Preventing Fractures:

New Ways to Measure Bone Density and Quality

Introduction to Bone Health

Bone had been considered an inert material providing a framework for our muscles to propel all other organ systems around

Skeleton – just a muscle “coat hanger”?

≠

Our skeleton allows us to move and protects our vital organs but it is more than just a Plaster of Paris frame

- The skeleton is a complex organ system
- Bone is living tissue that constantly undergoes change caused by both mechanical and humoral factors

Our skeleton is integrated with all other organ systems through complex feedback loops and it functions in many capacities:

- Mineral reservoir
- Hematopoiesis
- Glucose and energy metabolism
- Immune system
- Endocrine system

Bone is affected by the same factors that affect our general health:

- Activity/Exercise
- Diet/Nutrition
- Lifestyle/Stress
- Genetics
- Toxins

Bone Health needs to be included in routine medical health care –

- or, ignore your bones and they will go away!

Unfortunately, current fracture trends indicate that the importance Bone Health is not appreciated!

Rates of osteoporosis and fragility fractures associated with osteoporosis are at epidemic levels

- It is estimated that osteoporosis affects approximately 200 million people world-wide
- It is also estimated that 10 million individuals over age 50 in the United States have osteoporosis

Each year an approximately 2 million individuals suffer a fracture due to osteoporosis

- Approximately 1 in 2 women and 1 in 5 men age 50 or older will experience a hip, spine, or wrist fracture sometime during their lives
- Approximately 40% of individuals are unable to return to their homes following a fragility fracture and require relocation to a nursing facility
- As many as 20% of individuals will die within 6 - 12 months of a fragility fracture

An additional 33.6 million individuals over age 50 have low bone density (osteopenia) and are at risk of fragility fracture

Osteoporotic-related fractures have an annual cost in the United States that parallels or exceeds the annual cost for myocardial infarction, breast cancer, and cerebrovascular accidents

- The cost of fragility fracture on society is not only a financial burden but it is a source of significant human suffering, lost productivity and lost independence
- Estimated costs of providing care for osteoporotic fractures among Medicare beneficiaries was approximately $14 billion in 2018
- The cost is expected to increase to over $23 billion in 2025

Bone Health care is preventative medicine –it is the core of

fracture prevention

- If a disease is diagnosed earlier treatment is often easier and less expensive
- Bone Health care is comparable to Heart Health care
- Early assessment followed by routinely scheduled monitoring is essential for preventative care!

What does it mean to “Assess Bone Health?”

For a practicing clinician the practical application of Bone Health Assessment is –

To determine if you have “Osteoporosis?”

The “proverbial” apple cart !!!!

It’s time to tip over the “proverbial” apple cart !!!!!!!

So, is the purpose of bone health assessment

to determine if you have “Osteoporosis?”

NO !!!!!!!!!!!!

Who cares if you have Osteoporosis ?!!!!

What ?!!!!!!!!!!

YES – who cares if you have Osteoporosis ?!!!!

The purpose of assessing Bone Health is **NOT** to determine if you have the diagnosis of “Osteoporosis.”

So, what are we trying to accomplish with a bone health assessment?

We are assessing the skeleton for -

Fracture Risk !!!!!!!

Osteoporosis does NOT reliably predict Fracture Risk !!!

So, how do you assess Fracture Risk ?

The FRAGILITY SCORE !!!!!!!

Fragility Score – What is it?

The Fragility Score (FS) is a number that represents the

micro-structural properties

of bone and therefore, it is an estimate of

Bone Strength

What does that really mean?

The Fragility Score is a value that can help determine the likelihood of a fragility fracture.

What is a fragility fracture ?

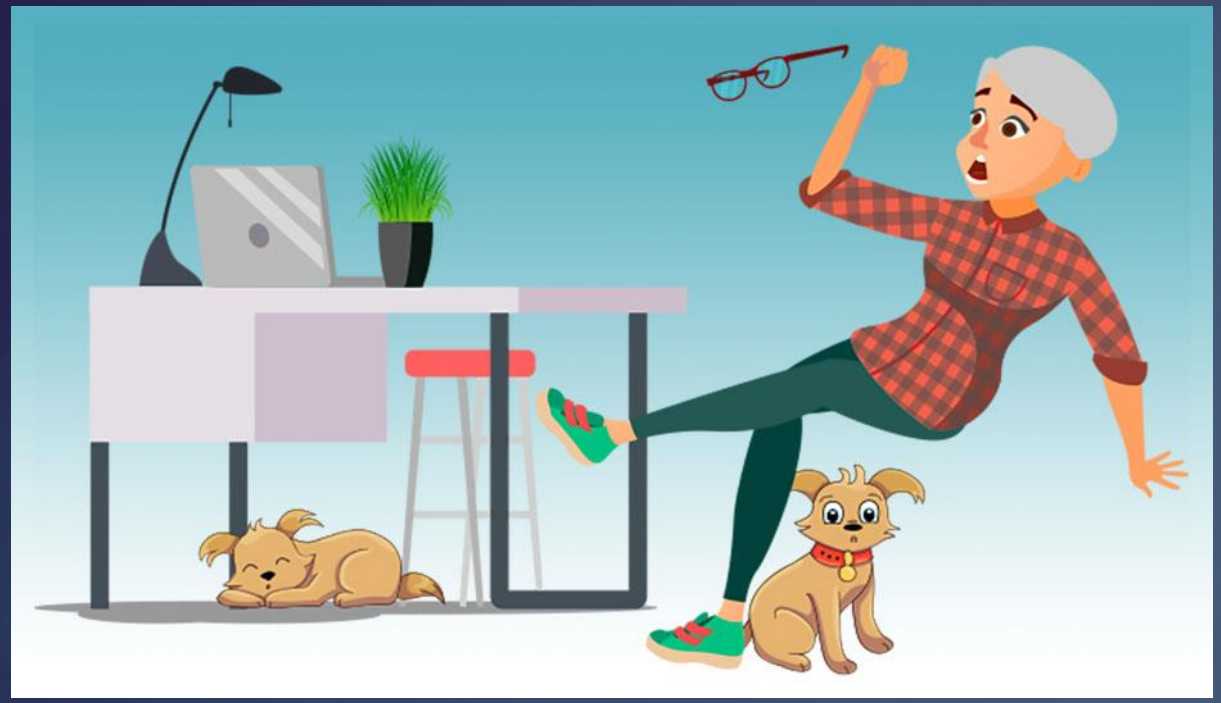
A fragility fracture is a fracture that results from a low-energy injury

High energy injuries


& SHIRTS
DENIM


Renh d
mmit

Low energy injuries



Fragility fractures:

- hip
- spine
- pelvis
- proximal humerus
- wrist

“Other” fractures attributed to bone fragility:

- periprosthetic fractures
- distal humerus
- distal femur
- proximal tibia
- distal tibia
- rib

Doesn’t a T-Score assess fracture risk ?

T-Scores determine if you have Osteoporosis

T-score is not a good predictor of fracture risk!!!!!

We are using the Fragility Score to determine Fracture Risk

So, is the Fragility Score better than a T-score at determining fracture risk?

YES !!!!!

Side Note !!!!!!!!

It is very important that when anyone makes a significant claim that may be opposite of what you have heard, do not let them get away with it without asking questions such as:

Please explain what you are basing that statement on!

Peer reviewed academic literature *

* Scientific papers that are written by the researchers and submitted for publication in a scientific journal. The peer-reviewed journal editors will have committees of individuals who review the article and make sure that certain standards are met prior to the article getting published.

Clinical experience*

* Often, individuals giving lectures are asked to speak on a specific topic because they are considered to be experts on the topic due to their level of scientific or practical experience.

Academic discussion and even disagreement is part of normal medical discourse; however, dismissive statements such as:

“it isn’t ready for prime-time”

are a red flag for a lack of intellectual curiosity and are not meaningful contributions to academic discourse.

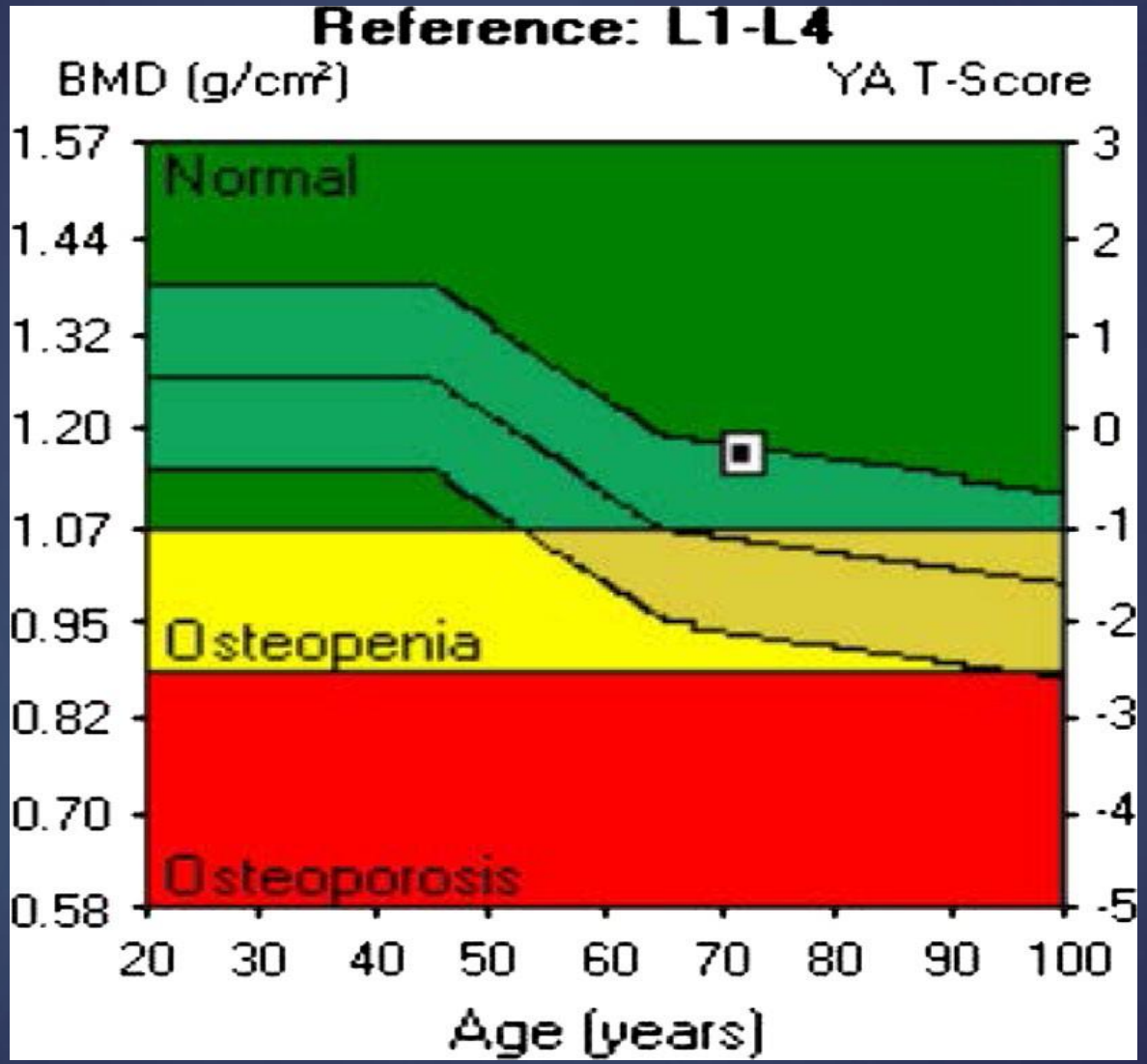
The purpose of Bone Assessment is to –

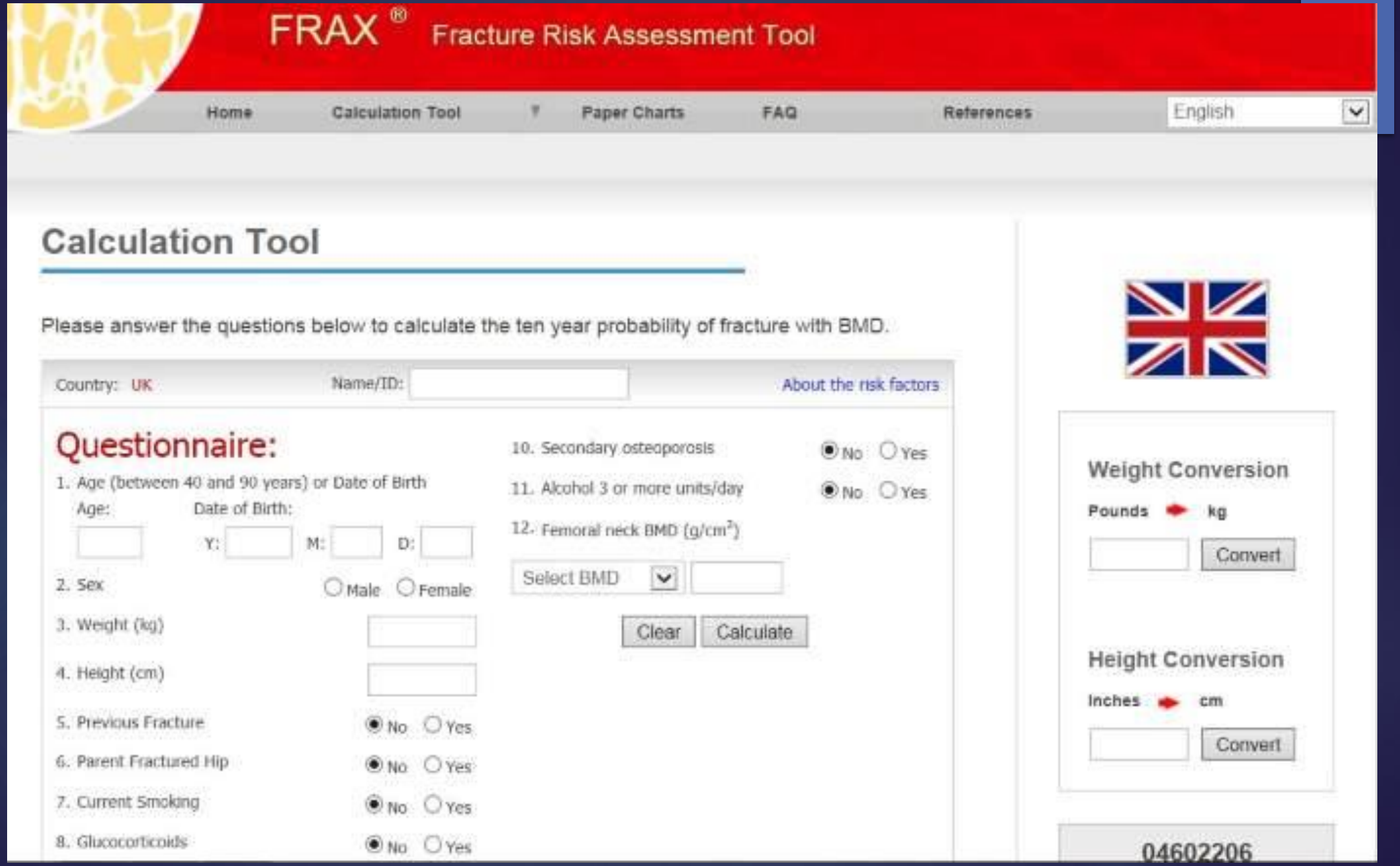
determine Fracture Risk!

Although low BMD has been recognized as the risk factor for fragility fracture, it has recently been shown that a majority of fractures actually occur in those without osteoporotic BMD

Multiple studies have documented that the majority of fractures occur in individuals not diagnosed with osteoporosis

- In one study 55% of women and 70% of men who sustained a fracture had “normal” or “osteopenic” BMD – T-Score ≥ -2.0
- The National Osteoporosis Risk Assessment observed that more than 2/3 of patients with hip fracture did not have osteoporotic BMD (i.e., they had osteopenia or normal BMD)
- These data consistently suggest that most fractures occur in those with BMD above the “osteoporotic” cutoff point


Reference: L1-L4
BMD (g/cm²)
YA T-Score
1.57
1.44
1.32
1.20
1.07
0.95
0.82
0.70
0.58
3
2
1
0
-1
-2
-3
-4
-5
Normal
Osteopenia
Osteoporosis
20
30
40
50
60
70
80
90
100
Age (years)


FRAX ® Fracture Risk Assessment Tool
Home
Calculation Tool
Paper Charts
FAQ
References
English
Calculation Tool
Please answer the questions below to calculate the ten year probability of fracture with BMD.
Country: UK
Name/ID:
About the risk factors
Questionnaire:
1. Age (between 40 and 90 years) or Date of Birth
Age:
Date of Birth:
Y:
M:
D:
2. Sex
Male
Female
3. Weight (kg)
4. Height (cm)
5. Previous Fracture
No
Yes
6. Parent Fractured Hip
No
Yes
7. Current Smoking
No
Yes
8. Glucocorticoids
No
Yes
10. Secondary osteoporosis
No
Yes
11. Alcohol 3 or more units/day
No
Yes
12. Femoral neck BMD (g/cm²)
Select BMD
Clear
Calculate
Weight Conversion
Pounds
kg
Convert
Height Conversion
Inches
cm
Convert
04602206

Density alone is not a measure of strength

- Although BMD has a predictive value, it's correlation to fracture risk can be best described as associative, and NOT determinative
- Therefore, measuring BMD is NOT be the best way of determining whether a bone is susceptible to fracture

The property of a material that determines whether or not a material fails when a force is applied is called its –

Strength (Stiffness)

The most recent research trends are evolving towards the assessment of the actual bone strength independent of BMD

The Fragility Score represents the Bone Strength !

Lecture goals:

- ✓ What is the Fragility Score
- ✓ How it differs from T-Score
- ✓ Why it is currently the best method to determine Fracture Risk !!!

Understand structural materials

Materials whose purpose is to transmit or support a mechanical force

Different types of structural materials

Concrete

Wood

Ceramic

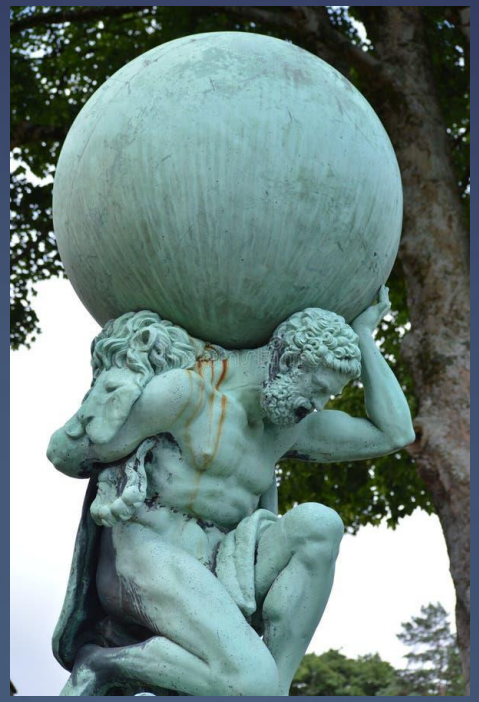
Plastic

Steel

Bone !!!!

