Ultrasonic Backscatter Difference Measurements of Cancellous Bone at 1 MHz

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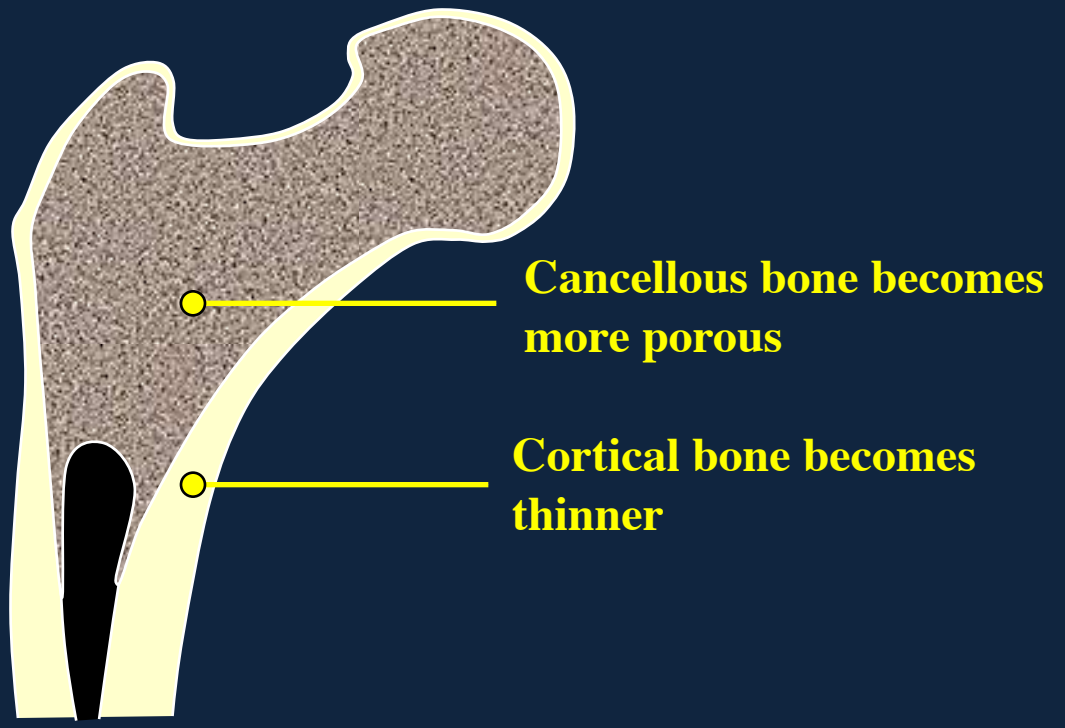
Motivation - osteoporosis

- A disease characterized by low bone mass and structural deterioration of bone tissue.
- Affects approximately 54 million individuals in the U.S.
- In 2025, there will be approximately 3 million osteoporosis-related fractures and is predicted to cost approximately $25.3 billion each year.

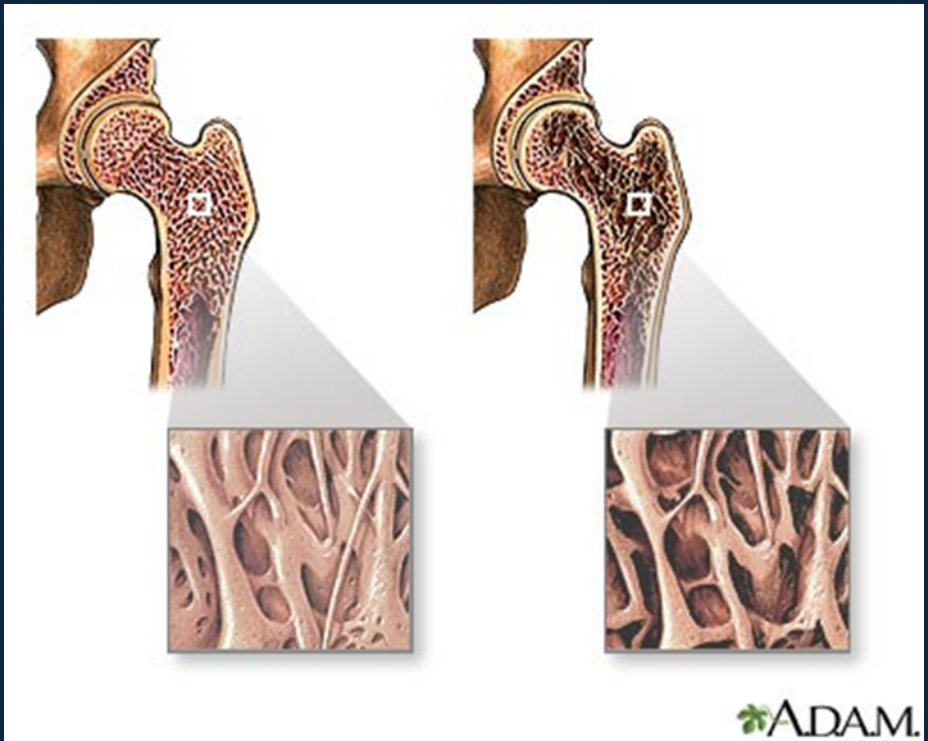
National Osteoporosis Foundation (NOF.org)

