP = deep imaging = poor frame rate**

This is because if sound must travel further, the machine has to wait longer before the next pulse can be sent out. The longer it takes to send all pulses out for a frame, the fewer frames that can be created per second.

- ➔ **To improve overall imaging, sonographers should not use excessive depth.**

To relate PRP to frame rate, let's use the previous examples.

Depth set to 10 cm = 130 microsecond PRP. With 100 pulses, the T-frame = 13,000 microseconds. The frame rate is in the reciprocal of 13,000 microseconds. BUT remember Frame rate is Hertz or a per second unit, so we need to convert 13,000 microseconds to 0.013 seconds. The reciprocal of 0.013 (1/0.013) = 77 Hz.

We then DOUBLED the depth to 20 cm, which DOUBLES the PRP. What do you think will happen to the frame rate if it is inversely related to depth? It should be half, so we'd expect the frame rate to reduce to 38.5 Hz.

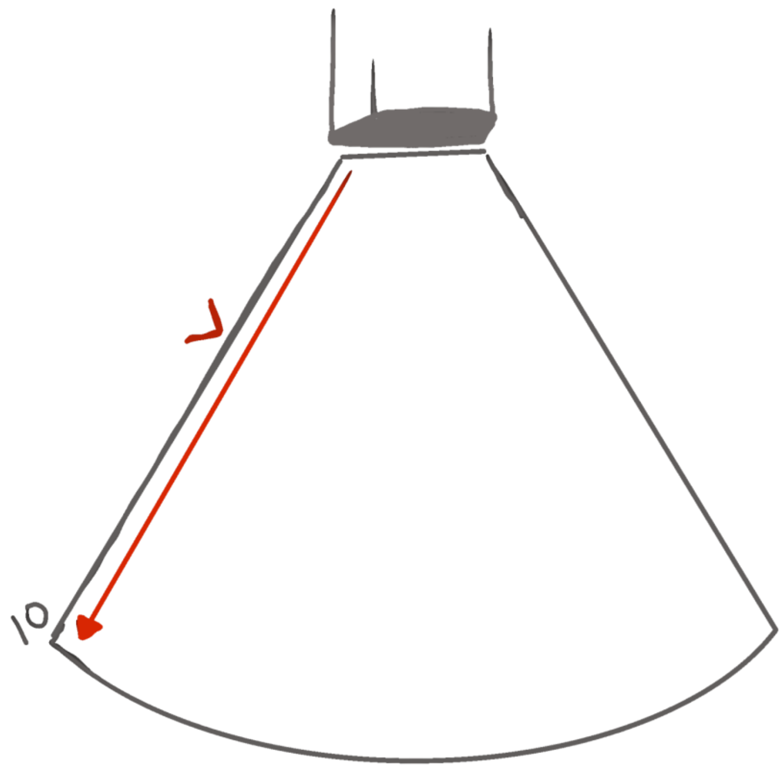
260 microsecond x 100 pulses = 26,000 microseconds = 0.026 second T-frame. 1/0.026 = 38.5 Hz Frame rate.

Main Takeaway

- ➔ **If PRP or depth increases, T frame increases, Frame Rate decreases, Temporal Resolution worsens**
- ➔ **If PRP or depth decreases, T frame decreases, Frame Rate increases, Temporal resolution improves.**

