Assessing the performance of clinical and pre-clinical ultrasound transducers using the Resolution Integral

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wellcome trust

British Heart Foundation
The heart research charity

Structure

- Assess the performance of clinical ultrasound transducers
- Assess the performance of clinical ultrasound transducers for pre-clinical imaging
- Assess the performance of commercially available pre-clinical transducers

Structure

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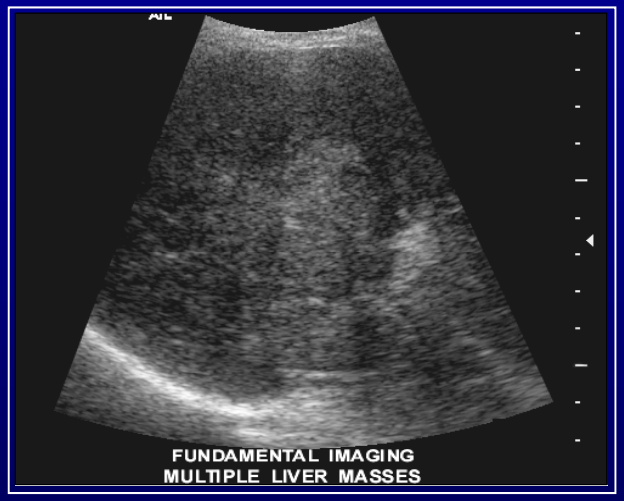
- Assess the performance of clinical ultrasound transducers for pre-clinical imaging
- Assess the performance of commercially available pre-clinical transducers

Image Quality

- History of the patient
- Sonographer experience
- Scanner performance

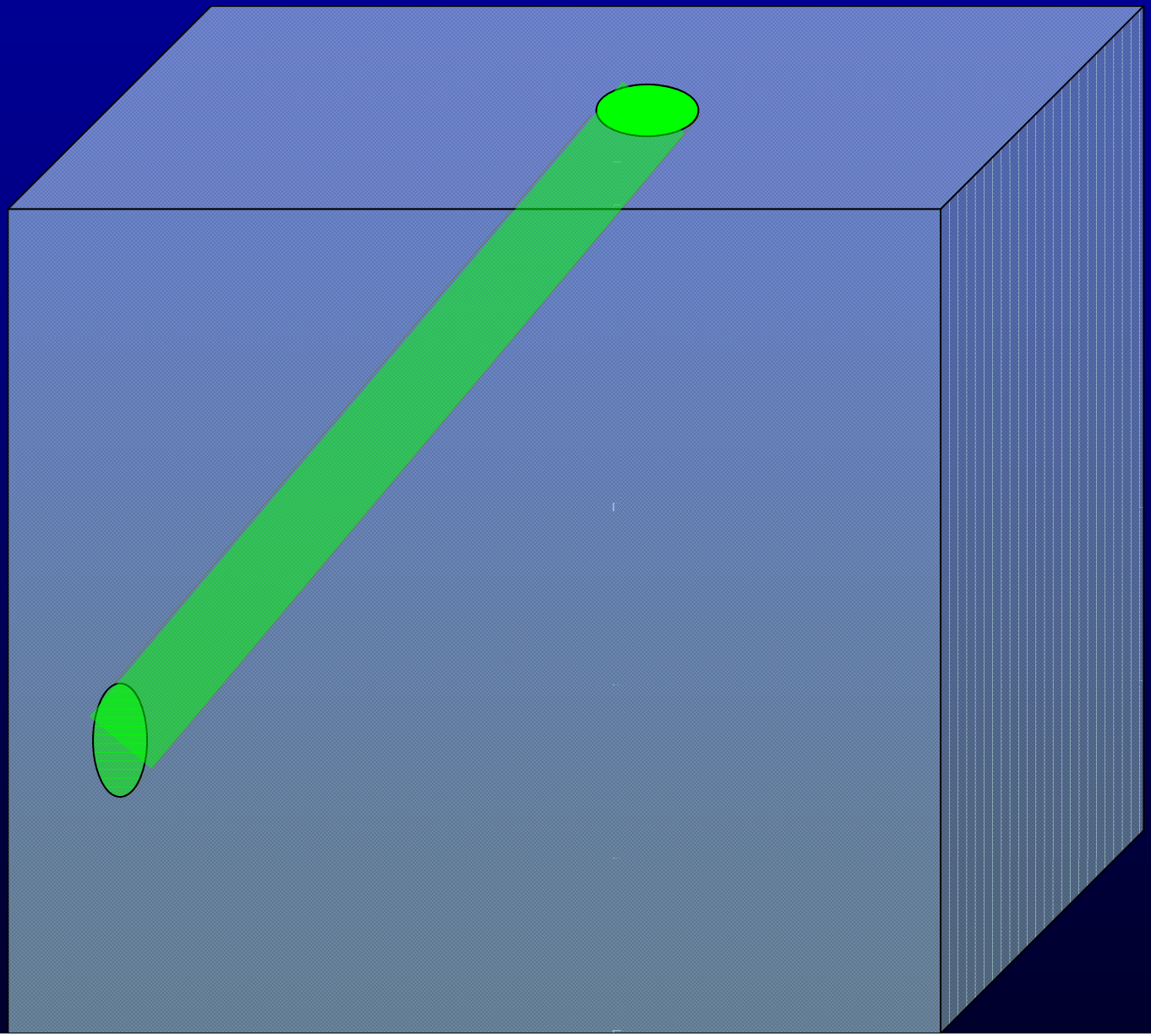


Quantitative Assessment of Scanners

Pipe diam (mm)

