Sononerds
in the classroom

ARDMS Topic:
Clinical Safety, Patient Care & Quality Assurance

Unit 17b: Contrast Harmonics

Sononerds Ultrasound Physics
Workbook & Lectures

Unit 17b: Contrast Harmonics

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Entire Unit 17b 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 17b: Contrast Harmonics

Tissue harmonics and contrast agents both rely on the ideas of “non-linear” behavior. When the non-linear behavior is the result of the sound beam interacting with the soft tissue, tissue harmonics are created. When the non-linear behavior is the result of the sound beam interacting with a bubble, contrast harmonics are created.

Even though these two ultrasound advancements have similar concepts and are integral to superior diagnostic imaging, their physics discussions look a little different, so unit 17 has been split into:

17a: Tissue Harmonics & 17b: Contrast Harmonics

Section 17b.1 Contrast Agents

➔ **Contrast agents are also known as microbubbles.**

These are tiny gas bubbles that are used to highlight anatomy and pathology within the body as they have a completely different appearance than blood or tissue.

Contrast agents are typically either injected (through an IV) or digested.

Currently, contrast agents are used widely in the cardiac ultrasound applications. General ultrasound is starting to use them more, but few are approved for use in the United States.

Common types of contrast agents used is the United States (approved by the Food and Drug Administration) for echocardiography are:

- Definity
- Imagent
- Optison
- Lumason

Contrast agents can help the sonographer with 3 major tasks:

➔ **Identify lesions when their echogenicity is similar to surrounding tissue**
➔ **Characterize lesions through documentation of arterial and venous phases**
➔ **Added Doppler detection in weak flow areas**

17b.1.1 Contrast Characteristics

Contrast agents must satisfy 5 rules:

1. **Safe**
2. **Metabolically inert**
3. **Long lasting**
4. **Strong reflector of ultrasound**
5. **Small enough to pass through capillaries**

On top of these rules, there are two characteristics of contrast agents that are important:

- ➔ **What the outer shell is made of**
- ➔ **What gas is used to make the microbubble**

The shell is responsible for trapping the gas and determines the contrast agent's stability and longevity in the blood. No shell means the bubbles will shrink and dissolve quickly. This is seen with agitated saline.The shell must be flexible, if it is was too rigid, the bubble would burst and could not produce harmonics.

The gas that is used inside the shell matters too for the stability and longevity. Small gas molecules may just leak out of the shell where large molecules may never dissolve.

Section 17b.2 Contrast Harmonics

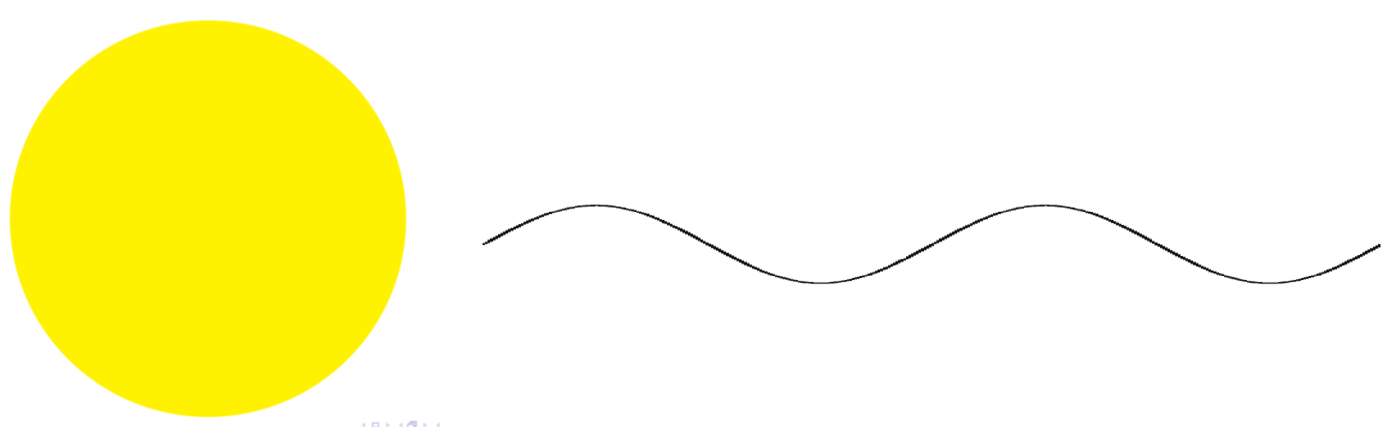
When the sound beam interacts with the injected contrast agent, the small bubbles interact with the wave. The bubbles will contract and expand as the sound waves propagate through them.