Bone 101

Femur cross section

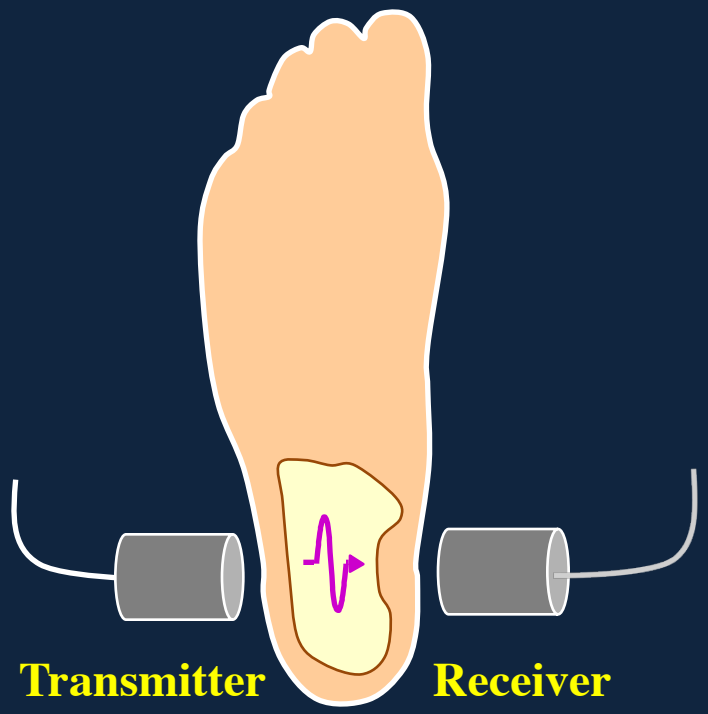


Effects of Osteoporosis

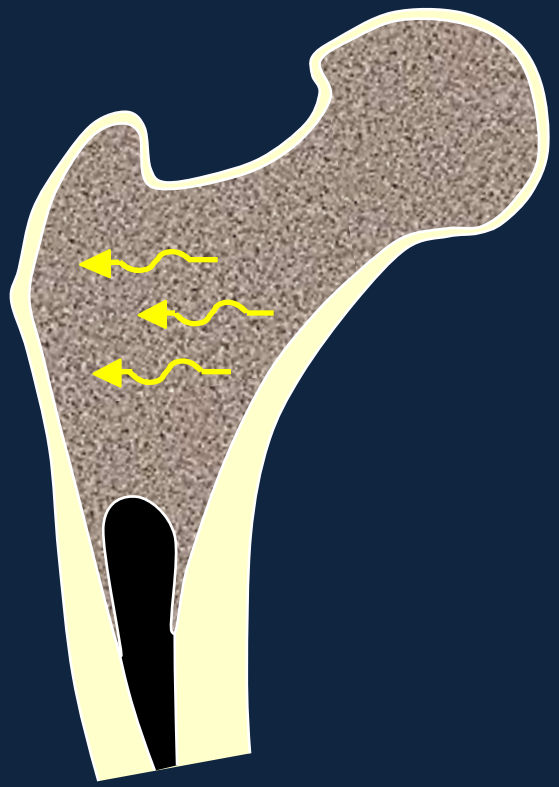


Ultrasonic bone assessment

- Variety of techniques.
- Many measure peripheral sites such as the heel.
- Clinically interesting sites such as hip and spine are inaccessible.