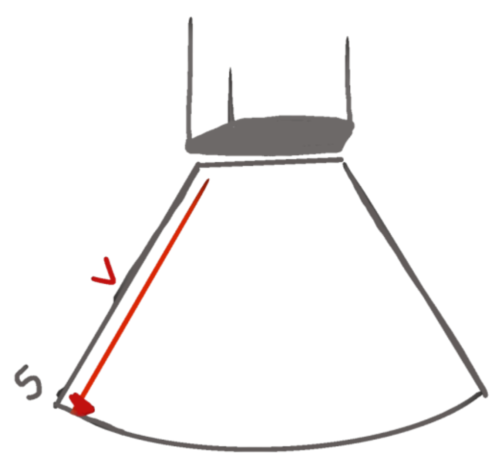
1 Focus
10 cm depth
9 scan lines

9 pulses per frame
Long PRP



1 Focus
5 cm depth
9 scan lines

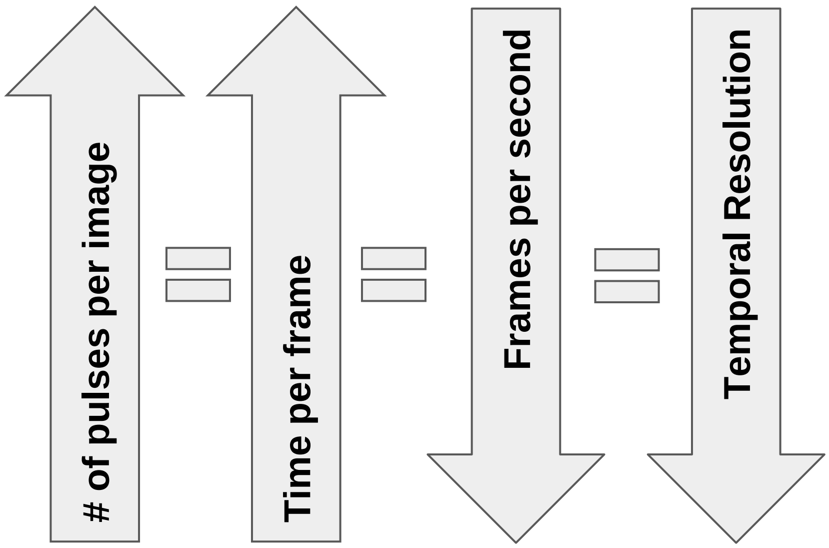
9 pulses per frame
Short PRP



➔ **Less depth improves temporal resolution because it takes less time to create 1 frame.**

13.3.3 Number of Pulses & Frame Rate

The number of pulses it takes to create a frame is directly related to T-frame and T-frame is inversely related to frame rate. This makes # of pulses inversely related to frame rate too.



So because of this:

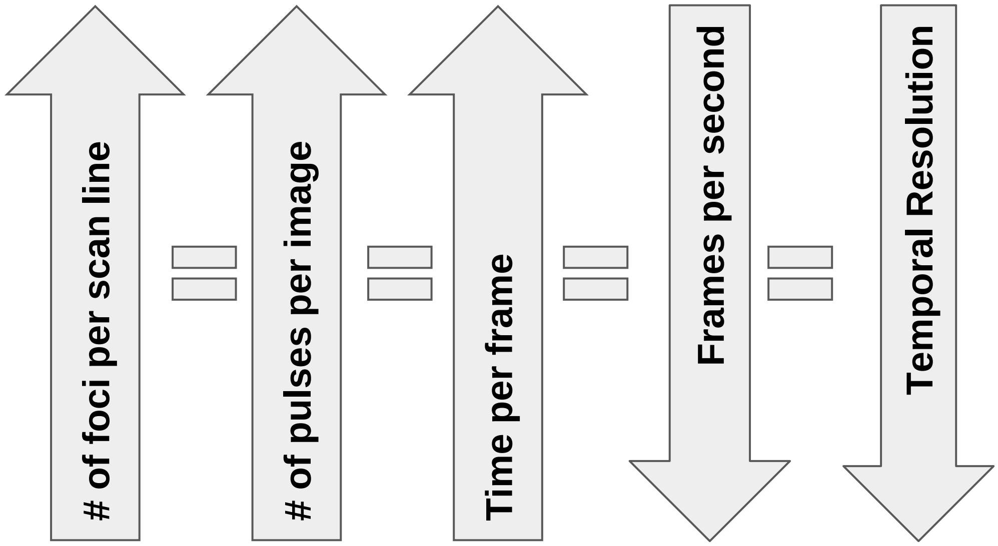
- **Fewer pulses per frame = improved frame rate**
- **More pulses per frame = poor frame rate**

There are three main things that will change the number of pulses per image:

- **Number of pulses per scan line (single focus vs. multi-focus)**
- **Sector size (wide, using all scan lines or narrow using few scan lines)**
- **Lines per angle of sector (line density)**

Number of Pulses per Scan Line

Each pulse can only have one focus. If the sonographer increases the number of foci, then more pulses are required to create each scan line.