8.0
6.0
4.0
3.0
2.0
1.5
1.0
0.75
0.5 x2
0.4 x2

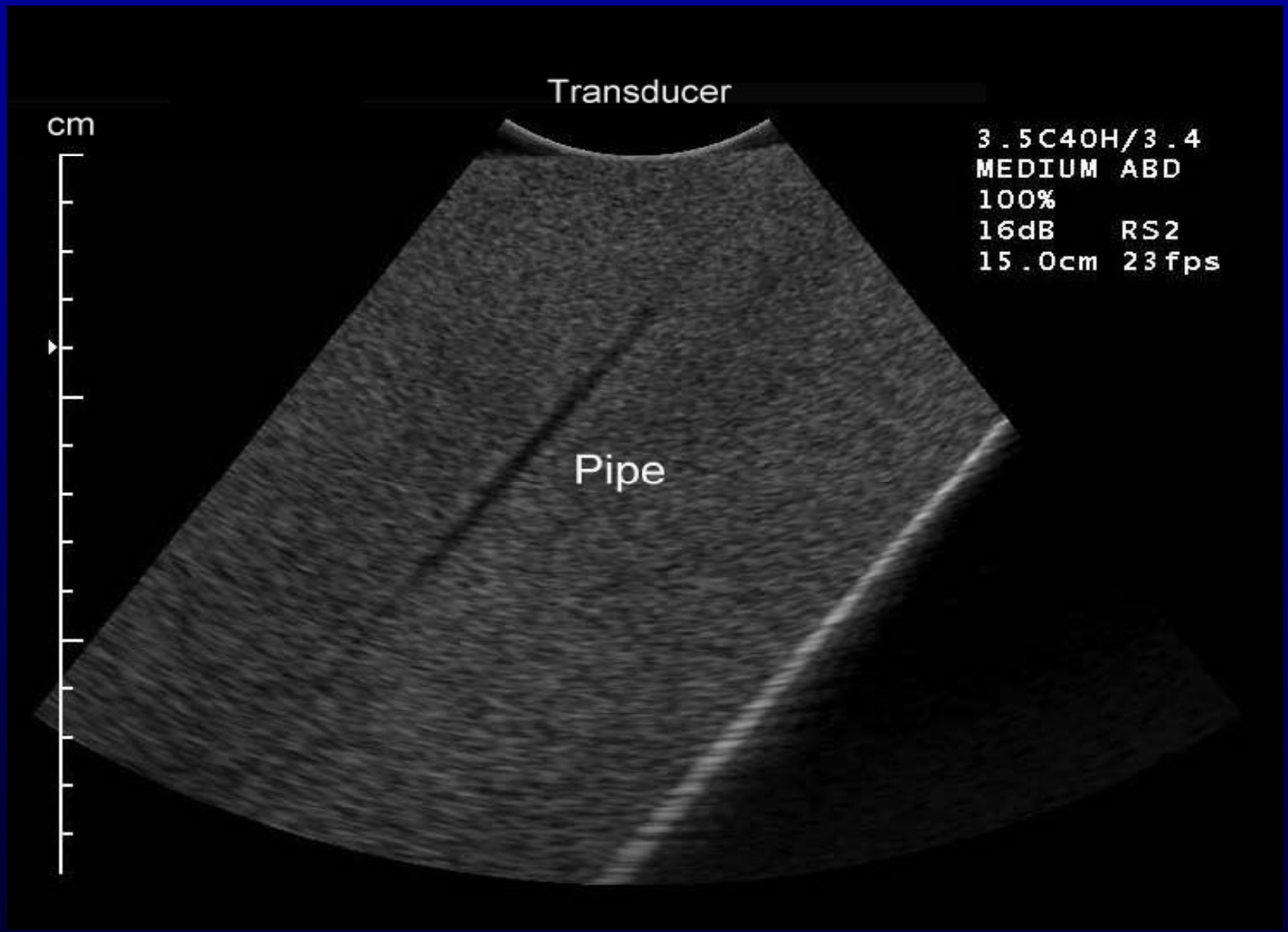
Quantitative Assessment of Scanners

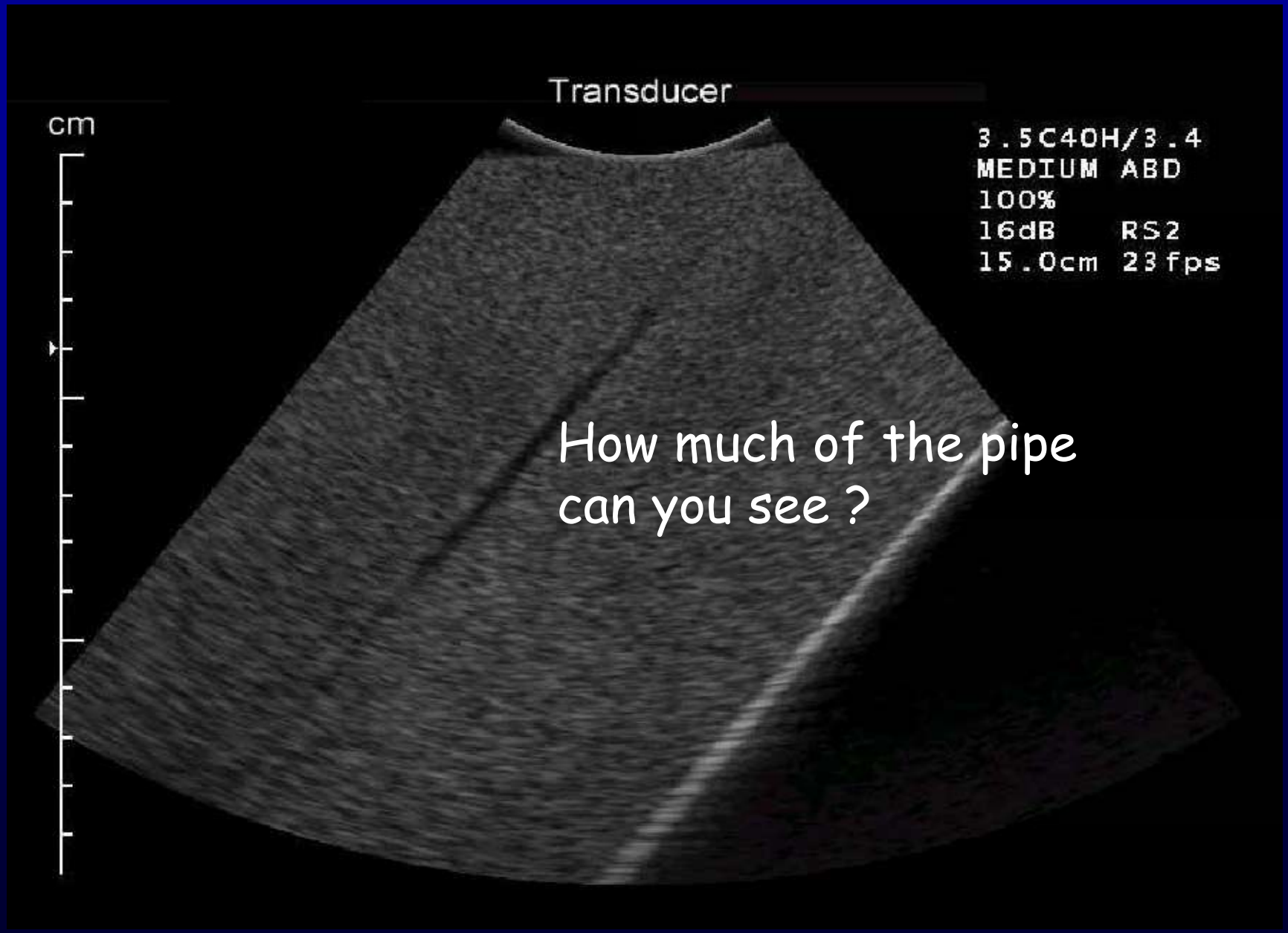


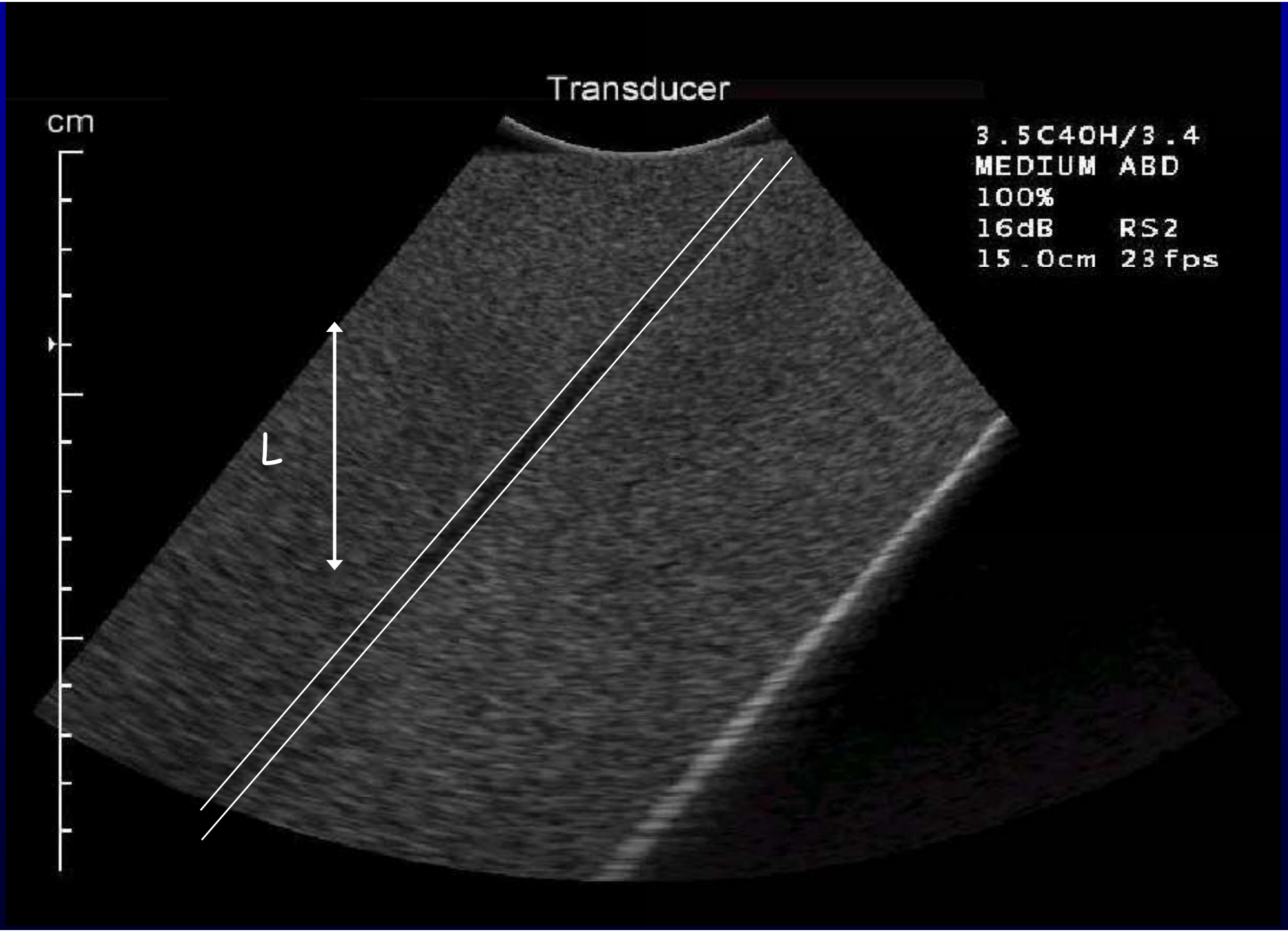
Quantitative Assessment of Scanners

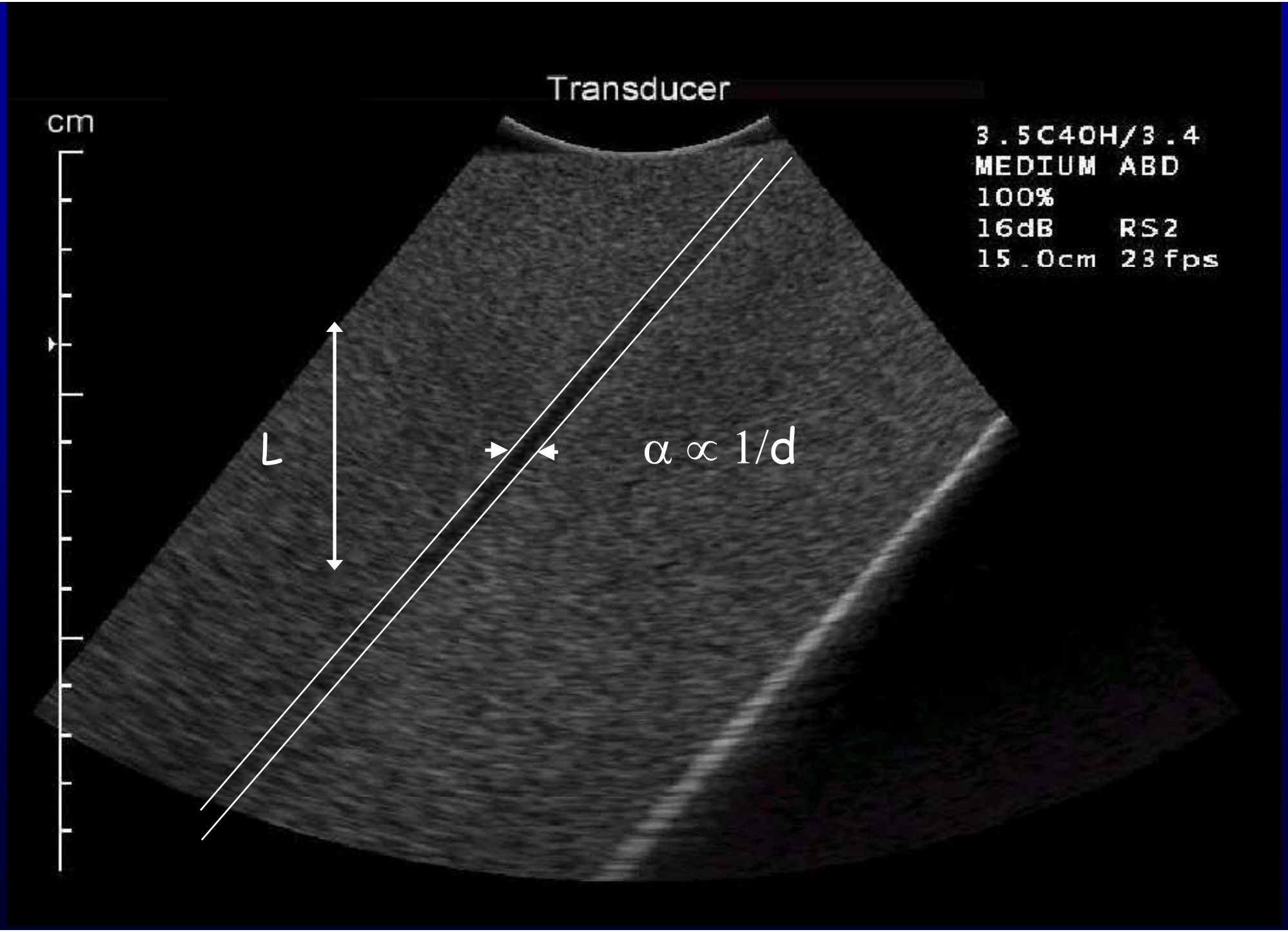
Edinburgh Pipe Phantom

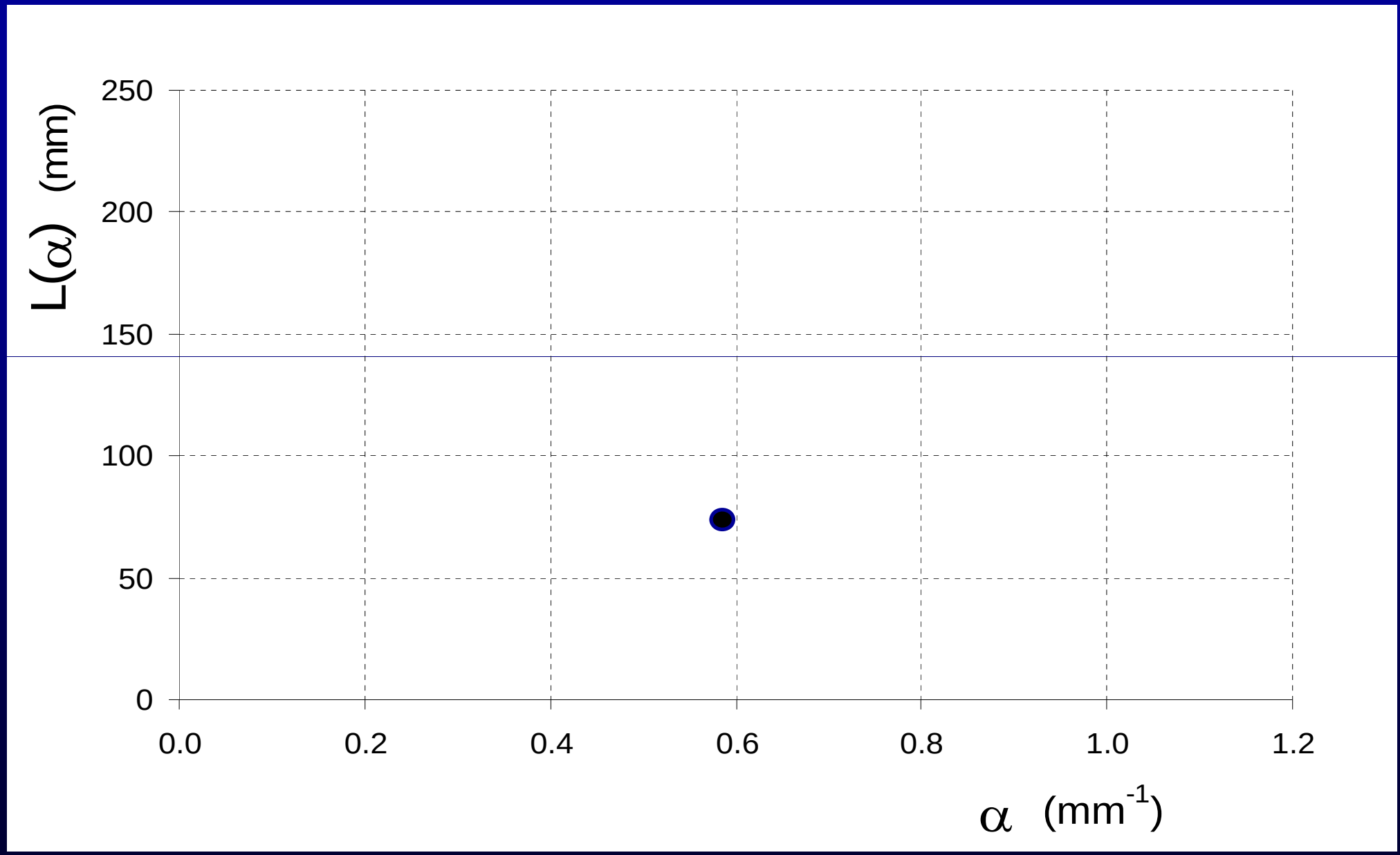
Quantitative Assessment of Scanners

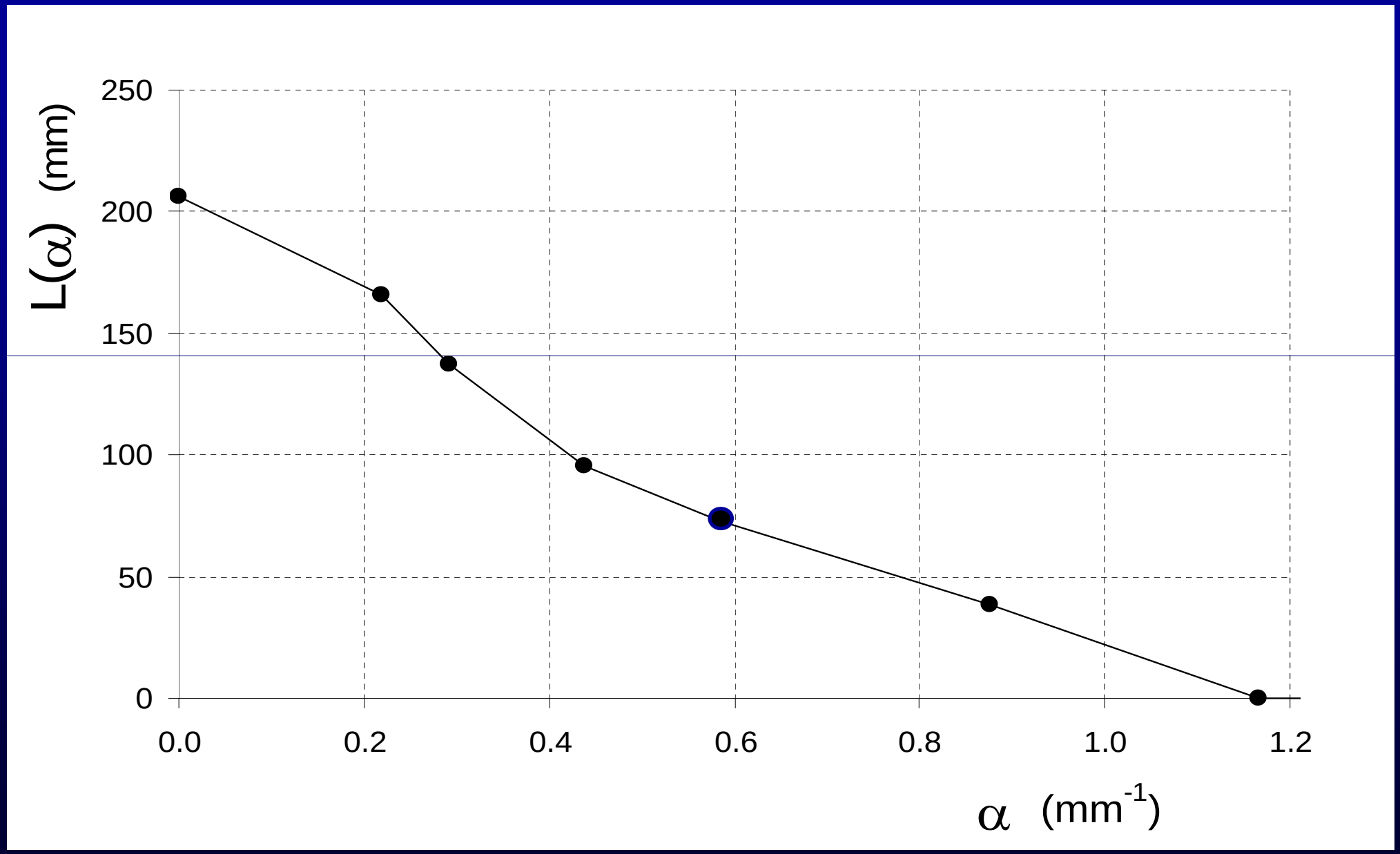


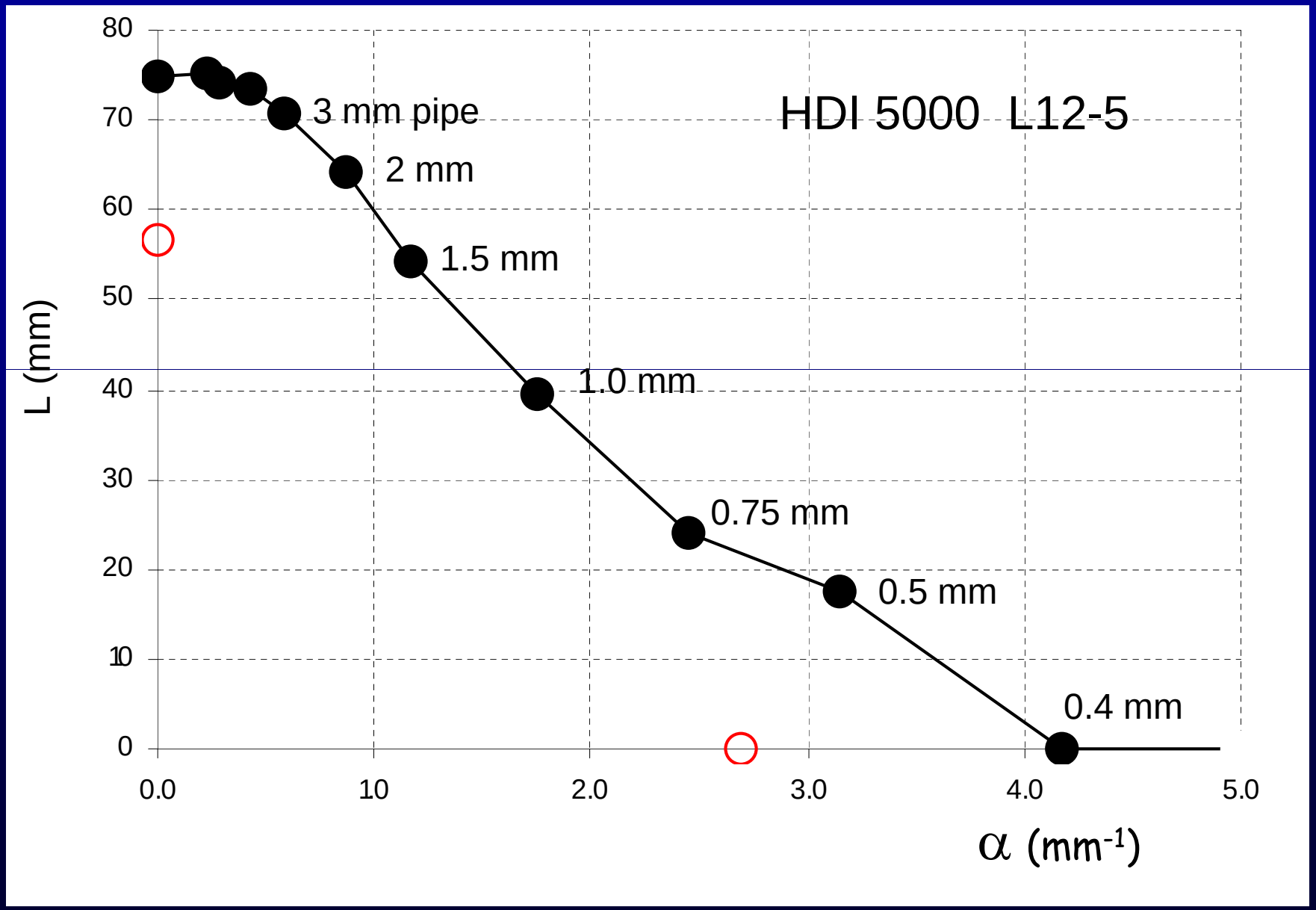

Transducer
cm
3.5C40H/3.4
MEDIUM ABD
100%
16dB RS2
15.0cm 23fps
How much of the pipe
can you see ?


Transducer
cm
L
3.5C40H/3.4
MEDIUM ABD
100%
16dB RS2
15.0cm 23fps

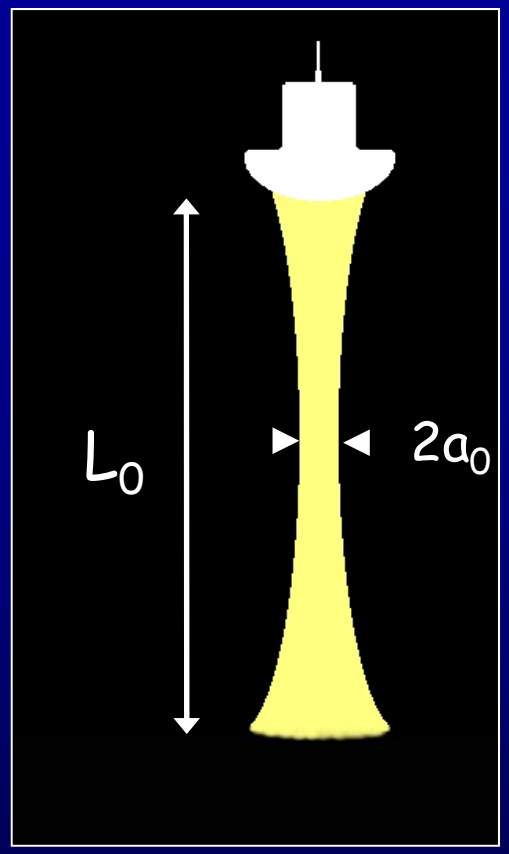

Transducer
cm
3.5C40H/3.4
MEDIUM ABD
100%
16dB RS2
15.0cm 23fps
L
α ∝ 1/d

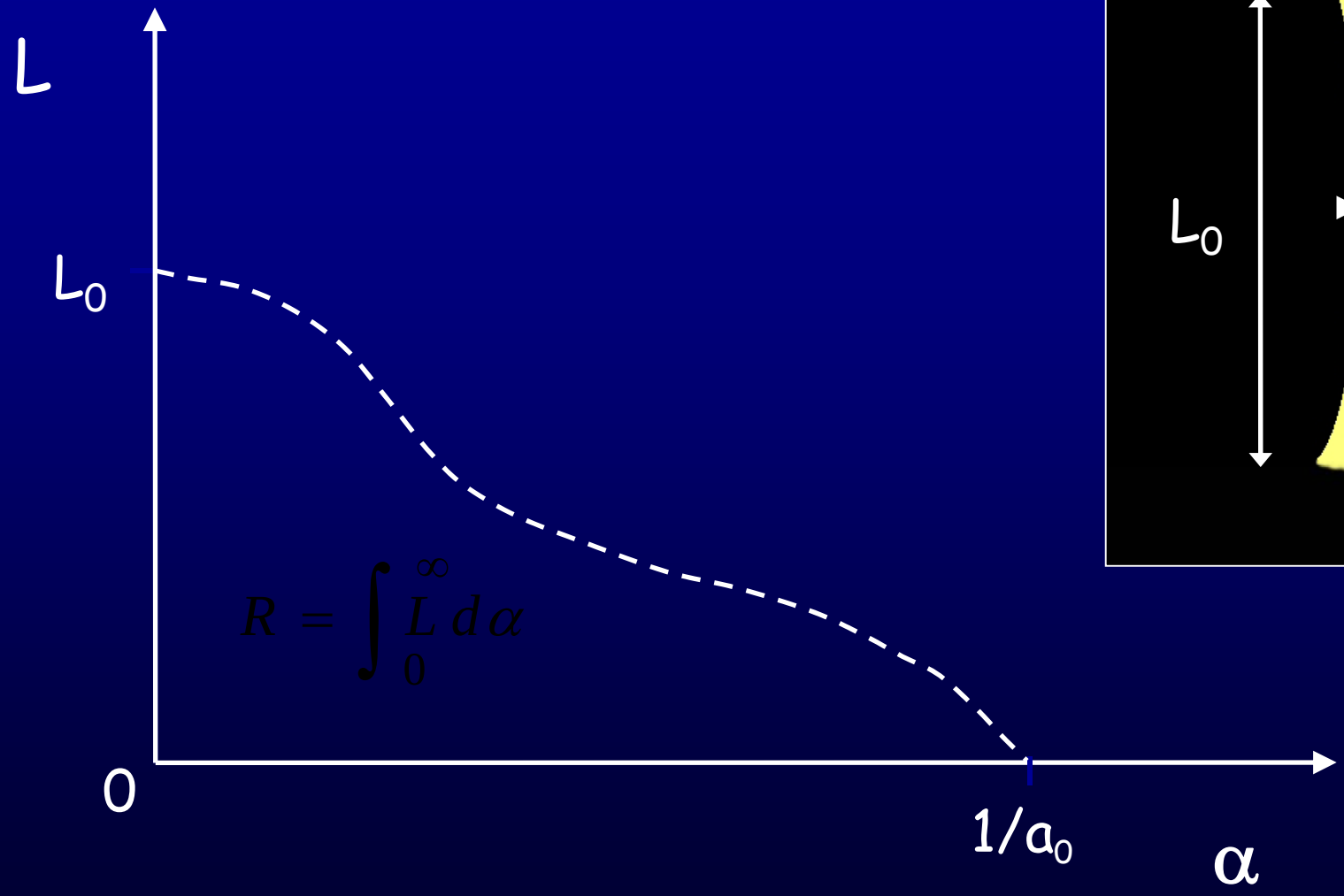

L(α) (mm)
250
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
α (mm-1)


250
200
150
100
50
0
L(α) (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
α (mm-1)

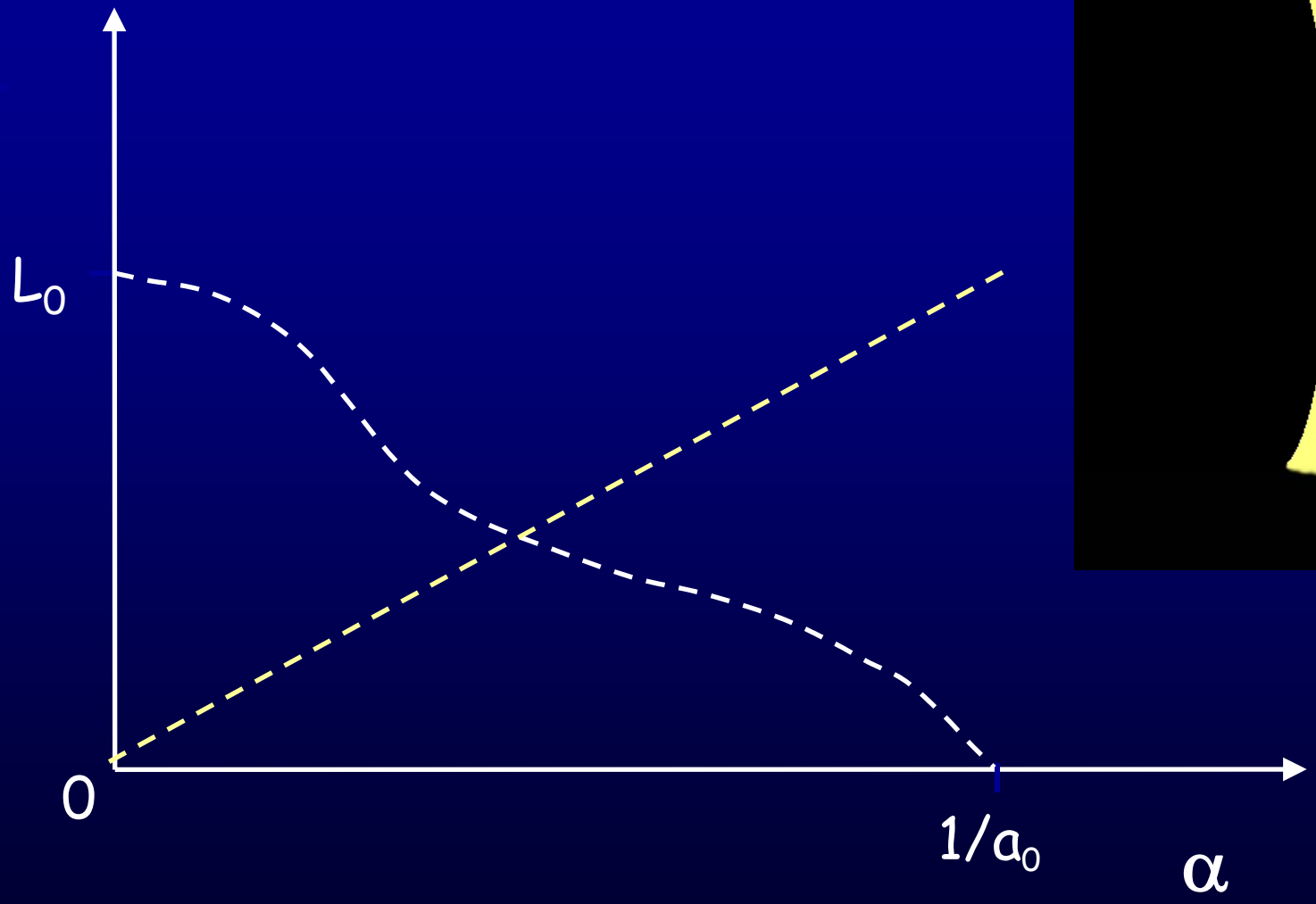

HDI 5000 L12-5
3 mm pipe
2 mm
1.5 mm
1.0 mm
0.75 mm
0.5 mm
0.4 mm
L (mm)
α (mm-1)
80
70
60
50
40
30
20
10
0
0.0
10
2.0
3.0
4.0
5.0