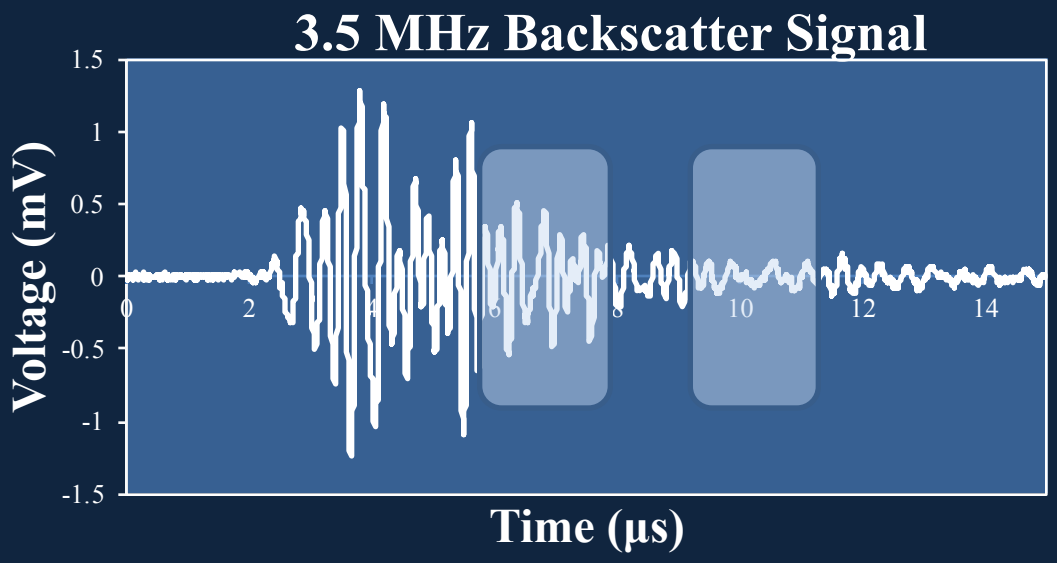


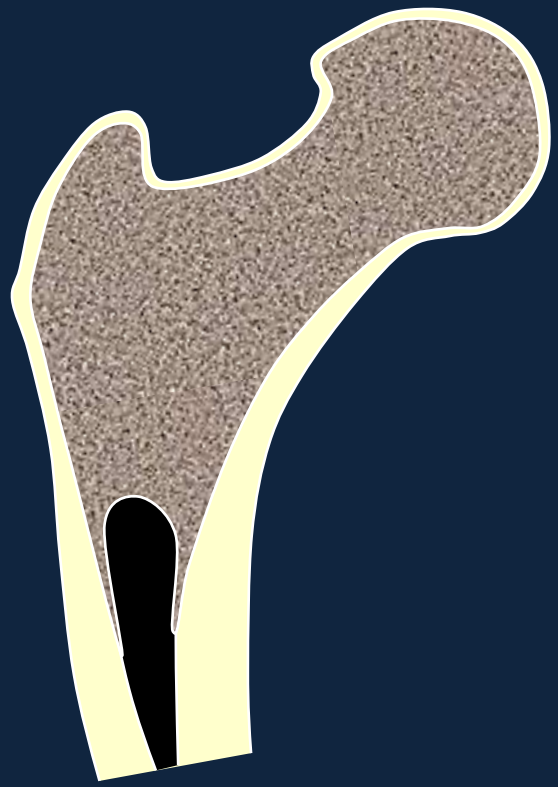
Approach: backscatter



- Single transducer transmits ultrasonic pulses.
- Returned signal is received by the same transducer.
- Easier to align with only one transducer

Backscatter difference technique

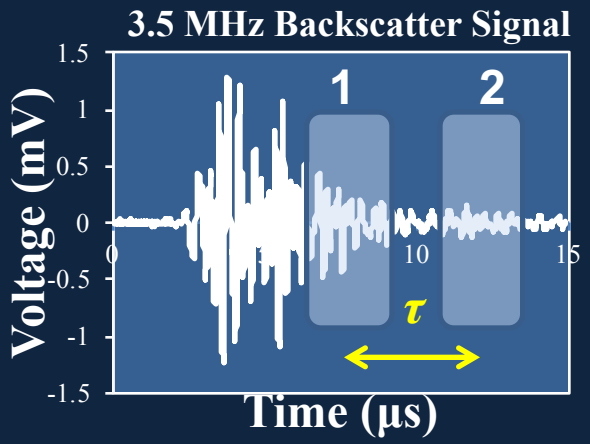


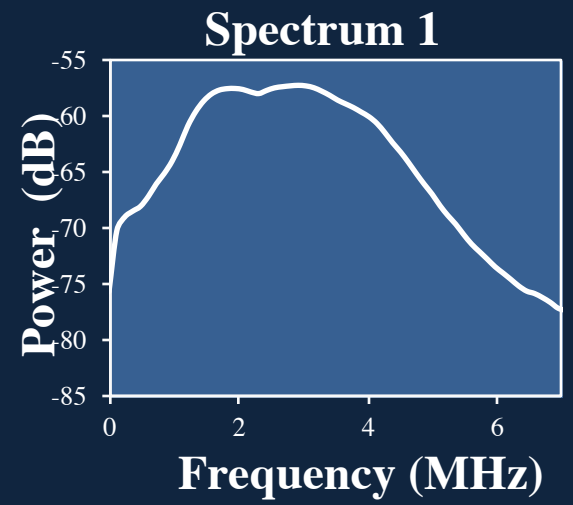


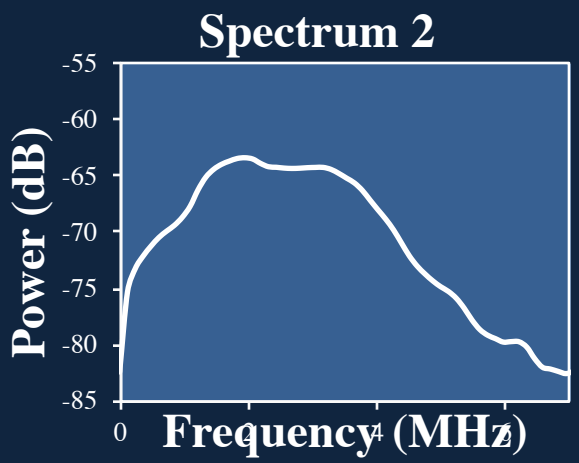
Two parameters based on power difference:

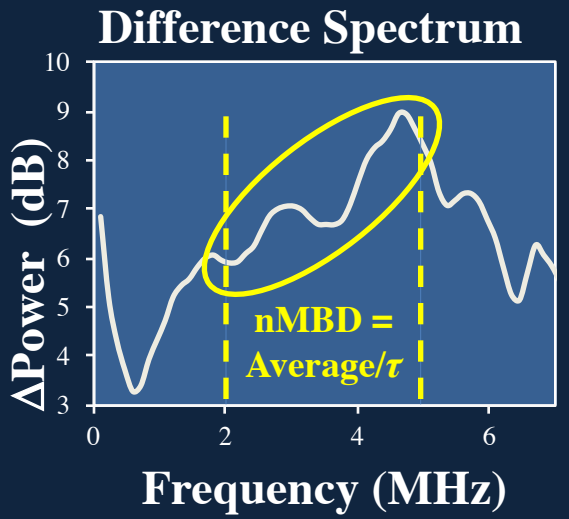
nMBD and nBAR

nMBD

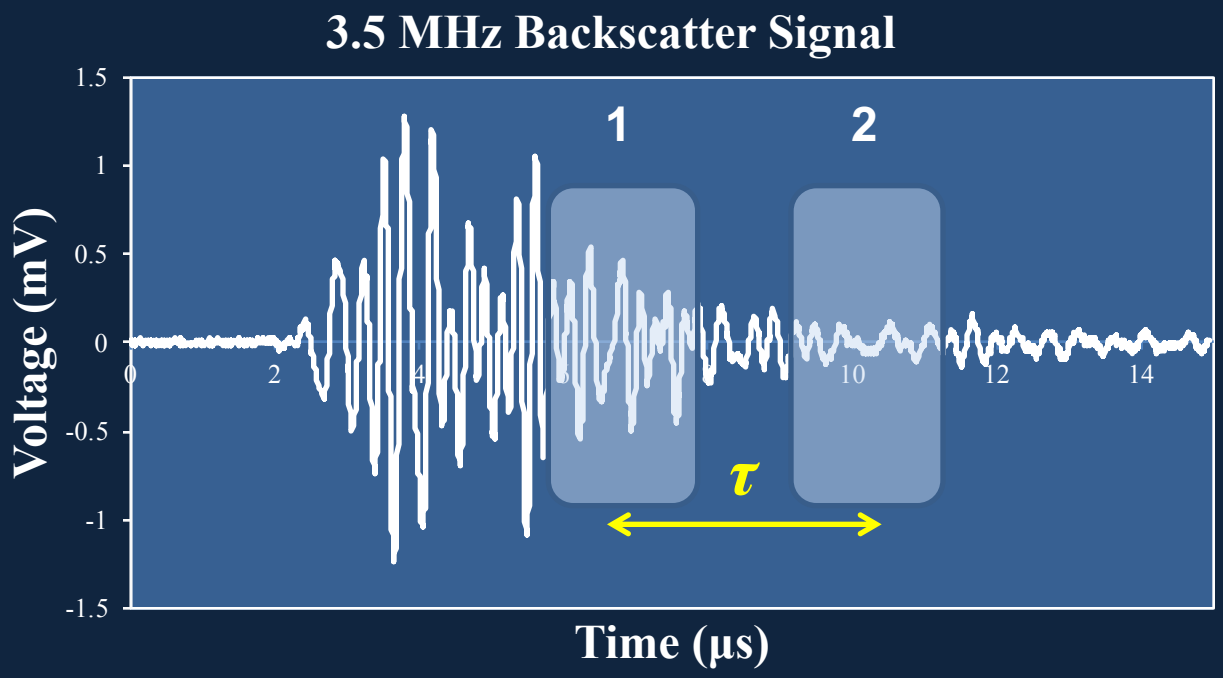

3.5 MHz Backscatter Signal
Voltage (mV)
1.5
1
0.5
0
-0.5
-1
-1.5
1
2
0
10
15
τ
Time (µs)


Spectrum 1
Power (dB)
-55
-60
-65
-70
-75
-80
-85
0
2
4
6
Frequency (MHz)


Spectrum 2
Power (dB)
-55
-60
-65
-70
-75
-80
-85
0
Frequency (MHz)