Bone is a structural material – it meets the criteria of a structural material

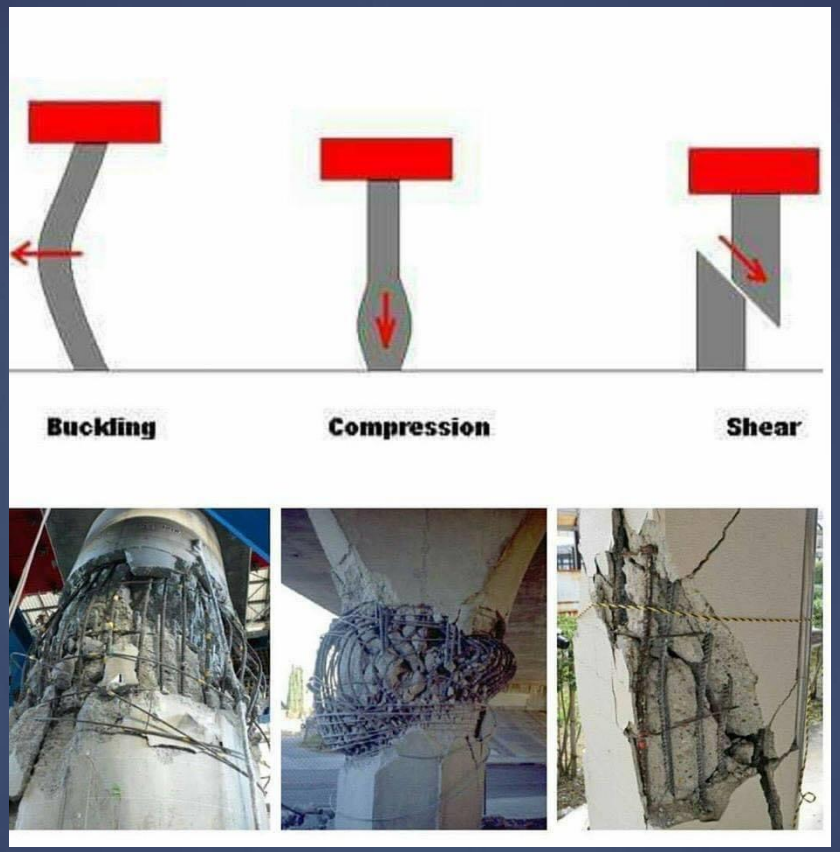
It provides a mechanical frame that withstands forces…..




shutterstock.com · 308792876

……and it can be mechanically manipulated

Also, all structural materials have limits to their capacity to withstand a loading force, and if that limit is exceeded the material will fail.


Buckling
Compression
Shear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A bone fractures when the force loading the bone exceeds the capacity of bone.

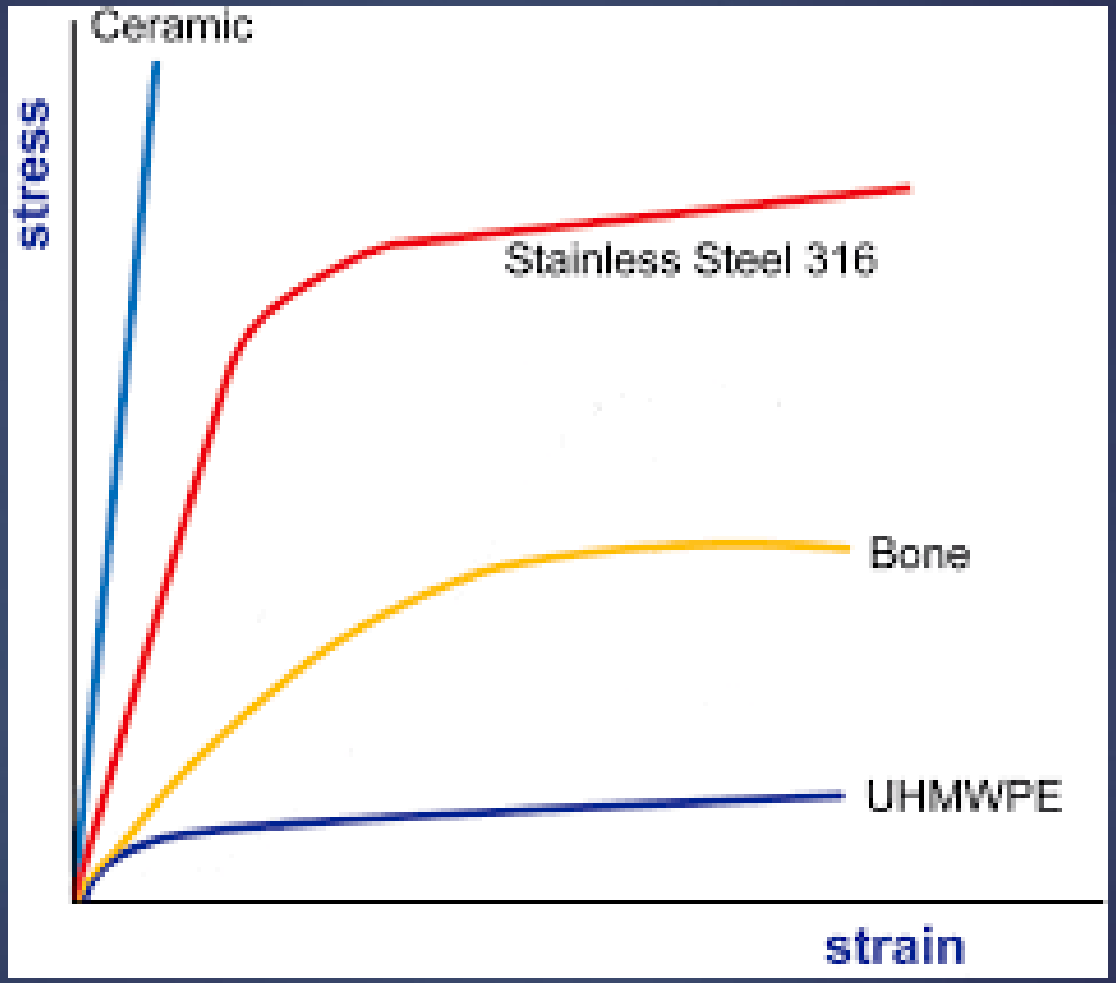

Fracture

Therefore, just like with any structural material it is important to determine when bone will fail

It would be appropriate to assess bone as an engineer would assess any structural material…..

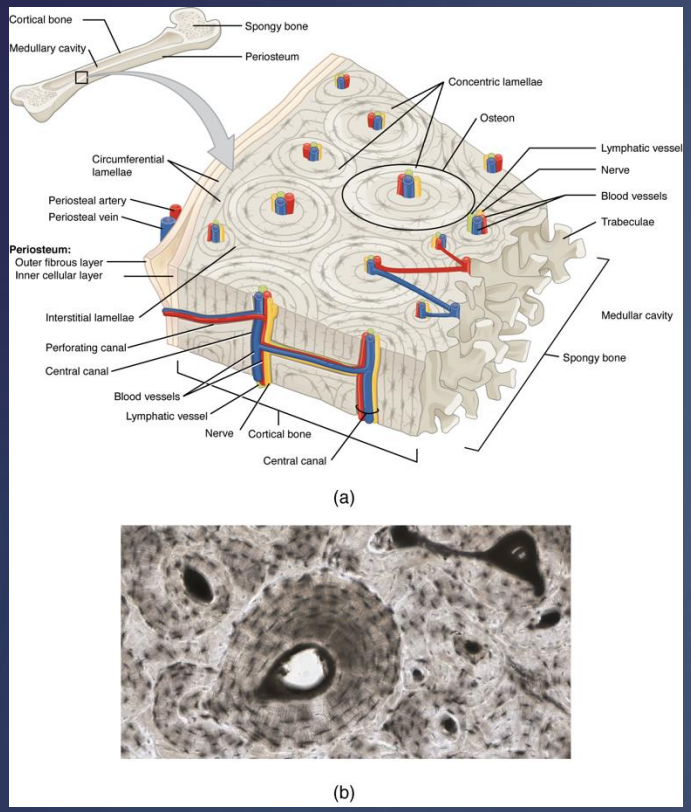
….by determining the properties that determine the material’s strength

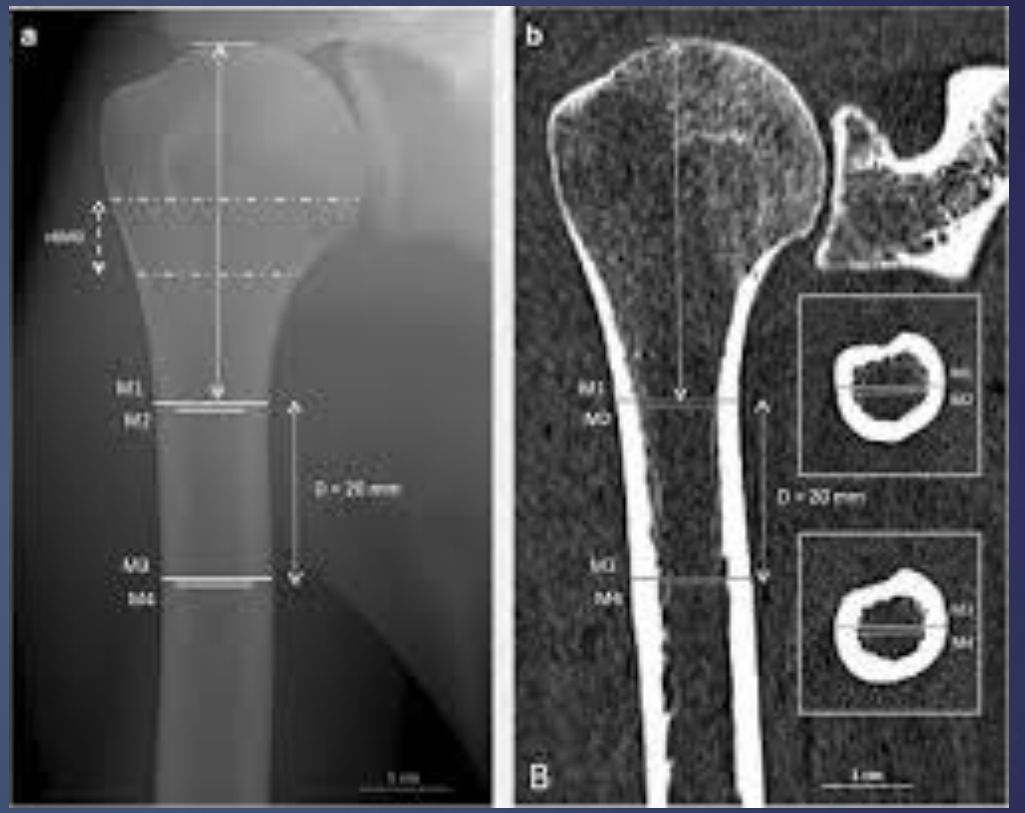
– its ability to withstand an applied force and not fail.


Ceramic
stress
Stainless Steel 316
Bone
UHMWPE
strain

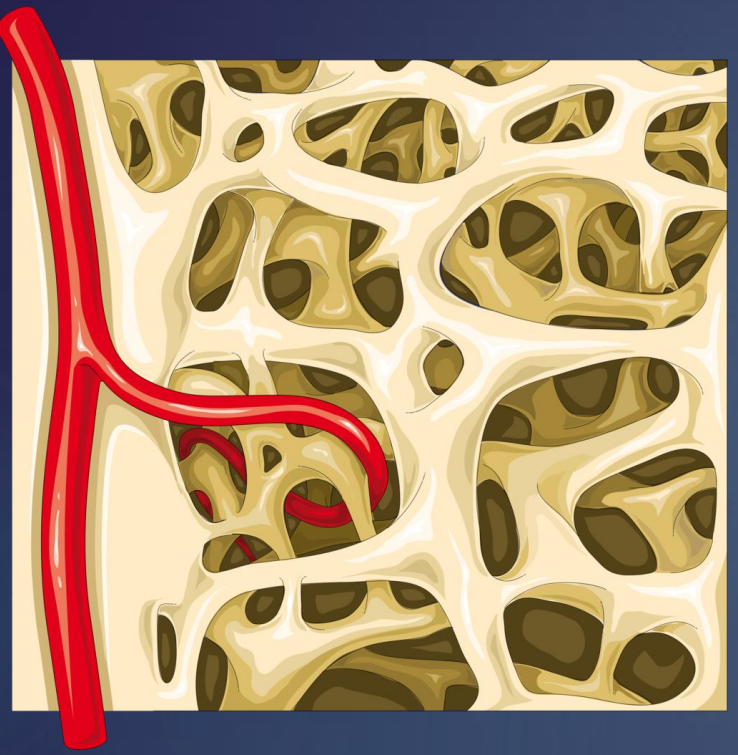
Bone is not uniform

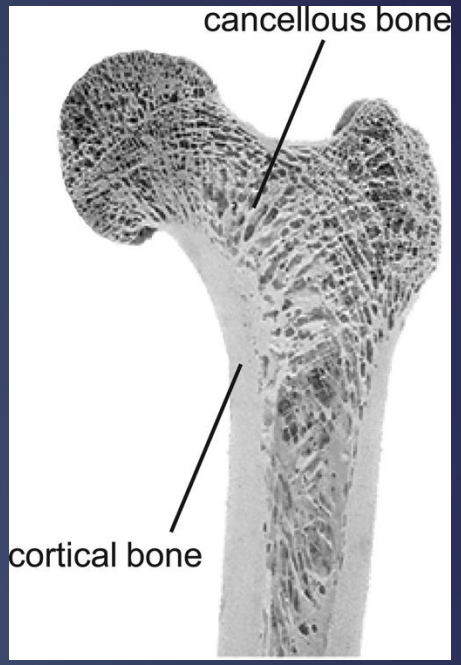
Cortical bone – Dense layered bone usually found in the middle of a long bone


Cortical bone
Spongy bone
Medullary cavity
Periosteum
Concentric lamellae
Osteon
Lymphatic vessel
Nerve
Blood vessels
Trabeculae
Circumferential lamellae
Periosteal artery
Periosteal vein
Periosteum:
Outer fibrous layer
Inner cellular layer
Interstitial lamellae
Perforating canal
Central canal
Blood vessels
Lymphatic vessel
Nerve
Cortical bone
Central canal
Medullar cavity
Spongy bone
(a)
(b)

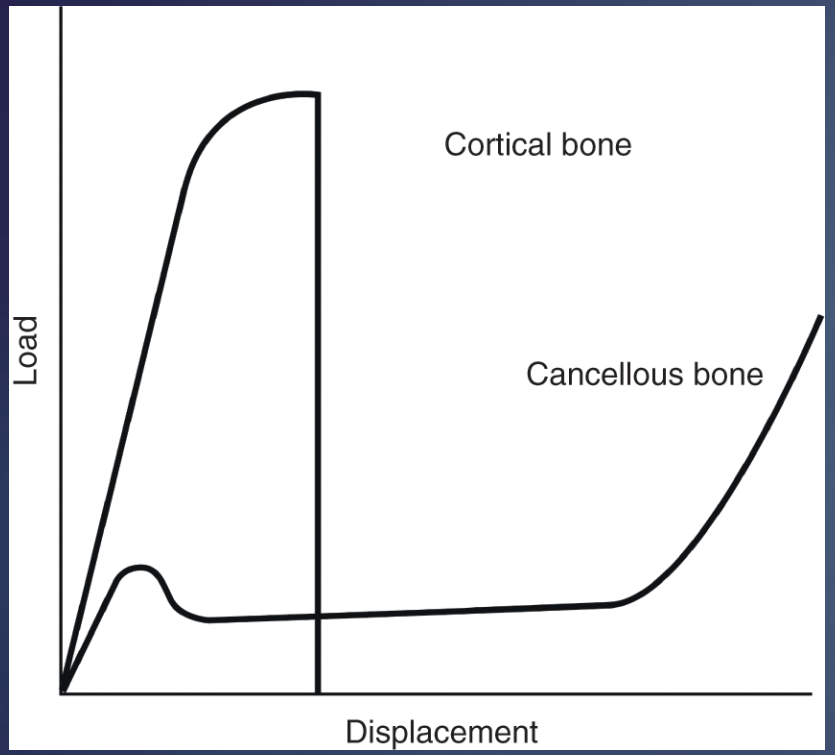

a
b
M1
M2
M3
M4
D = 20 mm
B

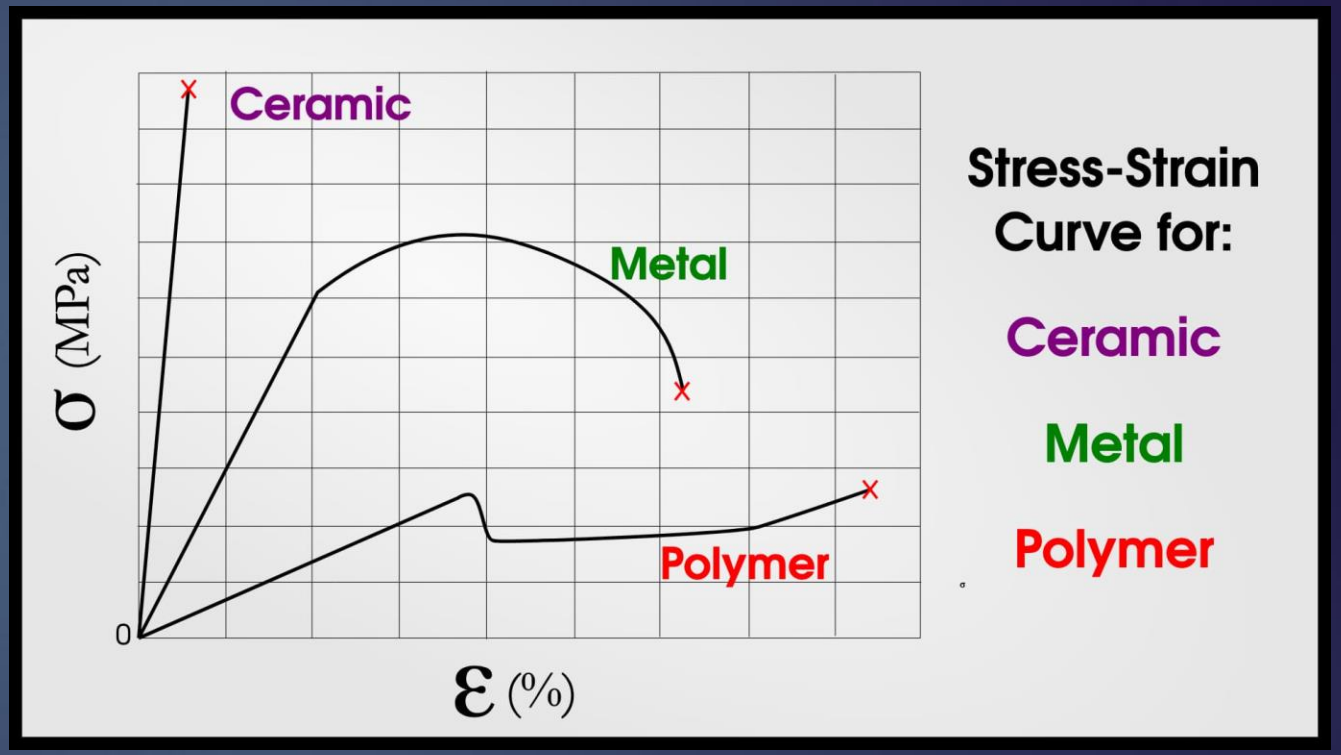
Trabecular bone – Woven bone usually found at the ends of long bones adjacent to joints and in the vertebral bodies




cancellous bone
cortical bone

There is a difference on how cortical bone and trabecular bone respond to forces


Cortical bone
Cancellous bone
Load
Displacement


Ceramic
Metal
Polymer
σ (MPa)
0
ε (%)
Stress-Strain Curve for:
Ceramic
Metal
Polymer

“Osteoporosis” is often used to describe structurally degraded bone with significantly decreased capacity to withstand a loading force resulting in structural failure – a Fragility Fracture.