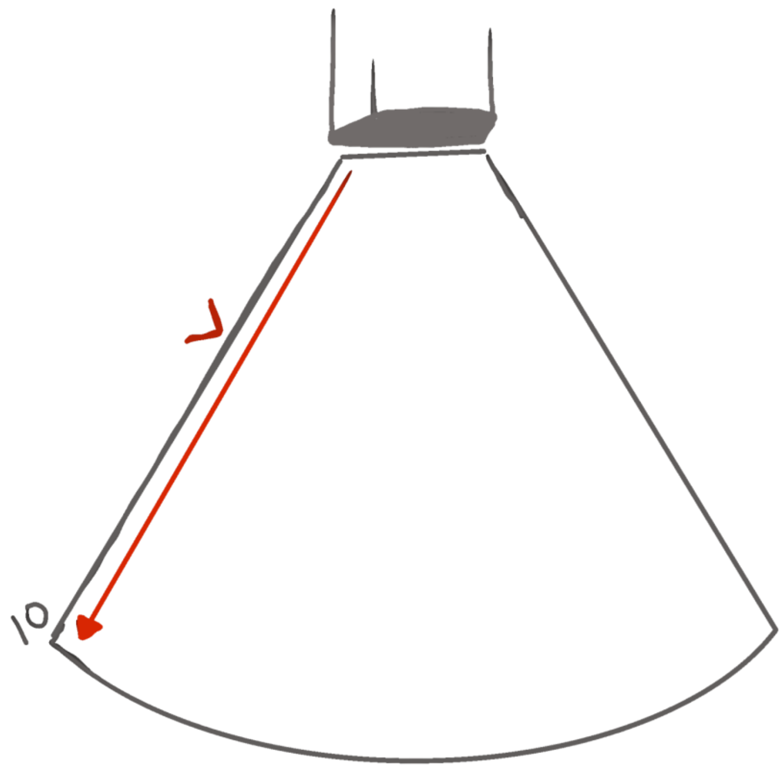
➔ **More foci will degrade temporal resolution, but improve lateral resolution**

Example: An image is created with 100 scan lines. The sonographer has one focus set. This means that 100 pulses are needed to create each image.

If the sonographer increases the number of foci to 4, now 400 pulses need to be created to make one picture.

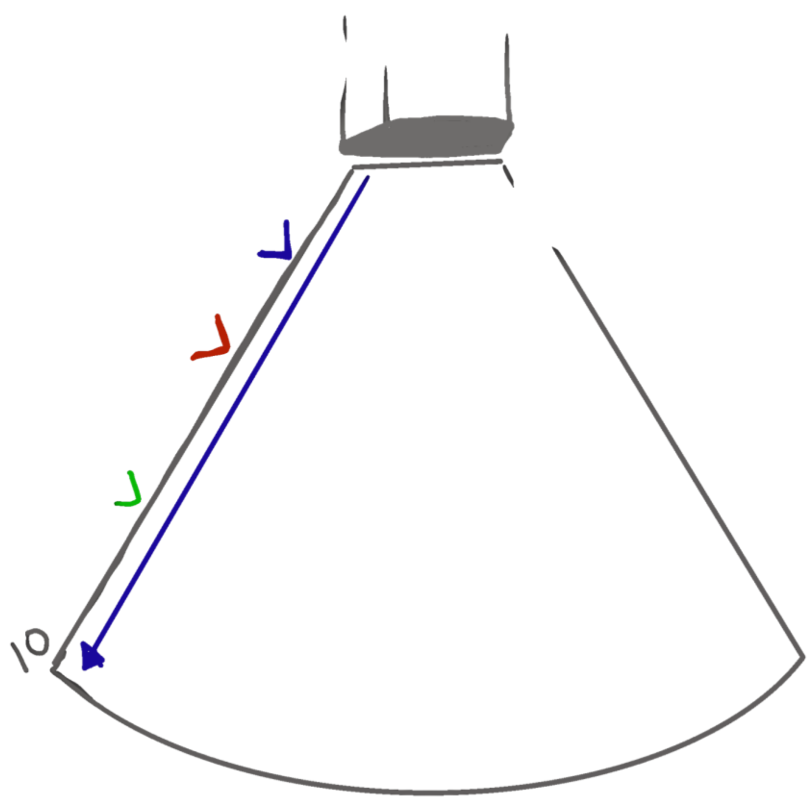
Waiting for 100 pulses to be sent, returned and processed is much different than waiting for 400 pulses to be sent, returned and processed. The frame rate for the 100-pulse picture is higher than the frame rate for the 400-pulse picture.