➔ **Resonance is the cyclic contraction and expansion of the bubbles.**

This is why contrast harmonics is sometimes referred to as resonance harmonics.

Recall that the sound wave has moments of compression (high pressure) and moments of rarefaction (low pressure). When these areas of the wave propagate through the bubble, the bubble responds in a very particular way:

➔ **Compression causes the bubble to shrink**
➔ **Rarefaction causes the bubble to expand**



BUT, because we know harmonics is produced from **non-linear** behavior, the bubble must contract and expand in an unpredictable way. The bubbles can only get so small due to pressure balancing, but they do not have a limit to how much they can expand (they'll just pop if they expand too much).

This means that **bubbles expand more than they shrink,** making the behavior of the bubble nonlinear which means harmonics!

The **peak rarefactional pressure** is the most valuable number regarding contrast harmonics since it has the larger effect on the bubble's expansion.

So important, that we have a formula to help us understand it:

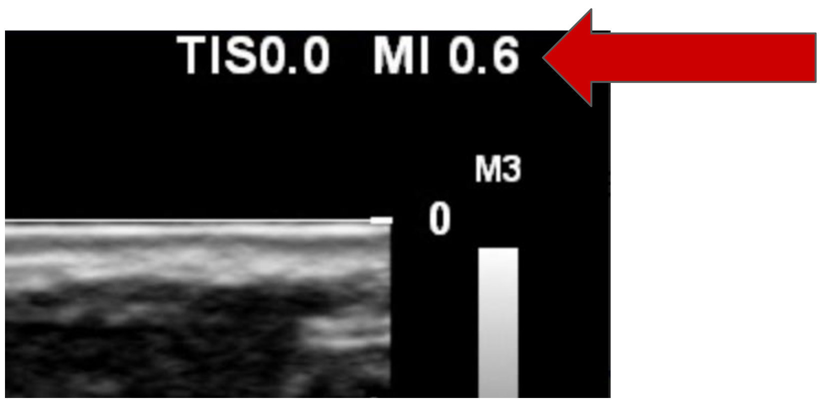
$$mechanical\ index = \frac{peak\ rarefaction\ pressure}{\sqrt{frequency}}$$

From this formula, we can see that when the mechanical index increases, the peak rarefactional pressure will also increase. Let's take a moment to talk about mechanical index before we get further into contrast harmonics.

17b.2.1 Mechanical Index

Mechanical index has been mentioned before and we will see it again in our discussion on bioeffects. Essentially, mechanical index tells us the force a sound beam has on the media. For the purpose of contrast harmonics, it helps us to understand the amount of force on the injected bubbles.

Mechanical index is monitored by the ultrasound system and displayed.



Mechanical index value allows for the estimation of contrast harmonics that will be created by a sound beam and relies on two factors:

- Frequency
- Peak pressure of the rarefaction

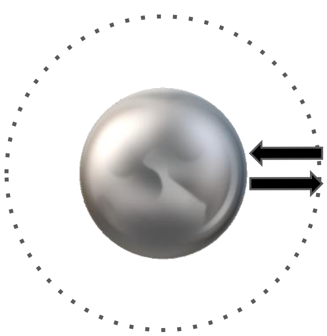
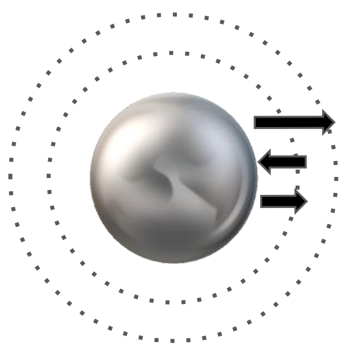
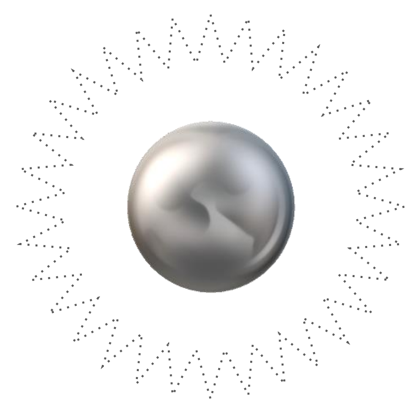
$$mechanical\ index = \frac{peak\ rarefaction\ pressure}{\sqrt{frequency}}$$

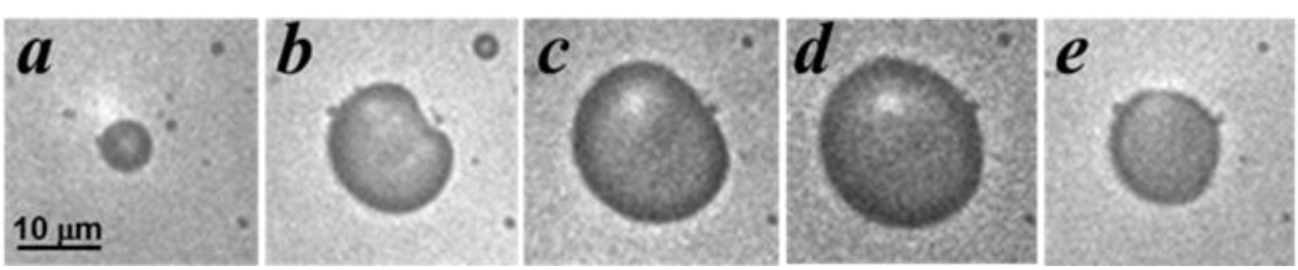
Lower Mechanical Index	**Higher Mechanical Index**
Small pressure variations	Large pressure variations
Higher frequency	Lower frequency

17b.2.2 Mechanical Index & Microbubbles

Depending on the value of the mechanical index, we can predict the amount of harmonics that will be created. If the MI is too low, no harmonics are created, if it is too high, bubbles might burst - we need MI to be in the perfect range to create adequate harmonics.

The microbubbles are about the size of red blood cells and just so happen to **resonate at frequencies between 2 to 4 Mhz.**