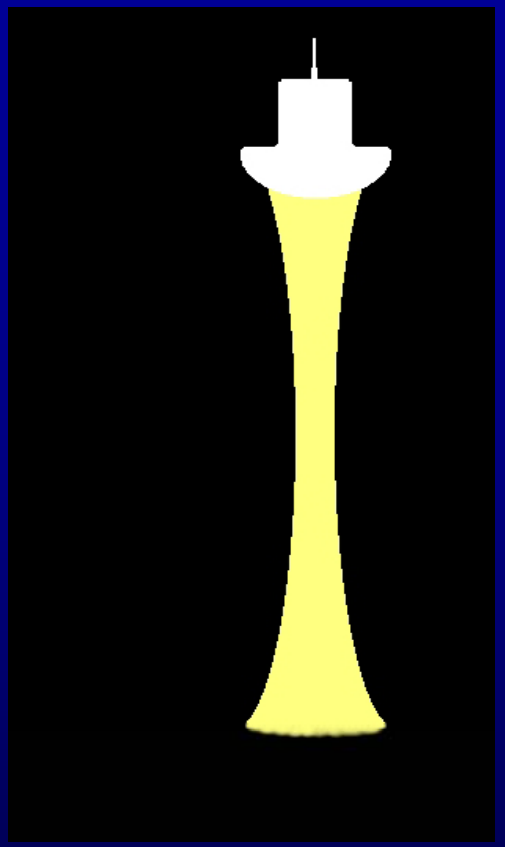
Resolution Integral R

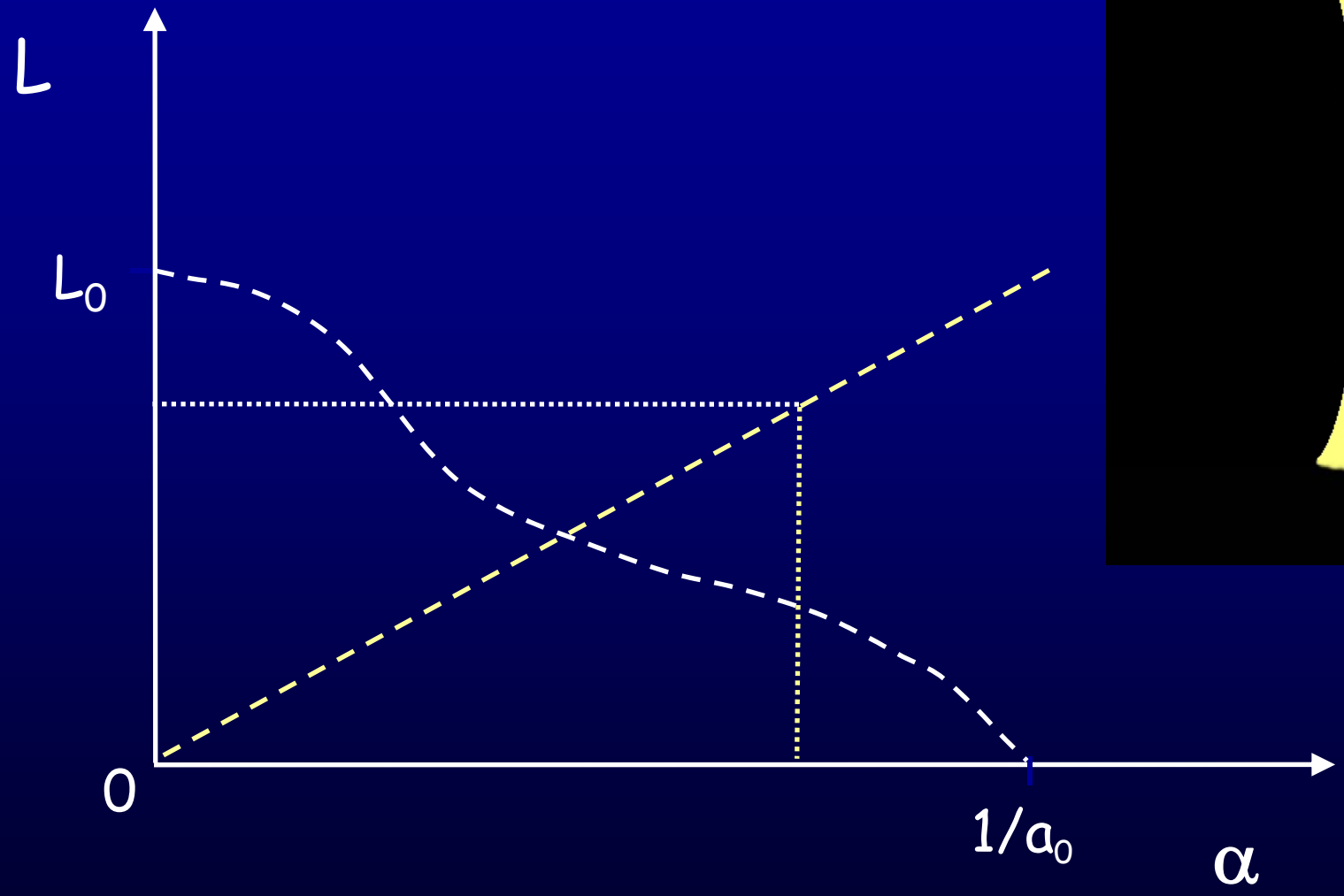


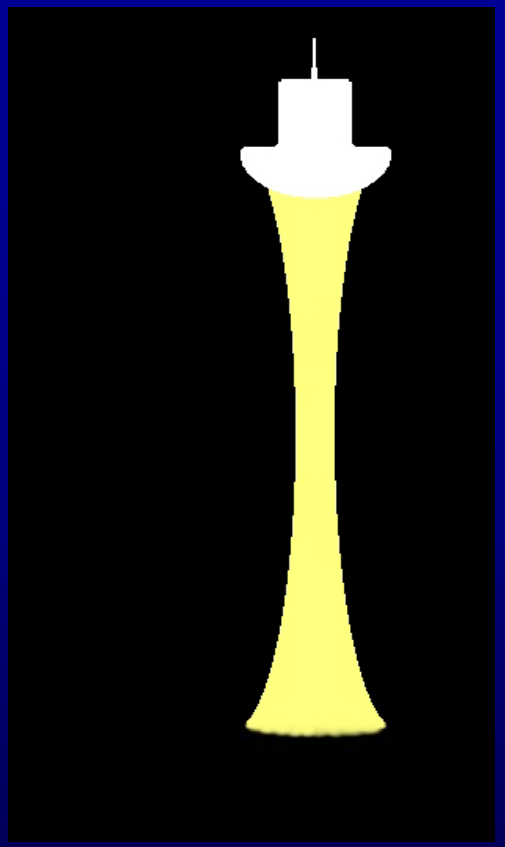


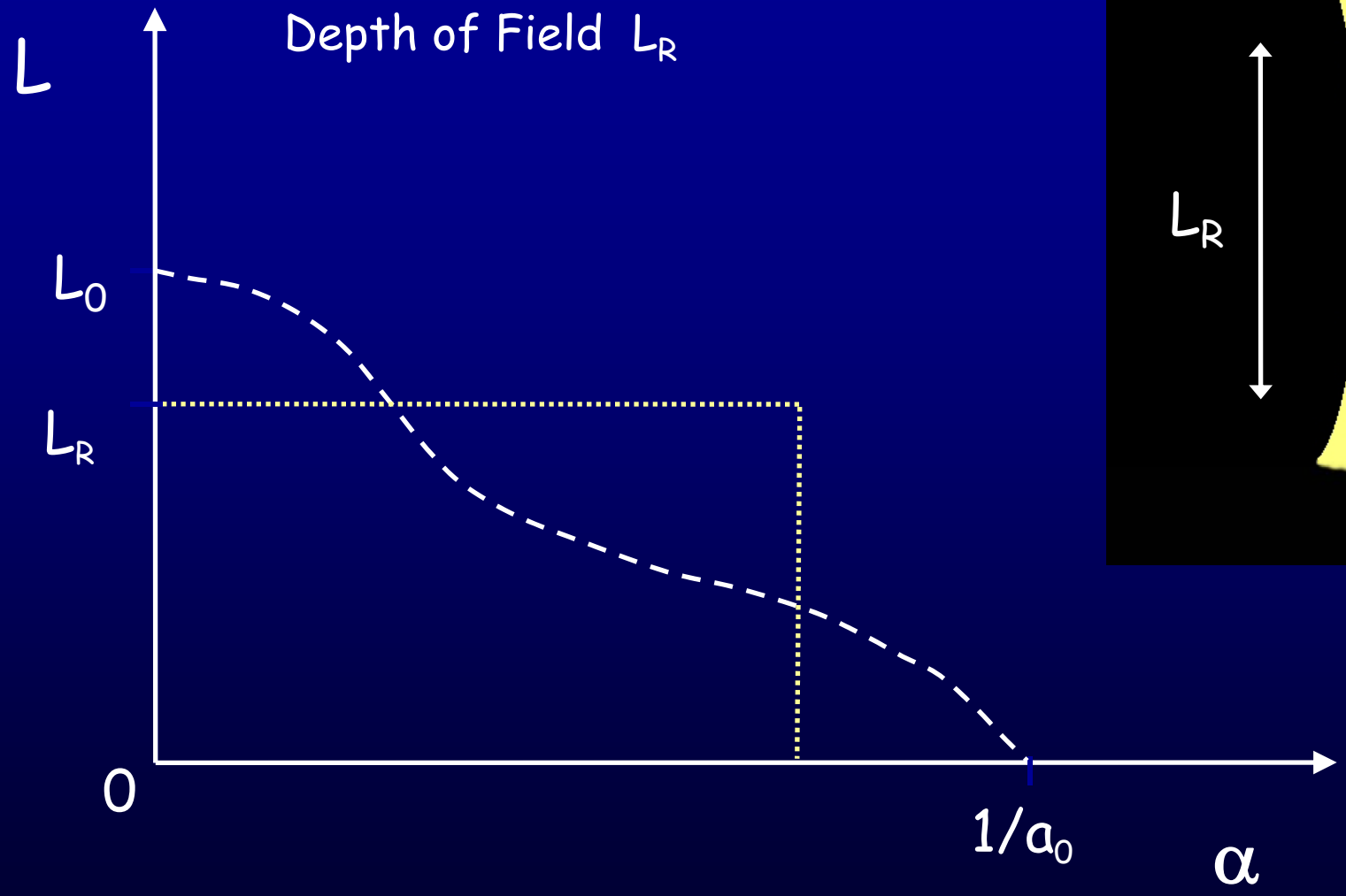
$$R = \int_0^{\infty} L \, d\alpha$$

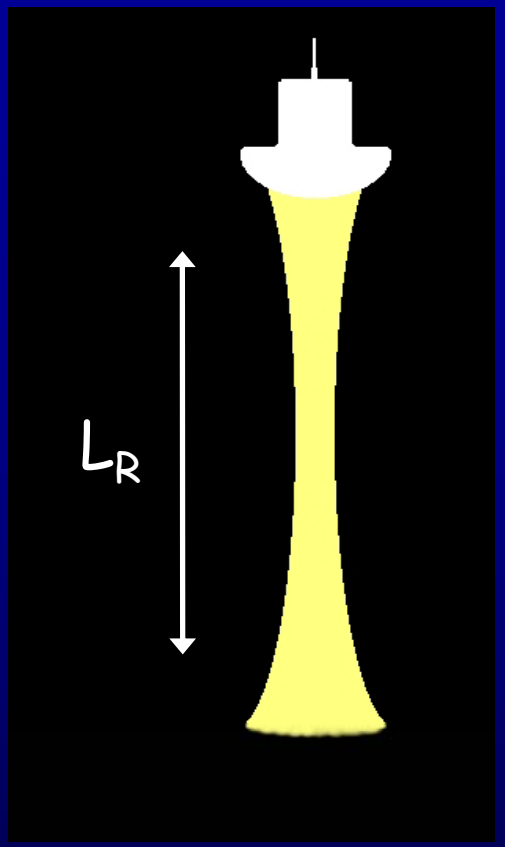

L
L_0
0
$1/a_0$
α

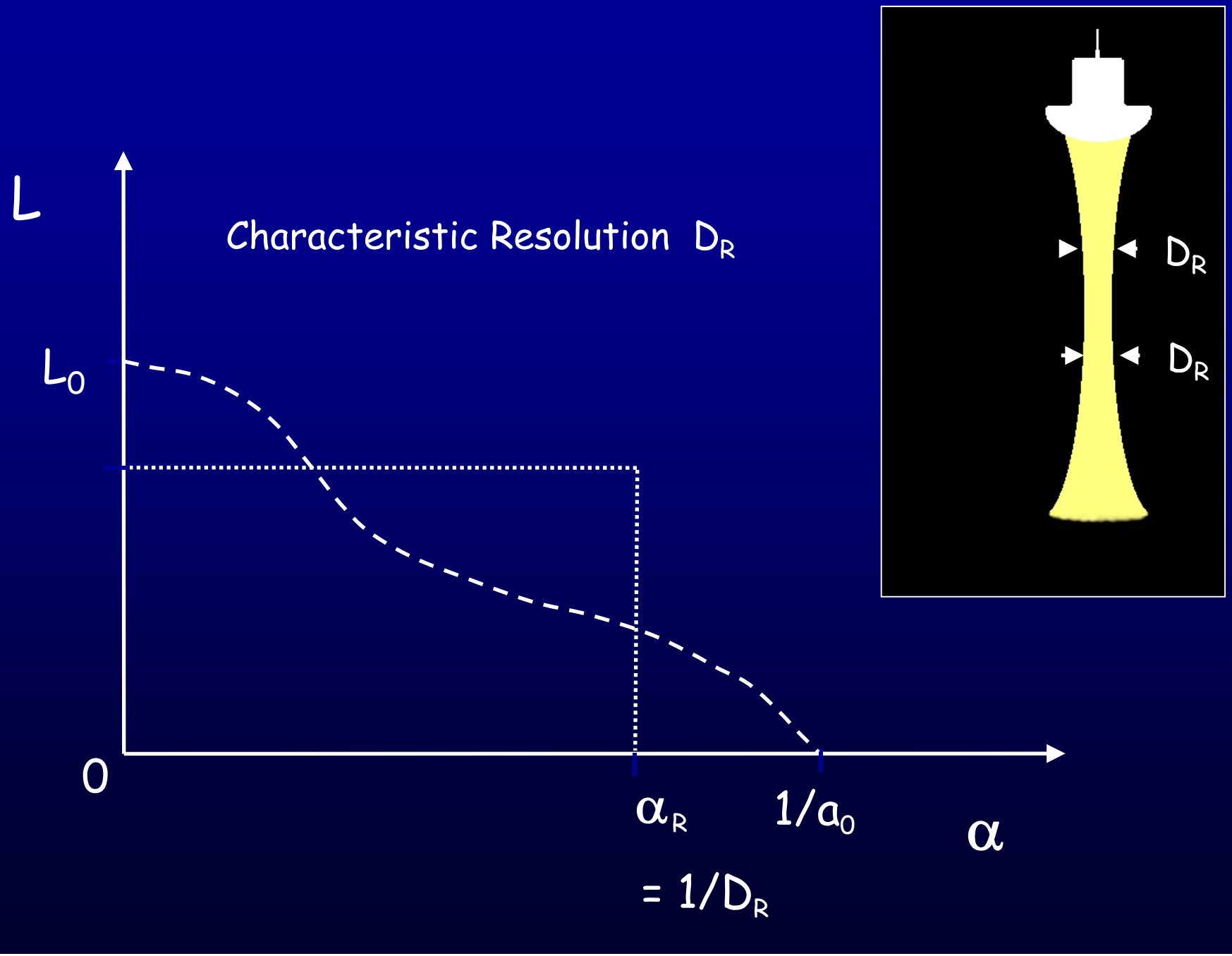



L
L_0
0
$1/a_0$
α




Depth of Field L_R
L
L_0
L_R
0
$1/a_0$
α

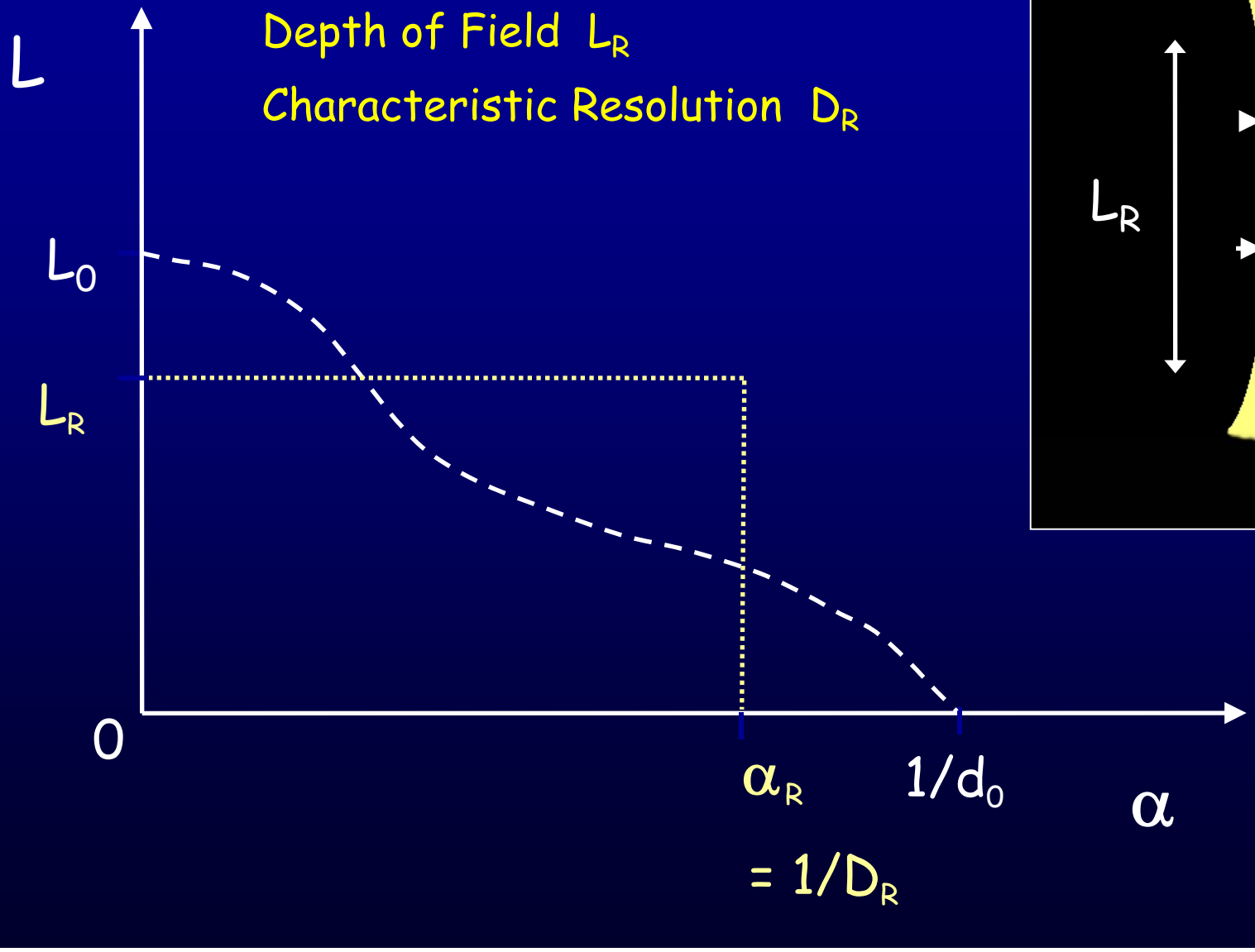

L_R

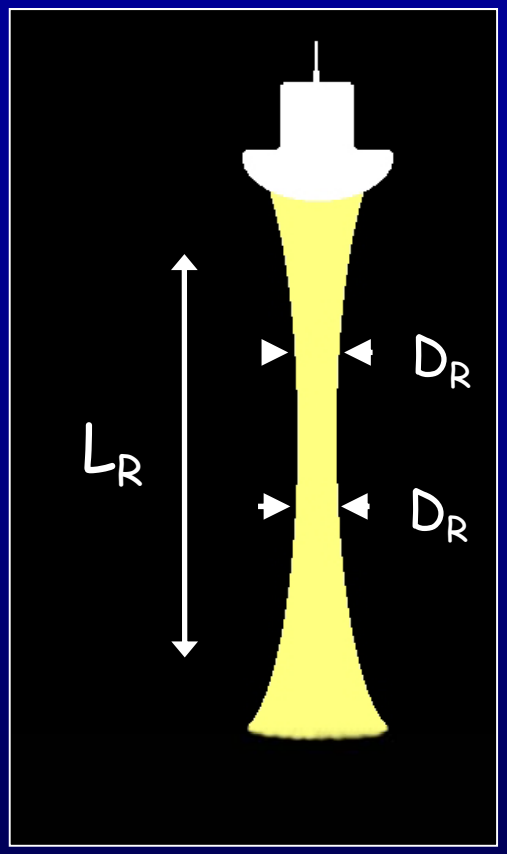

L
Characteristic Resolution D_R
L_0
0
α_R
$1/a_0$
α
$= 1/D_R$
D_R
D_R

Resolution Integral $R = L_R/D_R$

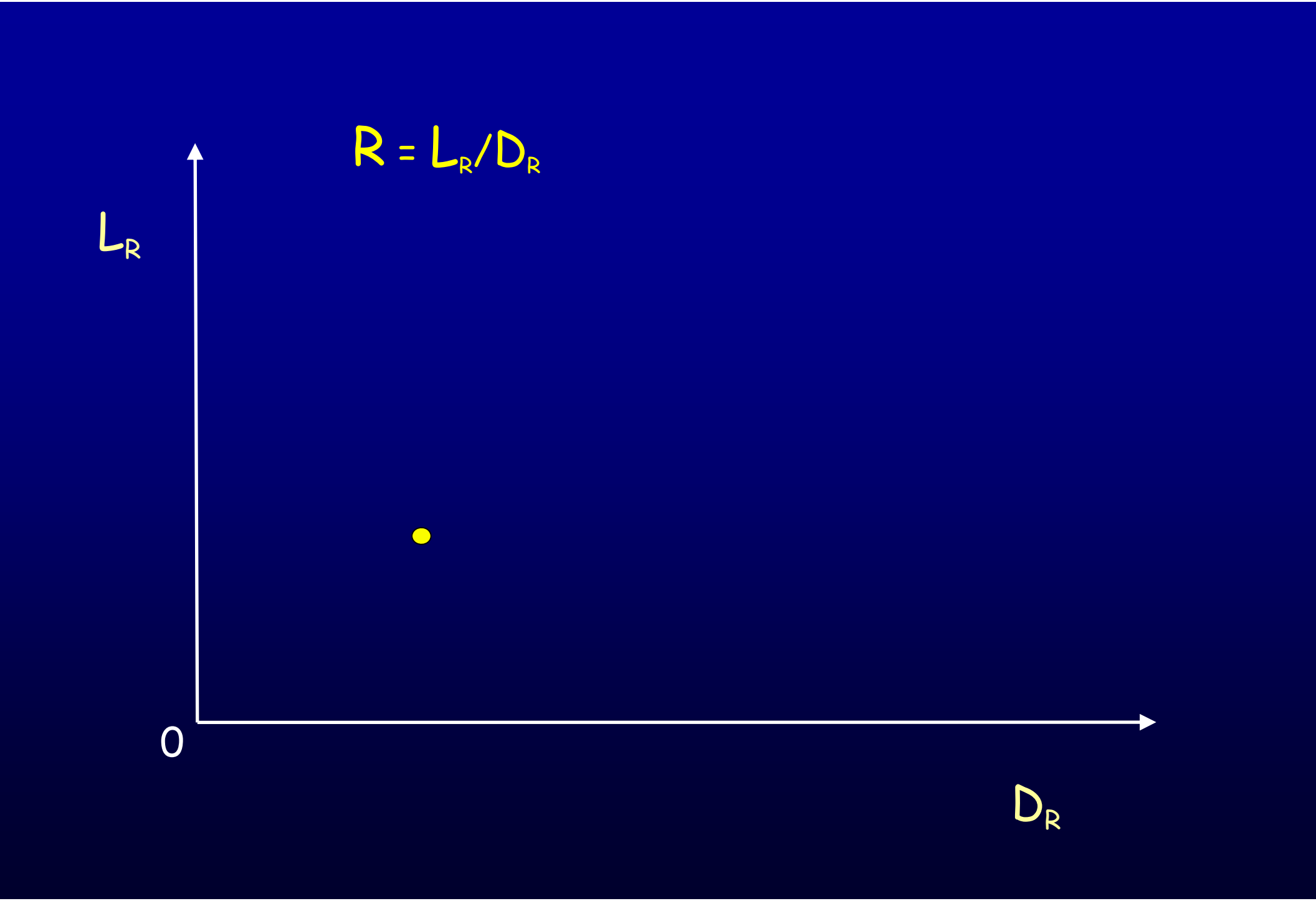
Depth of Field L_R

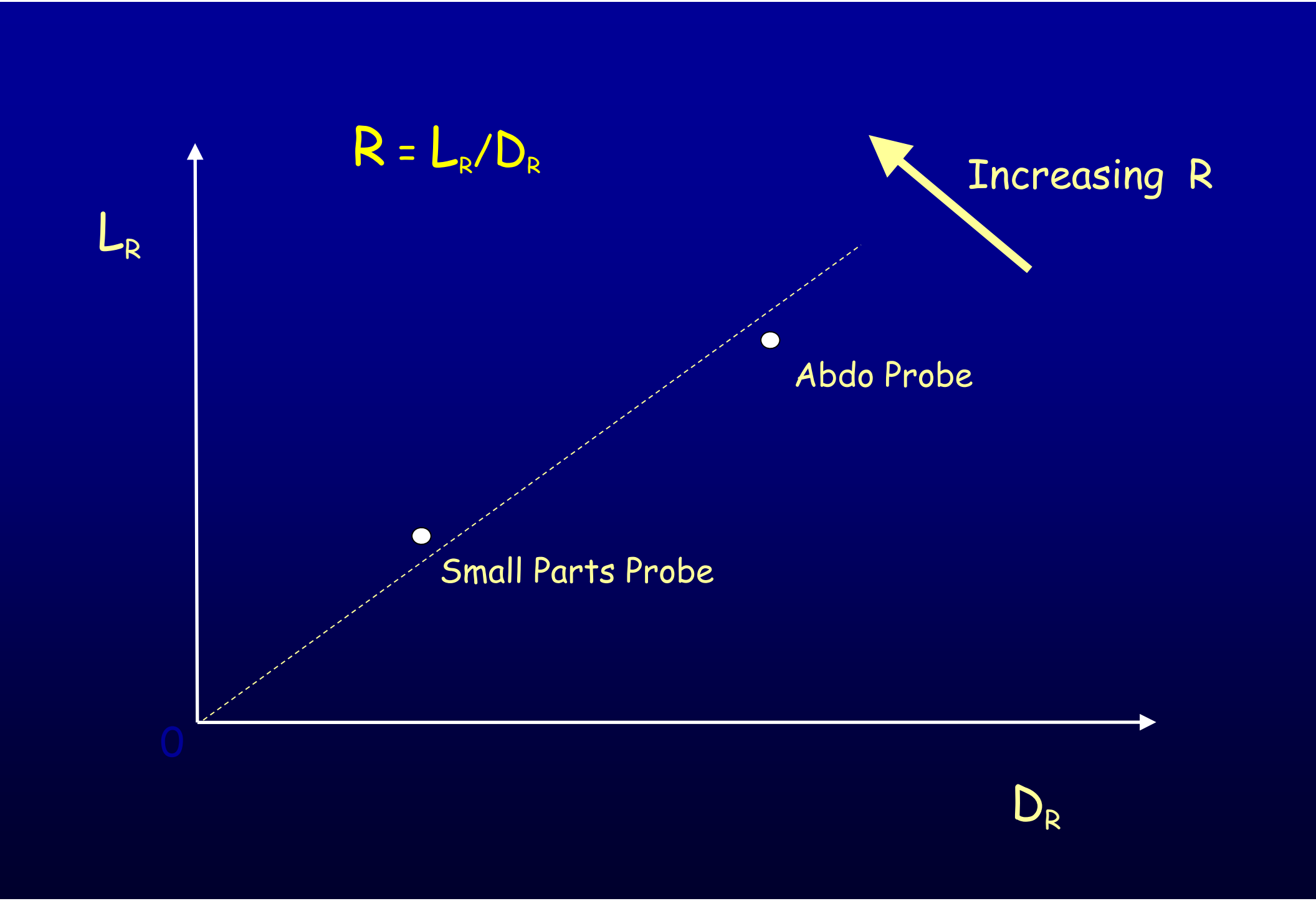
Characteristic Resolution D_R

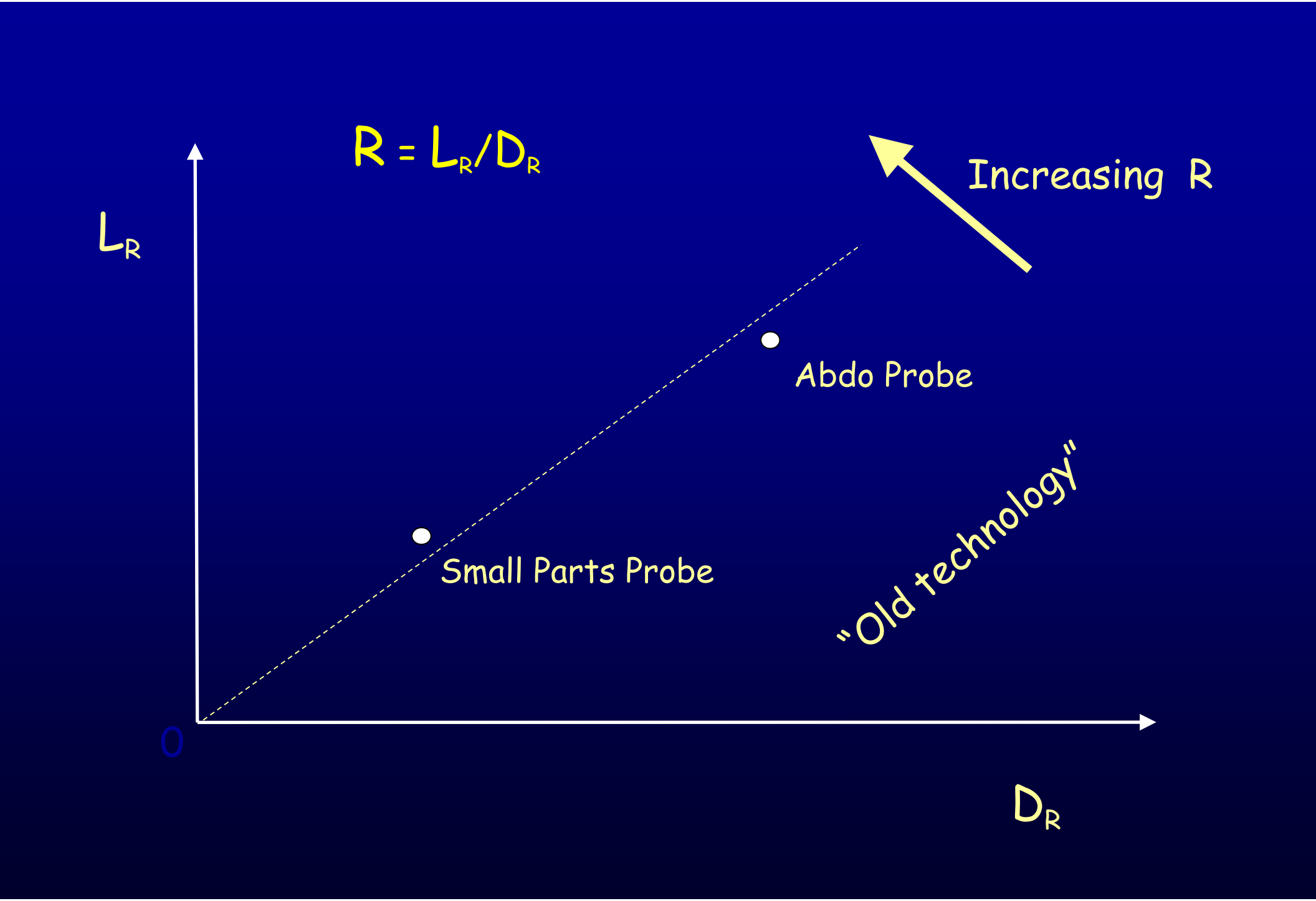


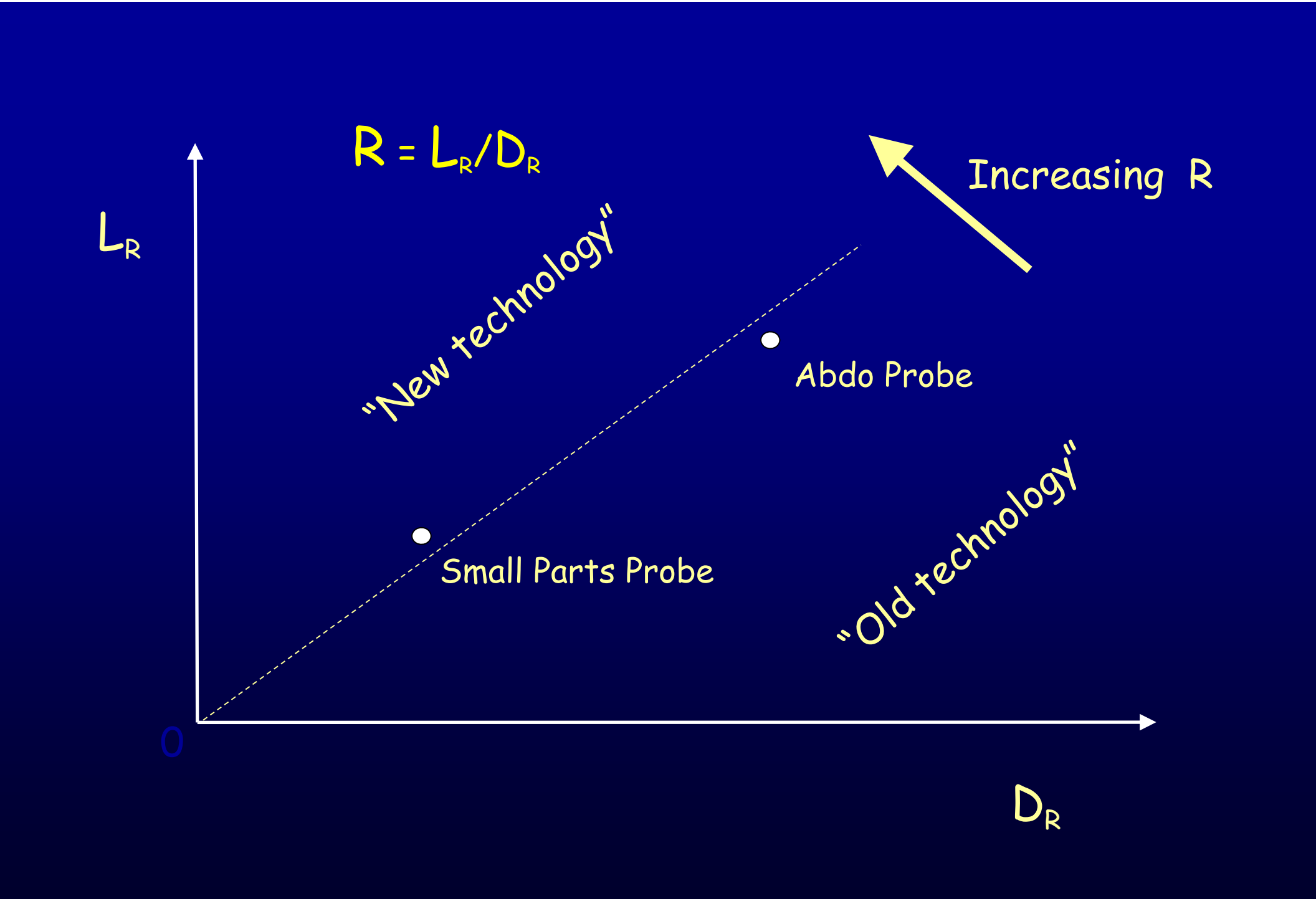


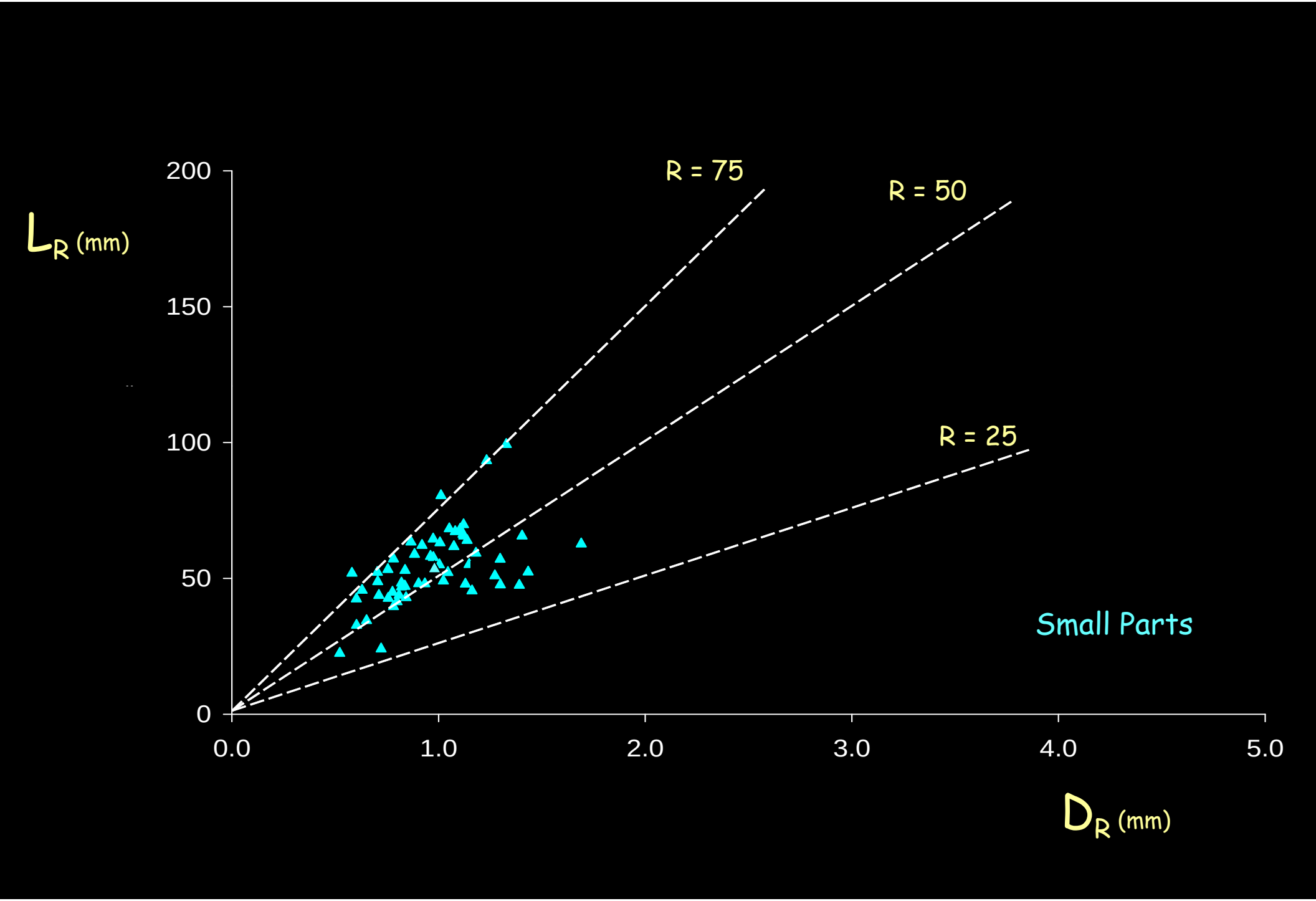
$R = L_R / D_R$

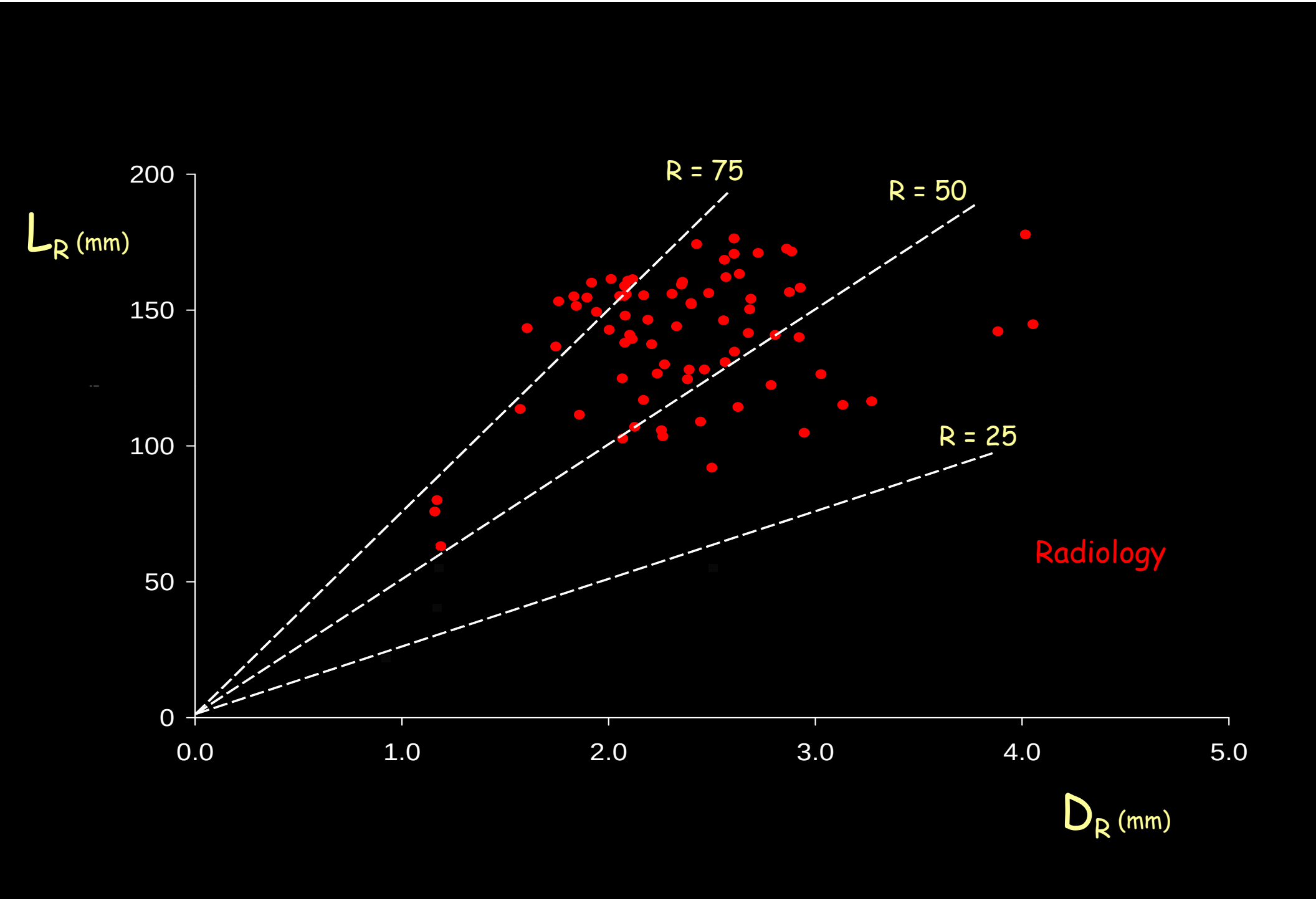


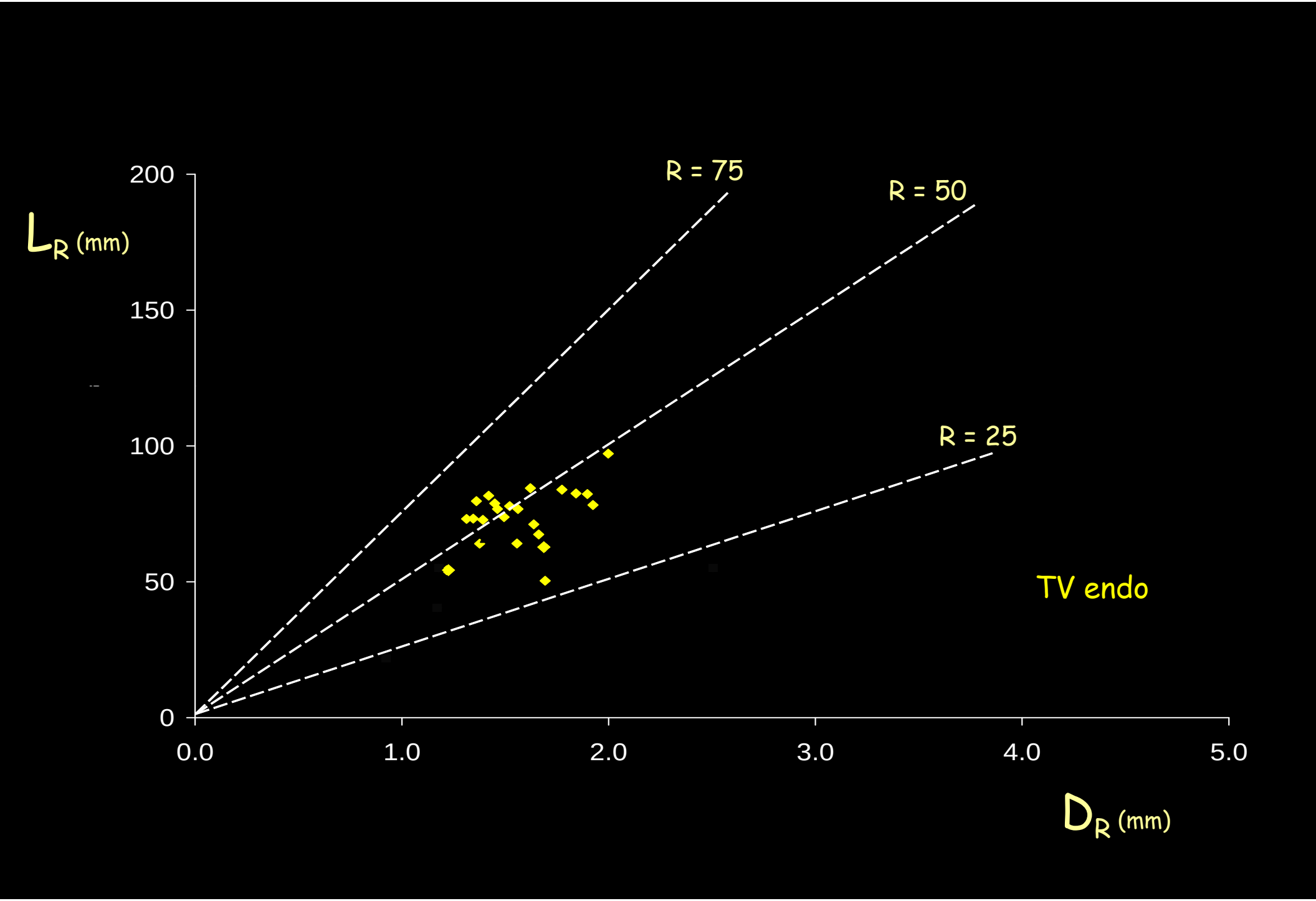

R = L_R/D_R
Increasing R
L_R
Abdo Probe
Small Parts Probe
0
D_R

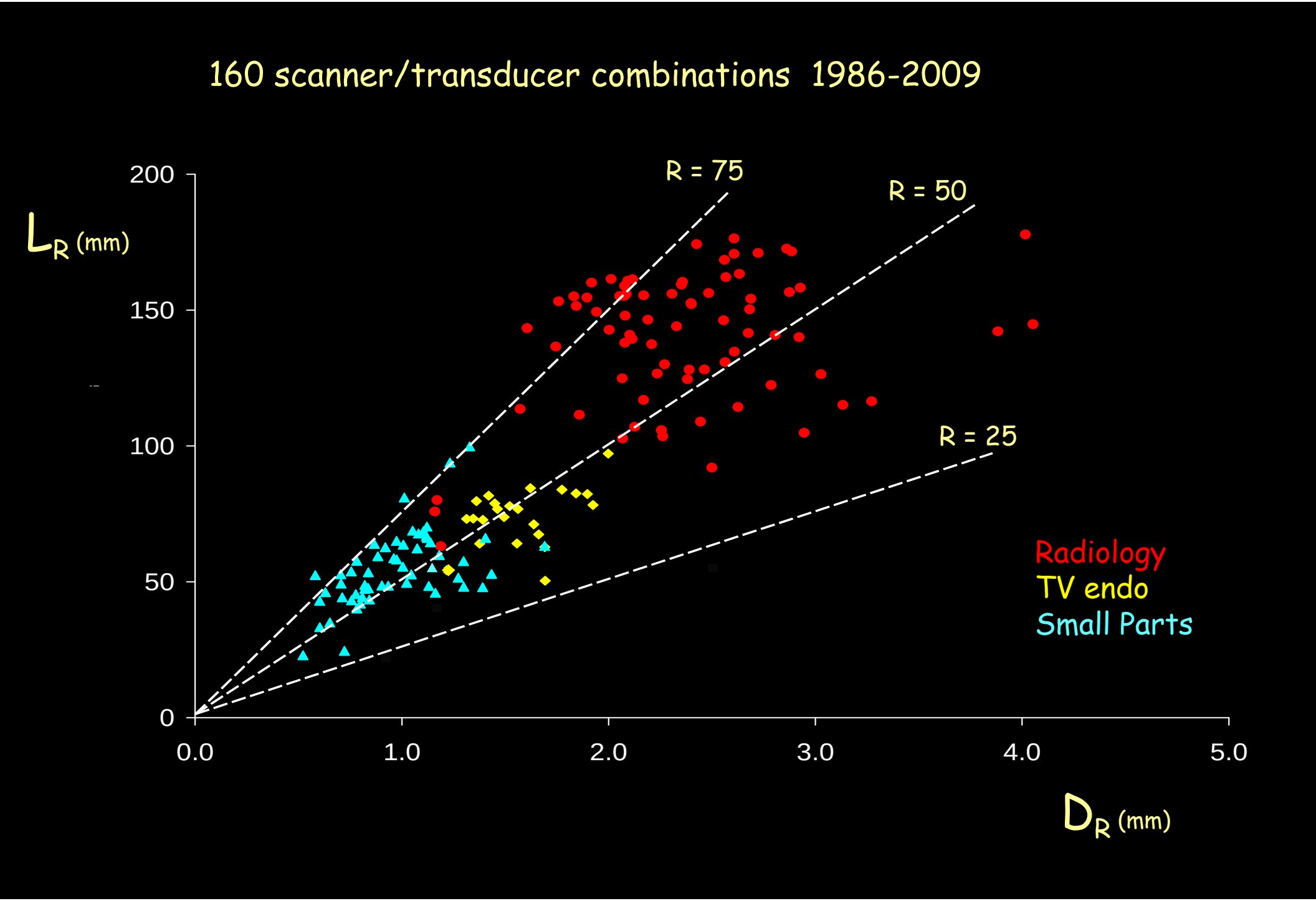

$R = L_R/D_R$
Increasing R
L_R
Abdo Probe
Small Parts Probe
"Old technology"
0
D_R

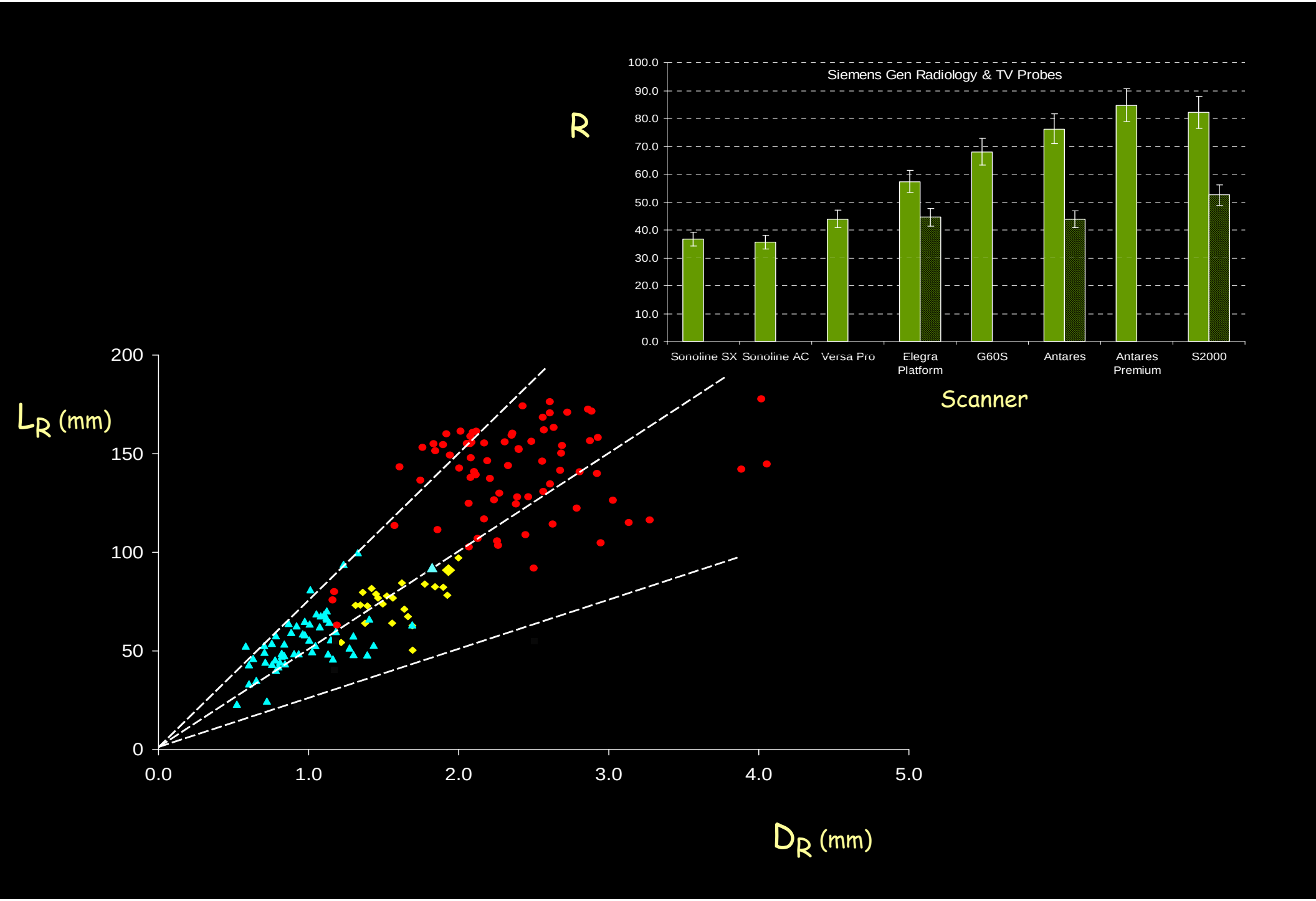

$R = L_R/D_R$
Increasing R
L_R
"New technology"
Abdo Probe
Small Parts Probe
"Old technology"
0
D_R

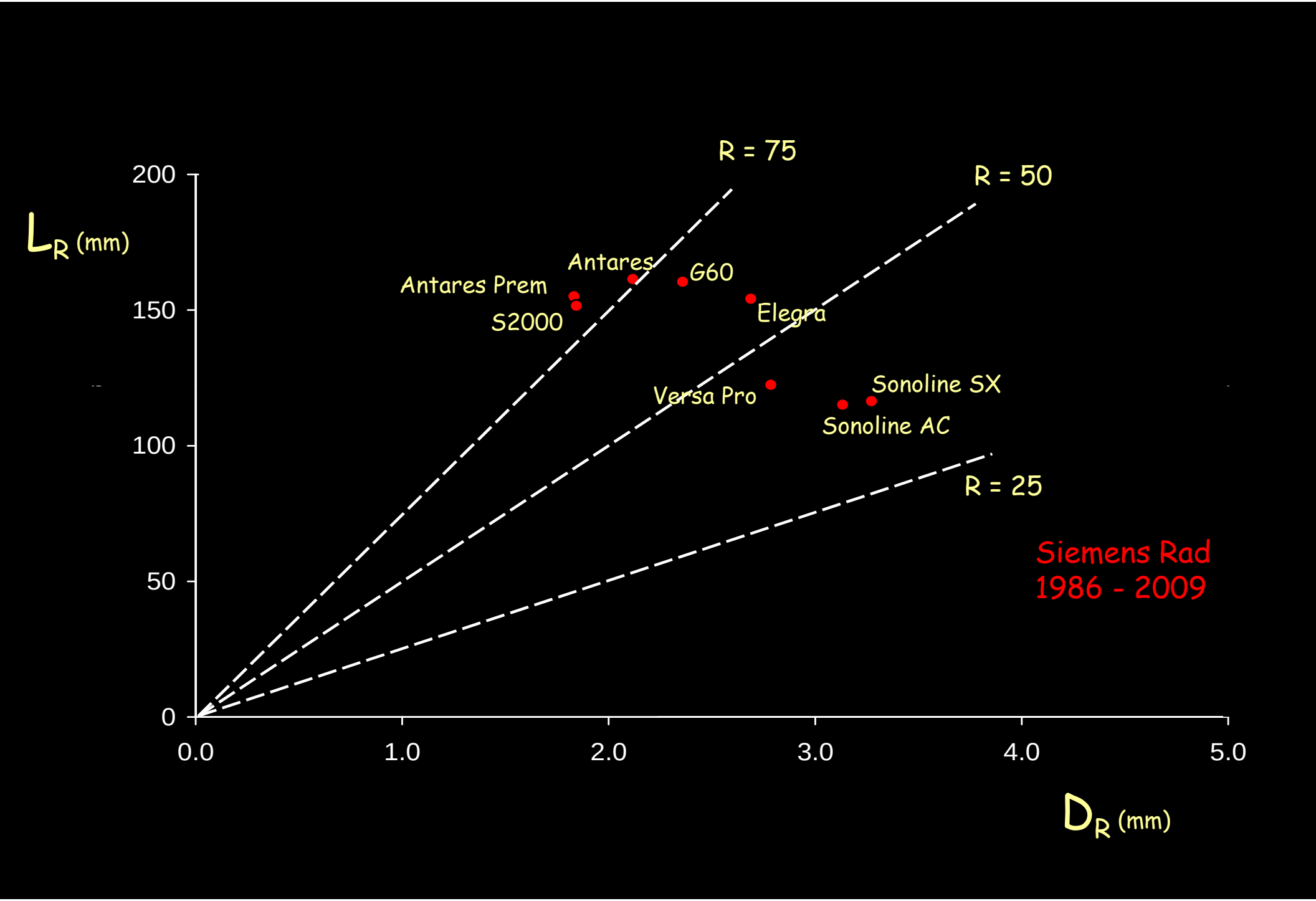

200
150
100
50
0
L_R (mm)
R = 75
R = 50
R = 25
Small Parts
0.0
1.0
2.0
3.0
4.0
5.0
D_R (mm)


R = 75
R = 50
R = 25
200
150
100
50
0
0.0
1.0
2.0
3.0
4.0
5.0
L_R (mm)
D_R (mm)
Radiology


R = 75
R = 50
R = 25
TV endo
200
150
100
50
0
0.0
1.0
2.0
3.0
4.0
5.0
L_R (mm)
D_R (mm)


160 scanner/transducer combinations 1986-2009
R = 75
R = 50
R = 25
200
150
100
50
0
L_R (mm)
0.0
1.0
2.0
3.0
4.0
5.0
D_R (mm)
Radiology
TV endo
Small Parts


R
Siemens Gen Radiology & TV Probes