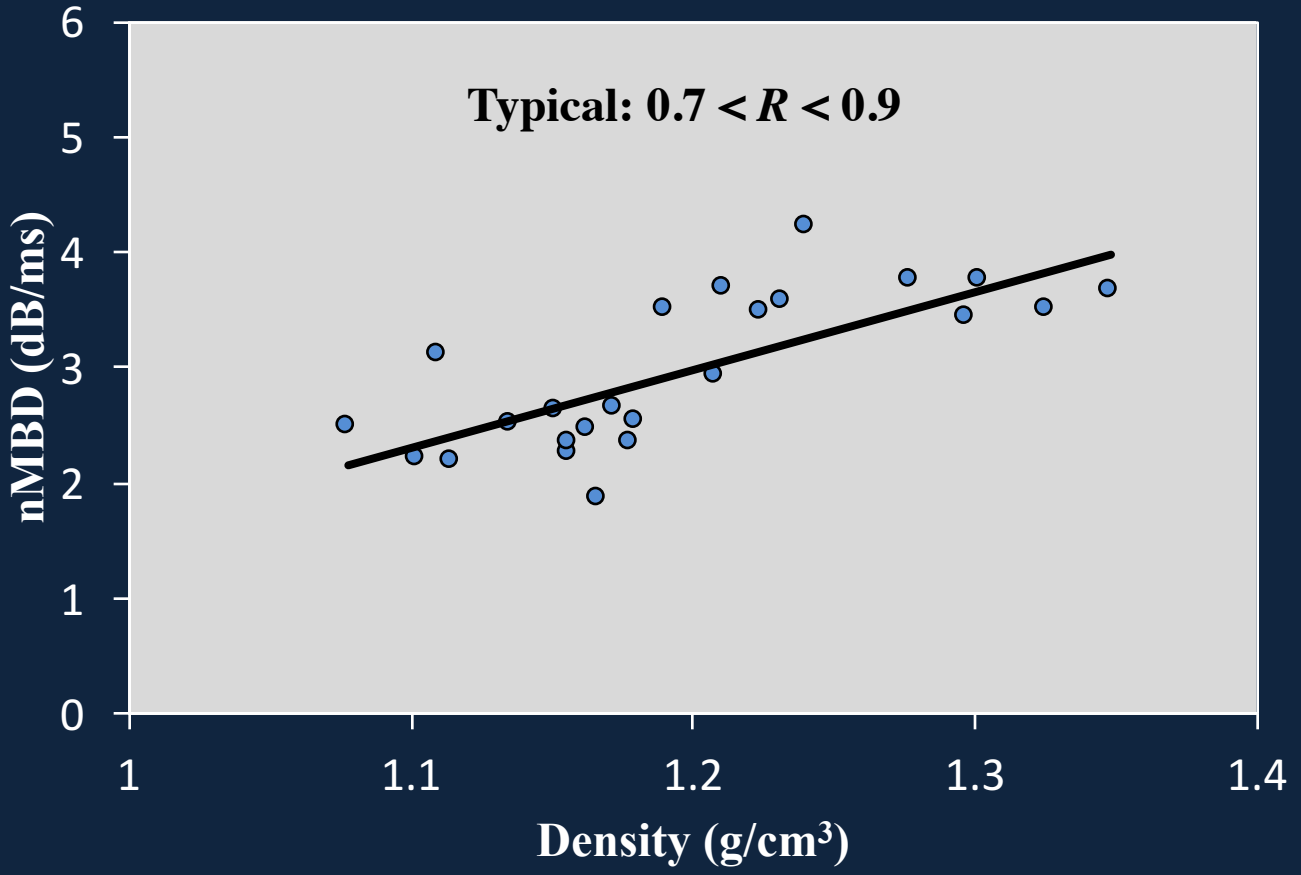

Difference Spectrum
ΔPower (dB)
10
9
8
7
6
5
4
3
0
2
4
6
nMBD =
Average/τ
Frequency (MHz)