1 Focus
10 cm depth
9 scan lines
9 pulses per frame
Long PRP



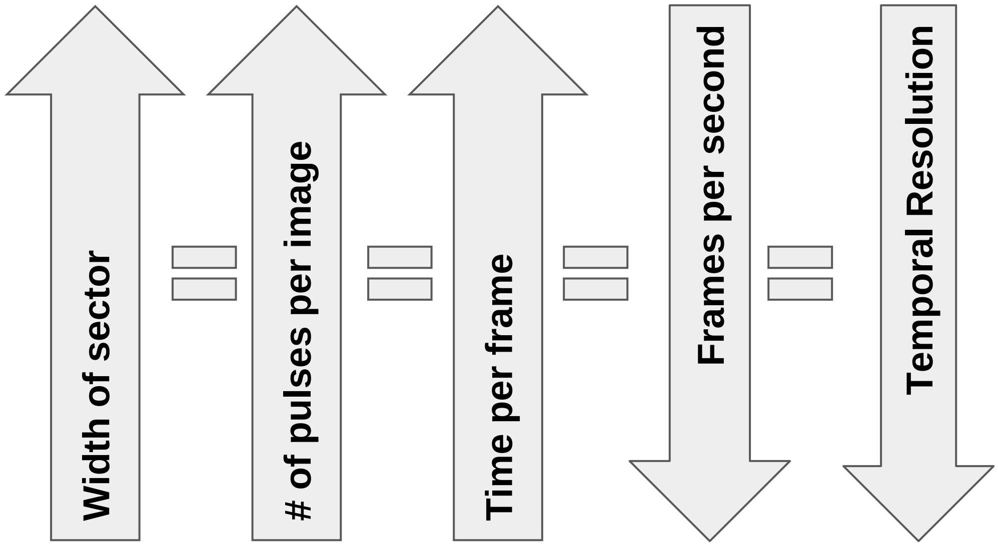
➔ **Less pulses per scan line improves temporal resolution because it takes less time to create 1 frame**

3 Foci
10 cm depth
9 scan lines
27 pulses per frame
Long PRP



Sector Size

The field of view is the anatomy that is visible while we are scanning. The size of the field of view depends on how wide or narrow the sector is.



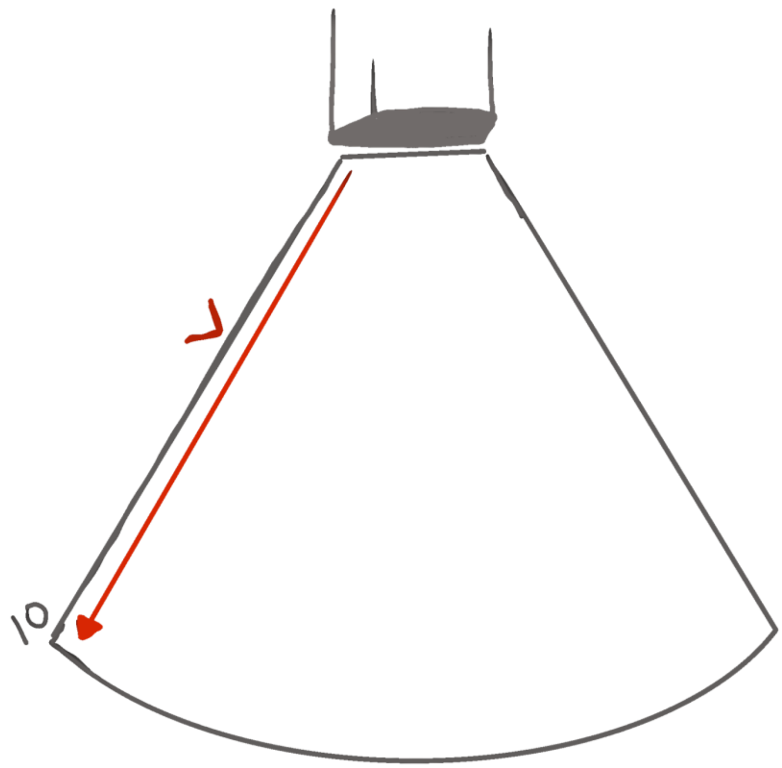
Wider fields of view require more scan lines, which means more pulses to create an image compared to narrow fields of view.

- ➔ **A wider field of view improves the amount of anatomy we can see, but degrades temporal resolution**

Example: The widest a field of view uses 100 scan lines. If only one focus is set, the image needs 100 pulses to sweep the whole field of view. If the sonographer decreases the field of view to where only 40 scan lines are used, the machine only needs 40 pulses to create the image. More frames can be created when there are less pulses to send, therefore narrow sector sizes improve temporal resolution.