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Sonoline SX
Sonoline AC
Versa Pro
Elegra Platform
G60S
Antares
Antares Premium
S2000
Scanner
L_R (mm)
200
150
100
50
0
0.0
1.0
2.0
3.0
4.0
5.0
D_R (mm)


R = 75
R = 50
R = 25
200
150
100
50
0
L_R (mm)
0.0
1.0
2.0
3.0
4.0
5.0
D_R (mm)
Antares Prem
Antares
G60
S2000
Elegra
Versa Pro
Sonoline SX
Sonoline AC
Siemens Rad
1986 - 2009

Structure

- Assess the performance of clinical ultrasound transducers
- Assess the performance of clinical ultrasound transducers for pre-clinical imaging
- Assess the performance of commercially available pre-clinical transducers

Of Mice and Men

- Experimenting on humans frowned upon
  - Alternatives
    - Nematode worm
    - Insects
      - Fruit fly
    - Fish (zebra fish)
    - Mammals
      - Mice
      - Rats
      - Pigs
      - Sheep
      - Primates

Objectives of Genetic Engineering

- Understand human disease processes
- Develop treatments and cures

Manipulating the Genome

- Natural mutations
- Chemical mutagenesis
- Knockout approach
  - Stop an existing gene from functioning
    - Random / Targeted
- Transgenic approach
  - Incorporation of a foreign gene into the genome of the target organism

Mouse Models

- Cancer
  - *Brain*
  - *Melanoma*
- Obesity-diabetes
- Polio
- Birth defects
  - Cleft pallet
  - Spinal defects
- Emphysema
- Cystic Fibrosis
- Sickle cell disease
- Glaucoma
- Parkinson’s Disease
- Deafness
- Cardiology
- Alzheimer's
- Drug testing
- Baldness
- etc

Characterisation

- Genotype
  - "internally coded, inheritable information“
  - The blue print for construction and maintenance of living organism.
- Phenotype
  - Describes the physical attributes of the organism
    - Atoms, molecules, cells, structures, metabolism, energy utilisation, tissues, organs, reflexes.