nBAR



$$nBAR = \frac{log_{10}\frac{V_{rms1}}{V_{rms2}}}{\tau}$$

Typical result for nMBD



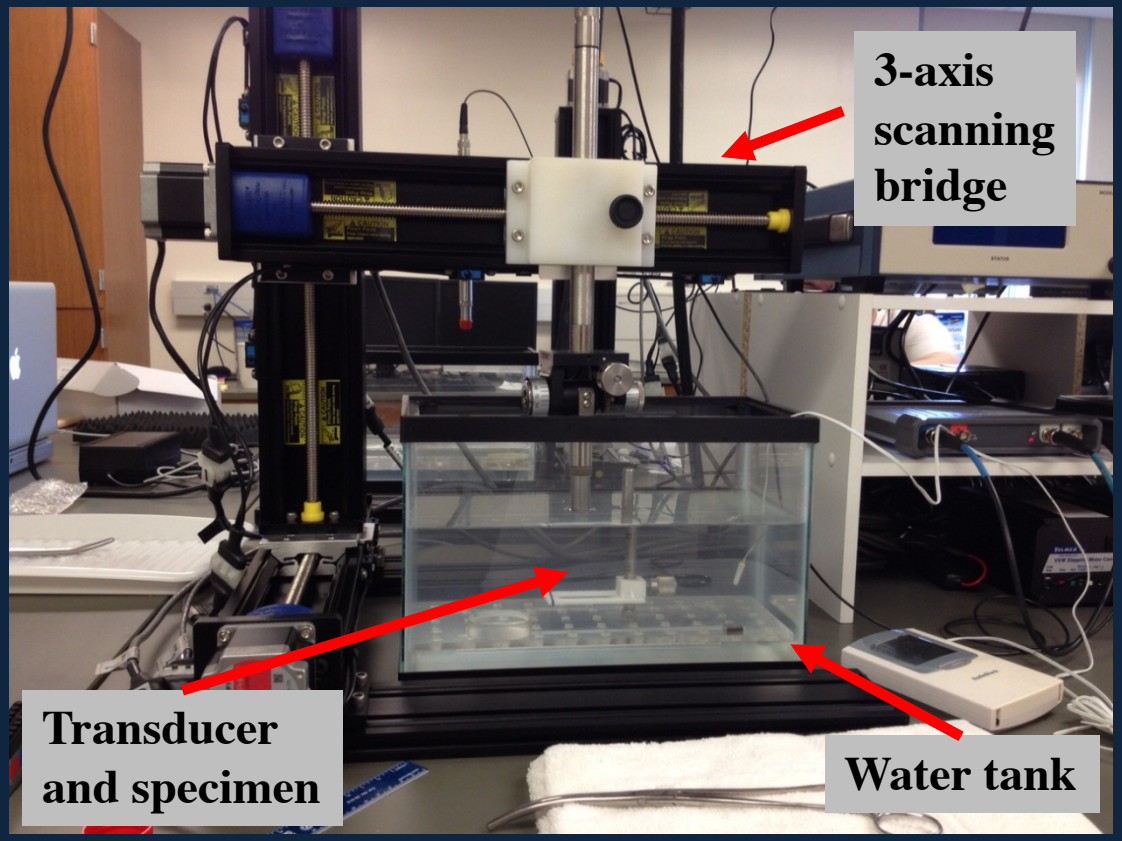
Research goal

- Previous studies have used transducer frequencies > 2 MHz.
- Lower frequency transducers may make it easier to access hip and spine.
- Research goal: Measure nMBD and nBAR with a 1 MHz transducer and evaluate sensitivity to bone density.