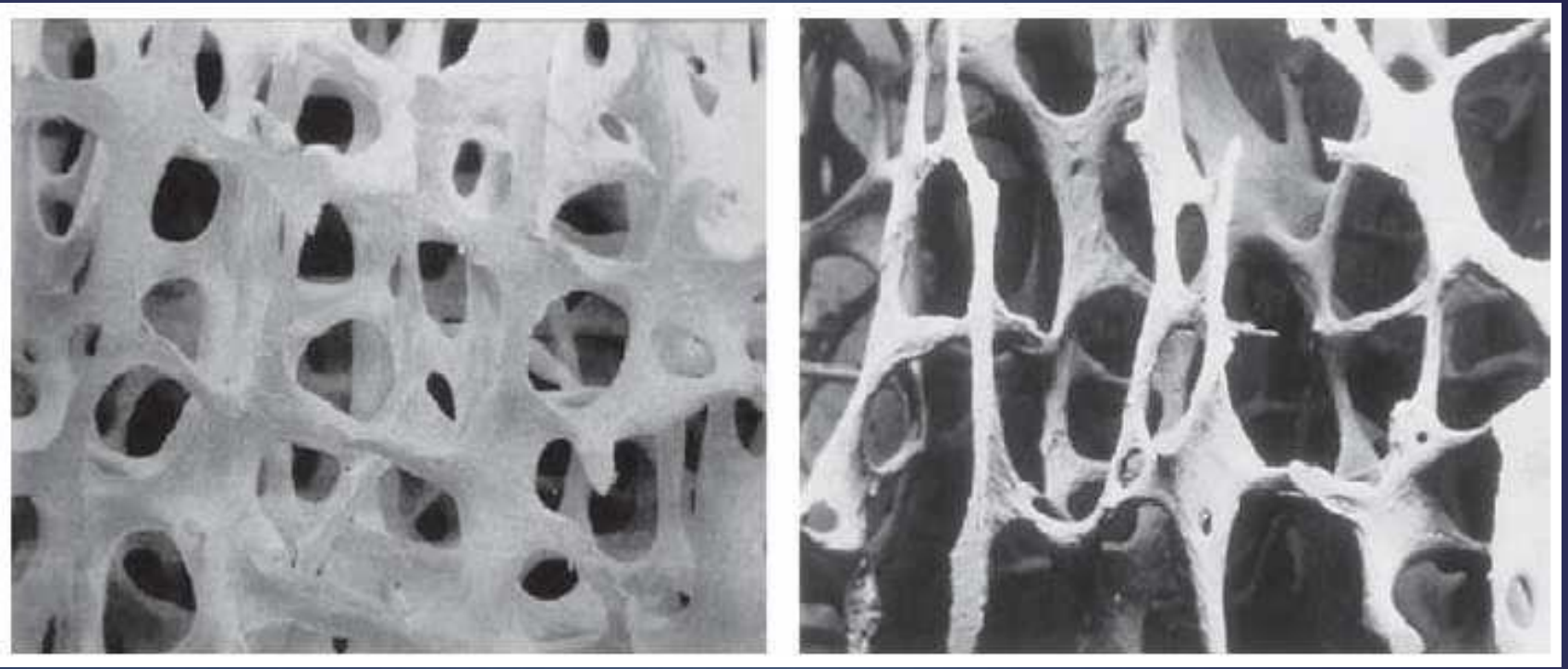
However, as we discussed “Osteoporosis” is not the appropriate term to use.

Degraded bone

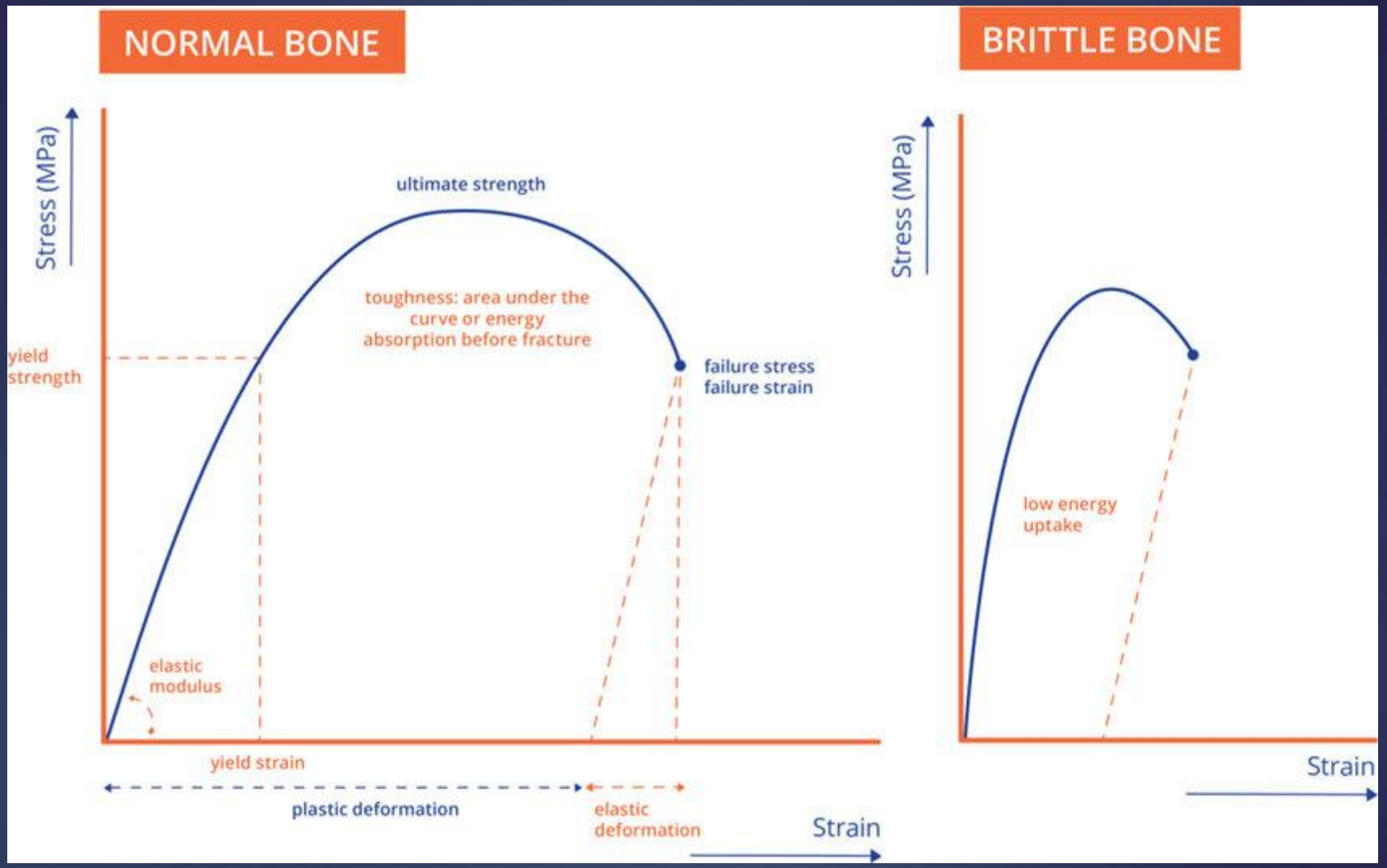
Weakened (weak) bone

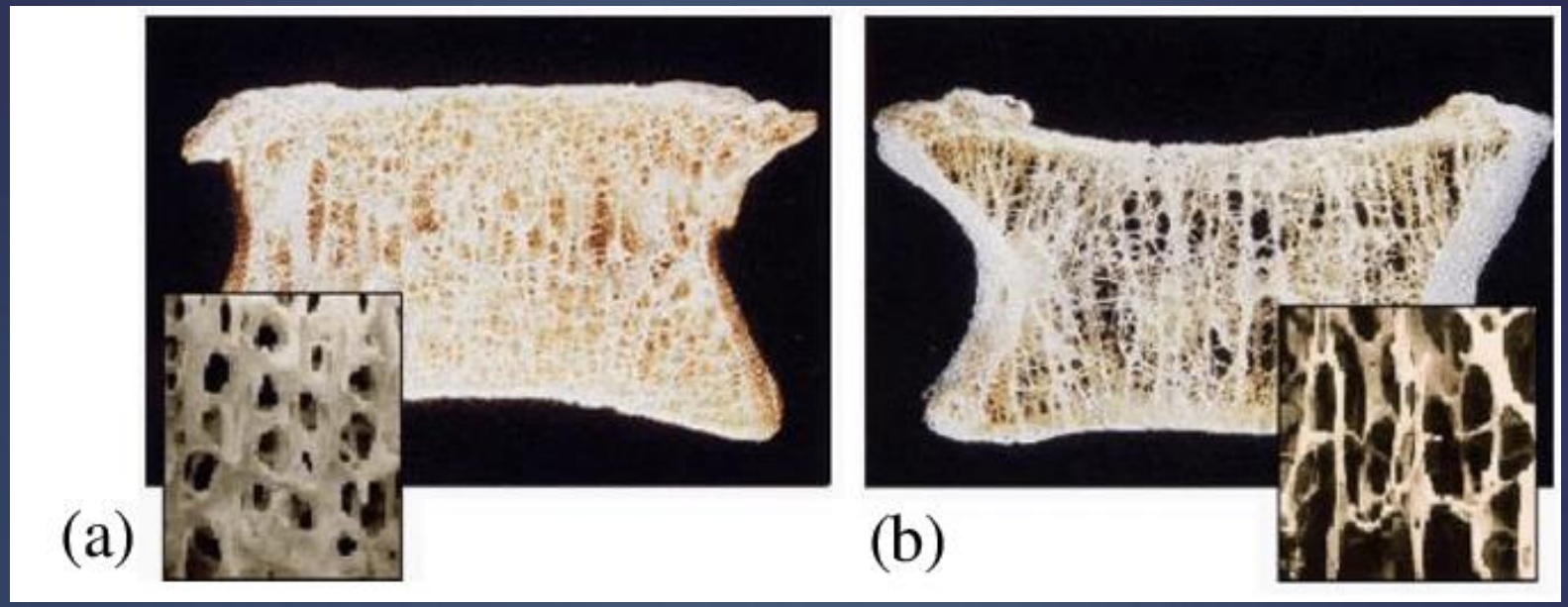
Structurally deficient bone

Brittle bone



An “brittle” bone will fail (fracture) due to a smaller force than a “normal” bone


NORMAL BONE
Stress (MPa)
ultimate strength
toughness: area under the curve or energy absorption before fracture
yield strength
failure stress
failure strain
elastic modulus
yield strain
plastic deformation
elastic deformation
Strain
BRITTLE BONE
Stress (MPa)
low energy uptake
Strain


(a)
(b)

Properties of Structural Materials

Physical properties

vs.

Mechanical properties

Physical Properties:

Characteristics of a material that cannot be changed without irreversibly altering the material

Physical Properties are the

Intrinsic properties of a material

Physical properties:

Density

Specific Gravity

Elasticity

Porosity

Conductivity

Chemical composition

Texture

Mechanical Properties:

How a structural material behaves under the effect of an applied load

Mechanical properties:

Strength

Hardness

Ductility

Elasticity

Fracture Toughness

Fatigue

Creep resistance

Density is a Physical Property

Strength is a Mechanical Property

Mechanical Properties:

The Mechanical Properties of a material are dependent on its intrinsic Physical Properties

Strength is a mechanical property

determined by multiple physical properties

that includes density

You cannot determine the mechanical property of a material by just measuring only **one** of the physical properties

How is the strength of a material determined?

Stress Vs. Strain – Young’s Modulus

Functional Loading

Tensile testing

Compressive strength testing

Yield strength testing

Chemical analysis

Stress-strain curve analysis

Torsional testing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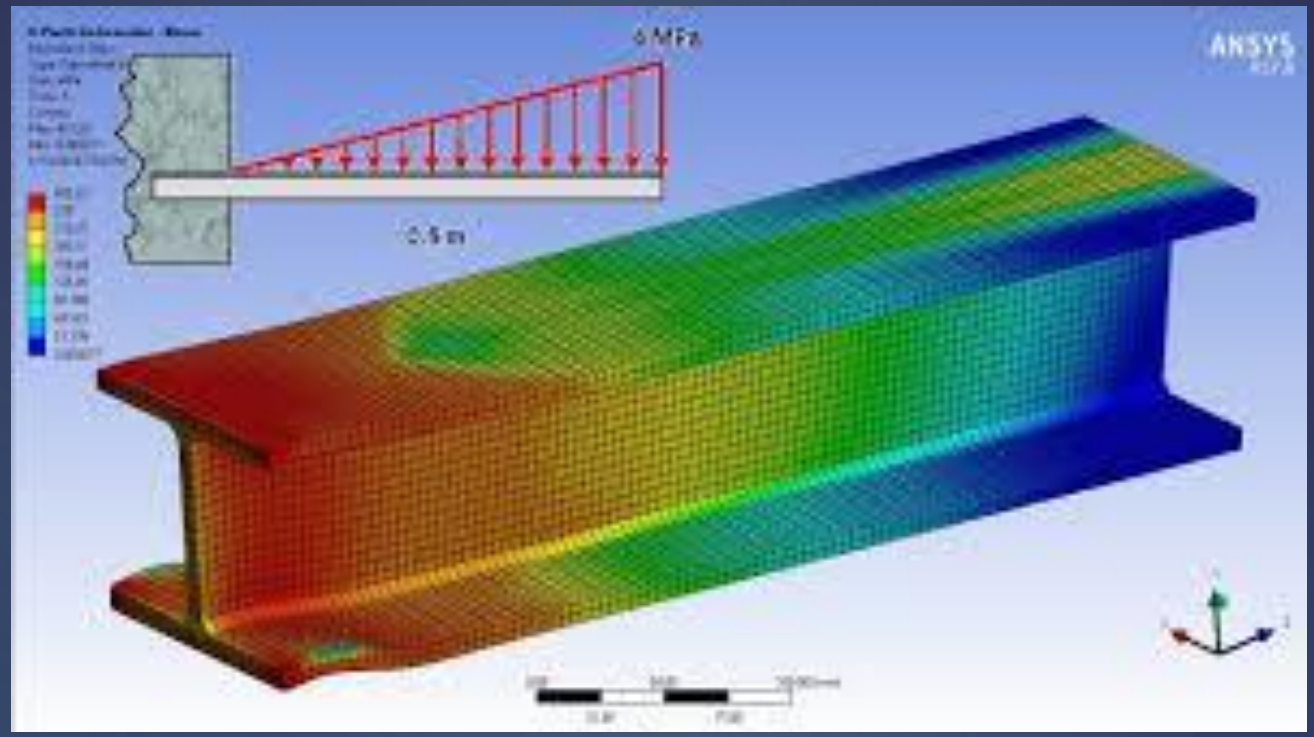
Finite Element Analysis

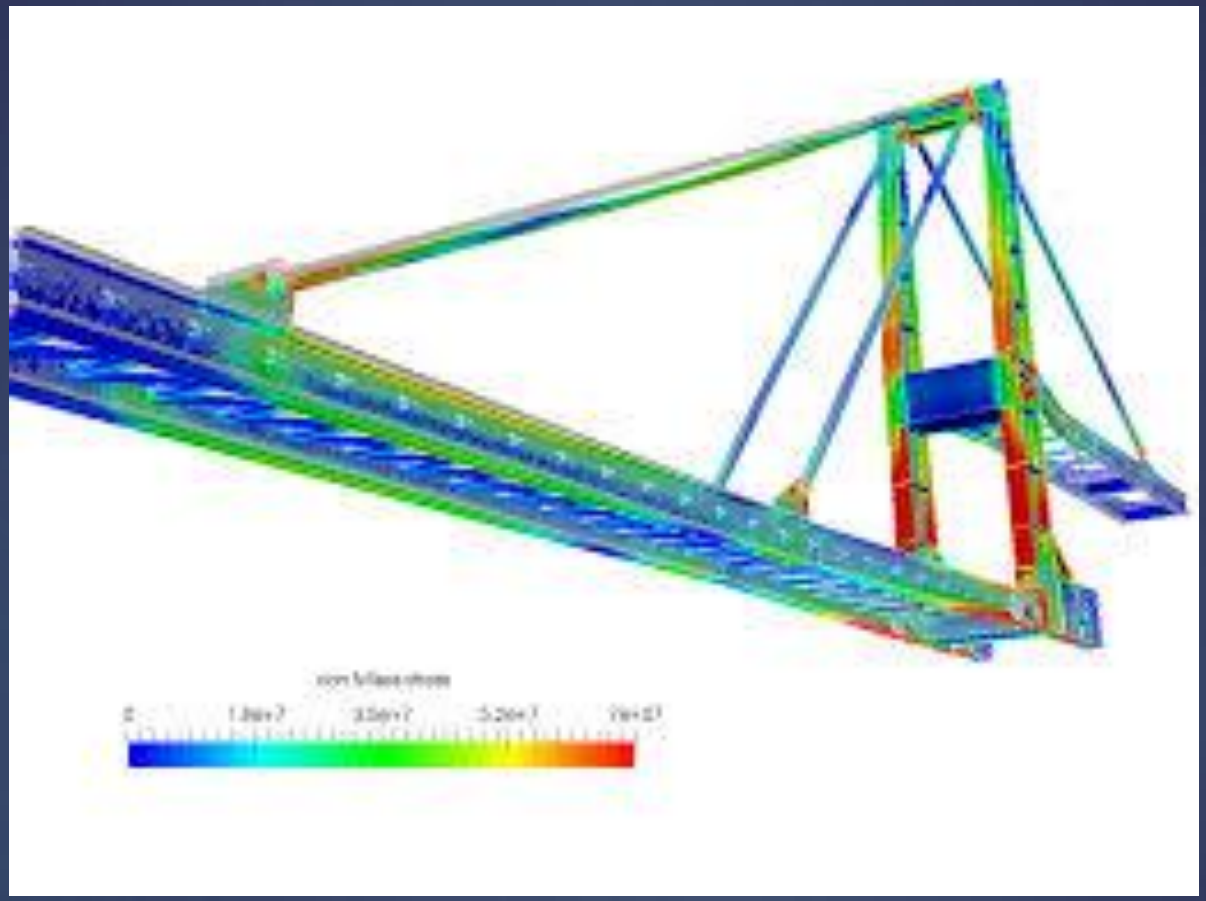
Industry often relies on

Finite Element Analysis

for strength assessment

A computer model is created based on designated structural properties of the material being tested.