Spot the Difference

Results of genetic changes may be -

obvious

or

may not

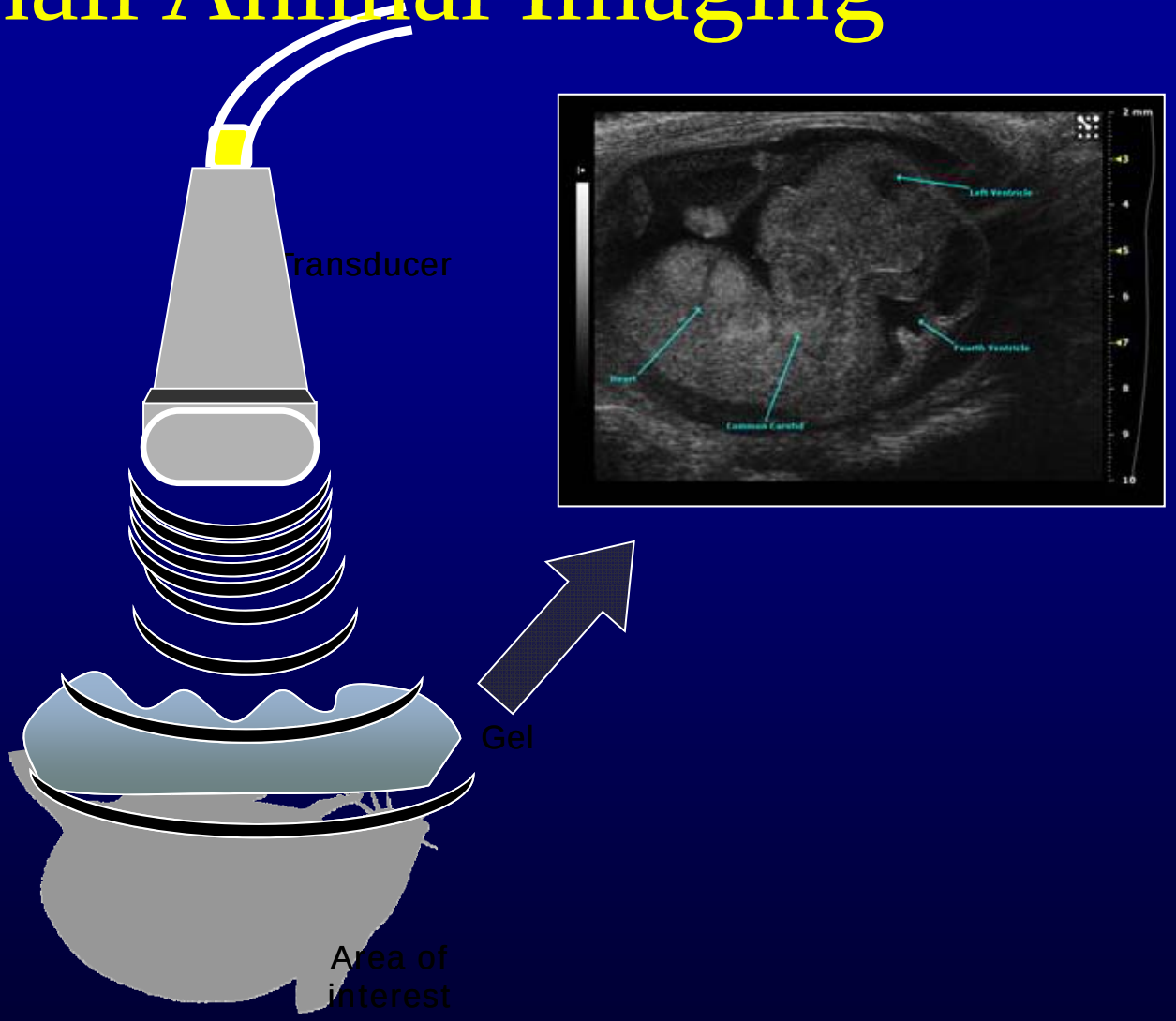
Phenotyping Methods

- Biochemical
- Behavioural
- Imaging
  - (Serial studies)

Ultrasound Scanners

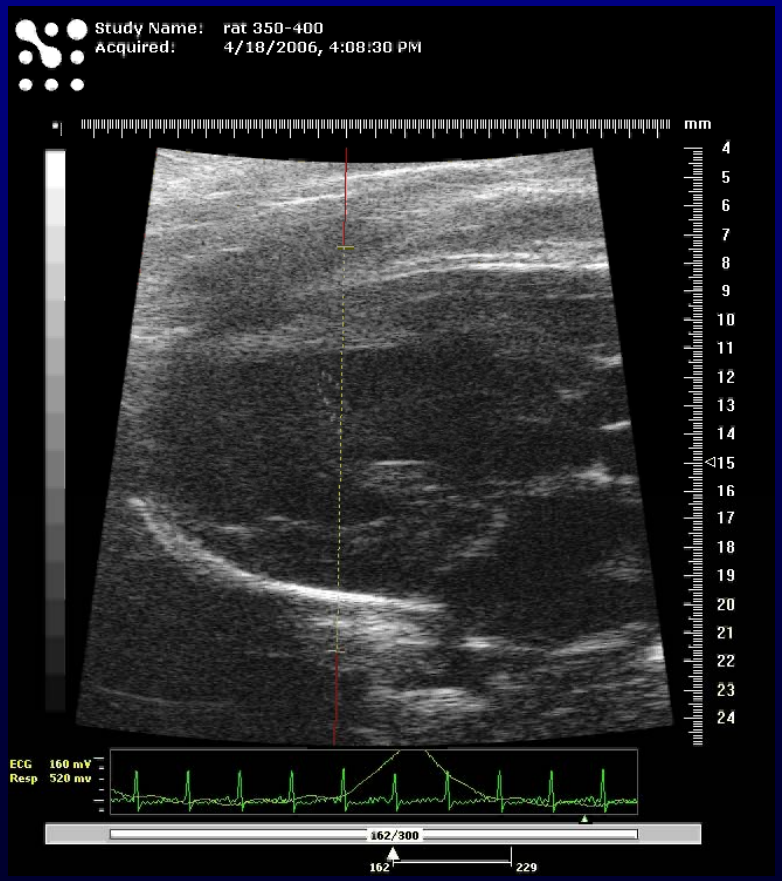
- Real-time
- High frame rate
- High resolution
- Portable
- Safe
- Convenient
- Moderate cost

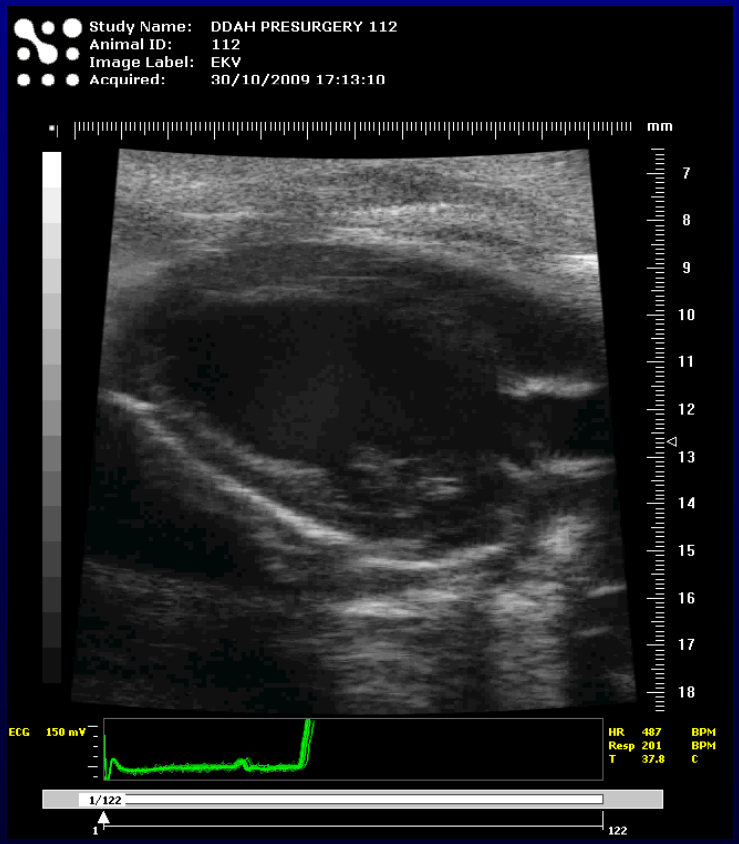
Small Animal Imaging



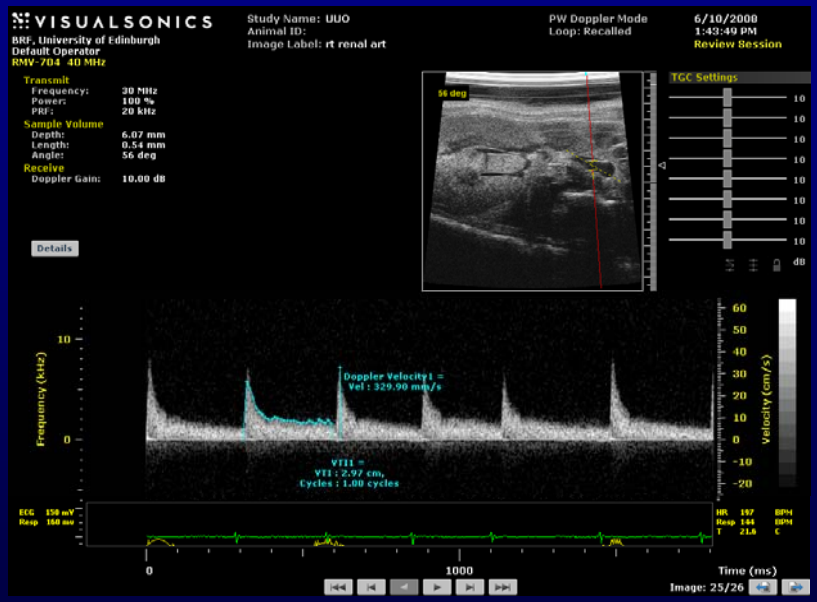
Small Animal Imaging

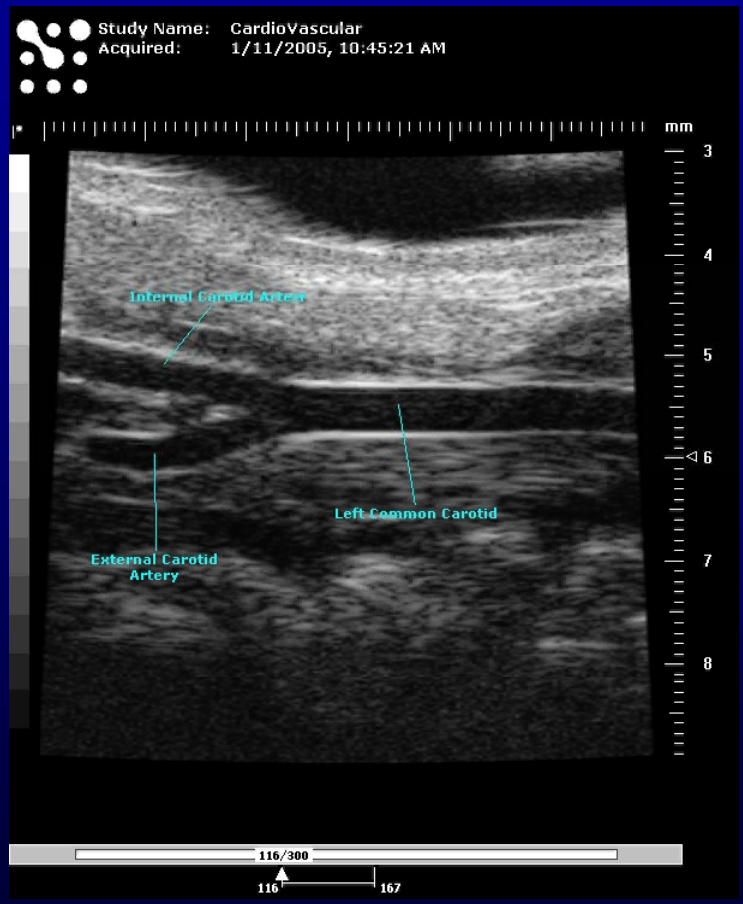
- Animal Imaging





Small Animal Imaging

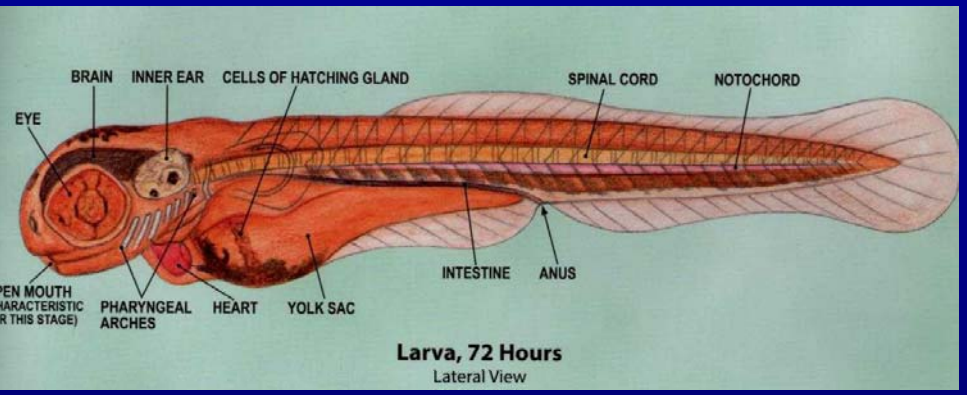


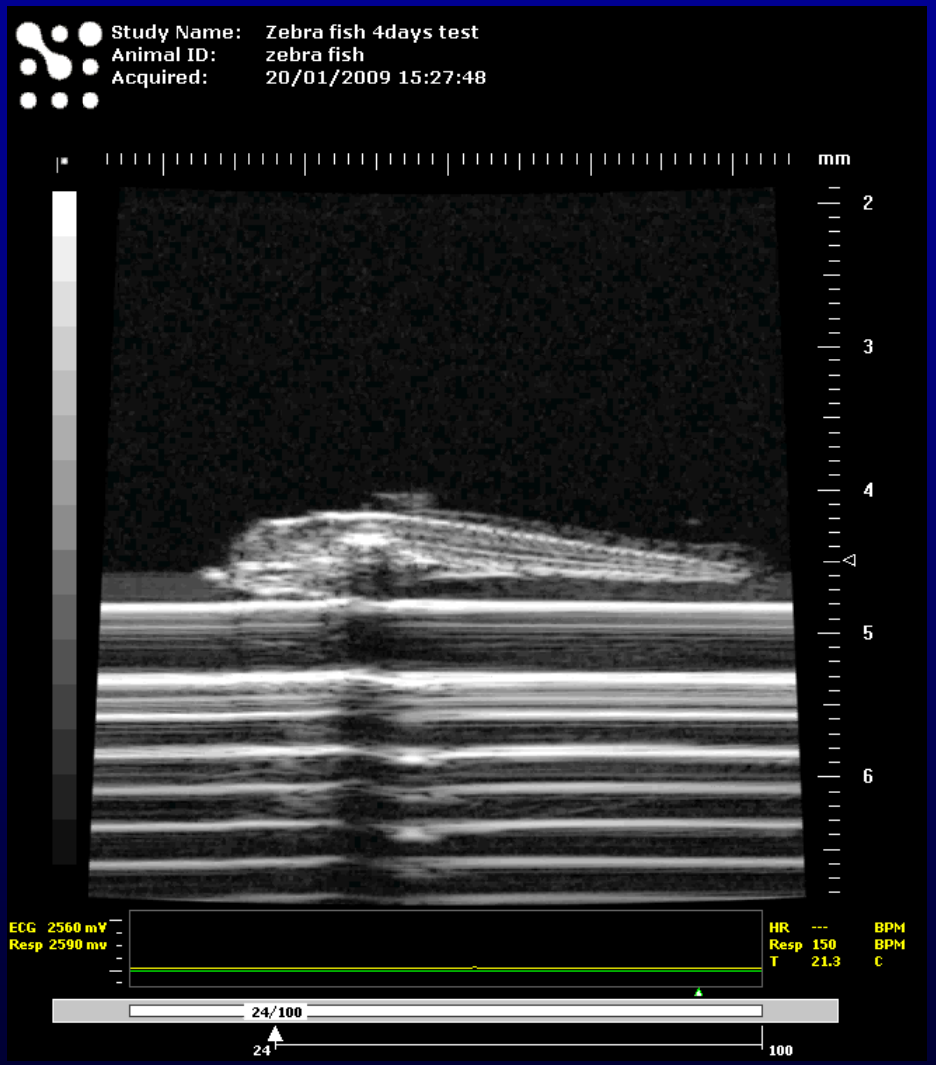


Courtesy of Visualsonics

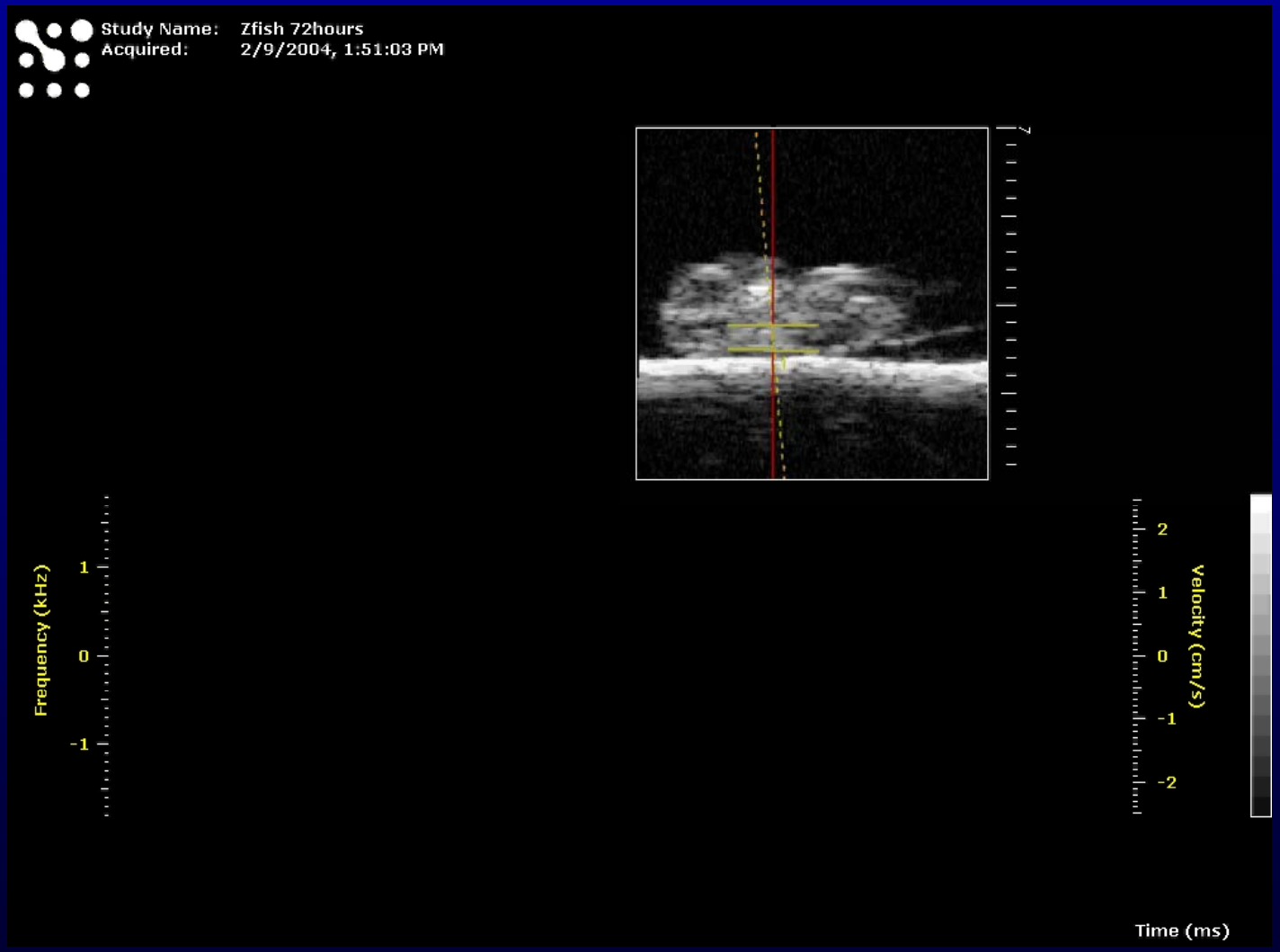
Small Animal Imaging

Small Animal Imaging – Zebra Fish





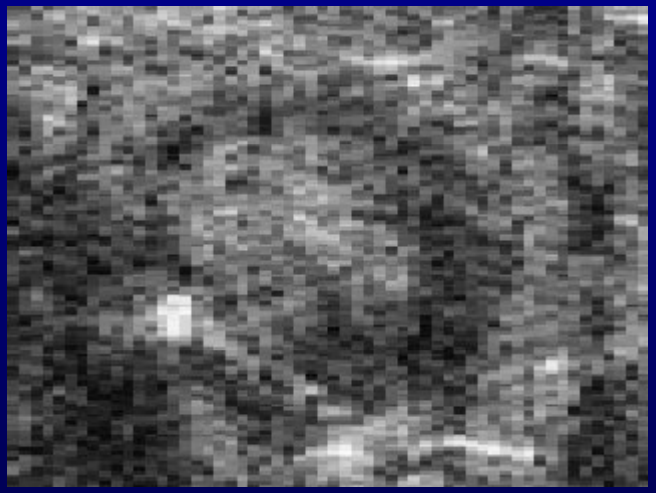
Small Animal Imaging – Zebra Fish

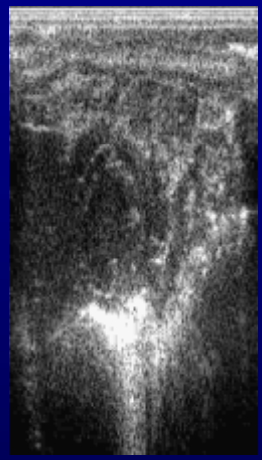


Scanners – Previous Work

Diasus – Dynamic Imaging

L8-16, L10-22 probes





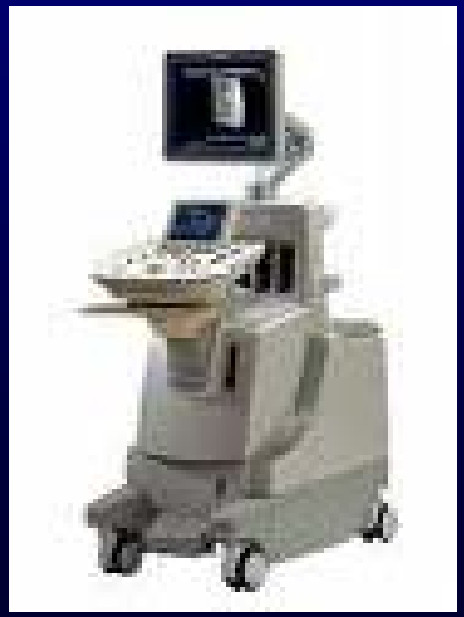
Mouse heart filled with ultrasonic contrast

Scanners

Micromaxx Scanner – Sonosite

Vevo770 - Visualsonics

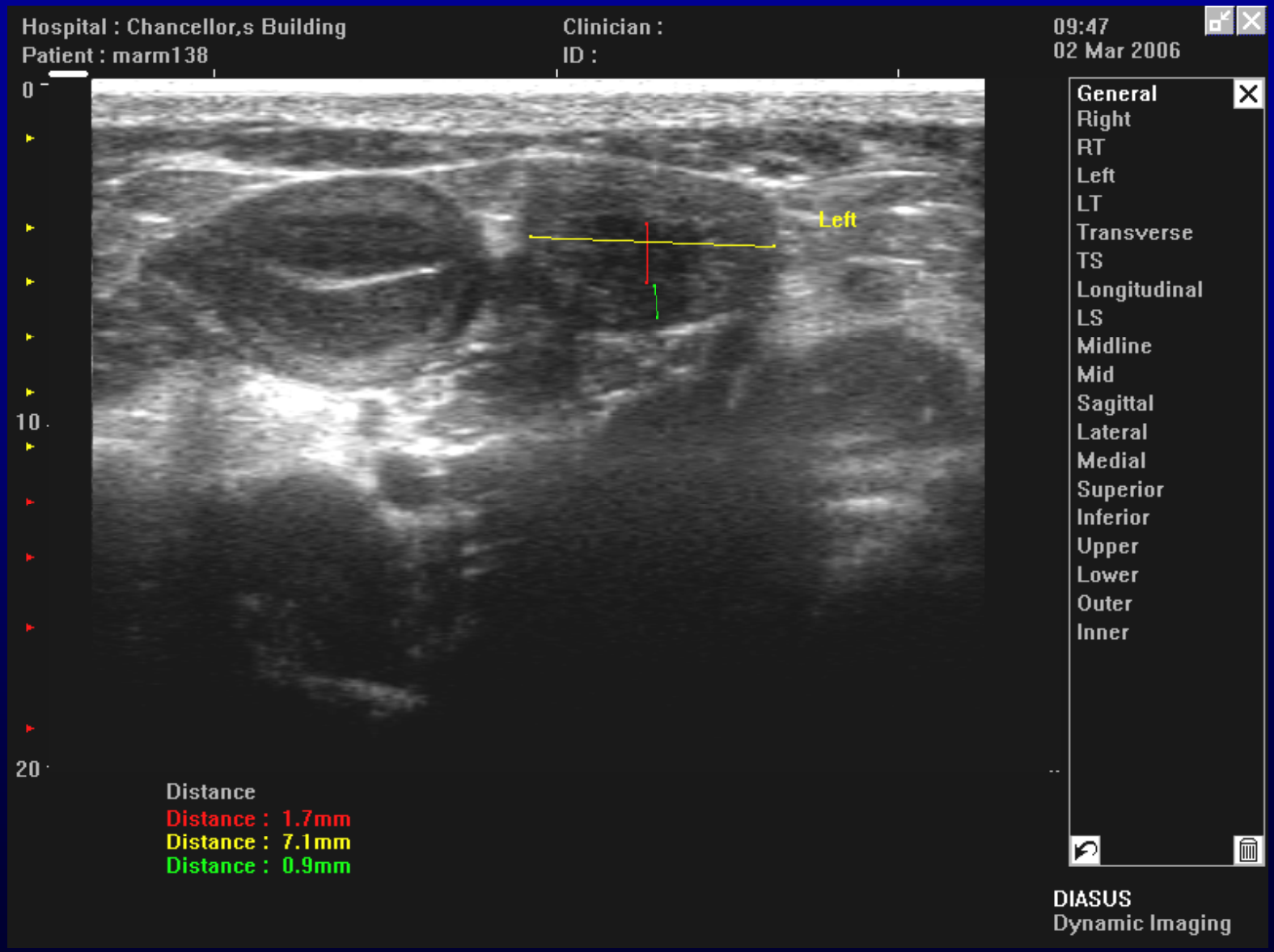
iU22 Philips



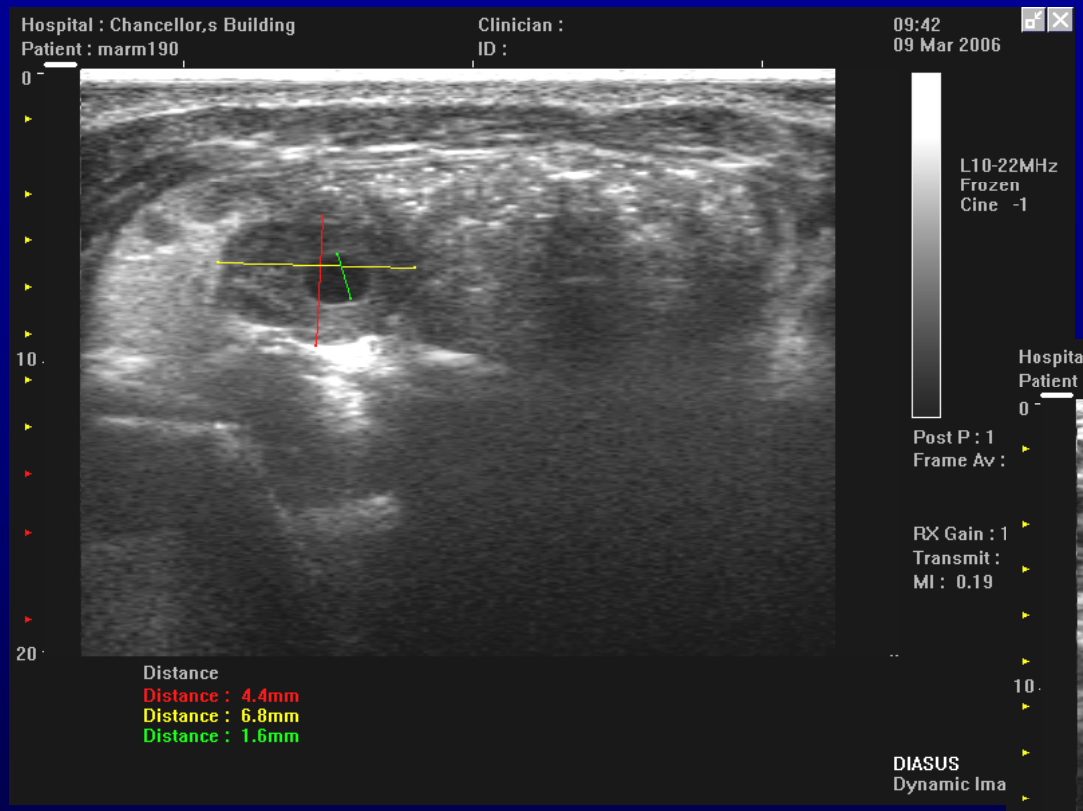
Subjects - Marmosets

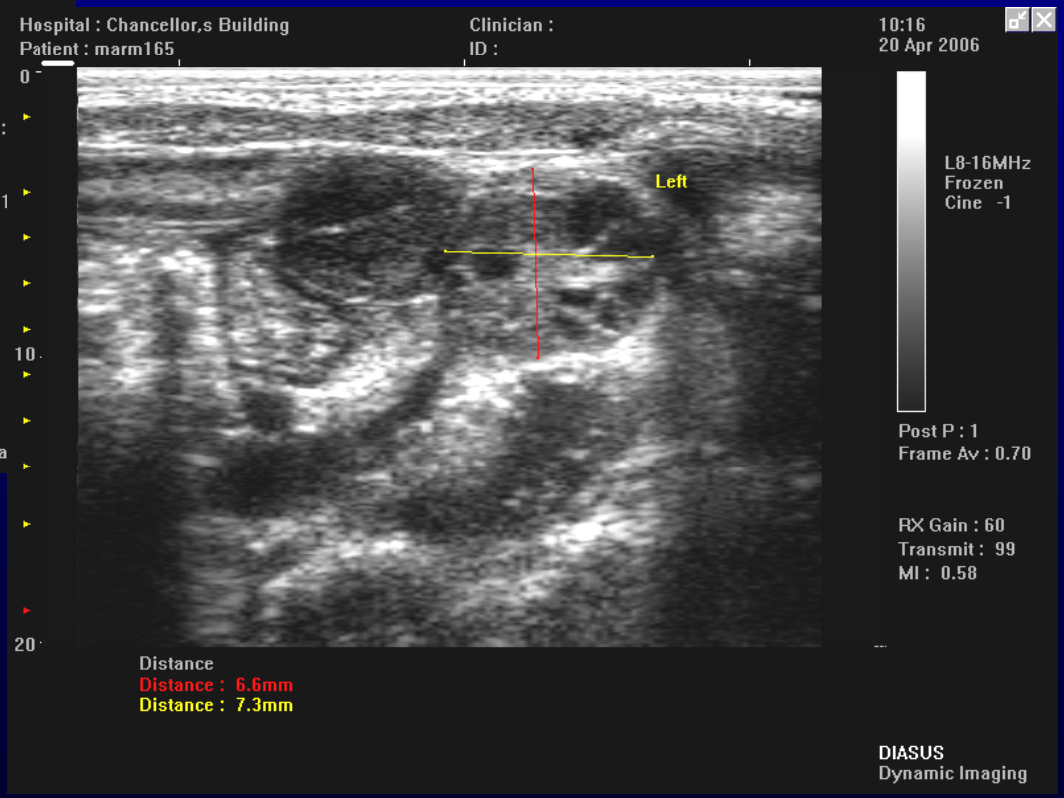
- 59 marmosets
- Held stationary by trained handlers
- Belly shaved for optimum imaging