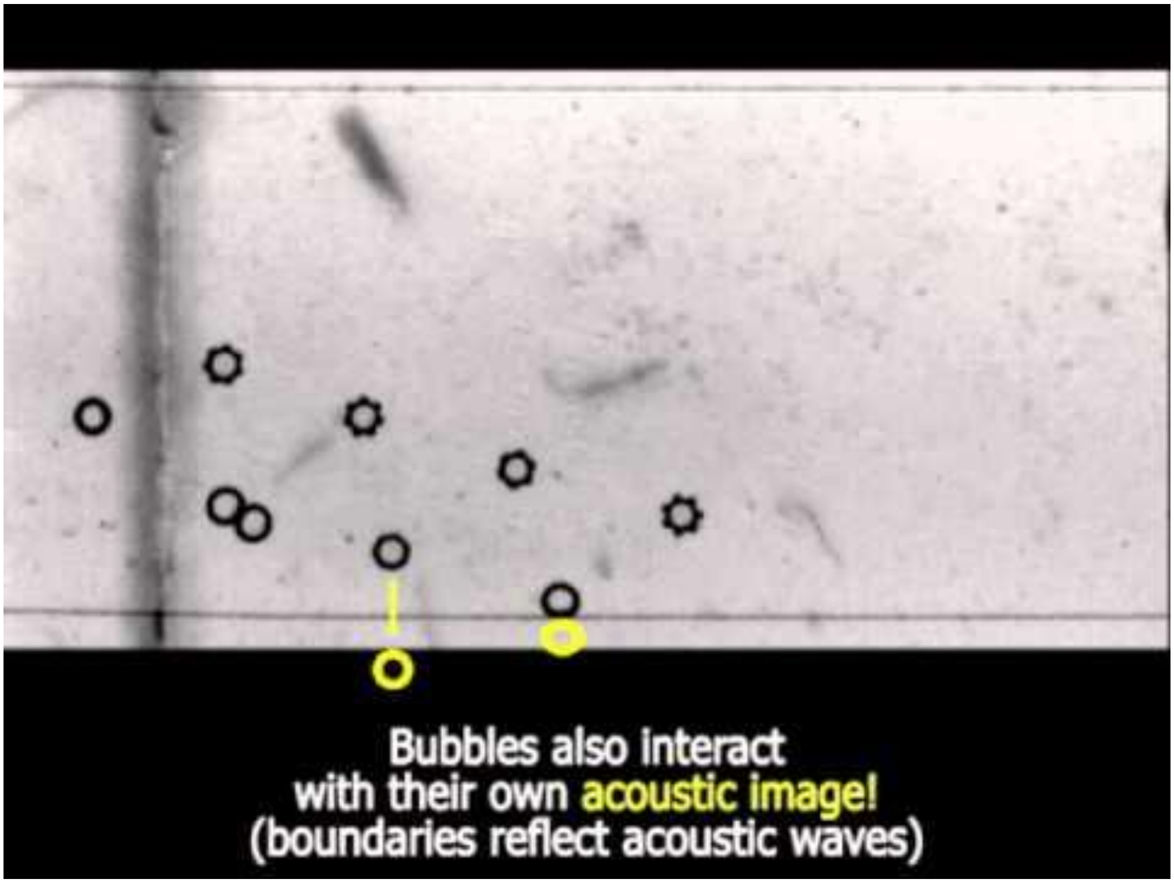
Low (MI < 0.1)	Mid (MI = 0.1 - 1)	High (MI > 1)
• **No Harmonics** • Even contraction & expansion • Weak beam 	• **Some Harmonics** • Non-linear behavior of bubbles • Moderate beam strength 	• **Greatest Harmonics** • Bubbles burst due to too much expansion • Strong beam 



Images provided by N De Jong, Erasmus University

This image shows a contrast bubble expanding and contracting in an ultrasound field.

This video is a neat representation of how the bubbles react under ultrasound as well. You can see as the bubble move under the beam, they take on different shapes as they are resonating or vibrating.

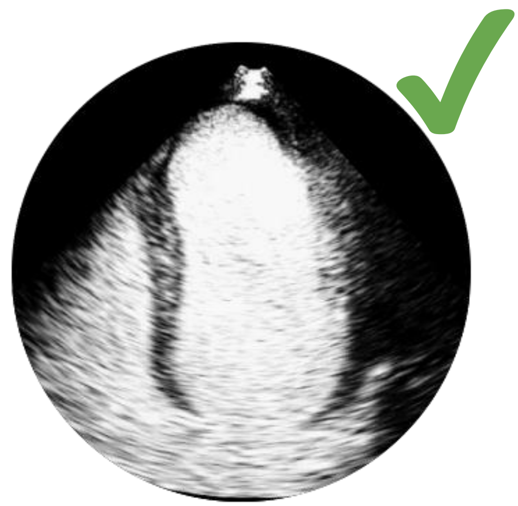


Section 17b.3 Contrast Imaging

Using echocardiography as an example - an ultrasound of the heart is performed without contrast.