1 Focus
10 cm depth
9 scan lines

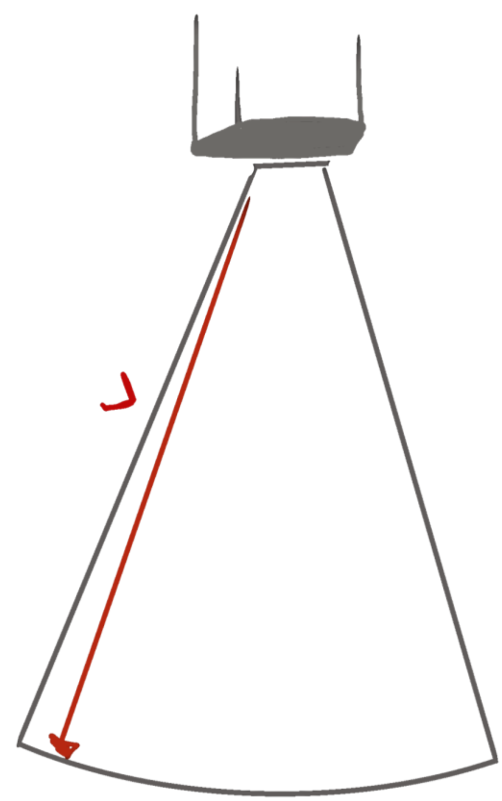
9 pulses per frame
Long PRP



1 Focus
10 cm depth
5 scan lines

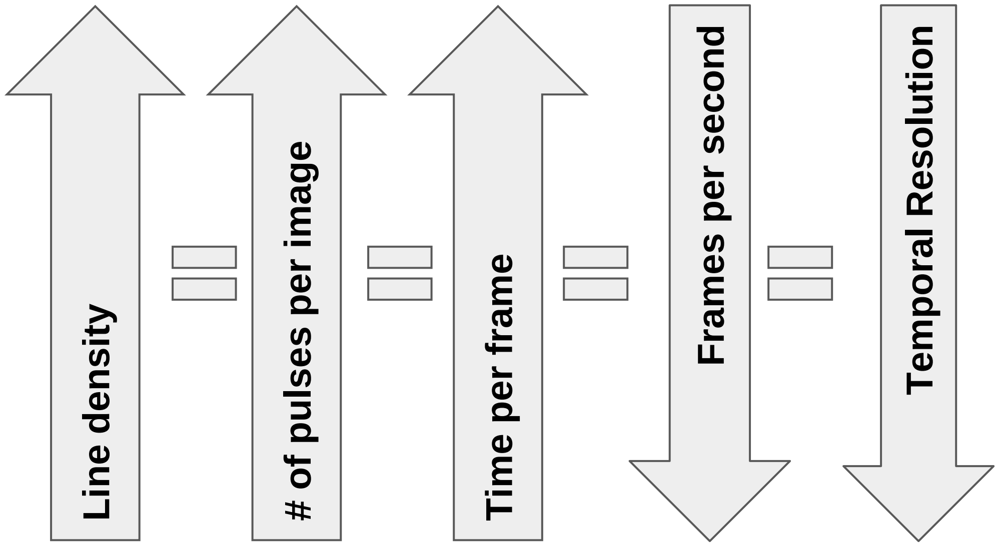
5 pulses per frame
Long PRP

➔ **Less pulses per frame improves temporal resolution because it takes less time to create 1 frame**



Line Density

The number of scan lines that create an image is called line density and can be adjusted by the sonographer (but not always an option).



- ➔ **If there are fewer scan lines, this is called low line density. This degrades spatial (detail) resolution but improves temporal resolution.**
- ➔ **If there are a lot of scan lines, this is called high line density. This improves spatial resolution but degrades temporal resolution.**

The number of scan lines producing an image, affects the number of pulses needed.