Qualitative study

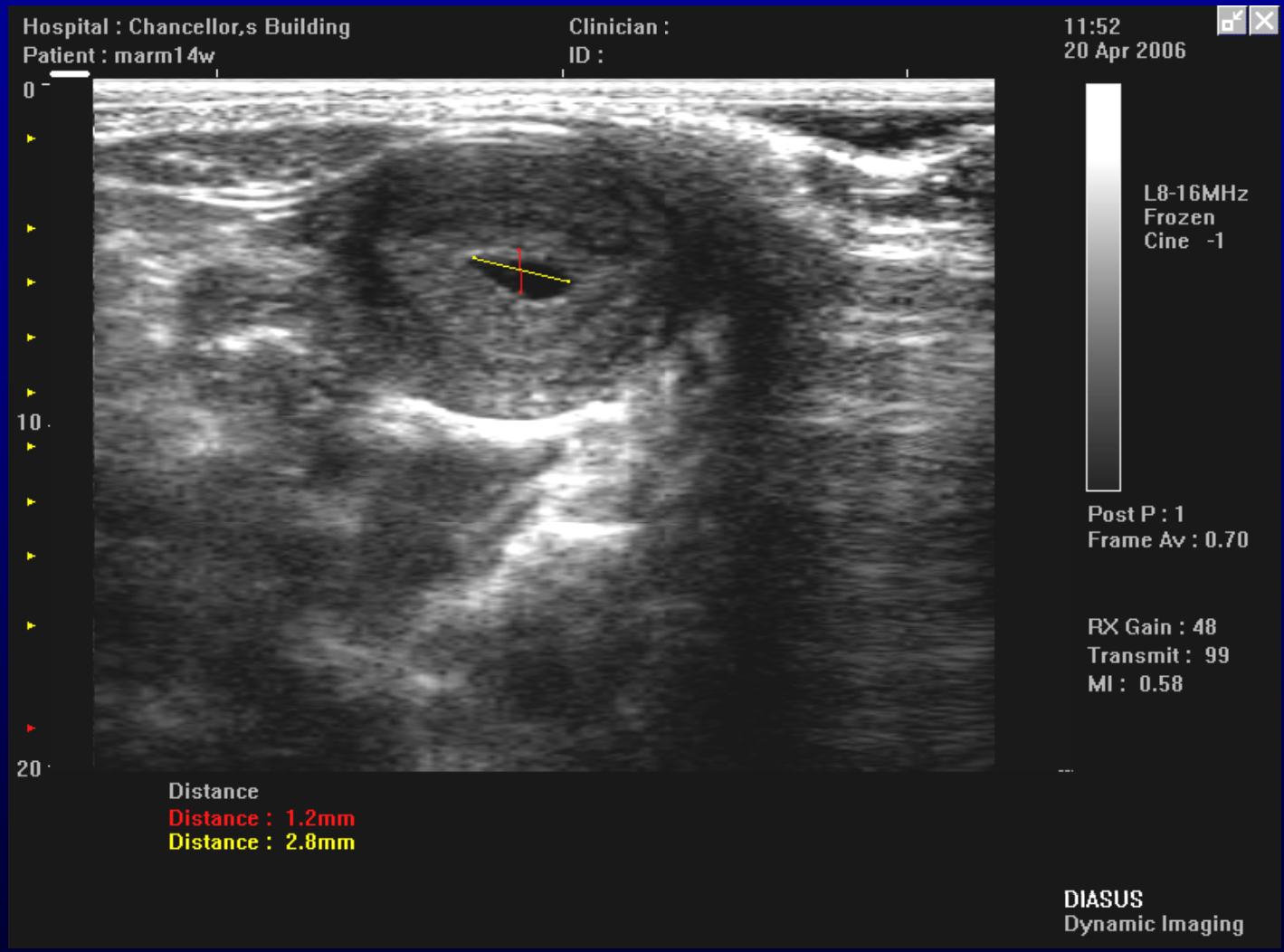


Qualitative study



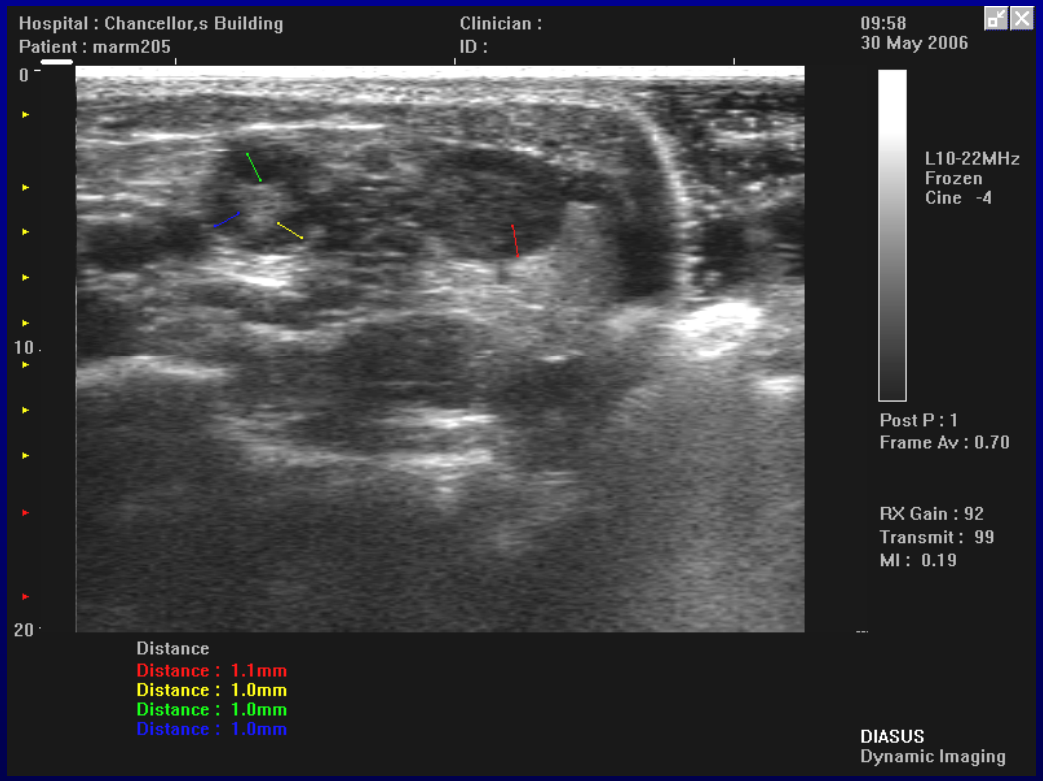


Qualitative study



Early pregnant uterus – approx 15 days

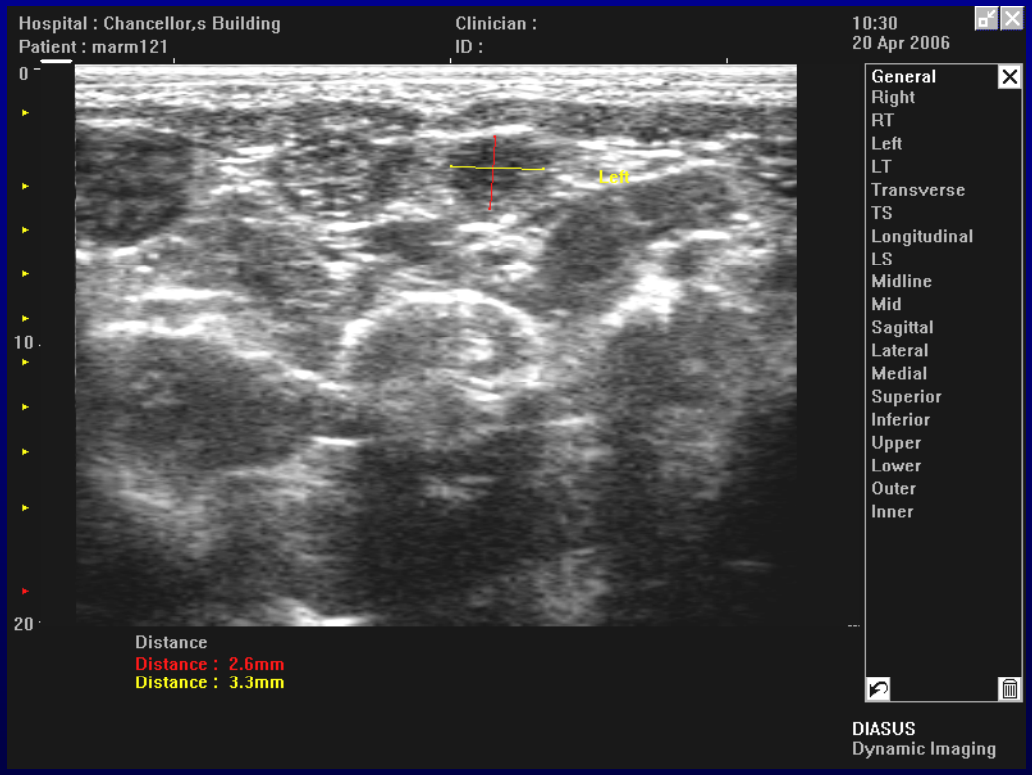
Comparative qualitative study



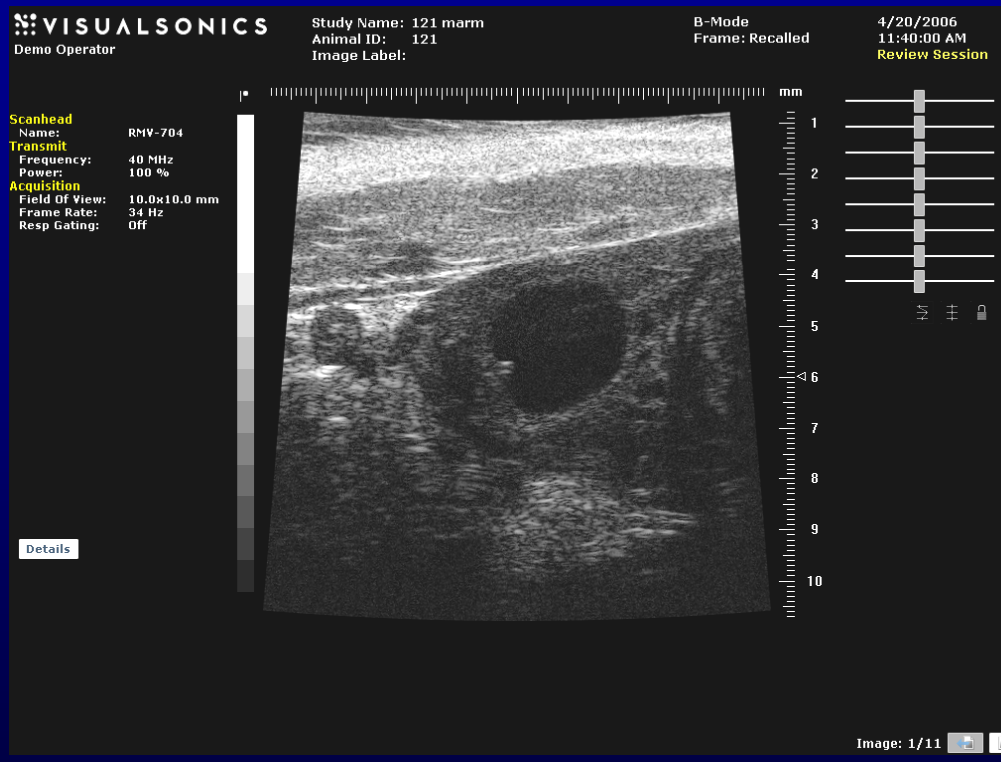
Diasus image showing 3 follicles in right ovary and 1 follicle in left ovary

Micromaxx image. Follicles not distinguishable in left ovary.

Comparative qualitative study

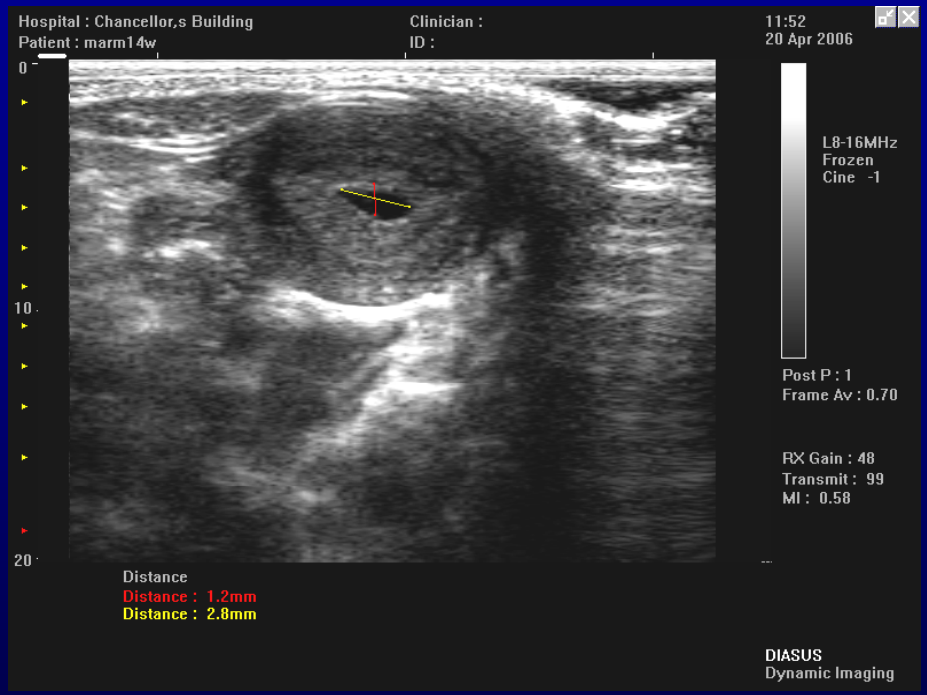


Diasus image showing follicle in left ovary

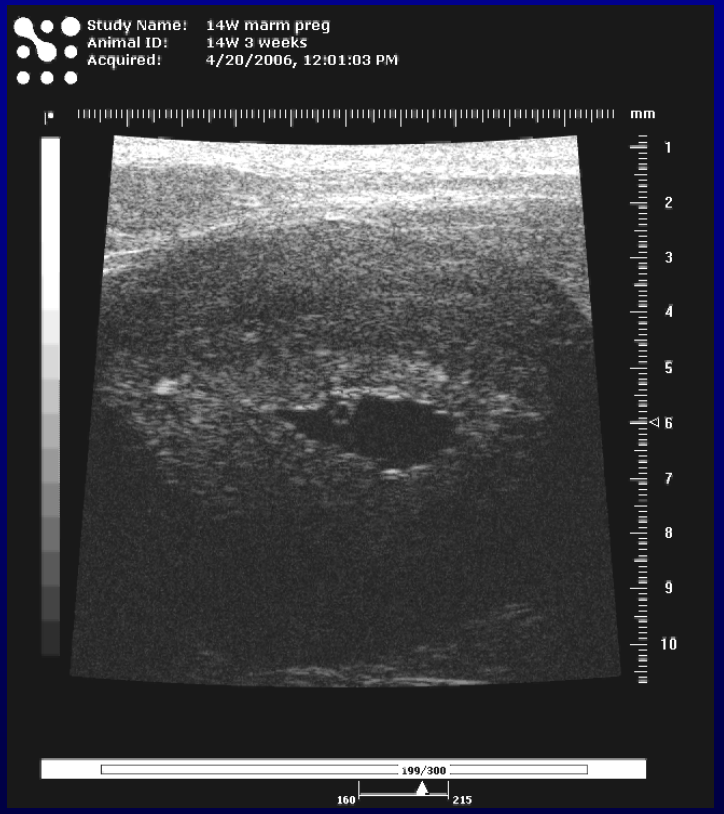


Corresponding image from Visualsonics scanner

Comparative qualitative study

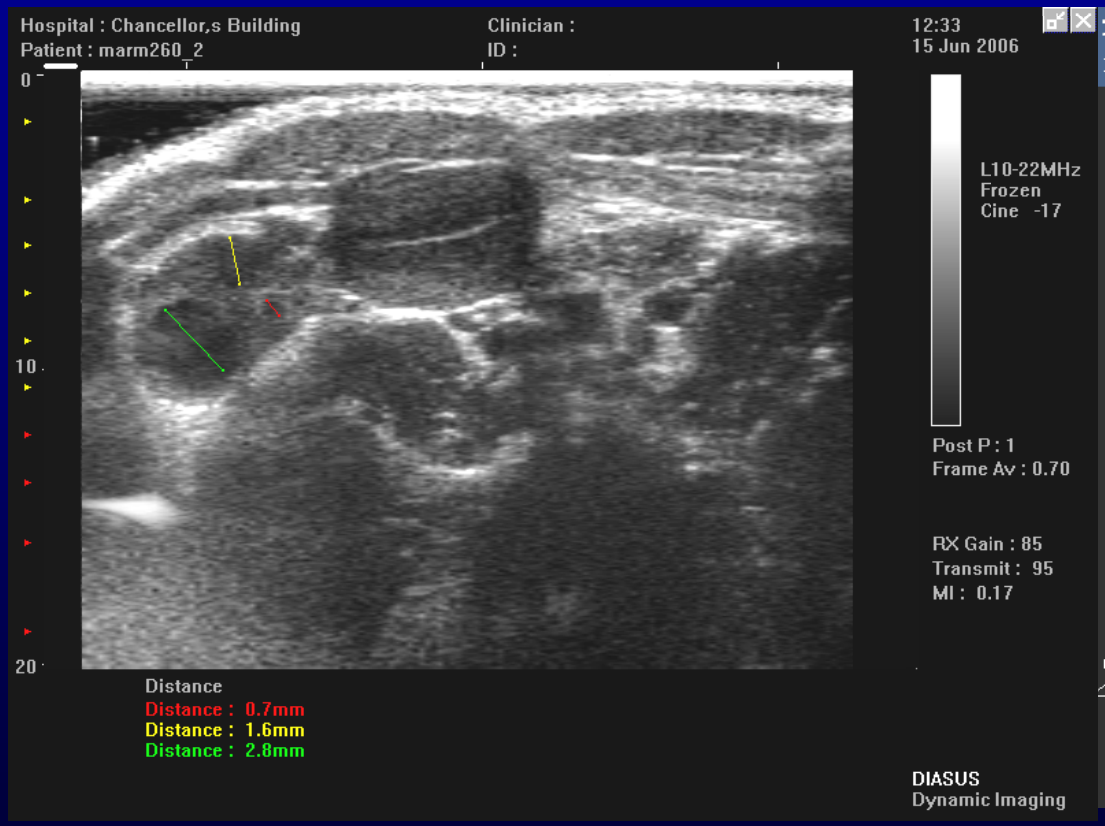


Diasus image showing early pregnancy

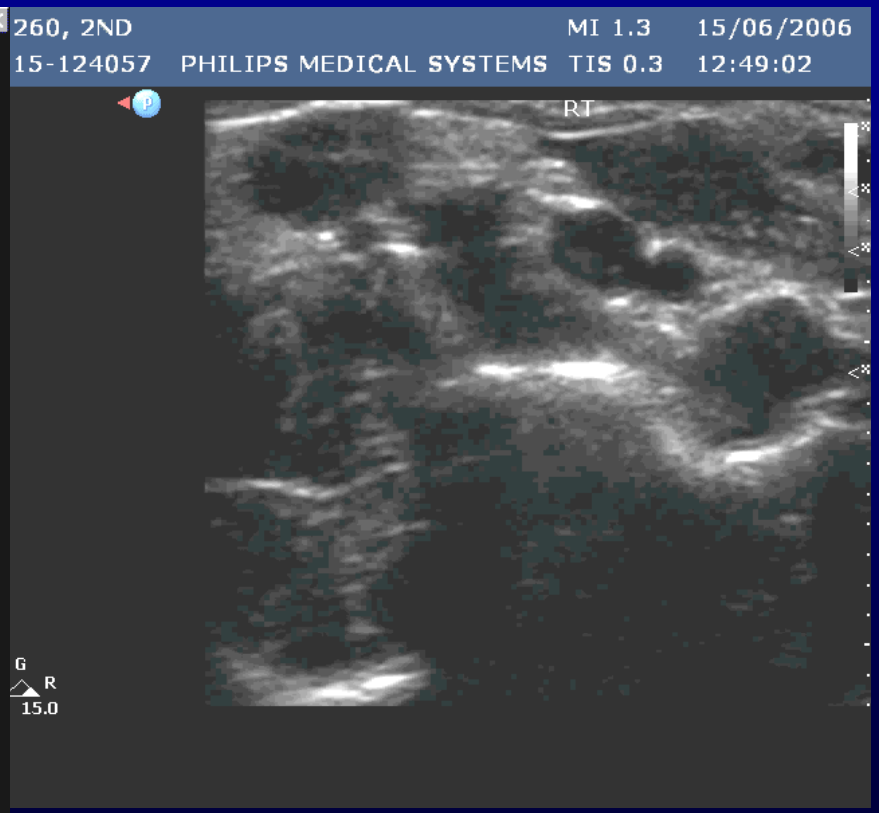


Corresponding image from Visualsonics scanner showing conceptus and endometrium

Comparative qualitative study

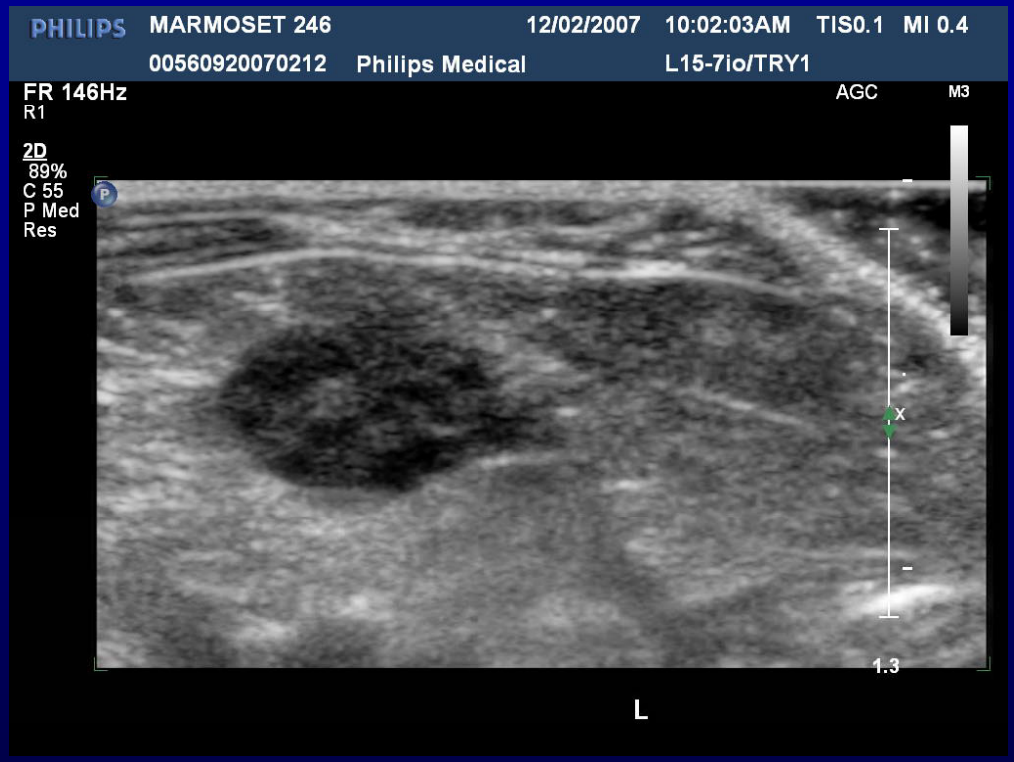


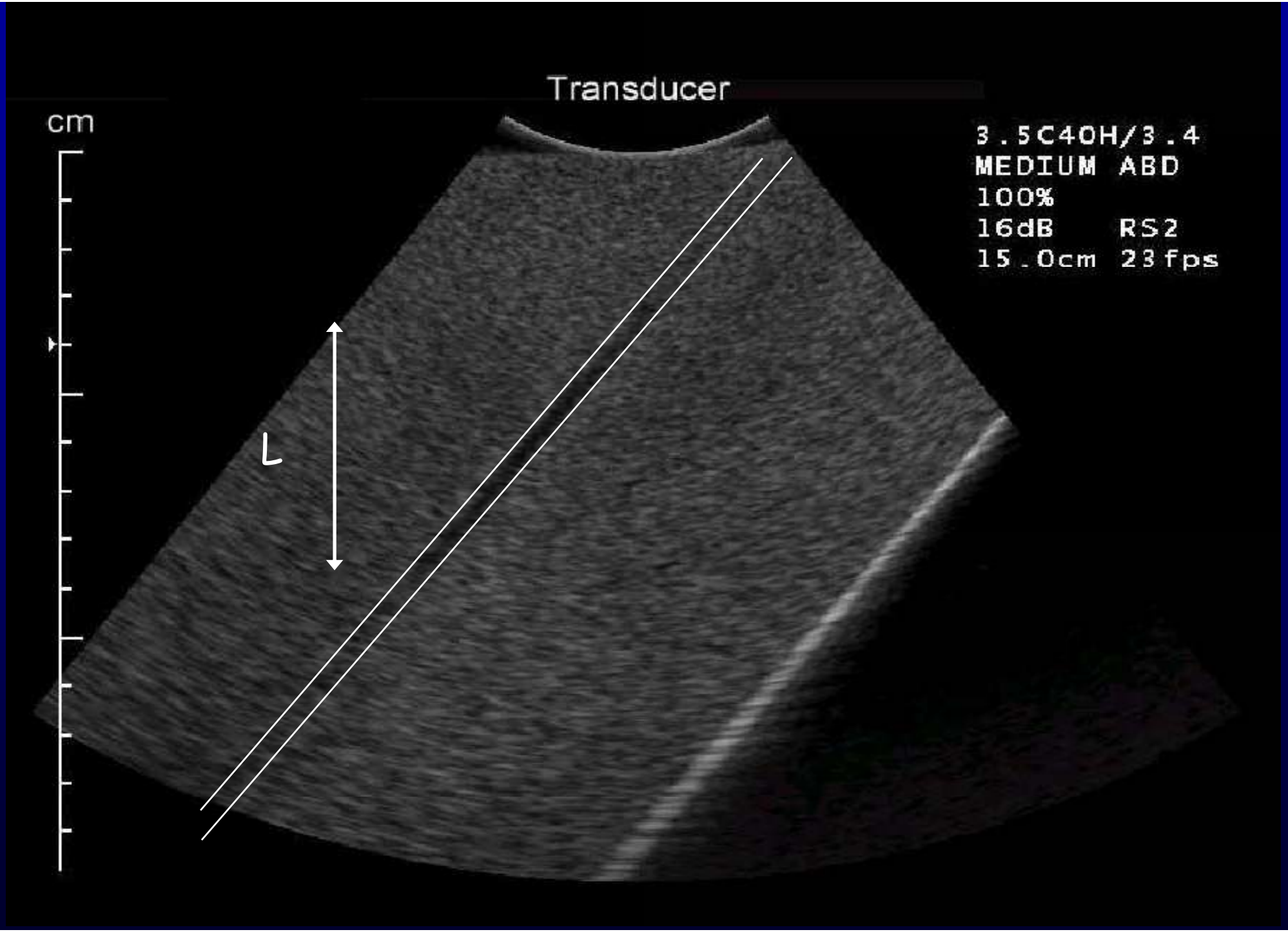
Diasus image showing three follicles in right ovary