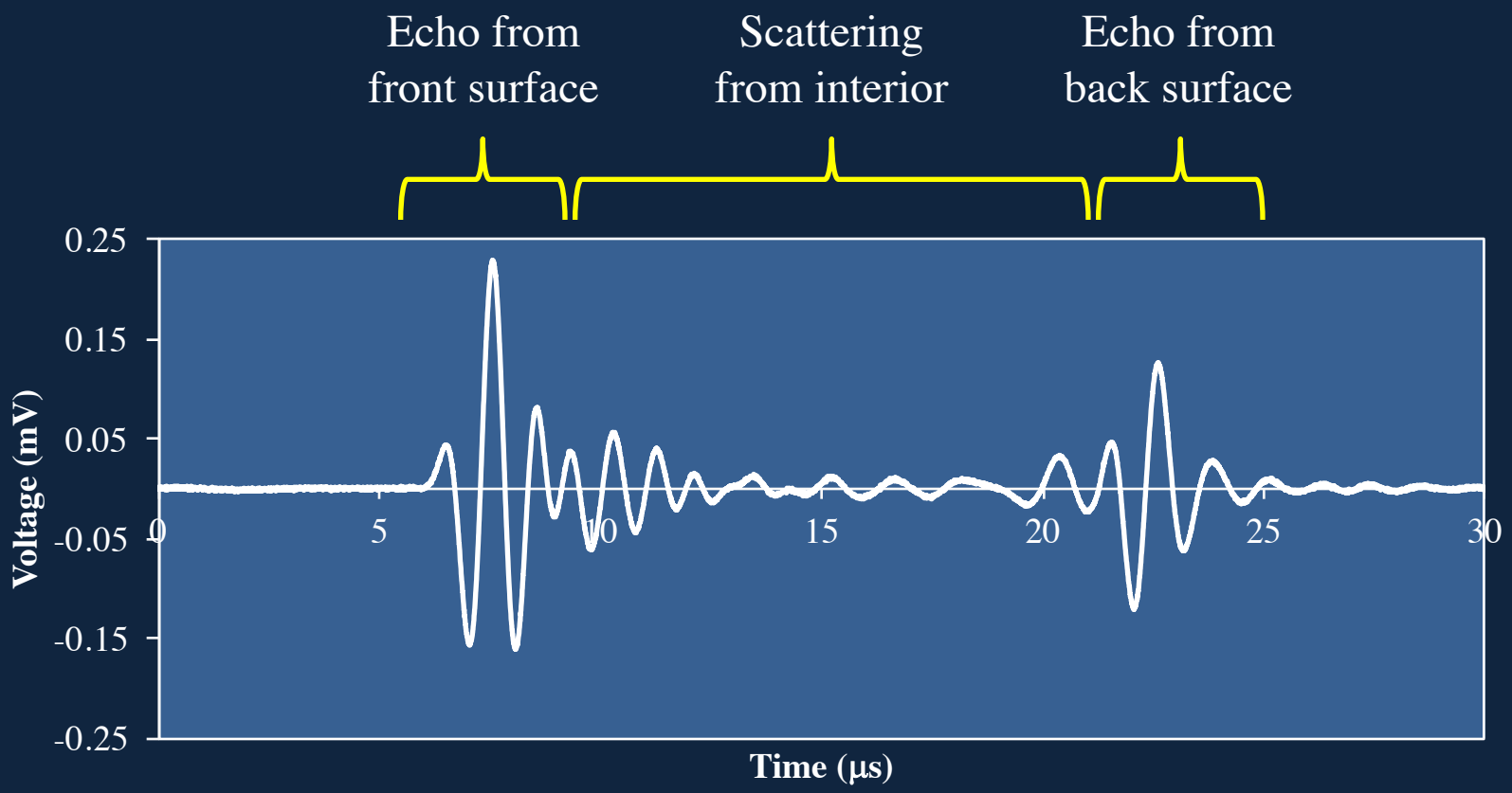
Specimens

- 53 cube shaped specimens
- 10 mm
- Prepared from 14 human femurs

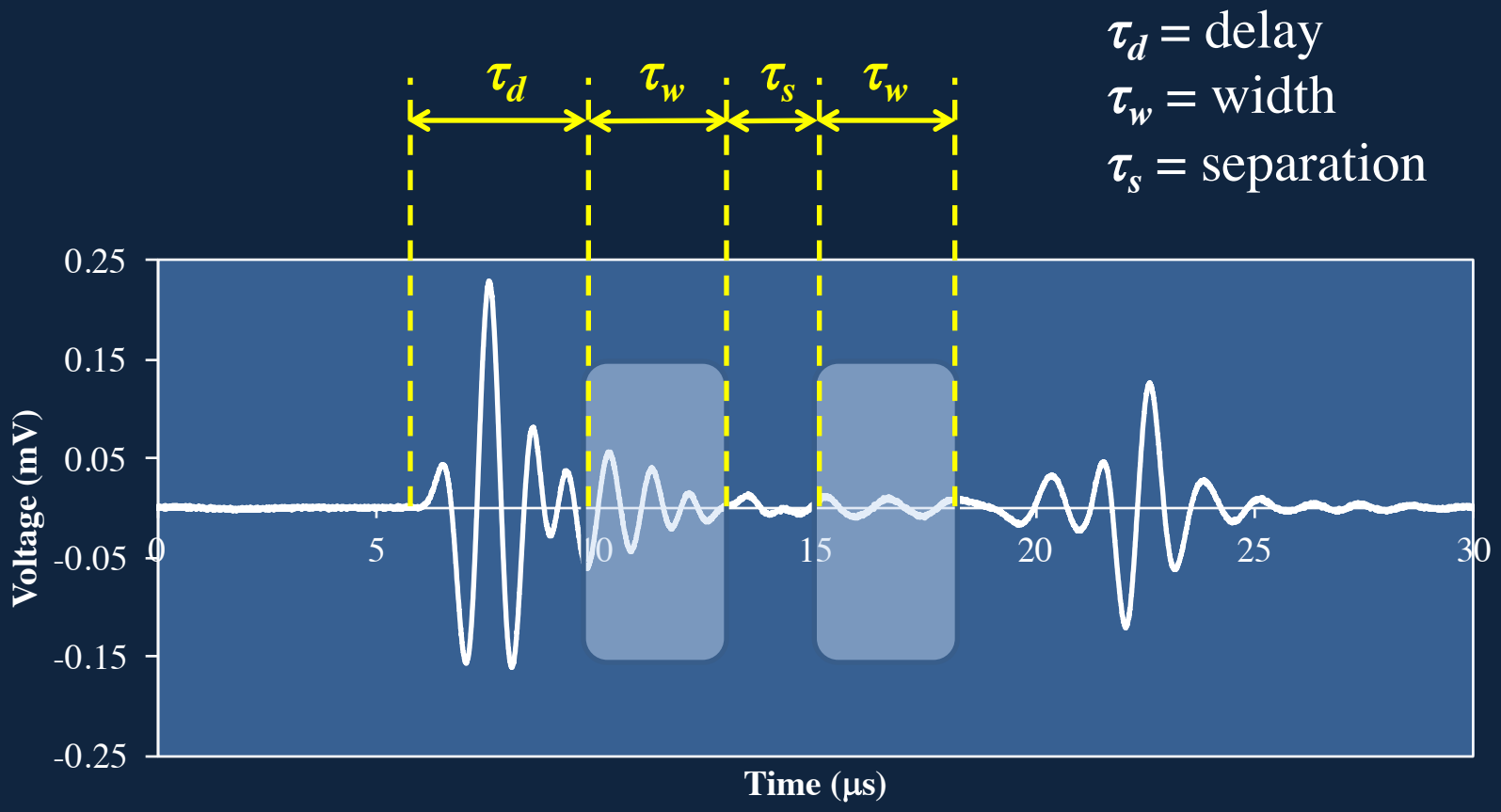
Scanning system



1 MHz backscatter signal



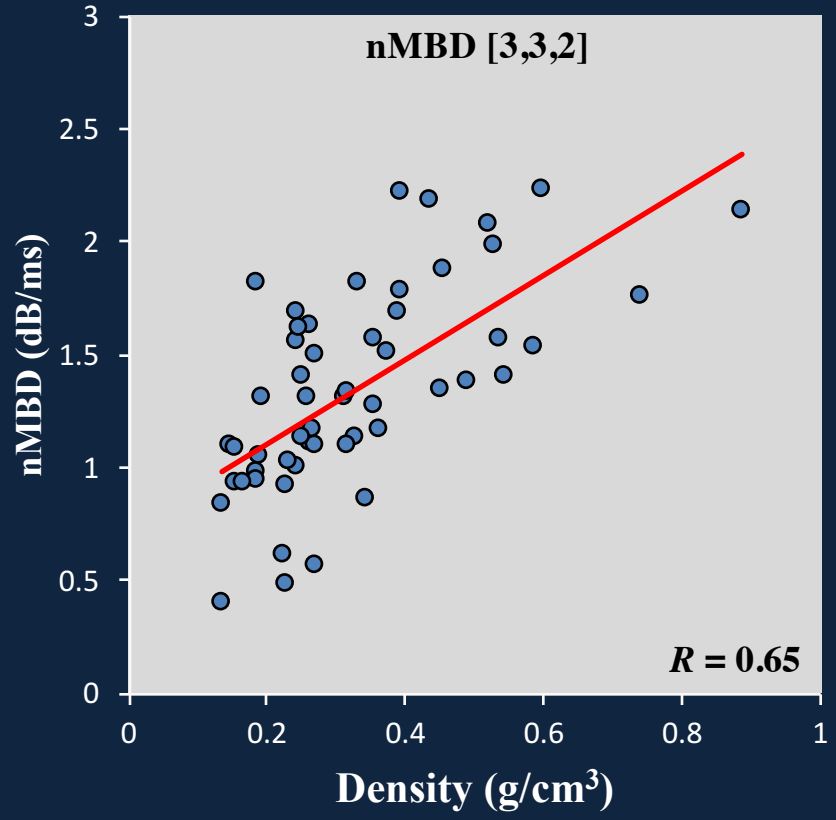
Gate Placement

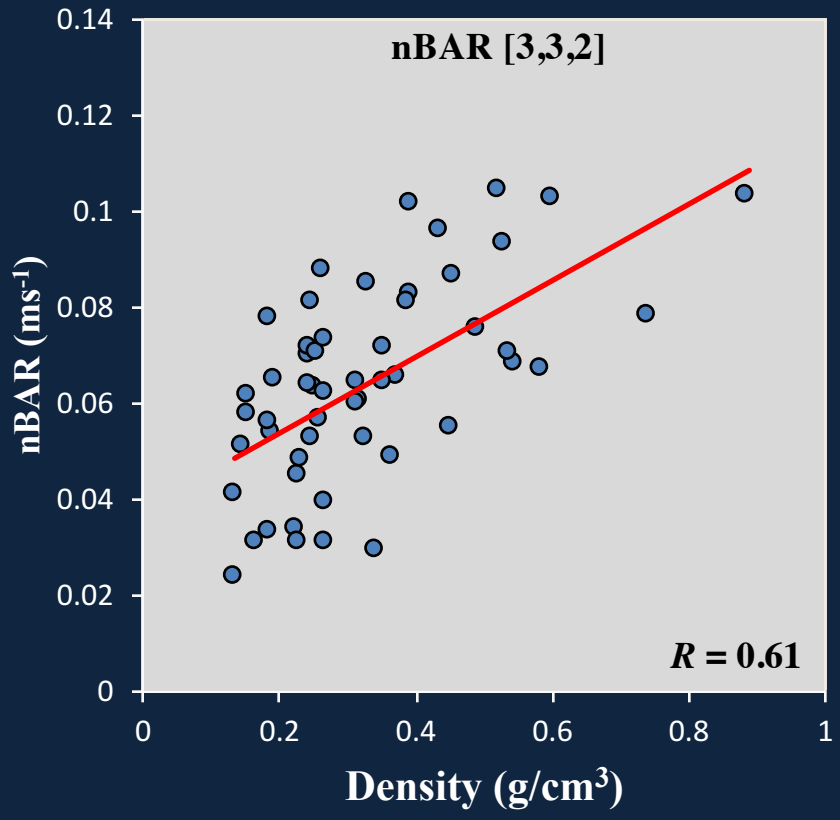


Gate combinations analyzed

Delay (τ_d)	Width (τ_w)	Separation (τ_s)	Notation
3	3	0	[3,3,0]
3	3	1	[3,3,1]
3	3	2	[3,3,2]
3	3	3	[3,3,3]
3	4	0	[3,4,0]
3	4	1	[3,4,1]
4	3	0	[4,3,0]
4	3	1	[4,3,1]
4	3	2	[4,3,2]
4	4	0	[4,4,0]
5	3	0	[5,3,0]
5	3	1	[5,3,1]
6	3	0	[6,3,0]

1 MHz Results





Summary of density correlations

Gate Choice $[\tau_d, \tau_w, \tau_s]$	nMBD	nBAR
[3,3,0]	0.49	0.56
[3,3,1]	0.56	0.58
[3,3,2]	**0.65**	**0.61**
[3,3,3]	0.63	0.58
[3,4,0]	0.61	0.60
[3,4,1]	0.66	0.59
[4,3,0]	0.41	0.32
[4,3,1]	0.49	0.32
[4,3,2]	0.50	0.34
[4,4,0]	0.44	0.35
[5,3,0]	n.s.	0.28
[5,3,1]	0.35	n.s.
[6,3,0]	0.28	n.s.

n.s. = not significant ($p > 0.05$)

Density correlation from other studies

Transducer Frequency	nMBD	nBAR
1 MHz	0.13 - 0.66	0.13 - 0.61
2.25 MHz (Hoffmeister 2012)	0.70 - 0.79	
3.5 MHz (Hoffmeister 2017)	0.65 - 0.90	0.48 - 0.89
5 MHz (Hoffmeister 2015)	0.83 - 0.87	0.74 - 0.77
5 MHz (Hoffmeister 2012)	0.89 - 0.91	
7.5 MHz (Hoffmeister 2012)	0.90 - 0.94	
10 MHz (Hoffmeister 2012)	0.95	

Conclusions

- Using a 1 MHz transducer, nMBD and nBAR demonstrate statitically significant correlations with density for most gate combinations.

- Overall, the correlations obtained in the present study are weaker compared to correlations obtained in previous studies that used higher frequency transducers.

- Clinical applications of this technique will probably perform better using transducer frequencies > 1 MHz.

Acknowledgments

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