Example: The system is set to create a 90-degree sector, with a scan line every two degrees. 90 x ½ = 45 scan lines per frame = 45 pulses

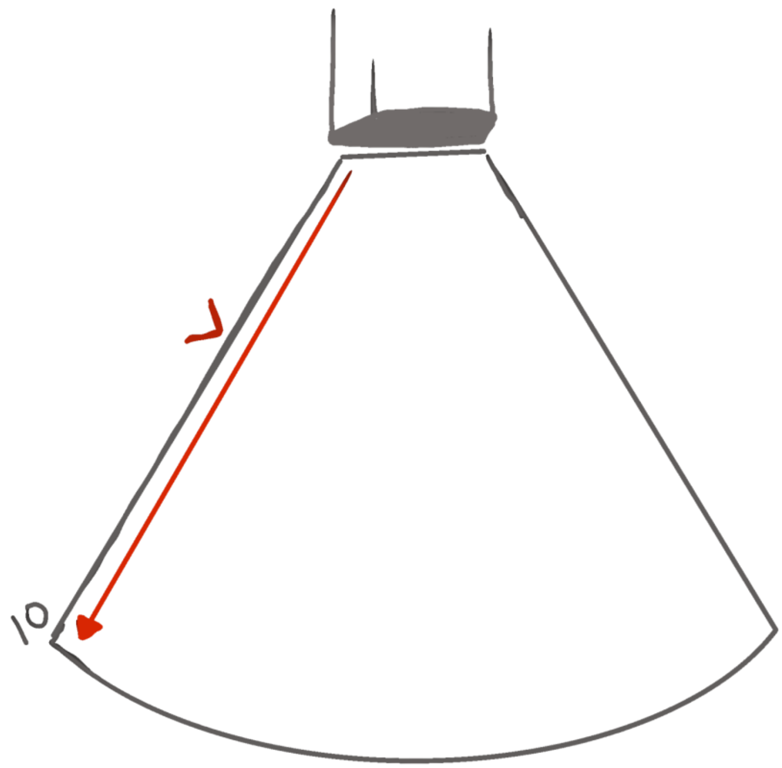
If the system is adjusted to create 1 line every degree, 90 x 1 = 90 scan lines, 90 pulses.

If the system is adjusted again to create 3 scan lines for every degree, 90 x 3 = 270 scan lines, or 270 pulses.

The 3-scan line system will have very good detail, but it will take much longer to create that image over the 1 scan line for every 2 degrees.

1 Focus
10 cm depth
9 scan lines

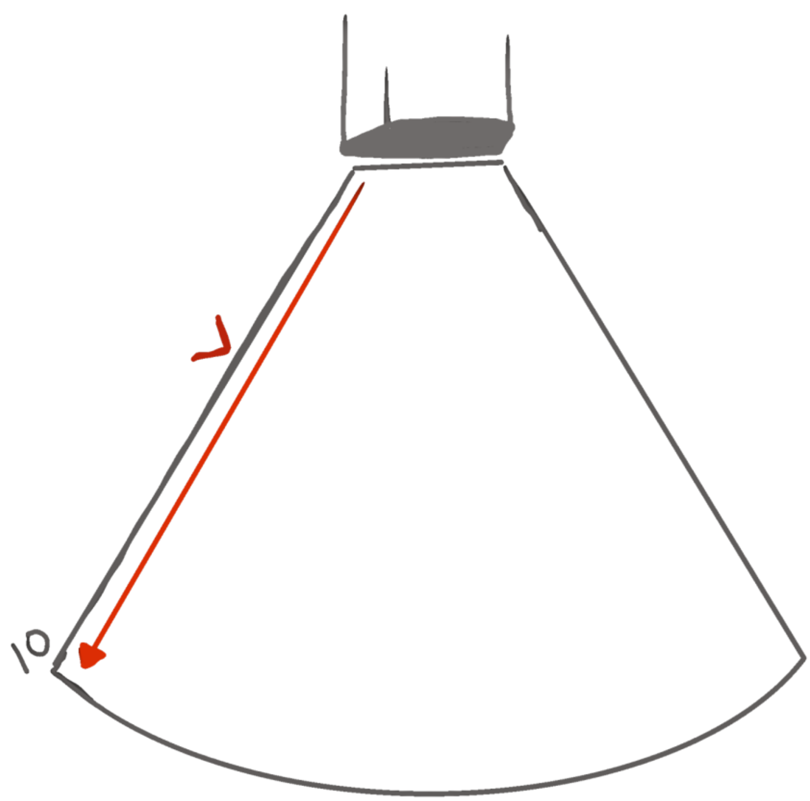
9 pulses per frame
Long PRP



1 Focus
10 cm depth
5 scan lines

5 pulses per frame
Long PRP

➔ **Less pulses per frame improves temporal resolution because it takes less time to create 1 frame**



Section 13.4 Image Quality

The settings that are controlled by the sonographer have a cascade of effects:

Shallow Imaging → short PRP → short T_{frame}→ Improved frame rate → Improved Temporal Resolution

But are you seeing all of the anatomy that you need? If you need more depth then...