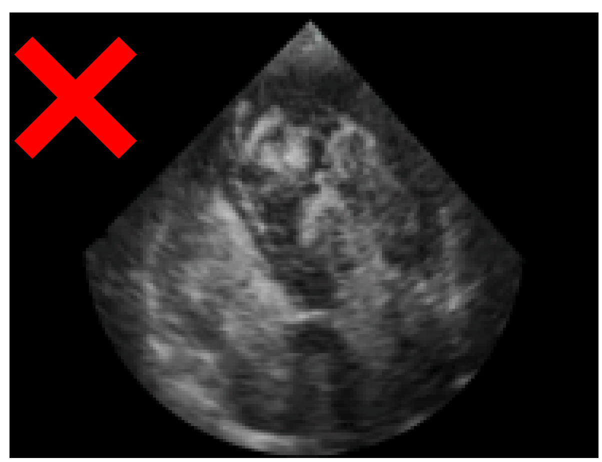
The microbubbles are typically injected into an IV. Once injected the sonographer captures images with the contrast agent circulating anywhere that blood can go.

If the MI is too low, no harmonics occur and the image appears to just have backscatter where the contrast agent is located.



Good harmonics are created from a moderate frequency and beam strength and the heart chambers are filled with enhanced visualization.

If the MI is too high, the bubbles are destroyed too quickly and the contrast cannot provide the same definition of the cardiac walls.

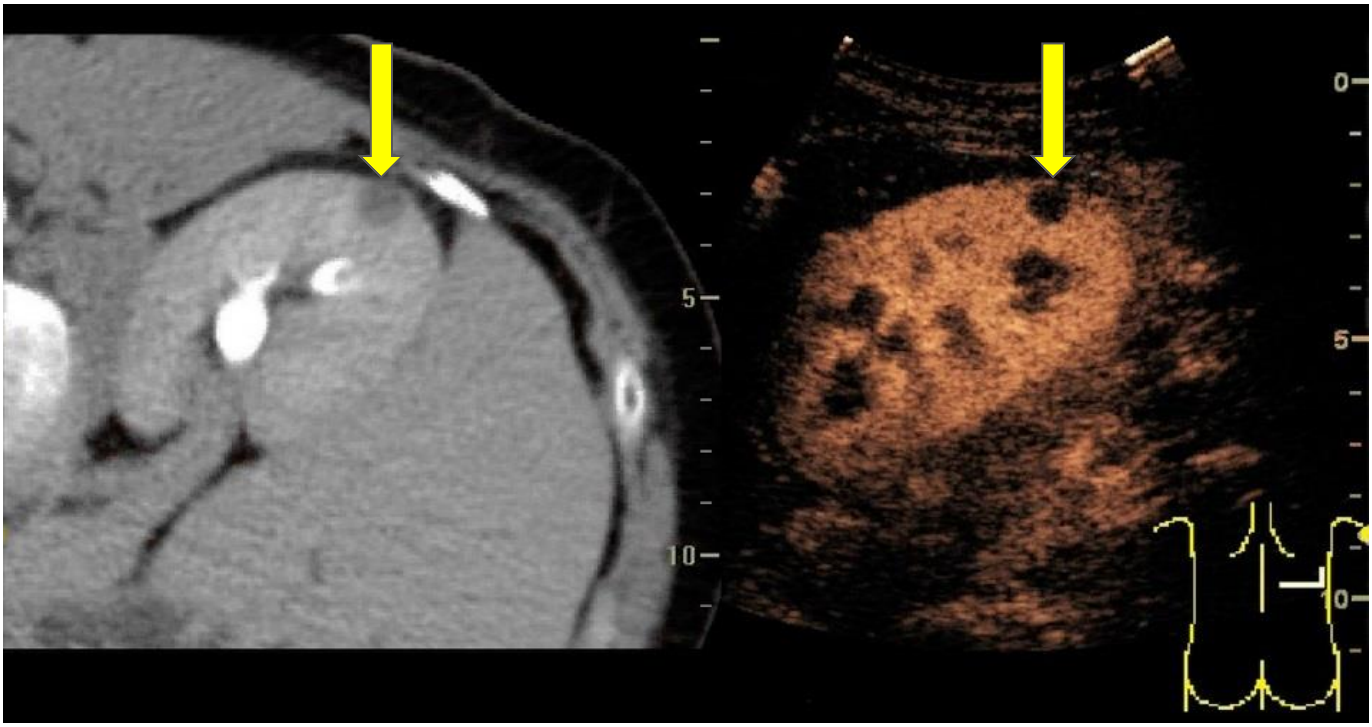


Using contrast in the echo setting helps to eliminate non-diagnostic exams due to low or non visualization of the cardiac motion.