6 MPa
0.5 m
ANSYS



Areas of fatigue/failure are identified based on the loading pattern and stresses experienced by the material as predicted by the computer model

Pretty complex stuff !!!!!!

Back to bone

Lucky for us we can just use the T-Score !

Right ?

No !!!!!!!!!!

Bone is a structural material !!!!!

Using Bone Mineral Density (BMD) and T-score are not a reliable way of determining fracture risk

Bone Mineral Density (BMD) and T-score are measures of only the density of the bone

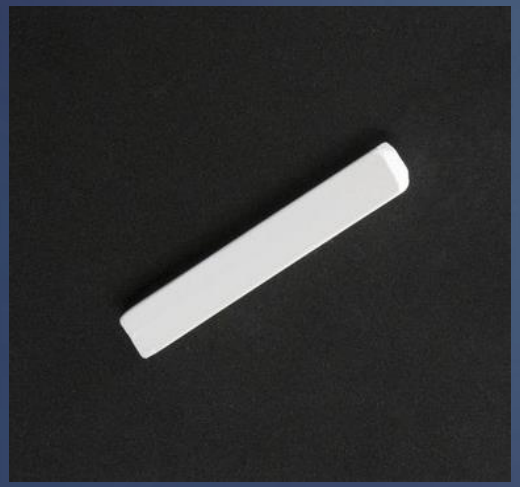
Measuring density alone at best is an incomplete way to measure the strength of a material !!!!

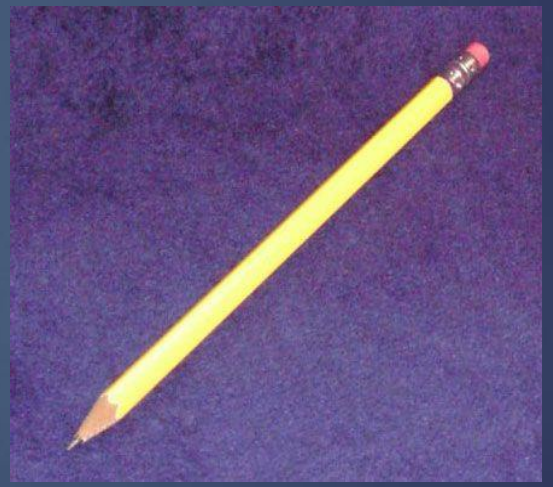
Low BMD has been recognized as the risk factor for fragility fracture

However, it has been shown that a majority of fractures occur in those individuals who do not have Osteoporosis

Density alone is not a measure of strength !!!!!!

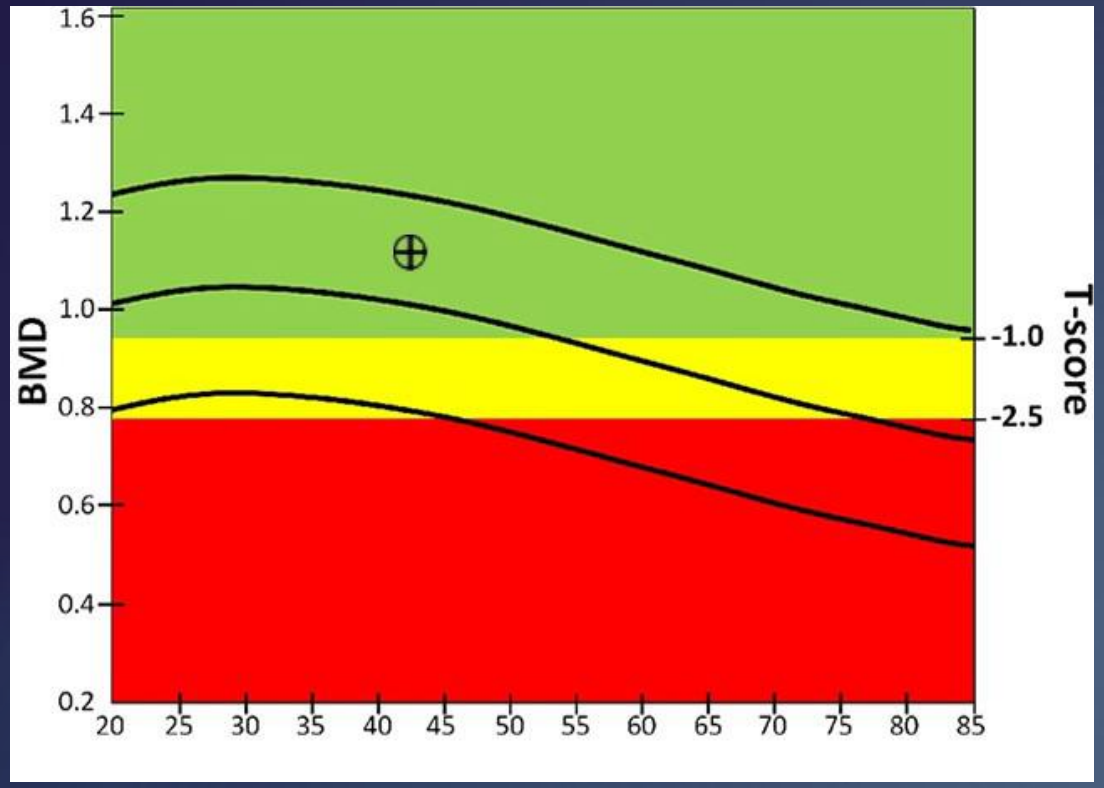
Simple example

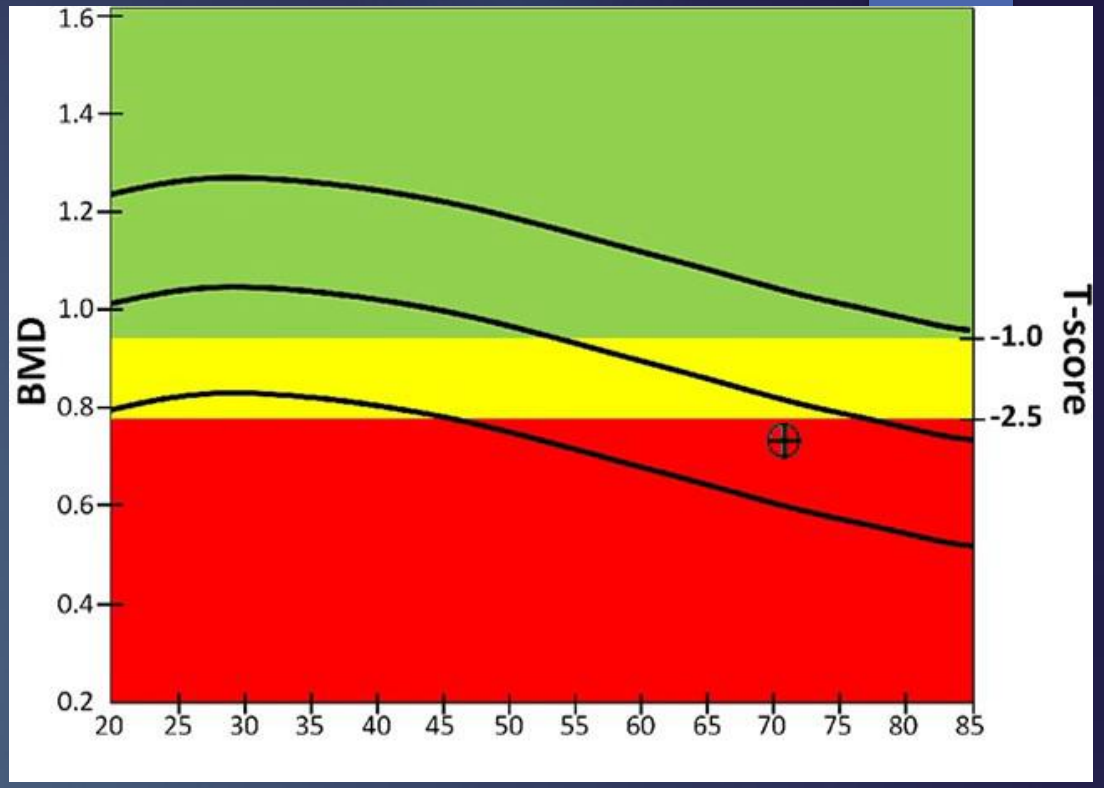


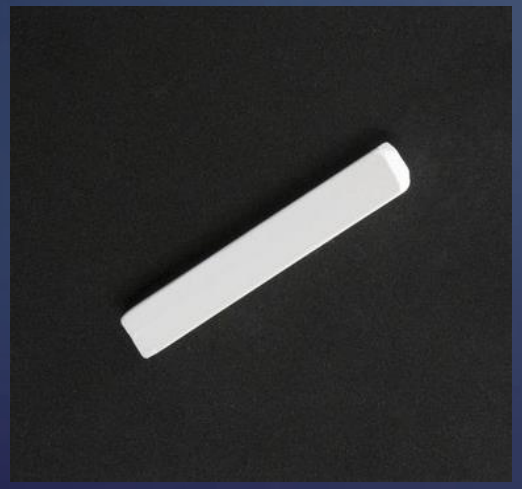


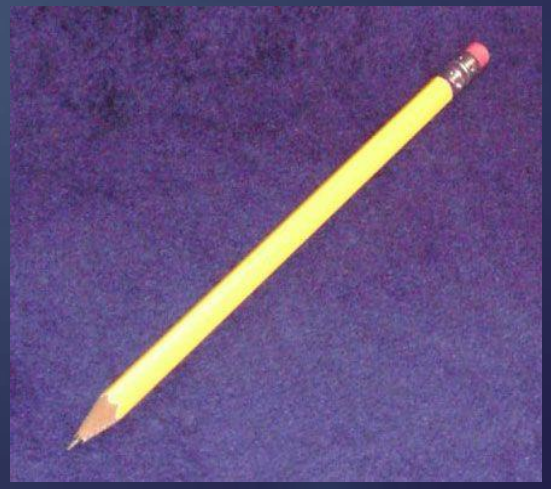
Documented densities:

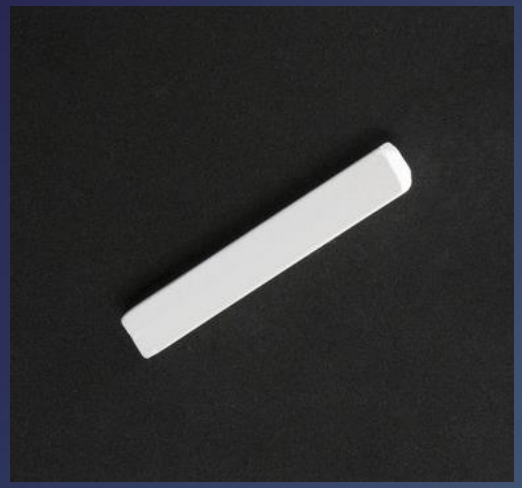
- Chalk – 2600 kg/m^3
- Pencil (wood) – 300-800 kg/m^3

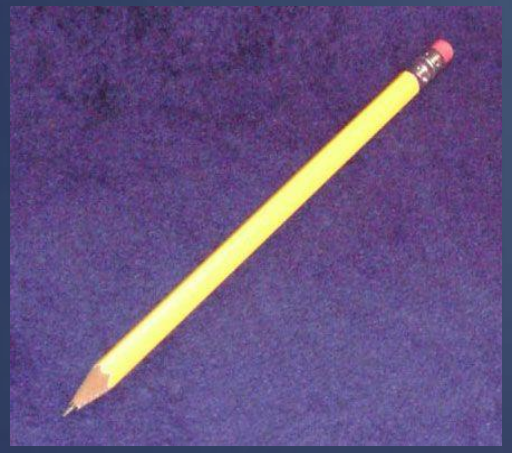

BMD
T-score
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-1.0
-2.5
20 25 30 35 40 45 50 55 60 65 70 75 80 85


BMD
T-score
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-1.0
-2.5
20 25 30 35 40 45 50 55 60 65 70 75 80 85









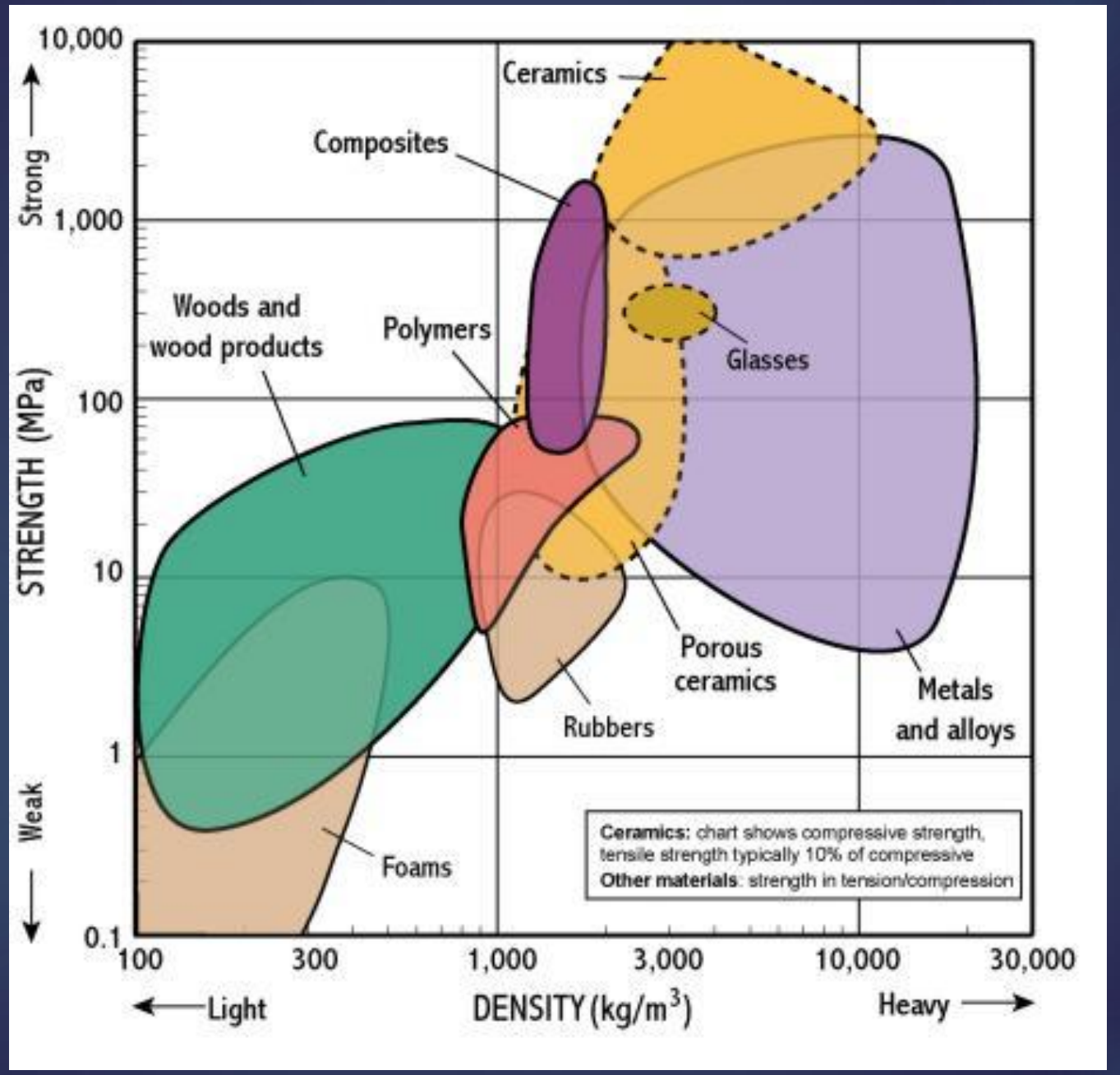
Therefore, measuring Density alone does NOT determine fracture risk !!!

There are other factors that will determine

if a structural material (bone) will fail (fracture)

If measuring density was the best way of determining whether a structural material would fail, then why aren’t we building houses out of chalk?

Would you buy and/or live in a chalk house?