Deep Imaging → Long PRP → Long T_{frame}→ Worse frame rate → Worse Temporal resolution

1 focus per scan line → 1 pulse per scan line → short T_{frame}→ Improved frame rate → Improved Temporal Resolution

But are you seeing creating an image with enough lateral resolution? If you add more foci...

Many foci per scan line → many pulses per scan line → Long T_{frame}→ Worse frame rate → Worse Temporal resolution

Narrow sector →few pulses per image → short T_{frame}→ Improved frame rate → Improved Temporal Resolution

But are you seeing all of the anatomy that you need? If you need a wider field of view...

Wide Sector → many pulses per image → Long T_{frame}→ Worse frame rate → Worse Temporal resolution

Low Line Density → few pulses per image → short T_{frame}→ Improved frame rate → Improved Temporal Resolution

But are you seeing enough spatial resolution? Increasing the line density...

High Line Density→ many pulses per image → Long T_{frame}→ Worse frame rate → Worse Temporal resolution

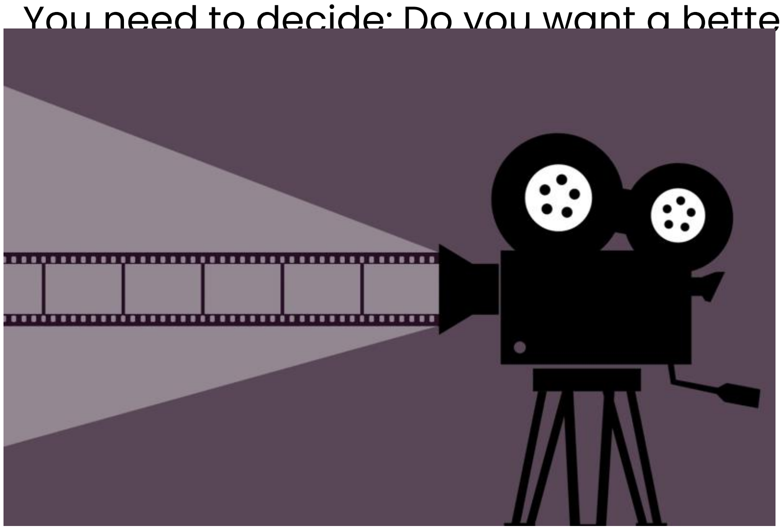
As you have seen, the settings controlled by the sonographer can improve temporal resolution, but usually comes at the price of worsening another type of resolution or not seeing all of the anatomy.

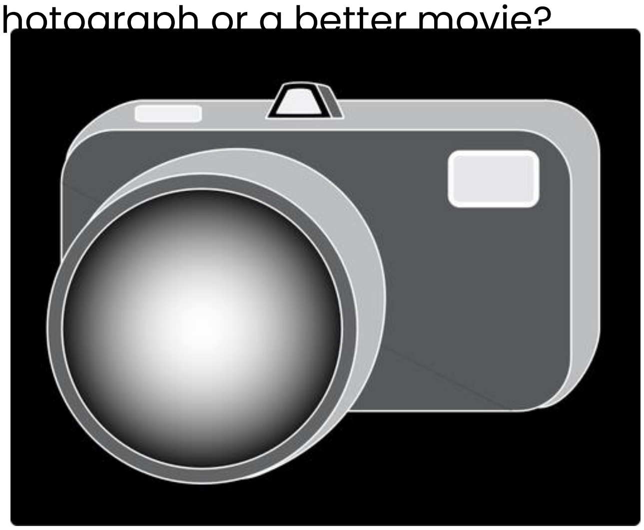
As the sonographer, you need to decide what is appropriate for the anatomy you are imaging.

Sonographers looking at moving structures in real time or want to capture a cine clip of moving structures will want to focus on less foci, narrow sectors, less scan lines and least amount of depth as these all improve temporal resolution.

Sonographers looking at stationary objects will be able to increase the foci, increase the line density, and increase the depth and sector view to fit all the anatomy as these improve lateral and spatial resolution.

You need to decide: Do you want a better photograph or a better movie?