These images are from the Definity website, a very popular contrast agent used in the US.

For other organs like the liver and kidneys, contrast agents are just starting to gain traction in the US, but in Europe they are being used widely to evaluate lesions.

Watching how contrast flows into the lesion, how long it stays and then washes out, the radiologist/provider can better determine malignancy risk without performing a biopsy.

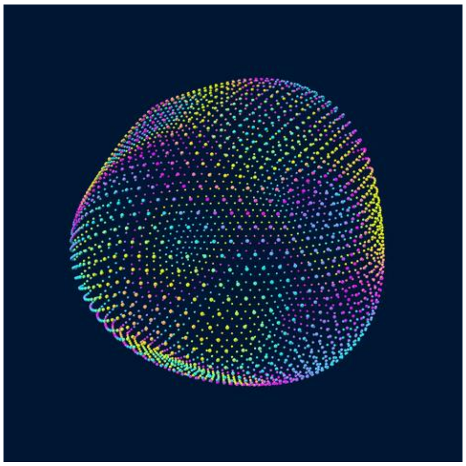


By Kristoffer Lindskov Hansen, Michael Bachmann Nielsen and Caroline Ewertsen - (2015). "Ultrasonography of the Kidney: A Pictorial Review. Diagnostics 6 (1): 2. DOI:10.3390/diagnostics6010002. ISSN 2075-4418. (CC-BY 4.0), CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=64824528

In this image, the arrow on the left is pointing to an area on a kidney seen on CT of unknown etiology. The contrast enhanced ultrasound of the kidney show now contrast flowing into the area, therefore this has been deemed to be a cyst (a benign finding).

Section 17b.4 Activities ← Link to Answers

1. The shrinking and expanding of the bubble is called:



2. What are the 5 rules of contrast agents?

1	
2	
3	
4	
5	

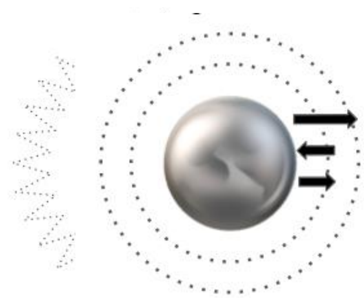
3. Sort the statements & images:

LOW MI ______________________ MID MI ______

______________________ HIGH MI

No Har

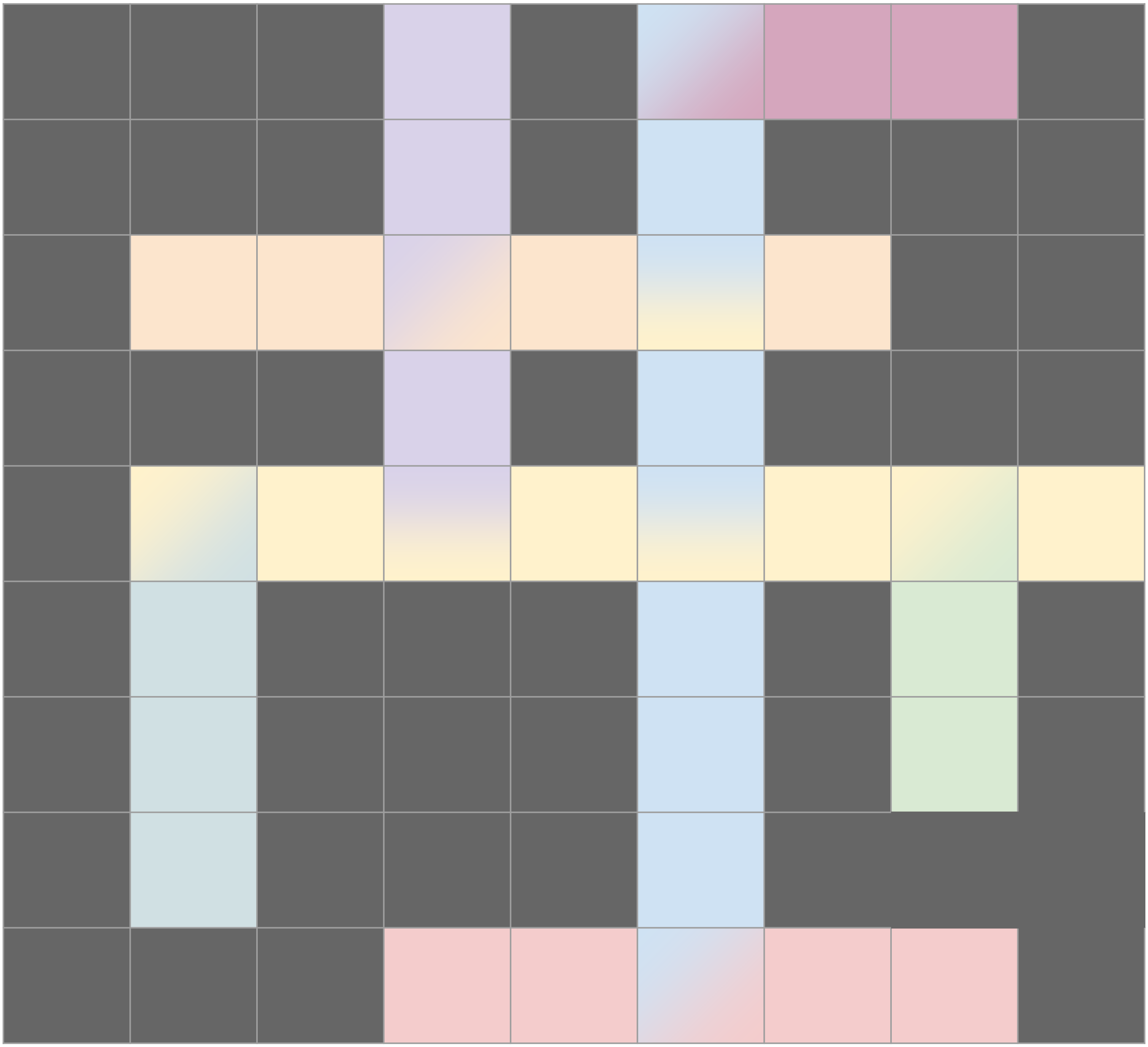
Strong Harmonics



4. If the dotted circle represents the original size of the bubble, where would you expect to see the size of the silver buble?

COMPRESSION

RAREFACTION



ACROSS

If the MI is too low harmonics will _____ be created.

MIs over 1 create _____ harmonics

The shell must be _____ so it does not break.

During rarefaction, the bubble expands the most. If it expands too much, the bubble could _____.

DOWN

Gas molecules that are too small may leak, molecules that are too ____ may not dissolve.

Bubbles resonate in a _____ behavior.

Microbubbles resonate at frequencies between two and _____MHz.

Higher mechanical indices are seen with _____ frequencies.

Section 17b.5 Nerd Check!

1. What is another name for contrast agents?
2. How are contrast agents administered?
3. What ultrasound modality typically uses contrast in the United States?
4. What are three things contrast agents can help with?
5. What are the 5 rules contrast agents must follow?
6. What characteristics are important when creating a contrast agent and why?
7. What is resonance?
8. What happens to the bubble during compression?
9. What happens to the bubble during rarefaction?
10. How do the bubbles behave when they are creating harmonics?
11. Do bubbles have the capability to shrink more or expand more?
12. What happens when a bubble expands too much?
13. What parameter has the biggest influence on how much a bubble with expand?
14. What is the formula for mechanical index?
15. How are mechanical index and rarefaction related?
16. How are mechanical index and frequency related?
17. At what frequency do contrast agents resonate at?
18. What happens if the MI is too low?
19. What happens if the MI is too high?
20. How do we achieve good harmonics?
21. How do contrast agents help the sonographer?