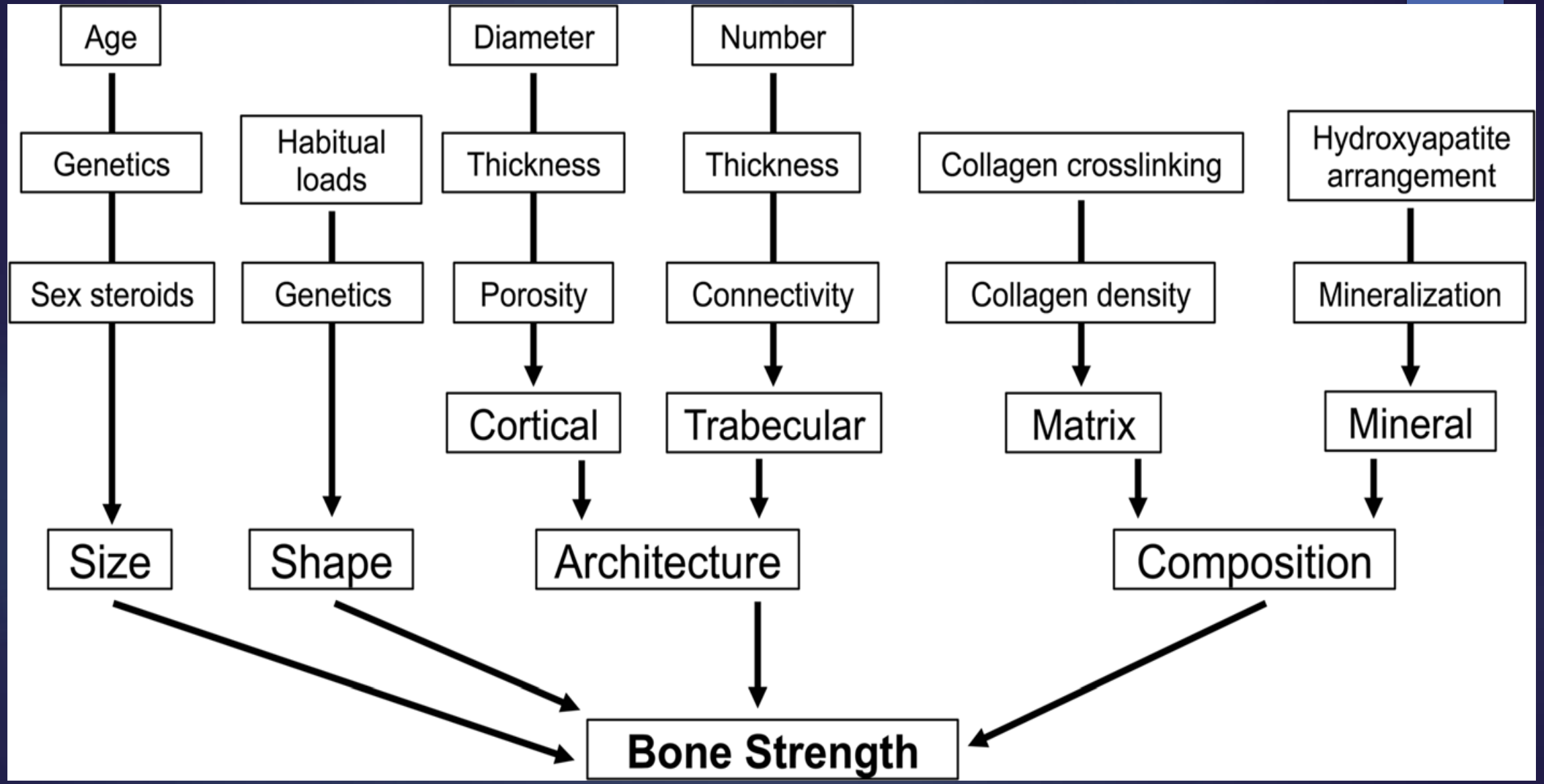

10,000
1,000
100
10
1
0.1
Strong
Weak
STRENGTH (MPa)
Ceramics
Composites
Woods and
wood products
Polymers
Glasses
Porous
ceramics
Rubbers
Metals
and alloys
Foams
Ceramics: chart shows compressive strength,
tensile strength typically 10% of compressive
Other materials: strength in tension/compression
100
300
1,000
3,000
10,000
30,000
Light
DENSITY (kg/m3)
Heavy

Physics and engineering principles still apply in a doctor’s office

It is not a “physics-free zone”

Strength is the mechanical property of a material that needs to be measured to determine whether or not the material fails when a force is applied

The most recent research trends are evolving towards the assessment of the actual bone strength independent of BMD


Age
Genetics
Sex steroids
Size
Habitual loads
Genetics
Shape
Diameter
Thickness
Porosity
Cortical
Number
Thickness
Connectivity
Trabecular
Architecture
Collagen crosslinking
Collagen density
Matrix
Hydroxyapatite arrangement
Mineralization
Mineral
Composition
Bone Strength

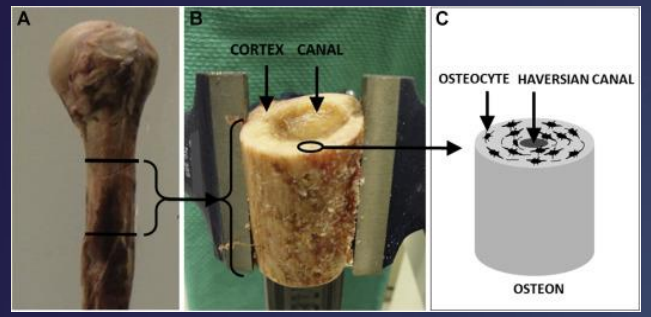
The Bone Strength diagram shows the importance of multiple micro-structural properties that determine the strength of the bone

Bone strength can be determined by measuring:

the micro-structural properties of bone

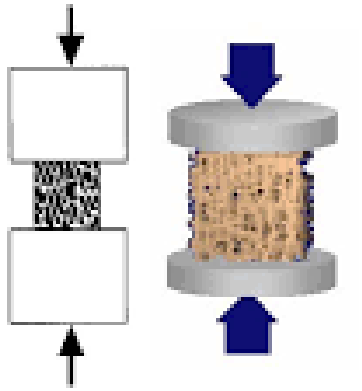
How can that be done?

Mechanical testing



How to test bone? – Compression testing

Compression Testing



Advantages:

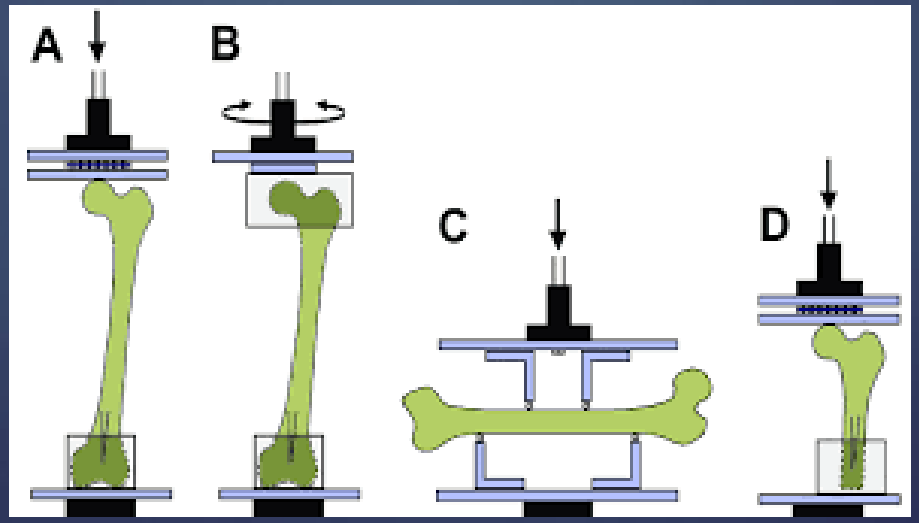
- Easy calculations
- Uniaxial

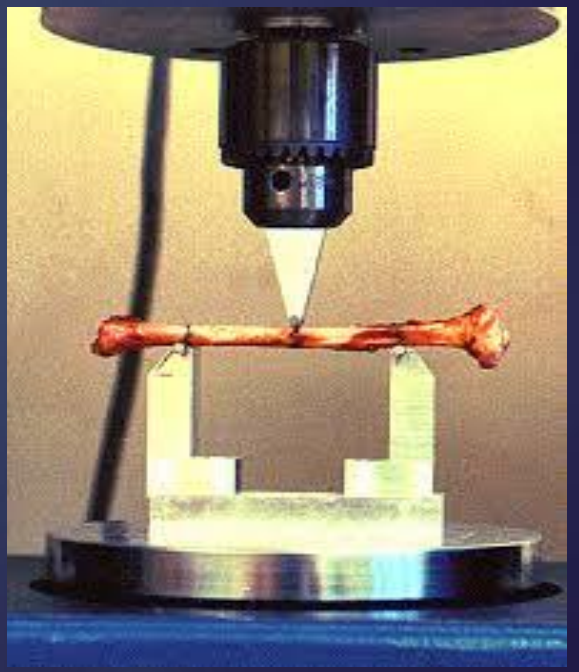
Disadvantages:

- Careful specimen preparation
- Principal material axes?
- End conditions?
- Spatially changing properties
- Specimen size requirements

Calculated parameters:

Apparent compressive strength,
Apparent modulus of elasticity



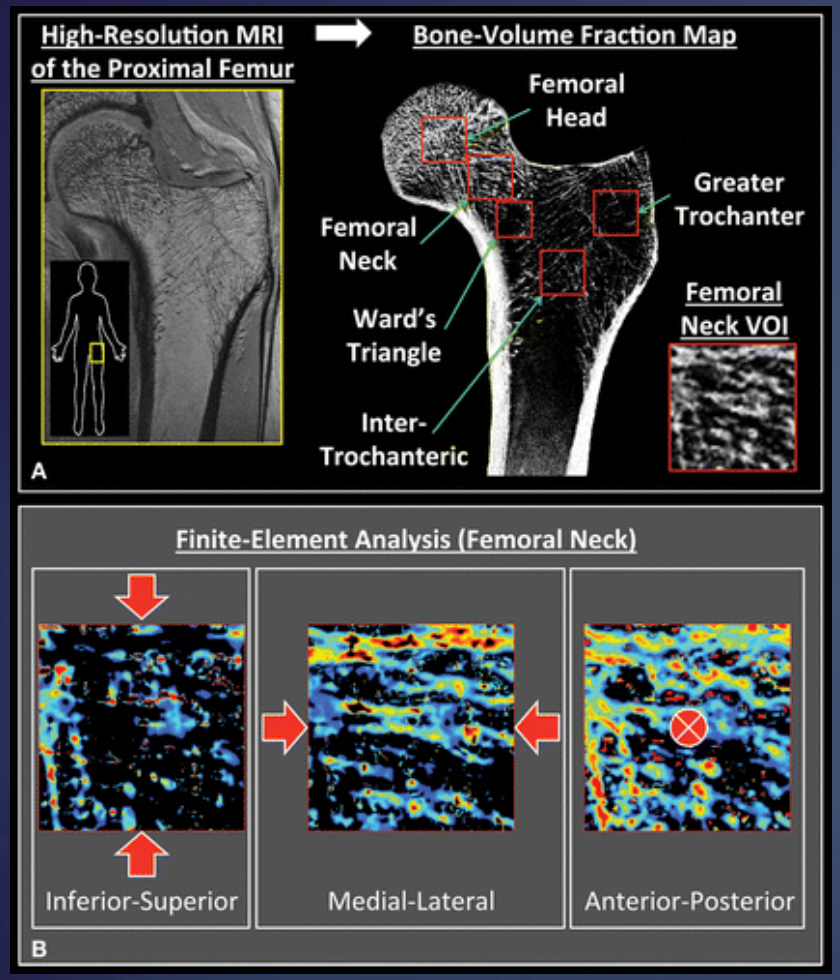


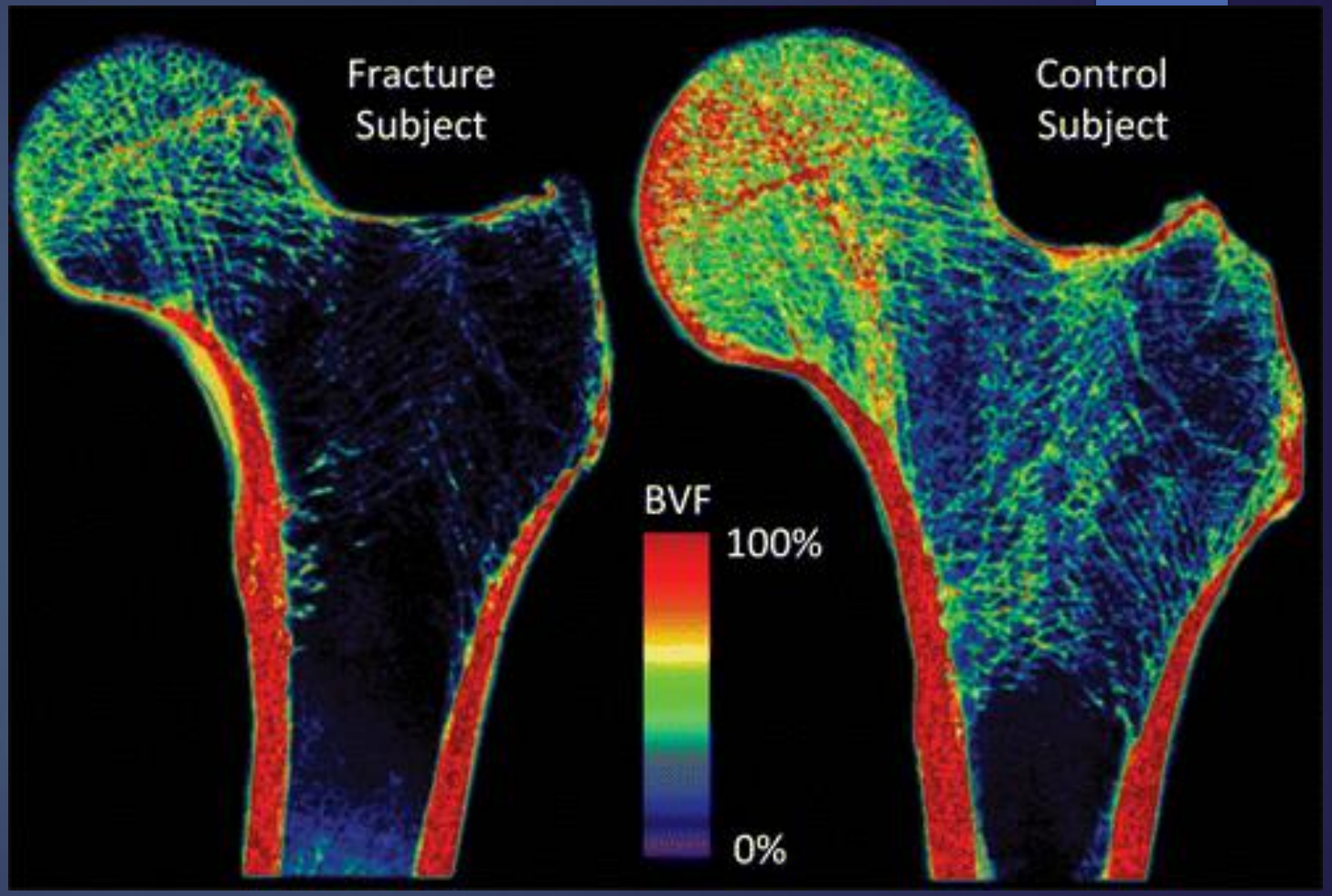
So how can we measure the strength of a bone without yanking it out of your body?

Finite Element Analysis

Finite Element Analysis

based on CT (or MRI) obtained data


High-Resolution MRI of the Proximal Femur
Bone-Volume Fraction Map
Femoral Head
Greater Trochanter
Femoral Neck
Ward's Triangle
Inter-Trochanteric
Femoral Neck VOI
A
Finite-Element Analysis (Femoral Neck)
Inferior-Superior
Medial-Lateral
Anterior-Posterior
B


Fracture Subject
Control Subject
BVF
100%
0%

However, it is still investigational

CT - high radiation doses

High cost

Limited availability

- Not a good method for generalized screening

Ultrasound

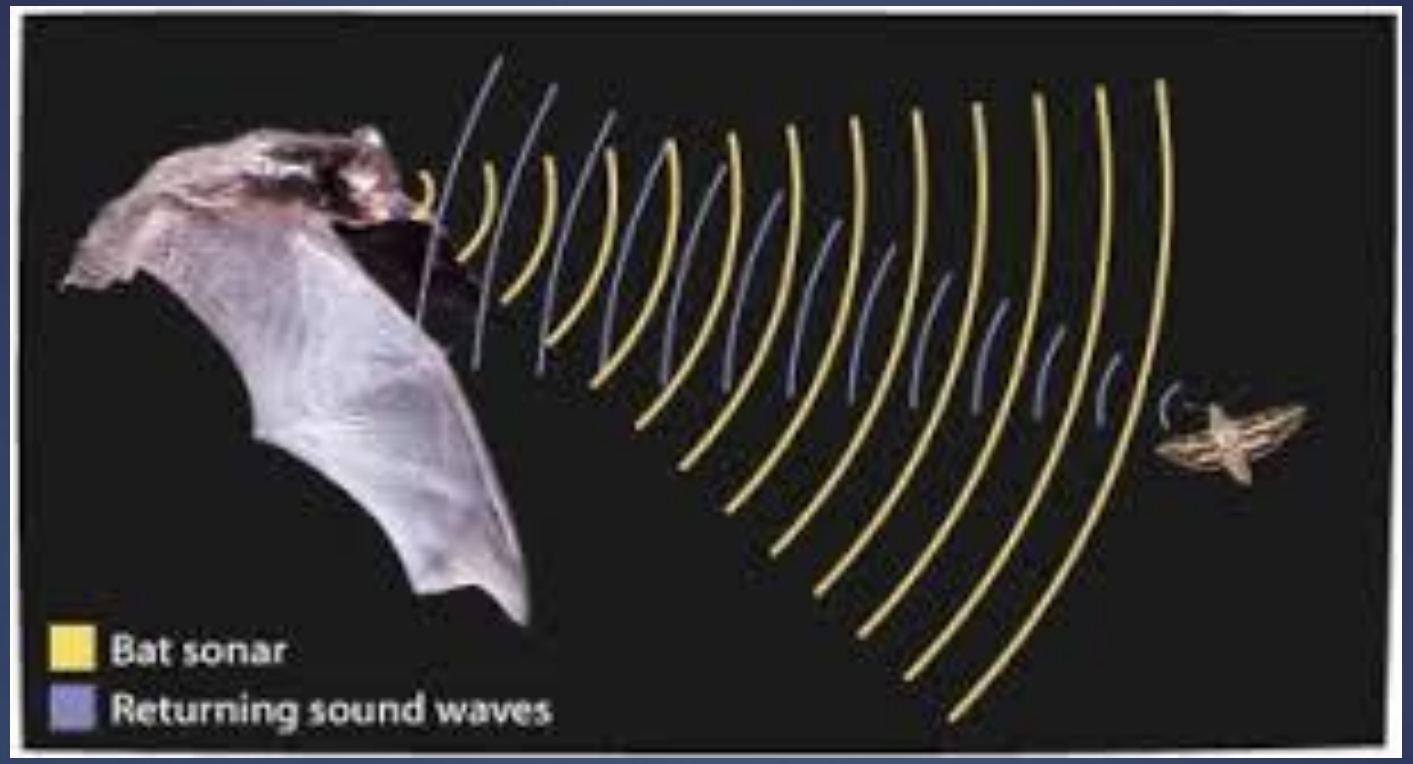
Fortunately, ultrasound has the capacity to perform an assessment on structural materials including bone !!!!