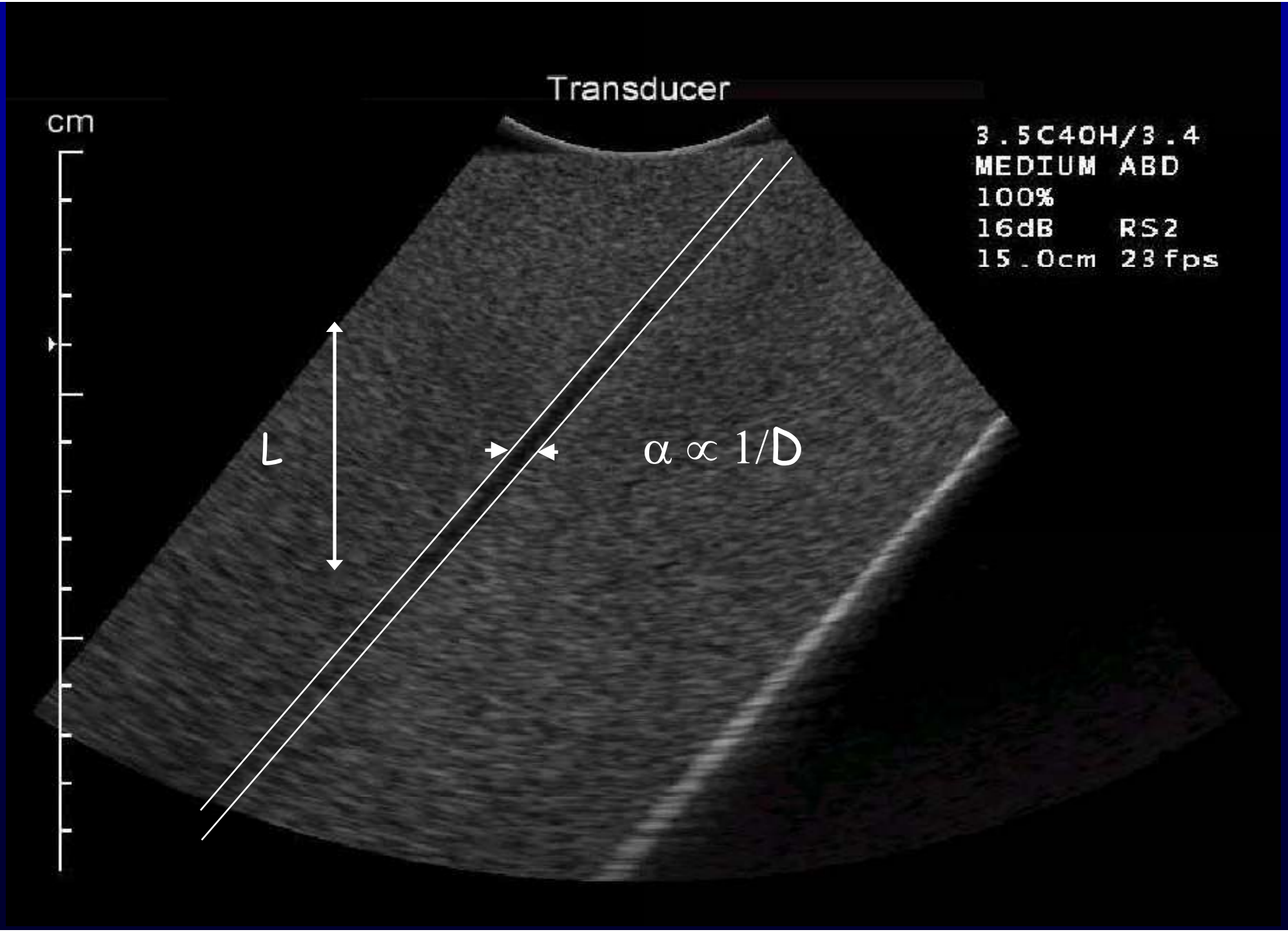


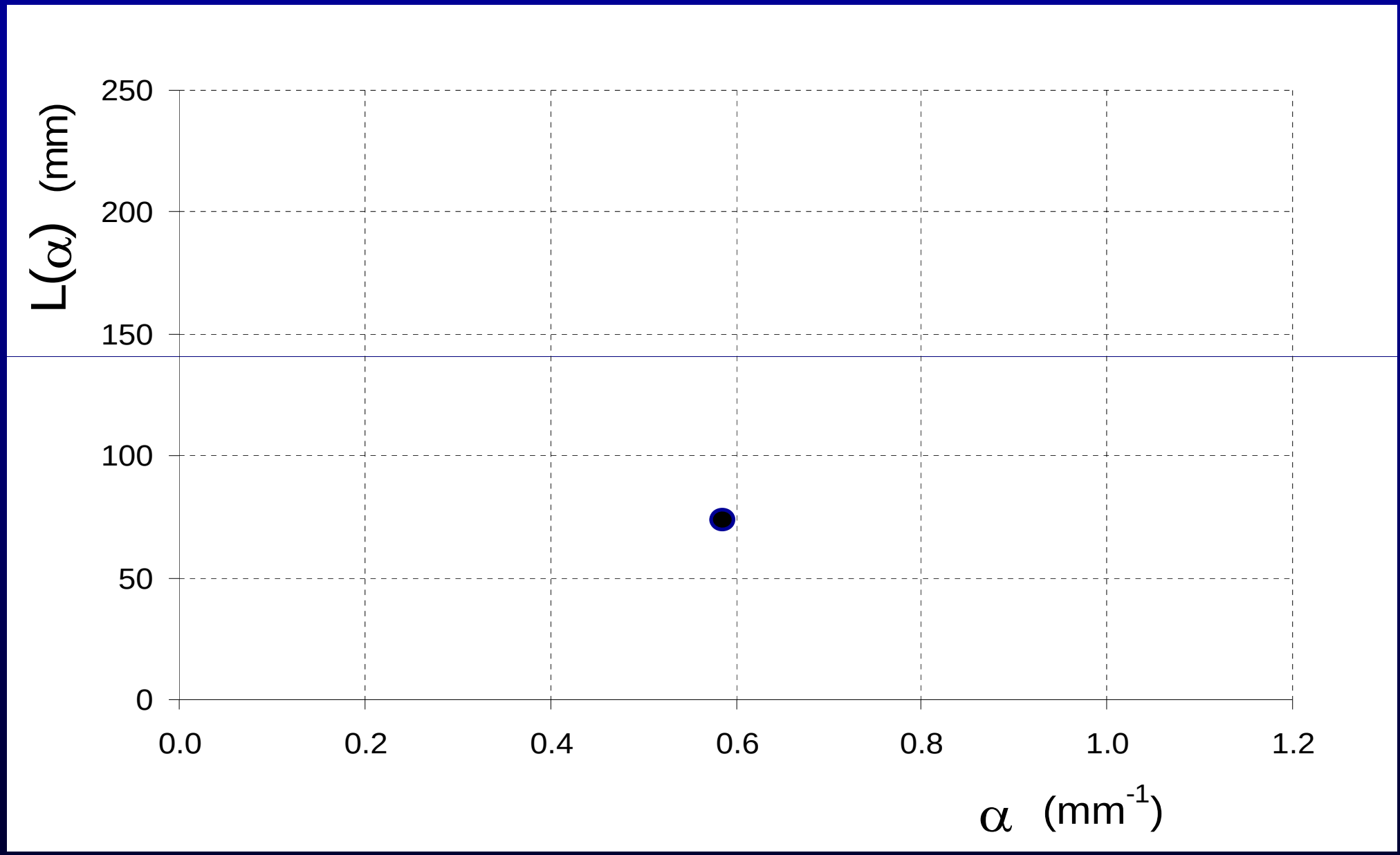
Philips image showing indistinc image of right ovary

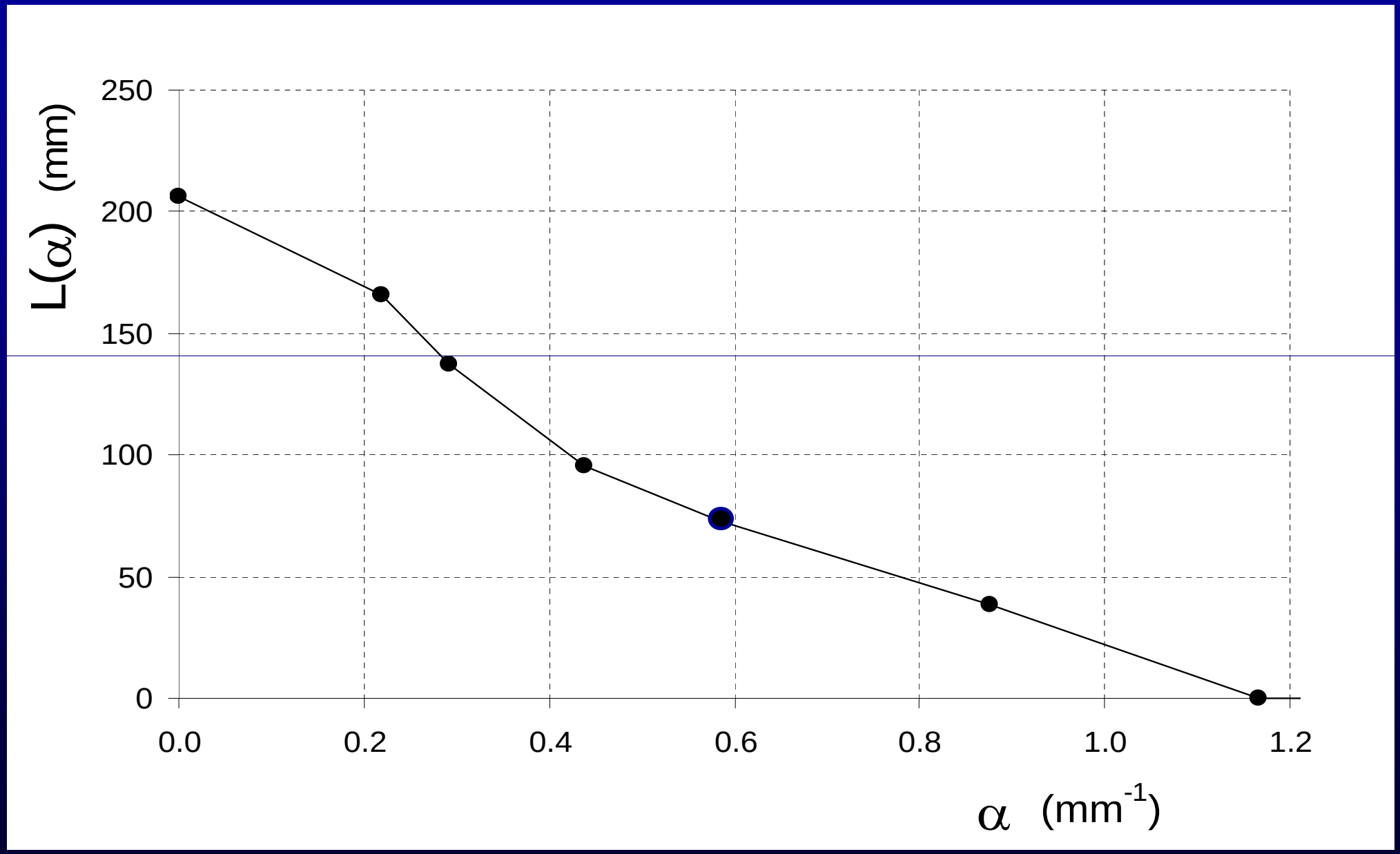
Philips Scanner (second session)



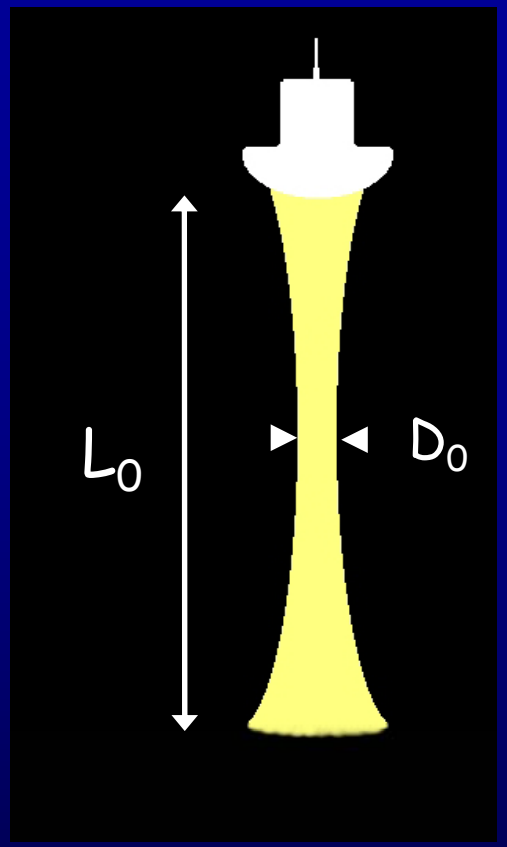

Transducer
cm
L
3.5C40H/3.4
MEDIUM ABD
100%
16dB RS2
15.0cm 23fps

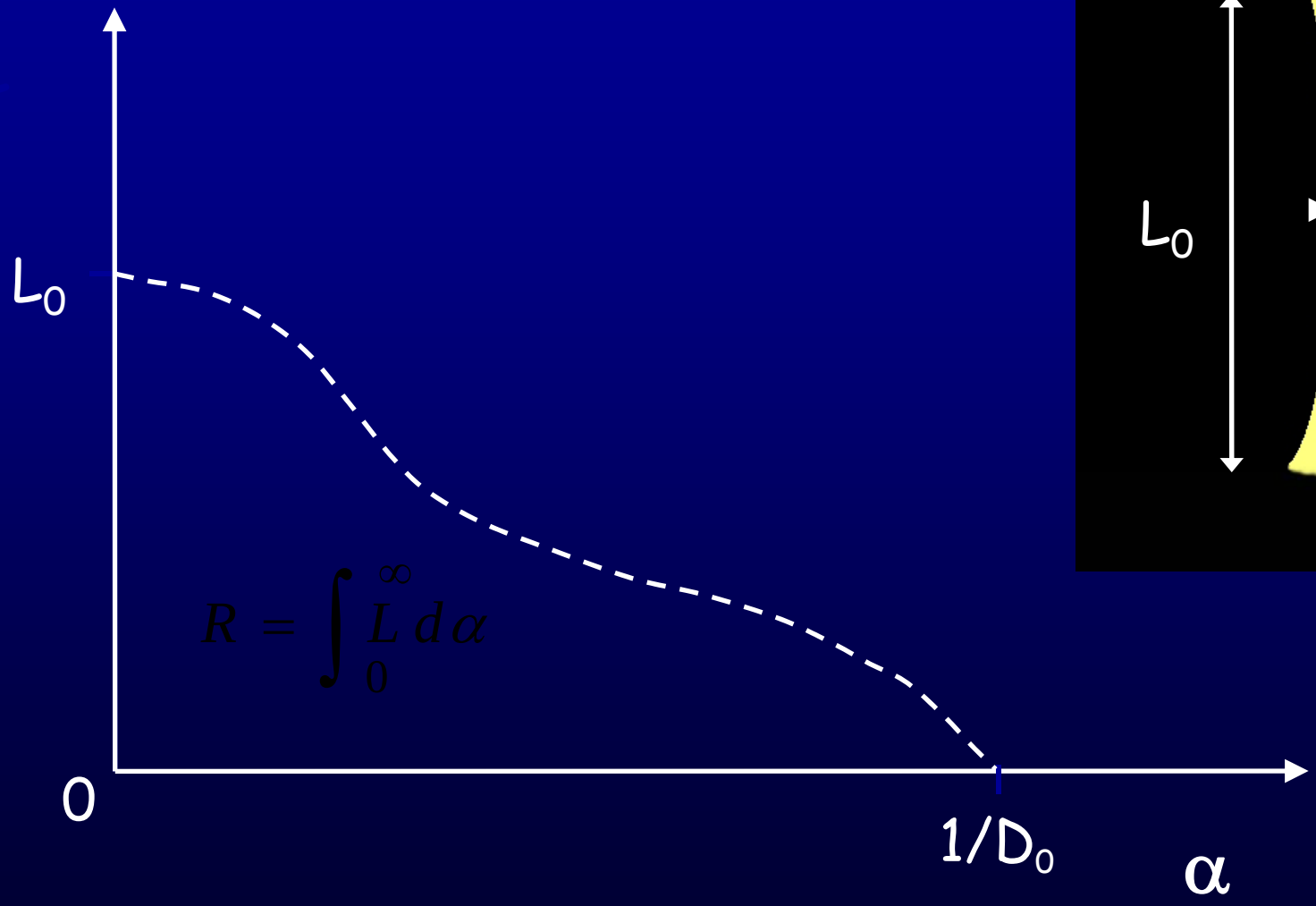

Transducer
cm
3.5C40H/3.4
MEDIUM ABD
100%
16dB RS2
15.0cm 23fps
L
α ∝ 1/D


L(α) (mm)
250
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
α (mm-1)


250
200
150
100
50
0
L(α) (mm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
α (mm-1)