Better/higher Frame Rate	Worse / Lower Frame Rate
Shallower imaging	Deeper imaging
Single focus	Multiple foci (improves lateral resolution
Narrow sector	Wide Sector
Low line density	High line density (improves spatial resolution)

Section 13. 5 Activities ← Link to Answers

1. The sonographer wants to take cine clip of the mitral valve moving for the cardiologist. What four things should they do to optimize their cine clip

#1	
#2	
#3	
#4	

2. Complete the chart.

Frame Rate	T-Frame
75 Hz	
	.02 seconds
20 Hz	
	0.1 seconds

3. Complete the chart, referring to question #2.

What happened to the T-Frame when the Frame Rate increased?	
What happened to the Frame rate when T-Frame decreased?	
By your observations, this means that T-frame and Frame Rate are _____ related.	

4. The machine settings are at:

- 1 focus
- 250 scan lines
- 90 degree sector
- 17 cm depth

What will happen if the sonographer...

(improve or worsen)	Temporal Resolution will...	Lateral Resolution will...	Spatial Resolution wlil...
Increases to 4 foci?		I	
Reduces line density?			
Increases depth?			
Reduces sector to 50 degrees?			

An image is created with 160 lines. The PRP is 1/1000 of a second. And there are 3 foci being used. What is the frame rate (not T_{frame})?

In general, what will happen to the frame rate if the sonographer reduces the foci down to one focus? (Increase or Decrease?)

An image is being created by a machine with one focus and line density set at 1 scan line per degree in a 120-degree sector. The PRP is 1/1000 second. What is the frame rate (not T_{frame})?

In general, what will happen to the frame rate if the sonographer increases the line density to the 2 lines per degree? (Increase or Decrease from the frame rate above)

An image is being created by a machine with 2 foci and line density set at 1 scan line per degree in a 30-degree sector. The PRP is 1/1000 second. What is the frame rate (not T_{frame})?

In general, what will happen to the frame rate if the sonographer increases the sector to 90 degrees? (Increase or Decrease from the frame rate above)

An image is being created by a machine with 1 foci and line density set at 1 scan line per 3 degrees in a 90-degree sector. The PRP is 1/1000 second. What is the frame rate (not T_{frame})?

In general, what will happen to the frame rate if the sonographer increases the depth? (Increase or Decrease from the frame rate above)

Section 13.6 Nerd Check!

1. What is static scanning?
2. How was one picture made in static scanning?
3. Can moving anatomy be seen with static scanning?
4. When can modern machine's make more "movie like" images?
5. What is temporal resolution?
6. What is good temporal resolution?
7. Why do we want improved temporal resolution?
8. Why many frames per second does the human eye see as continuous movement?
9. What is frame rate?
10. What is the one fixed determining factor of frame rate?
11. What are two factors that sonographer's can control regarding frame rate?
12. How are frame rate and the time is takes to complete one frame related?
13. What is T_{frame}?
14. How are T_{frame} and Frame rate related?
15. What are the two formulas for T_{frame}?
16. How is the # of pulses it takes to make a frame related to T_{frame} ?
17. How is PRP related to depth?
18. How is PRP related to T_{frame}?
19. How is depth related to T_{frame}?
20. If T_{frame} increases, what happens to frame rate & temporal resolution?
21. How do short PRPs and Long PRPs affect T_{frame}, Frame rate & Temporal resolution?
22. How do you change the PRP?
23. How do the number of pulses affect: T_{frame}, Frame rate & Temporal resolution?
24. What are 3 ways and examples of how the sonographer change the number of pulses per frame?
25. Why does increasing the number of foci increases the # of pulses per frame?
26. How do the number of foci affect temporal and lateral resolution?
27. How many foci can one pulse have?
28. What is the sector size referring to?
29. How does a wide or narrow sector size affect: T_{frame}, Frame rate & Temporal resolution?

30. How is line density calculated?
31. What is low line density?
32. How does low line density affect spatial resolution & temporal resolution?
33. Describe how each of these affects PRP, T_{frame}, Frame Rate & Temporal Resolution: Shallow imaging & Deep imaging
34. Describe how each of these affects Pulses per frame,, T_{frame}, Frame Rate & Temporal Resolution: 1 focus, multi-focus, narrow sector, wide sector, low line density & high line density
35. What are the changes the sonographer can make to create a better "movie?"
36. What are the changes the sonographer can make to create a better still image?