How ?

Sound waves have the ability to “carry” information

There are many examples where sound is used to “see things”

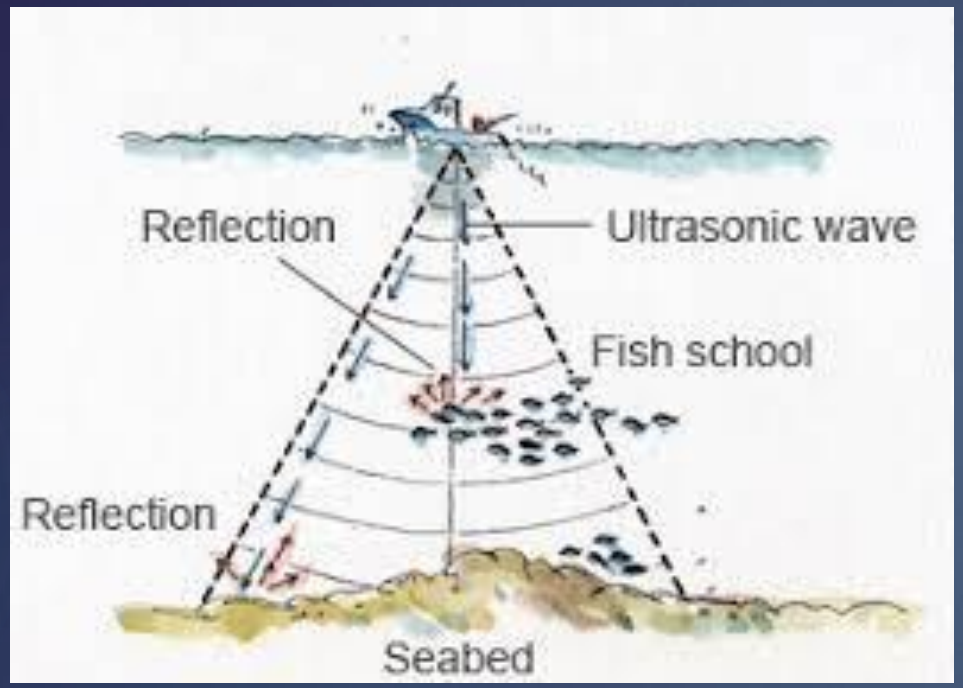
That’s exactly what a bat does -

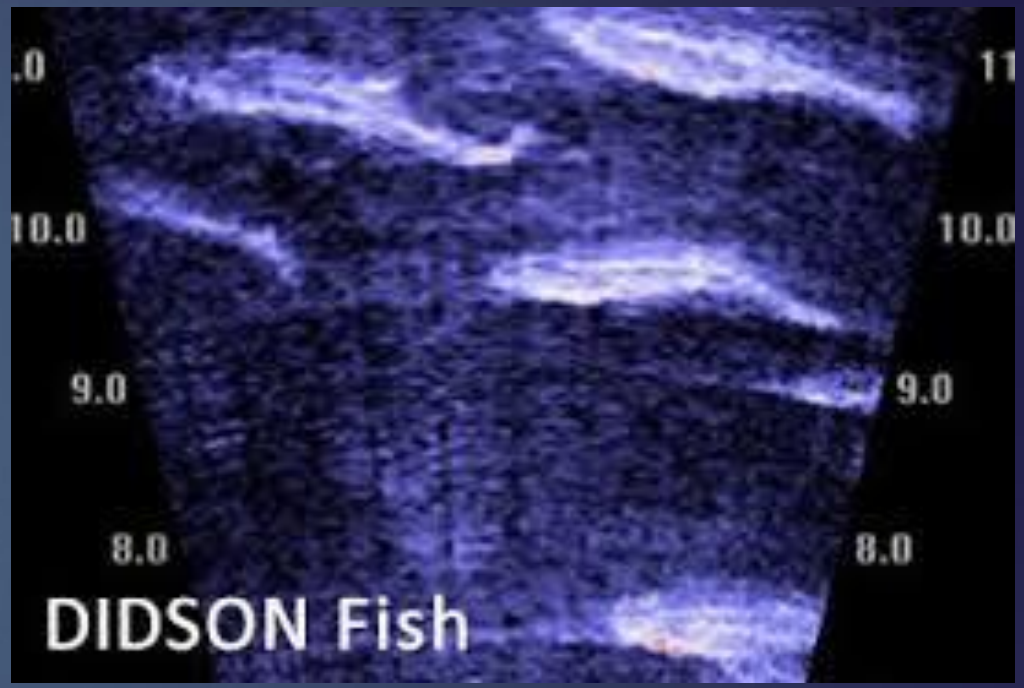

Bat sonar
Returning sound waves

and a submarine

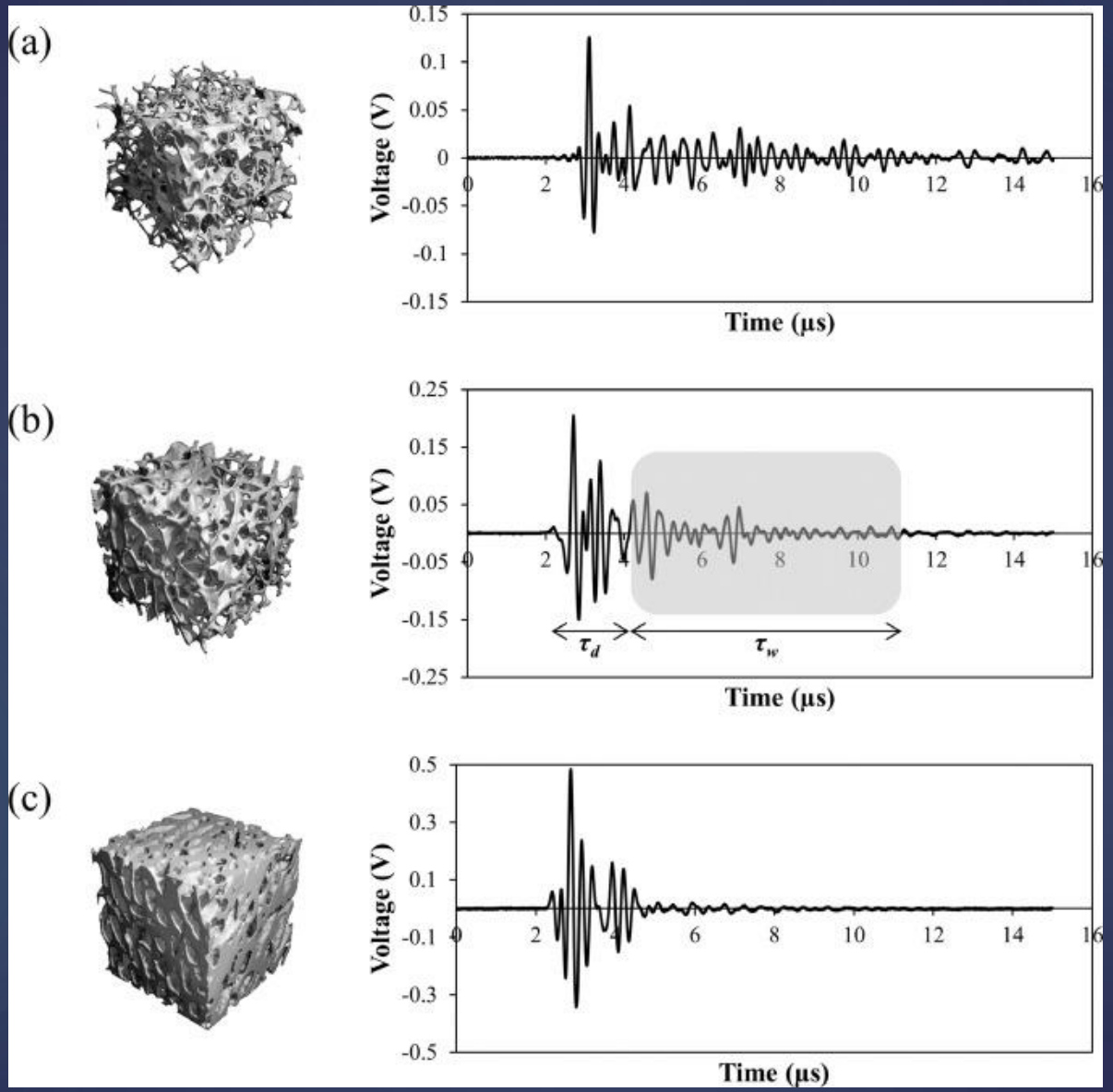

SONAR
SOUND NAVIGATION RANGING
shutterstock.com · 2158104583

and a fisherman


Reflection
Ultrasonic wave
Fish school
Reflection
Seabed


.0
11
10.0
10.0
9.0
9.0
8.0
8.0
DIDSON Fish

Numerous studies looked at how bone is affected by sound waves


(a)
(b)
(c)
Voltage (V)
Time (μs)
τ_d
τ_w

These studies demonstrated that bone would uniquely modify a sound wave that interacted with the bone.

In other words, the soundwaves coming back from bone (the echo) were modified by that bone.

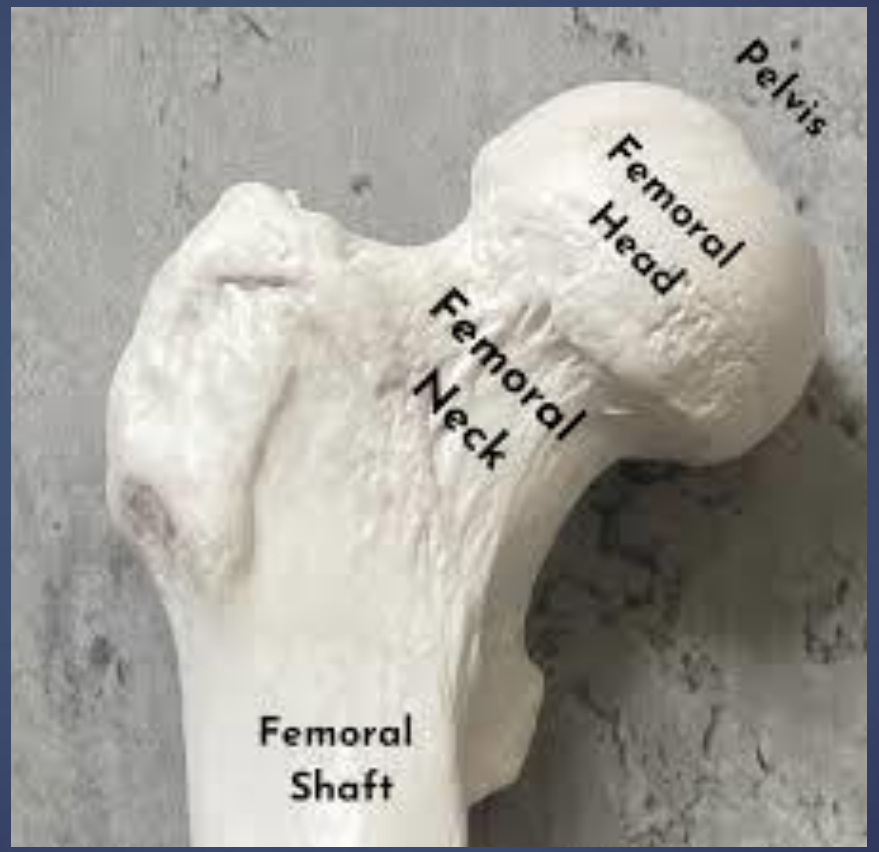
The structure of the bone modified the original soundwave

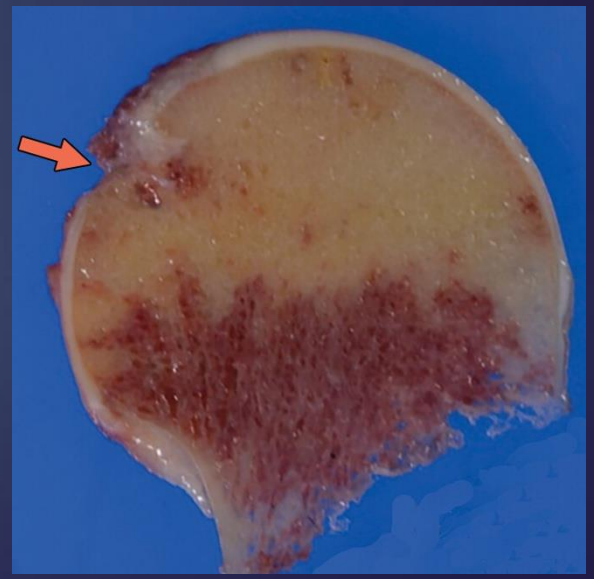
Analysis of the echoes can determine the structural properties of the bone

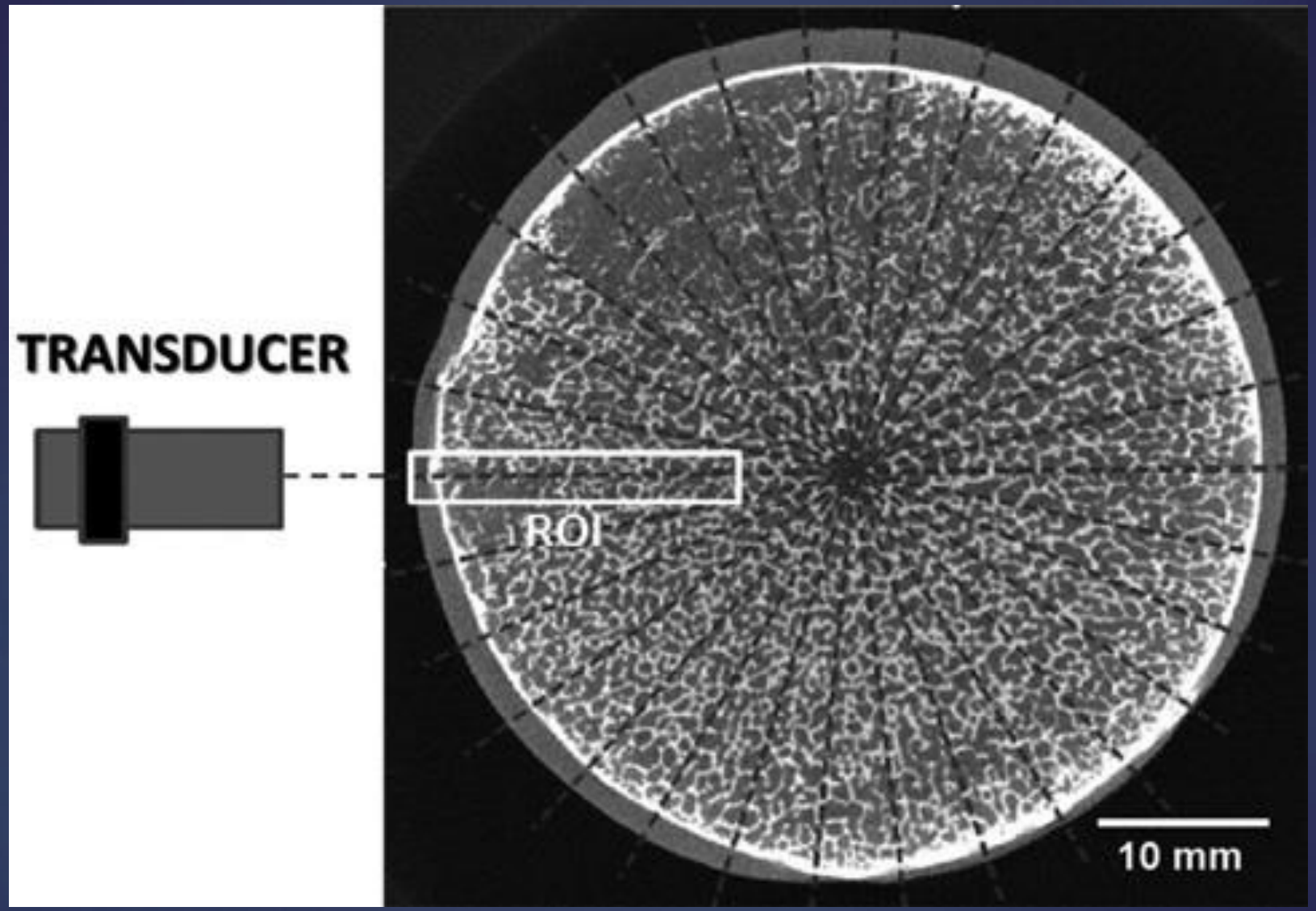
There are multiple experiments that confirmed that information on the structural properties was carried in the echo

An intriguing experiment was performed about ten years ago

A femoral head from a patient undergoing a THA was analyzed

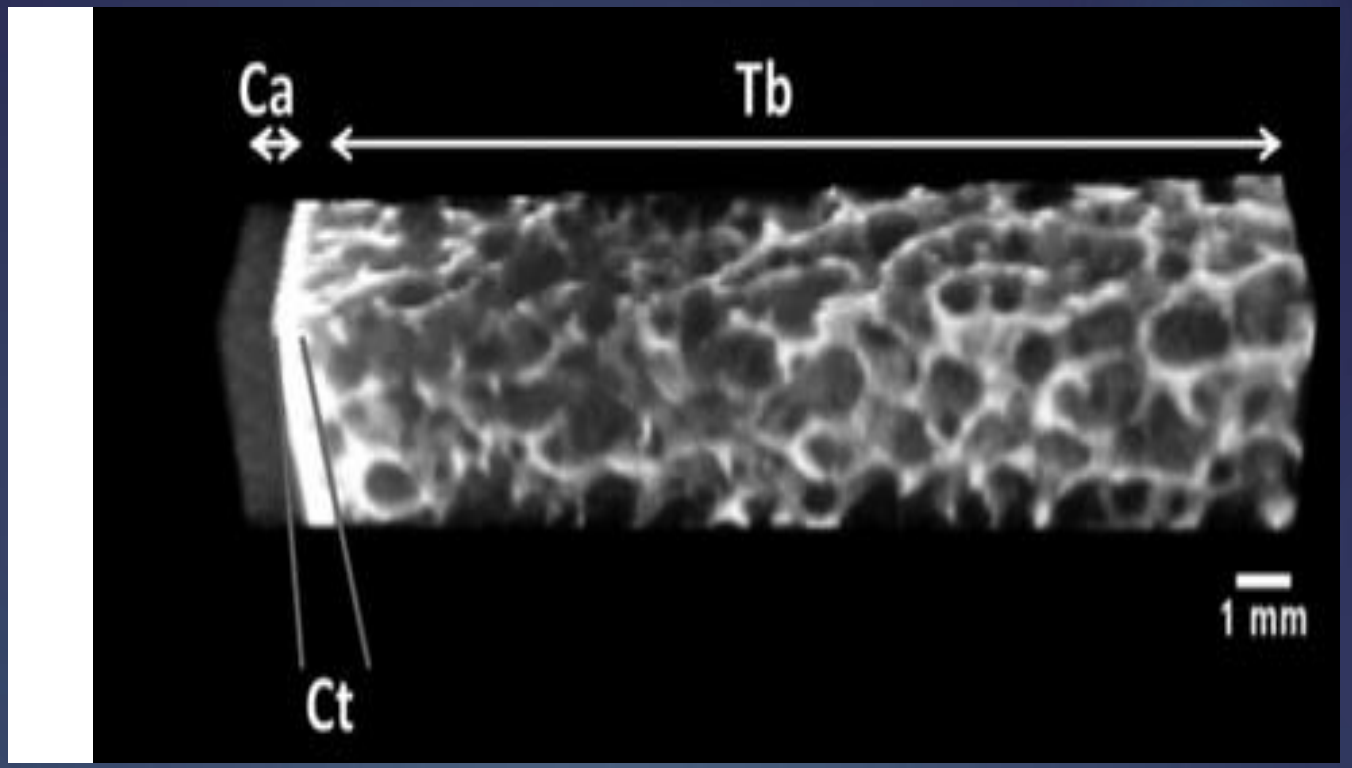

Pelvis
Femoral Head
Femoral Neck
Femoral Shaft

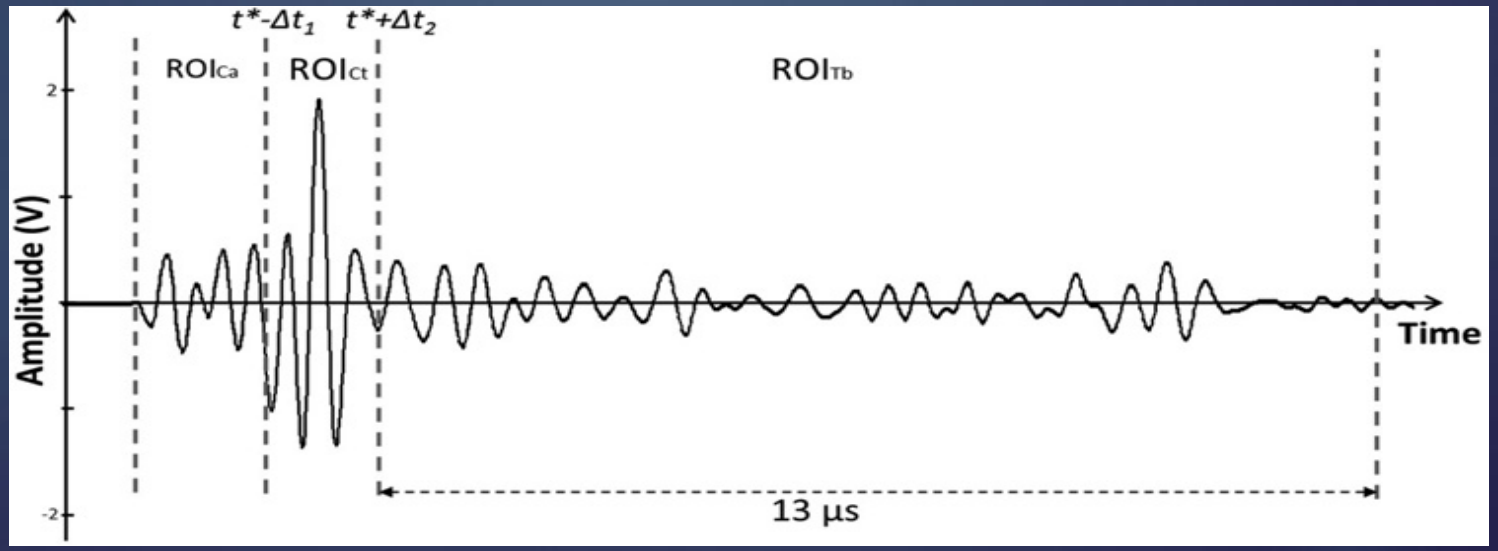



TRANSDUCER
ROI
10 mm

Micro-CT analysis of bone is capable of determining microstructural properties reported as the –

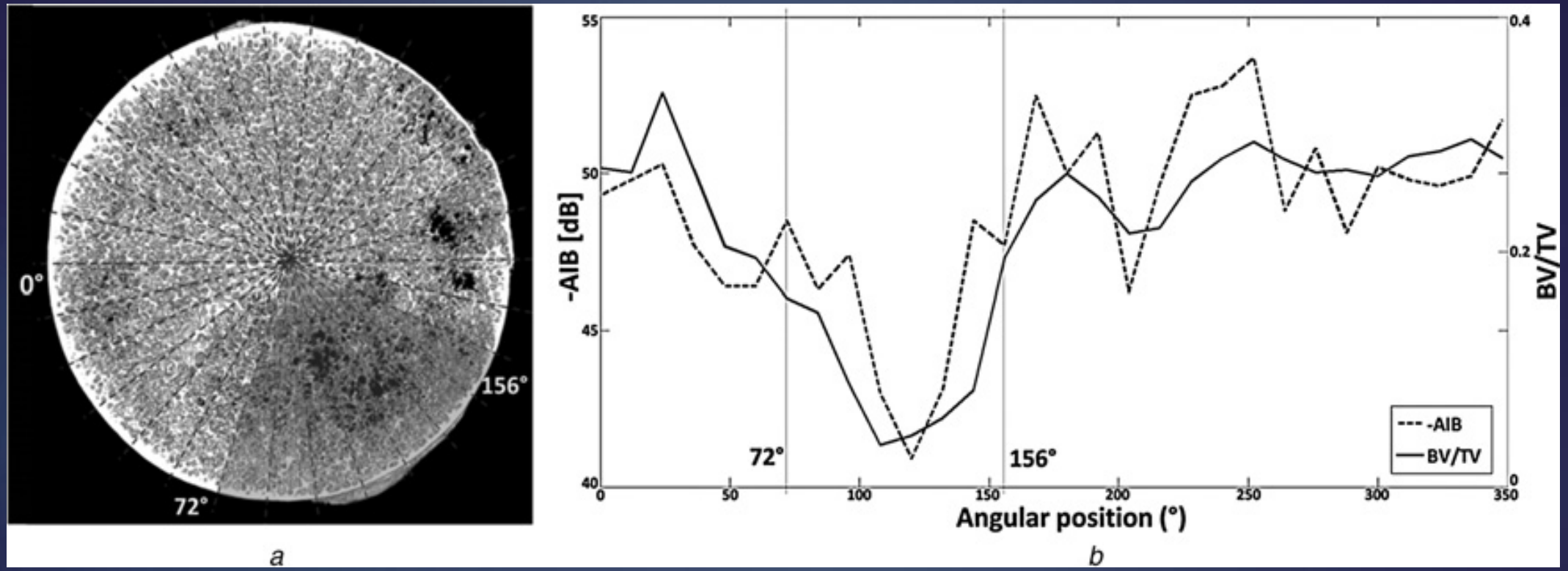
Bone Volume to Total Volume ratio (BV/TV)


Ca
Tb
1 mm
Ct


t*-Δt1
t*+Δt2
ROICa
ROICt
ROITb
2
-2
Amplitude (V)
Time
13 µs

The Apparent Integrated Backscatter (AIB)

- The AIB is a radio frequency wave (RF) isolated from the trabecular backscatter (echo)
- The AIB was processed and analyzed and it correlated with the trabecular region properties as quantified by micro-CT parameters


0°
72°
156°
55
50
45
40
0
50
100
150
200
250
300
350
0.4
0.2
0
-AIB [dB]
BV/TV
72°
156°
-AIB
BV/TV
Angular position (°)
a
b

Ultrasound has the capacity to determine structural properties of bone equivalent to CT scanning

Ultrasound can determine bone structure and

Bone Strength !!!!

REMS

What the heck is REMS?

Radiofrequency Echographic Multi Spectrometry

??????????

REMS is an ultrasound technology

that can measure the microstructural properties of bone

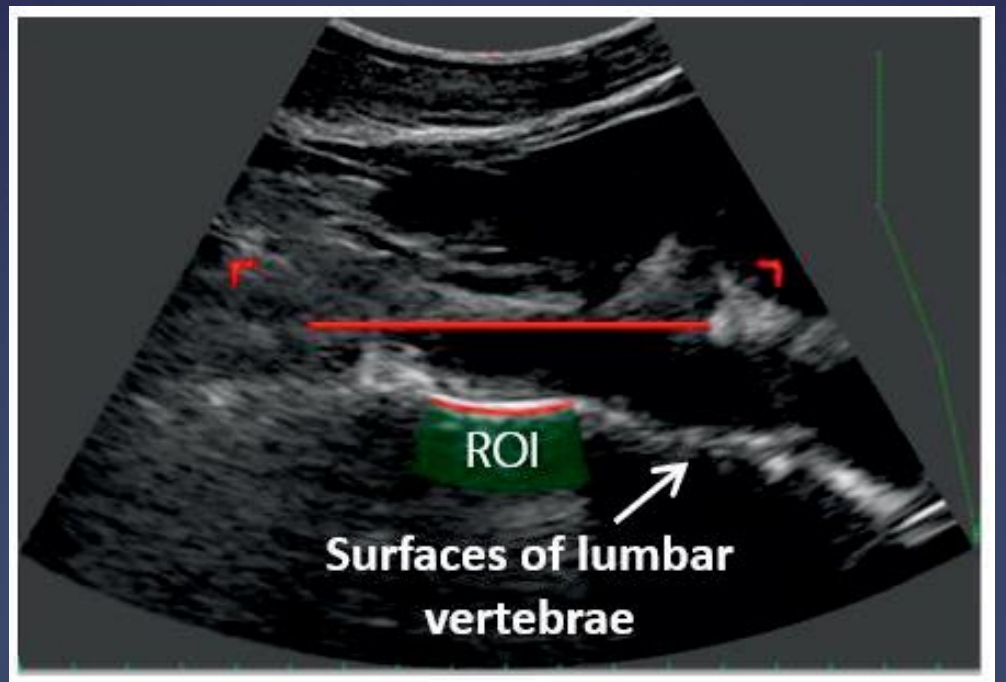
to determine the Bone Strength and report it as the –

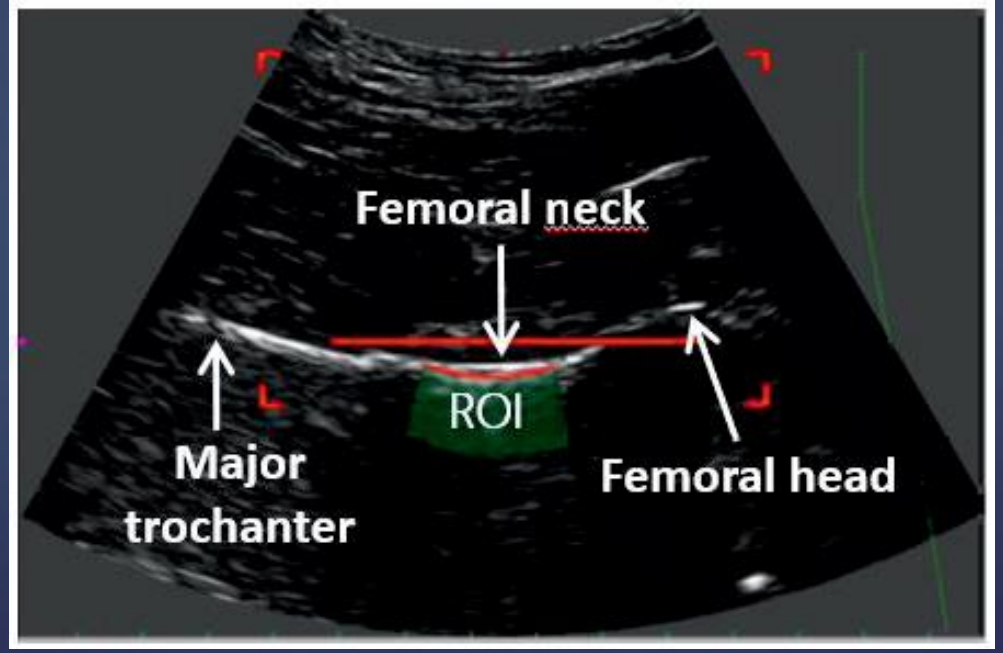
Fragility Score

What happens during a REMS scan?

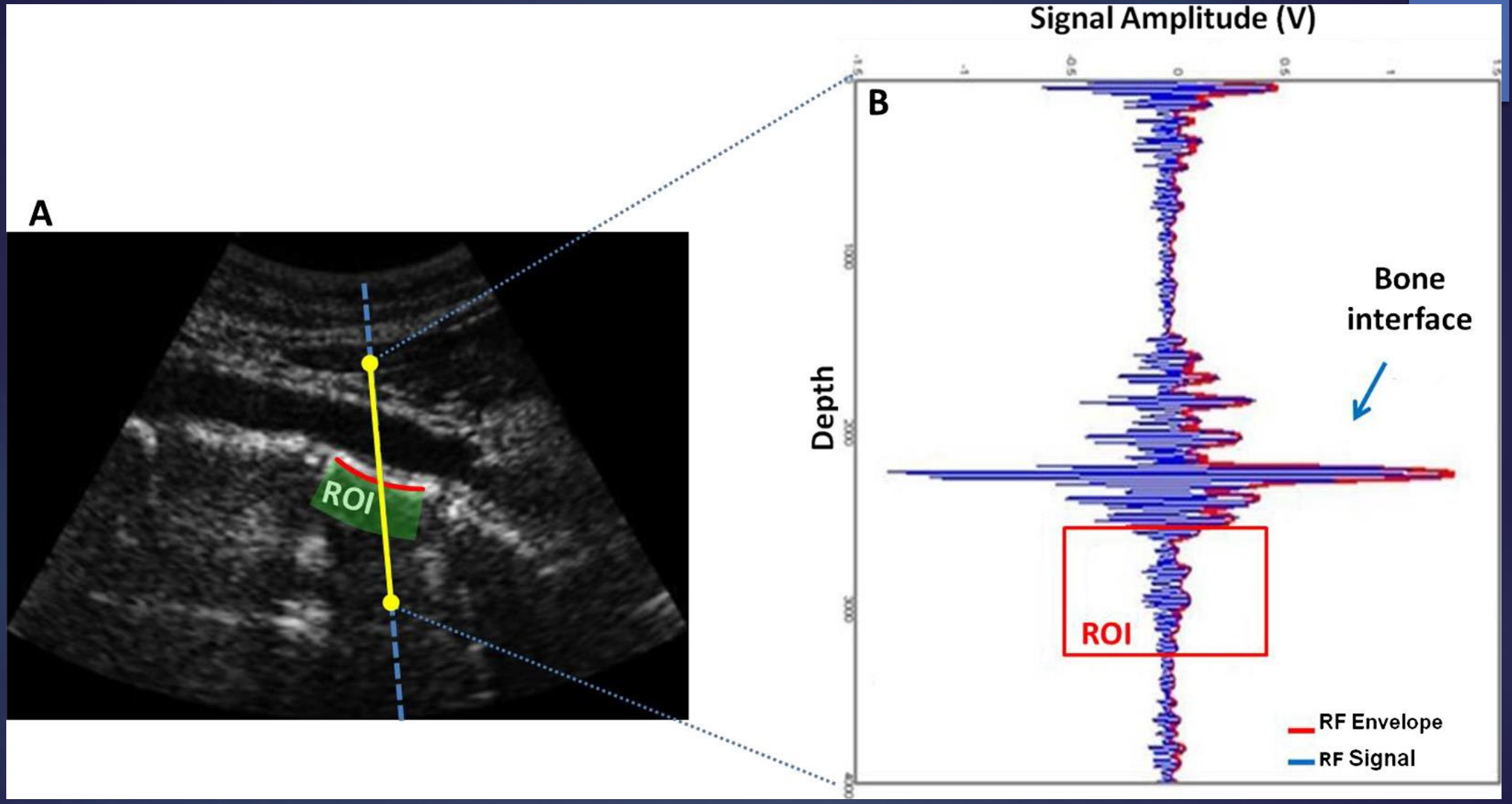
REMS generates a 3.5MHz pulse that penetrates the soft tissue and bone at the designated axial Region of Interest (ROI)

- A sequence of filtering and mathematical processing of the sound envelope yields the B-mode images used for correct ROI selection
- REMS will also collect and analyze the raw (unfiltered) backscatter radio frequency waves (RF)

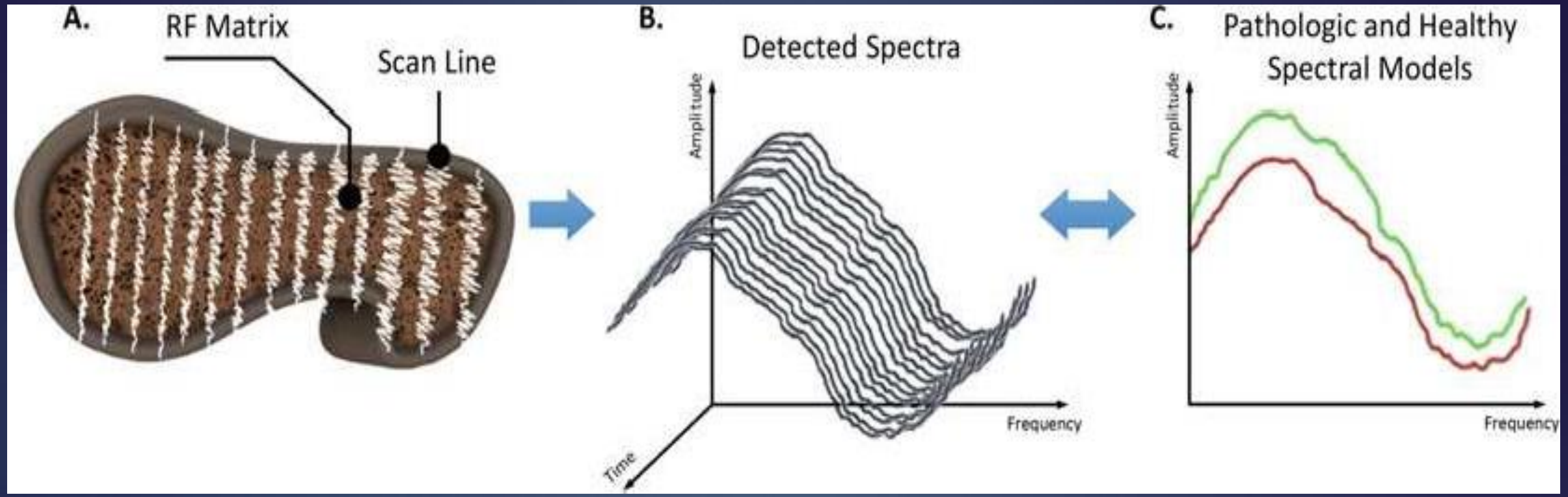

ROI
Surfaces of lumbar vertebrae


Femoral neck
ROI
Major trochanter
Femoral head

During a REMS scan of the femoral neck or lumbar vertebrae, the raw unfiltered backscatter ultrasound signals from the target bone are automatically identified and analyzed


A
ROI
B
Signal Amplitude (V)
Depth
Bone interface
ROI
RF Envelope
RF Signal

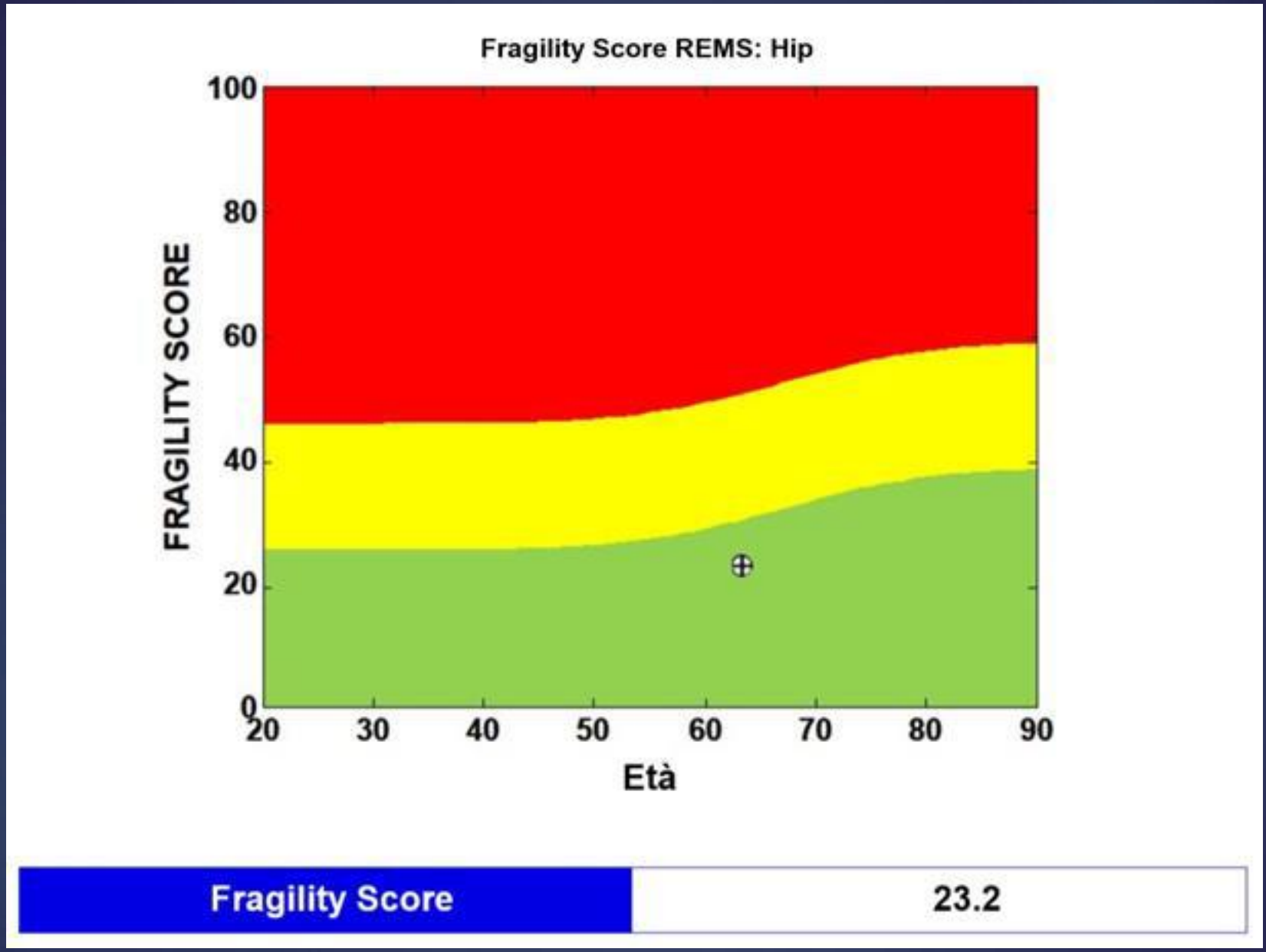
FS value is obtained by comparing the patient-specific spectral profiles with population-based models of “fragile” (individuals with a fragility fx) and “non-fragile” (individuals with no history of fragility fx)


A.
RF Matrix
Scan Line
B.
Detected Spectra
Amplitude
Frequency
Time
C.
Pathologic and Healthy
Spectral Models
Amplitude
Frequency

Fragility Score represents the number of sections of bone that have been determined to be more similar to bone in someone who has sustained a fragility fracture

- It is the proportion of normal to degraded bone that determines the strength of bone

Fracture risk assessment is determined in a qualitative manner with this graph


Fragility Score REMS: Hip
FRAGILITY SCORE
100
80
60
40
20
0
20
30
40
50
60
70
80
90
Età
Fragility Score
23.2

The graph is binary – it consists of two colors – red and green. Yellow is an add-on

Red represents the fragility score of the individuals who have sustained a fragility fracture

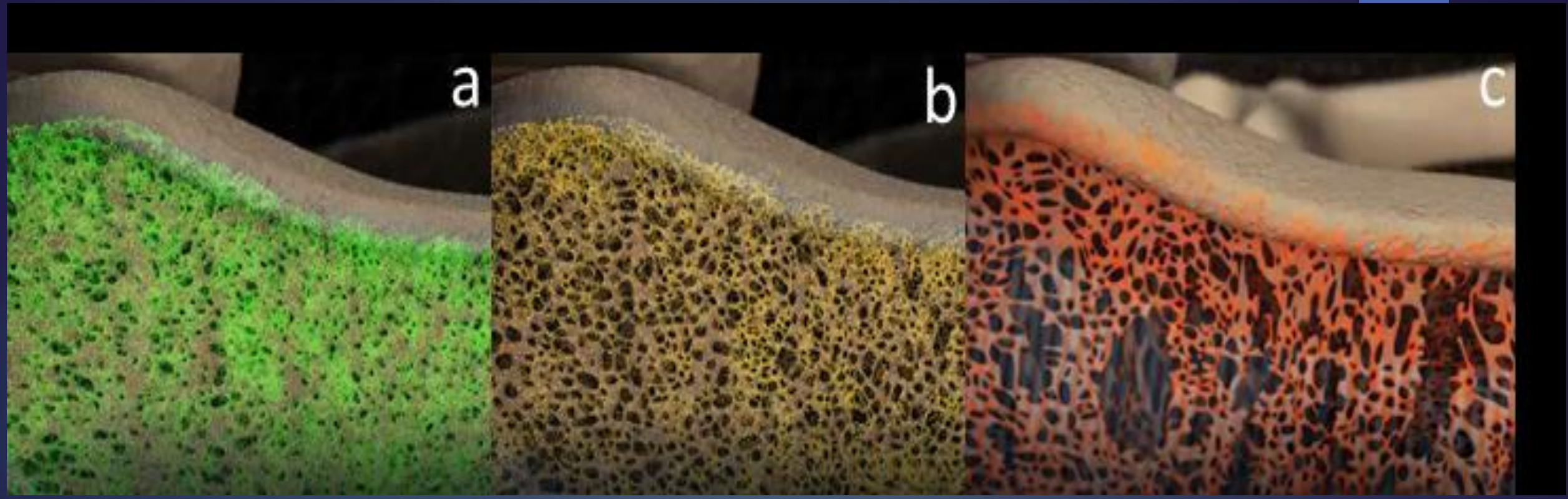
Green represents the fragility score of the individuals who have not sustained a fragility fracture

Therefore……

Green represents individuals with strong bone and LOW fracture risk

Red represents individuals with weak bone and a HIGH fracture risk

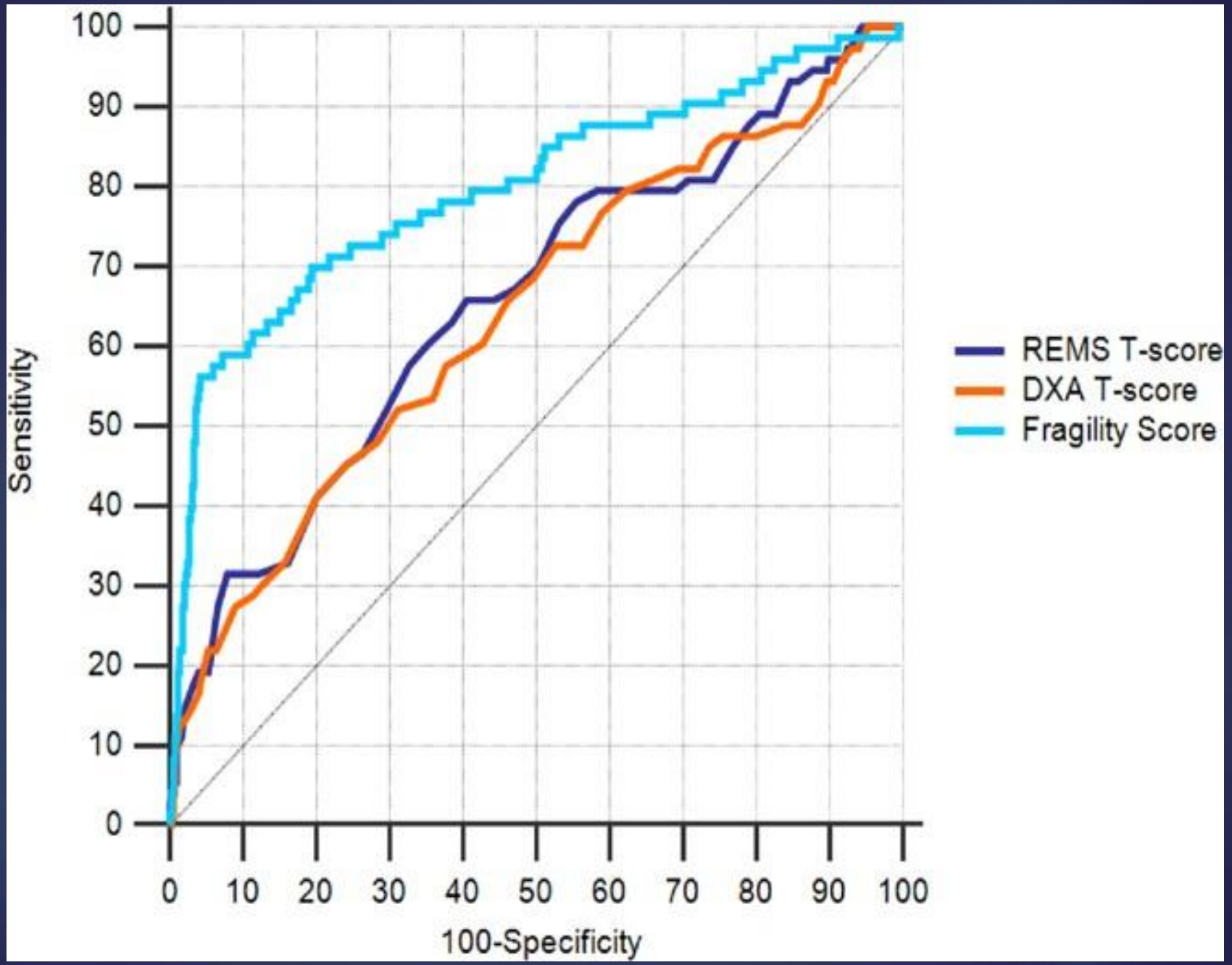
Yellow represents the transition zone from strong to weak bone



Bone internal microstructure:
a) normal - b) decreased - c) low

FS was compared with REMS and DXA determined BMD T-scores:

- FS was superior in the identification of patients at risk for incident fragility fractures compared to the BMD T-scores
- The Fragility Score can discriminate between patients with/without fragility fractures and the ROC area under the curve (AUC) was determined to be 0.80, a larger value than the AUC of the REMS-determined T-score (0.66) and of the DXA-determined T-score (0.64). This difference is statistically significant.


Sensitivity
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
100-Specificity
REMS T-score
DXA T-score
Fragility Score

Conclusion:

The Fragility Score was found to be an effective tool for the prediction of fracture risk in a population of Caucasian women, superior to the T-score values. Therefore, Fragility Score can be useful for the early identification and subsequent early treatment of bone fragility.

In my clinical practice, the Fragility Score is the cornerstone of my Bone Health consultations

Understanding fracture risk will help determine the appropriate treatment plan that may involve the use of medications

- A low Fragility Score indicates strong bone and a low fracture risk and therefore medication use is not likely to be indicated
- A high Fragility Score implies weak bone and a higher fracture risk and therefore medication use maybe indicated and should be discussed with the patient

* Medication is indicated to reduce fracture risk in patients determined to be at high fracture risk!

Provide good care:

- Look at the whole patient!
- One number should not determine the treatment regimen
- Do not blindly throw a prescription at a patient just because the FS is elevated (elevated fracture risk) - if the FS is high determine why the FS is elevated!
- Even if the FS is low indicating low fracture risk be sure to fully assess the patient's clinical risk factors (CRF)

Provide good medical care in a comprehensive care model !

Summary:

- Fragility score is a method of measuring the structure of bone to determine the bone strength
- Fragility score is the portion of bone that was determined to be degraded
- Fragility score predicts fracture risk using the fracture risk graph on page 2 of the REMS report
- Fragility score has a significantly higher ability to predict fracture risk compared to T-scores

Bone Health needs to be included in routine medical health care – *or…..*

…..Ignore your Bones &

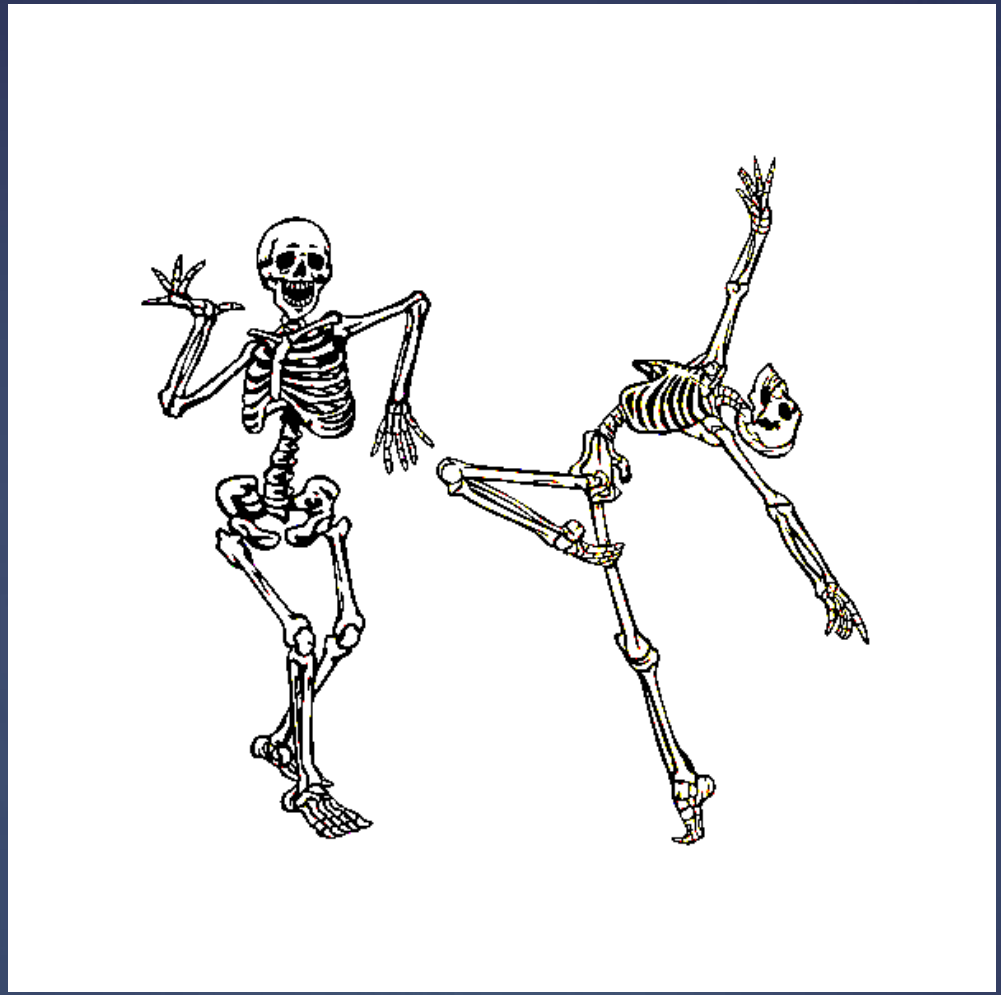
THEY WILL GO AWAY !!!!!

Now, if someone insists that you need medication just because you were diagnosed with “Osteoporosis” then you should reply -

Sticks and stones may break my bones –

but “Osteoporosis” does not reliably predict that !!!!

The Fragility Score does !!!!!!!!



Thank you for attending !!!!