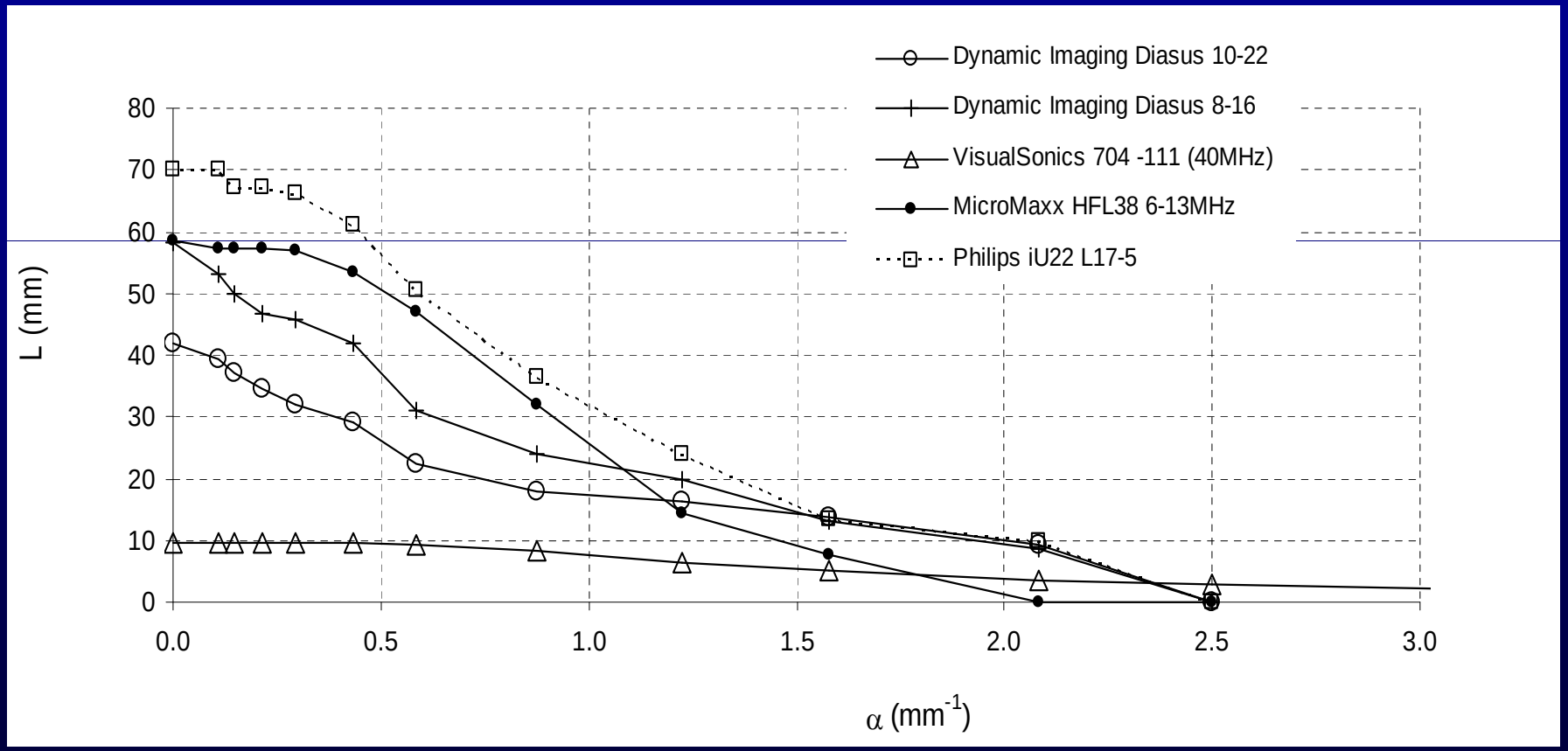
Resolution Integral R



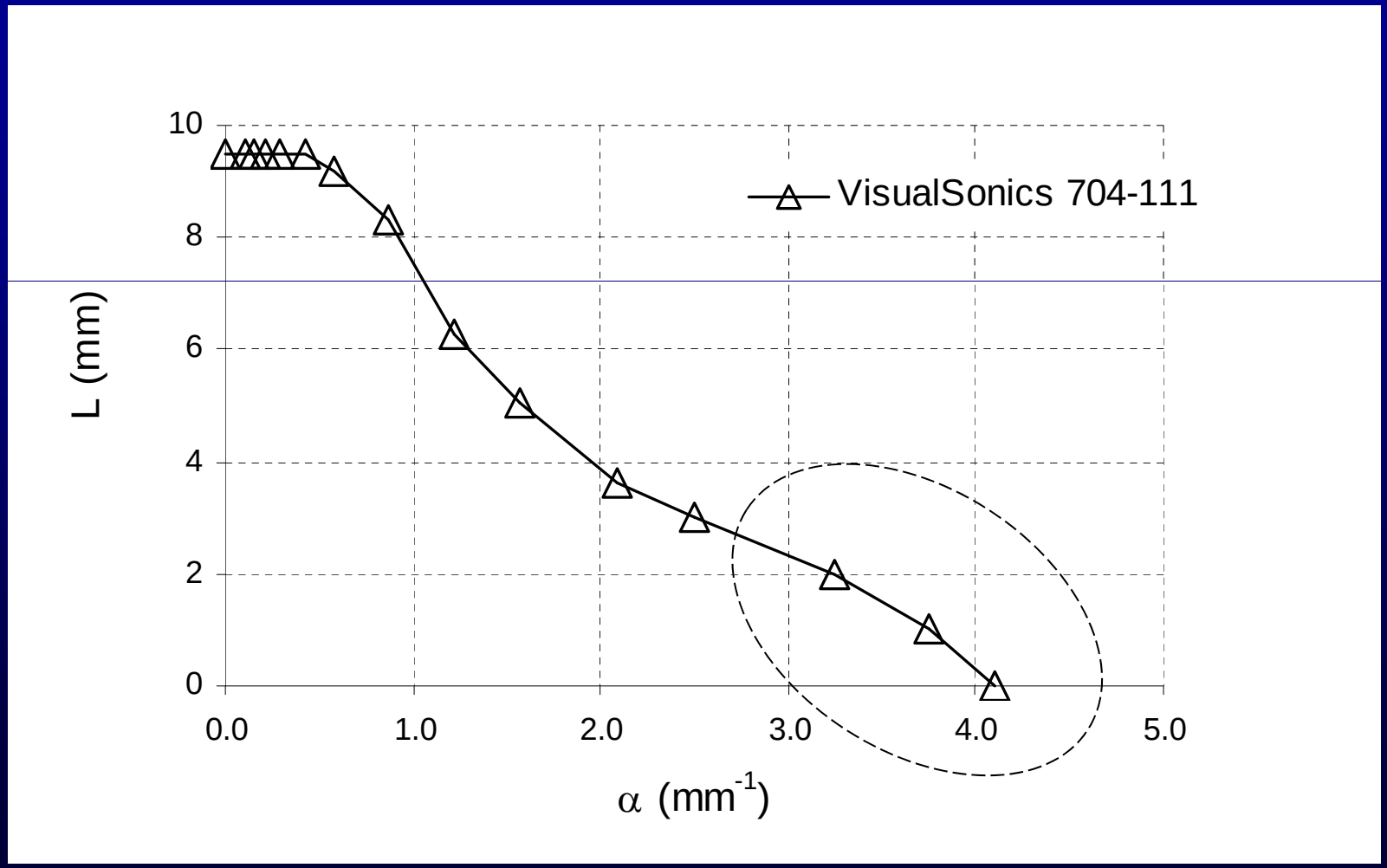


$$R = \int_0^{\infty} L \, d\alpha$$

Quantitative Assessment of Scanners



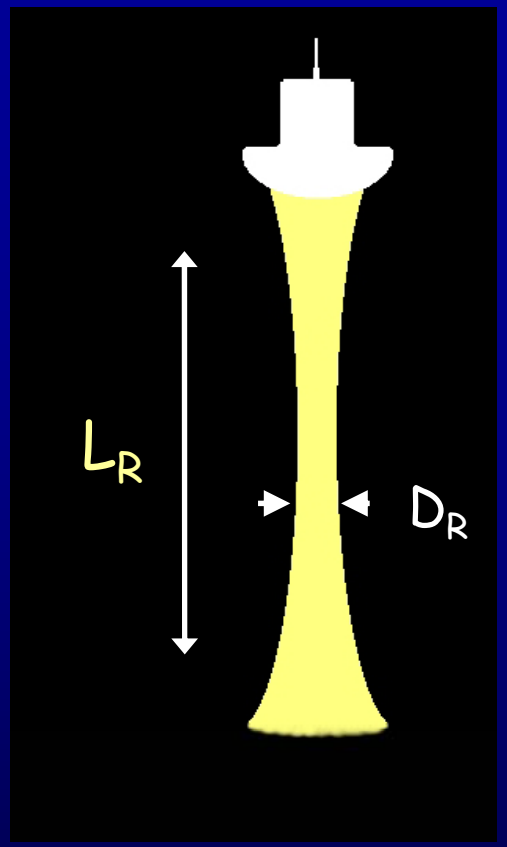
Quantitative Assessment of Scanners

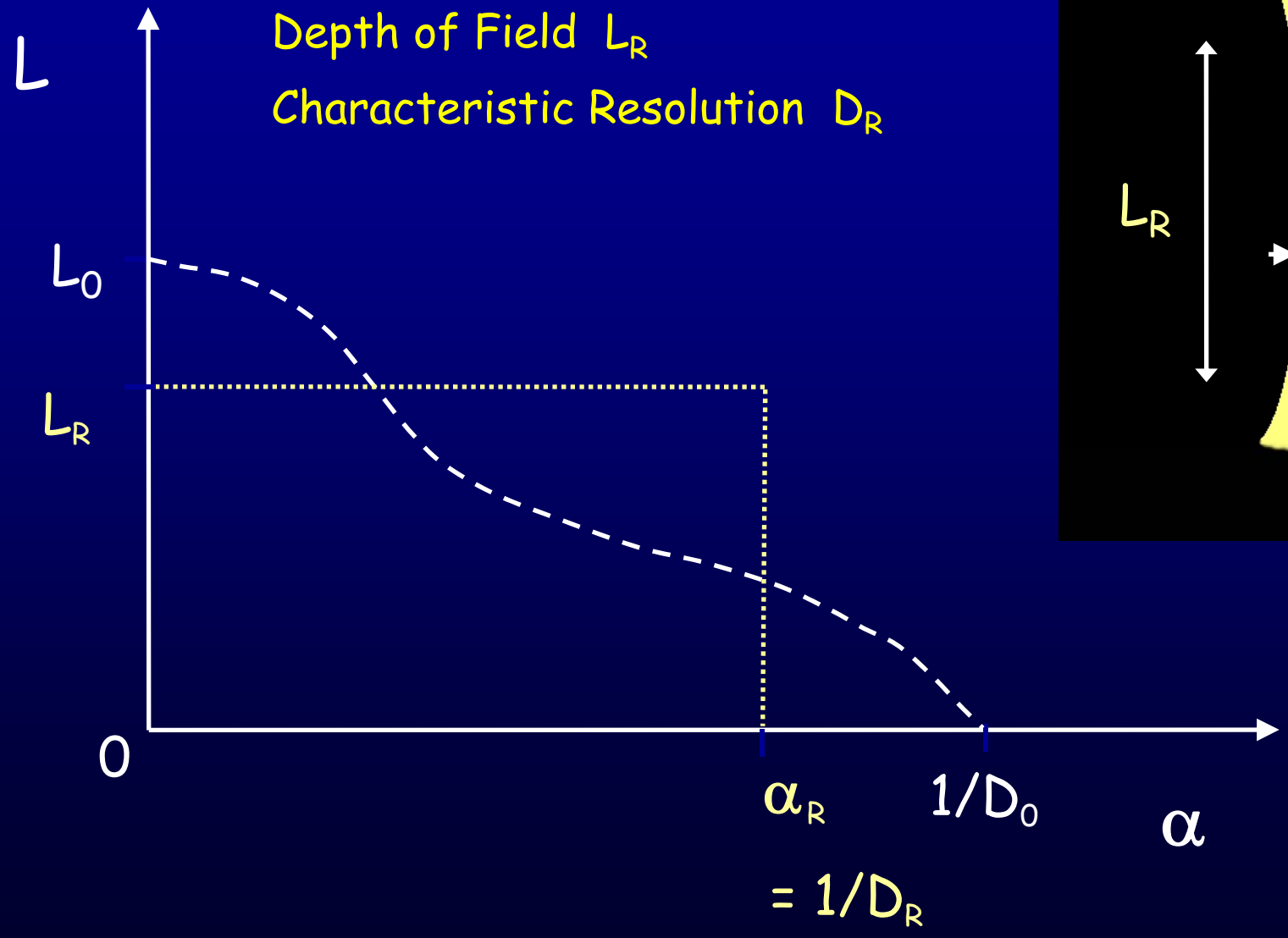


Resolution Integral $R = L_R/D_R$

Depth of Field L_R

Characteristic Resolution D_R





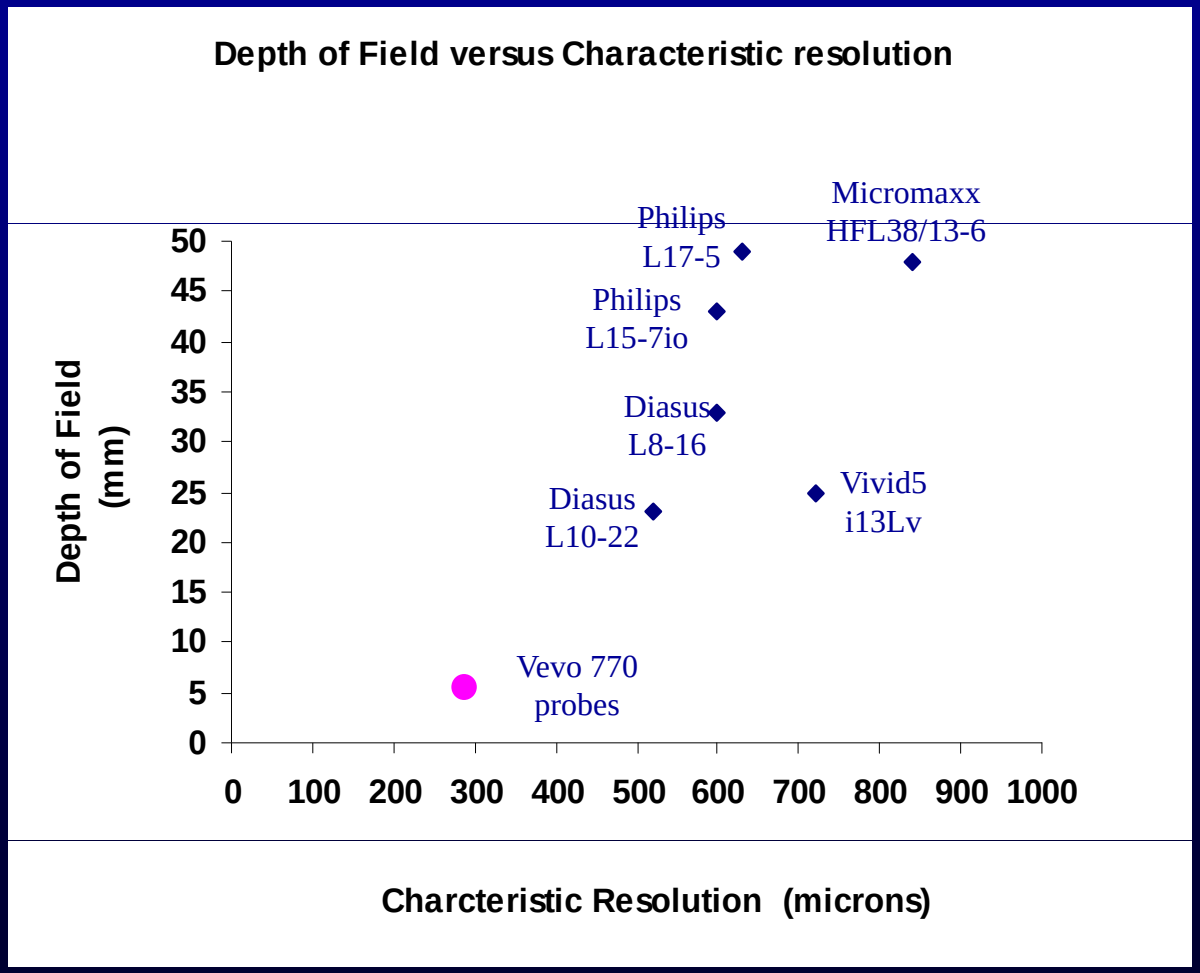
Ultrasonic Scanner Results

Scanner	Probe	Resolution Integral (R)	Depth of Field (mm)	Characteristic Resolution (mm)
Phillips iu22 scanner	L17-5	75	50	0.67
SonoSite Micromaxx scanner	HFL38 6-13 MHz	57	48	0.84
Diasus Scanner	L8-16	55	33	0.6
Diasus Scanner	L10-22	44	23	0.52
Visualsonics	704	20	7	0.35

Resolution integral, depth of field and characteristic resolution of the five ultrasonic transducers.

Table 1 Resolution integral, depth of field and characteristic resolution of the six ultrasonic transducers.

Results from Scanners using Clinical and Pre-clinical Pipe Phantoms



Visualsonics Vevo 770

- Single element probe
- Multiple probe heads to ensure focussed at necessary depth

Structure

- Assess the performance of clinical ultrasound transducers
- Assess the performance of commercially available ultrasound transducers for pre-clinical imaging
- Assess the performance of commercially available pre-clinical transducers

The Wellcome Trust High-Resolution Ultrasound Imaging Facility

April 2008

- RMV 704
- RMV 707B
- RMV 708
- RMV 710B
- RMV 711

Characteristics of probes - Manufacturer's data

Probe Name	Centre Frequency (MHz)	Lateral Resolution (μm)	Depth of Field (mm)
RMV 710	25	140	2.7
RMV707B	30	115	2.2
RMV 704	40	80	1.5
RMV708	55	70	1.4
RMV711	55	90	2.4

High Resolution Pipe Phantom

Pipes of diameter (micron):

1470

550

330

193

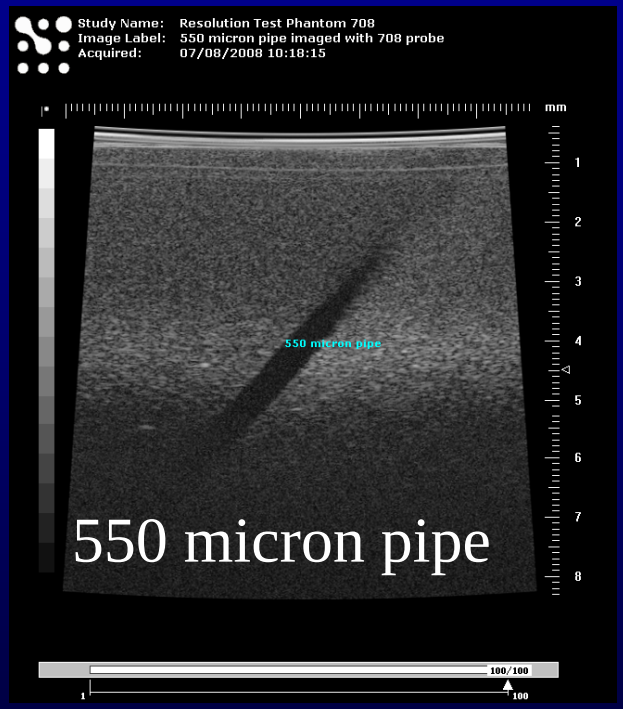
139

93

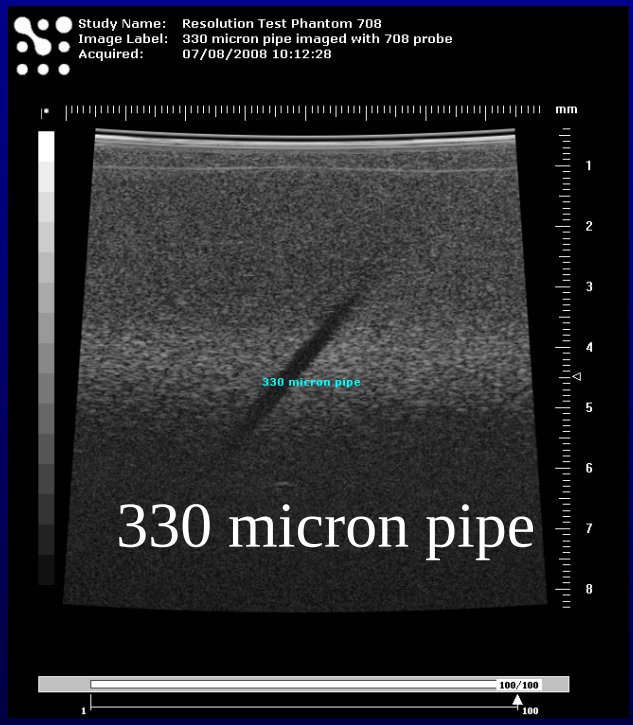
68

45

Example images of Pre-clinical Pipe Phantom Vevo 770

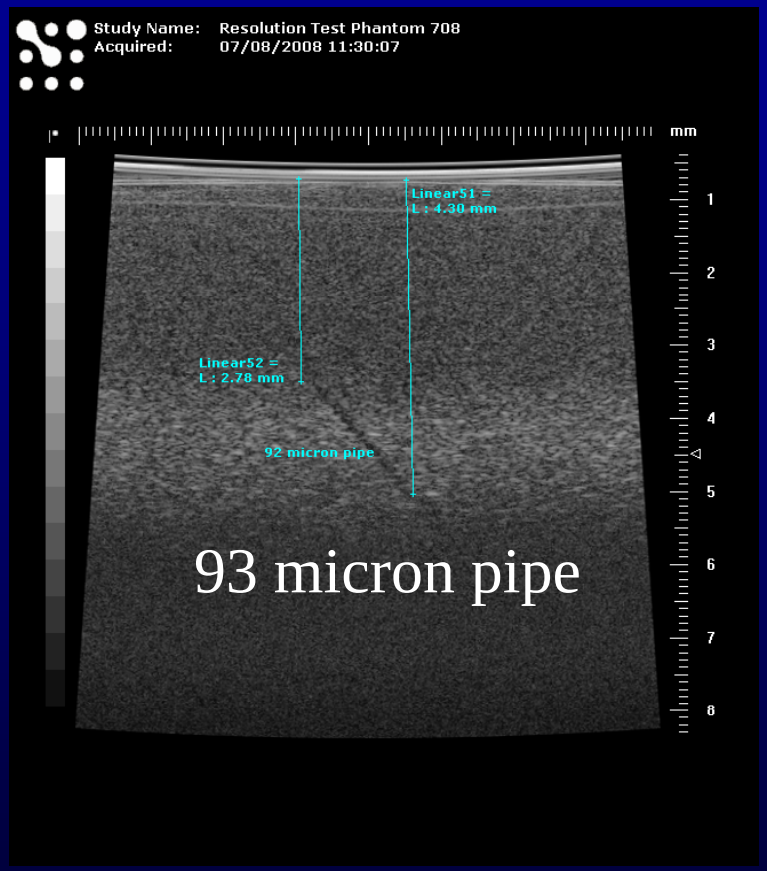


55MHz

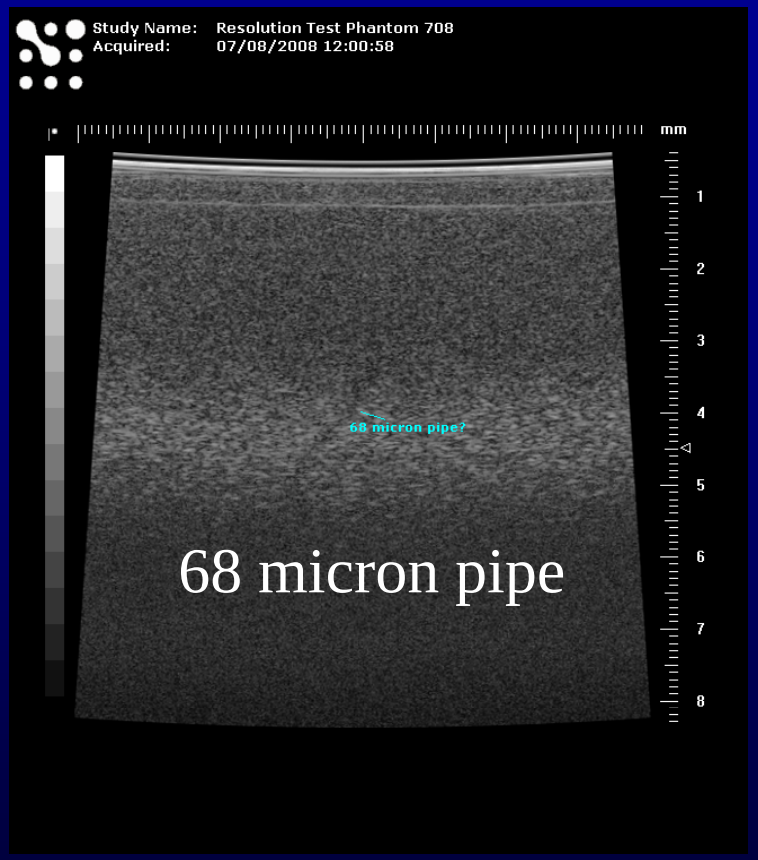


55MHz

Example images of Pre-clinical Pipe Phantom Vevo 770

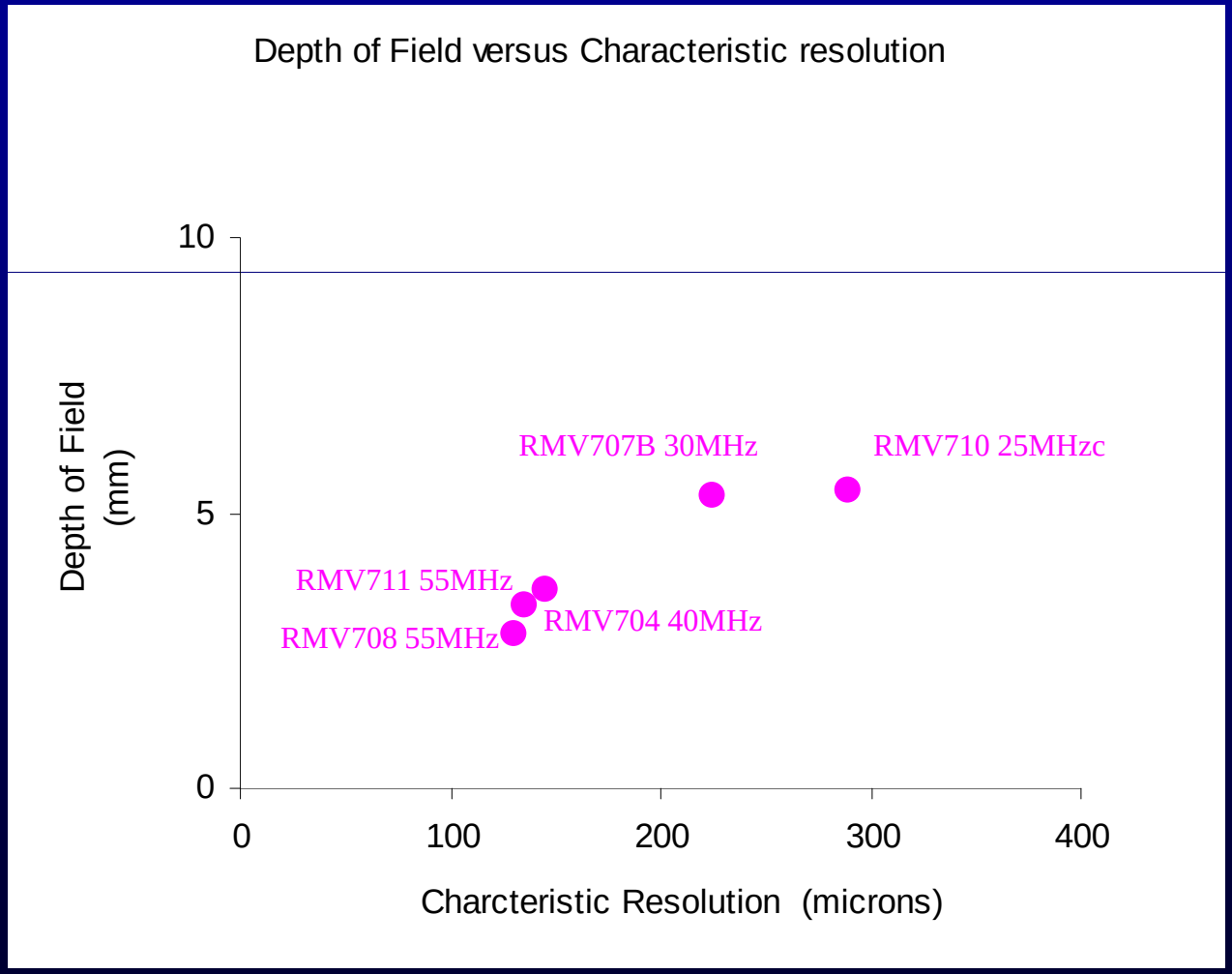


55MHz

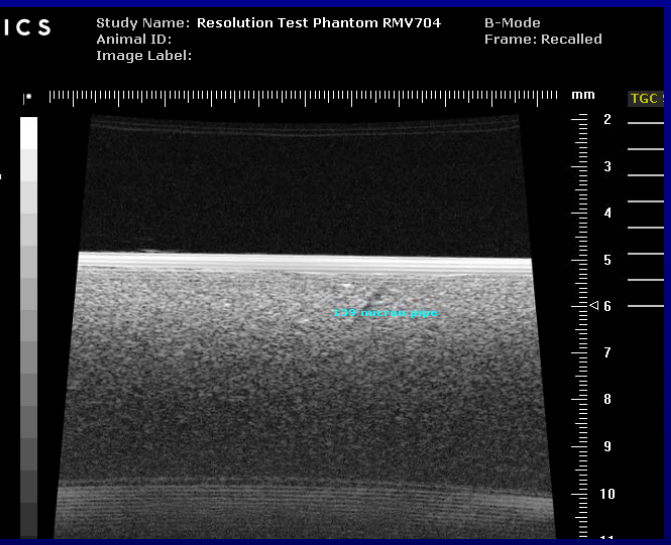


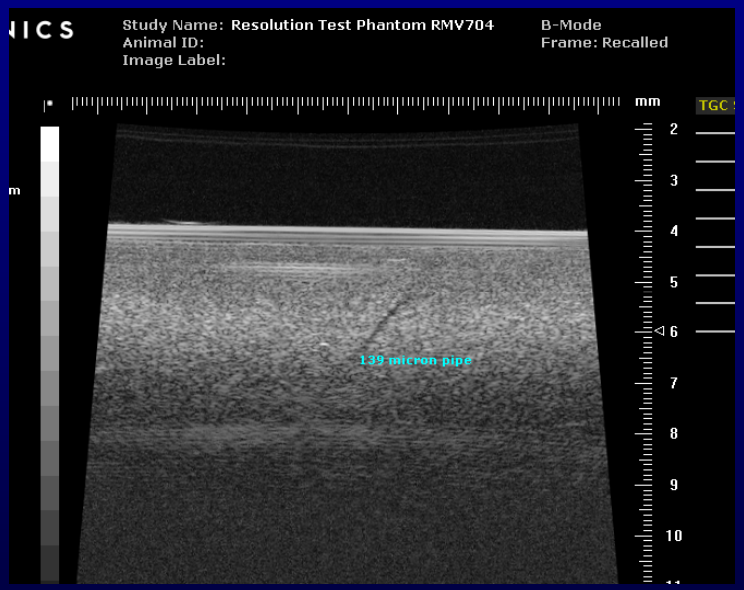
55MHz

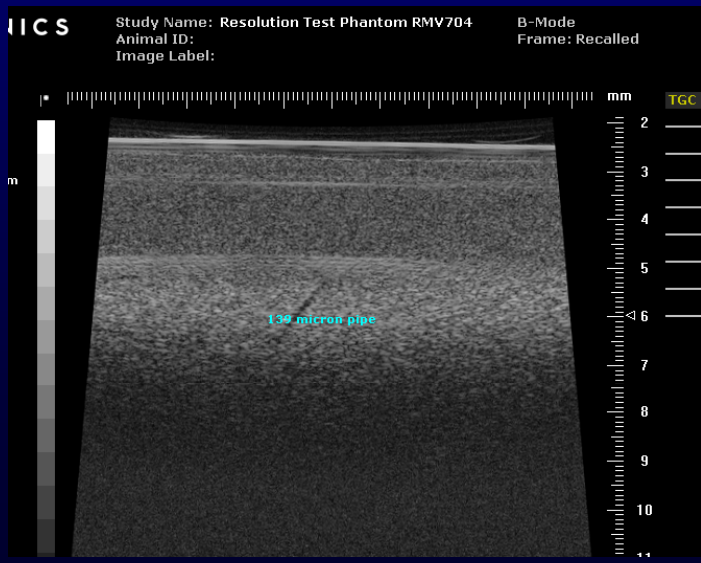
Results from Vevo 770 using Pre-clinical Pipe Phantom



Results from Vevo 770- RMV704 probe using tracking technique

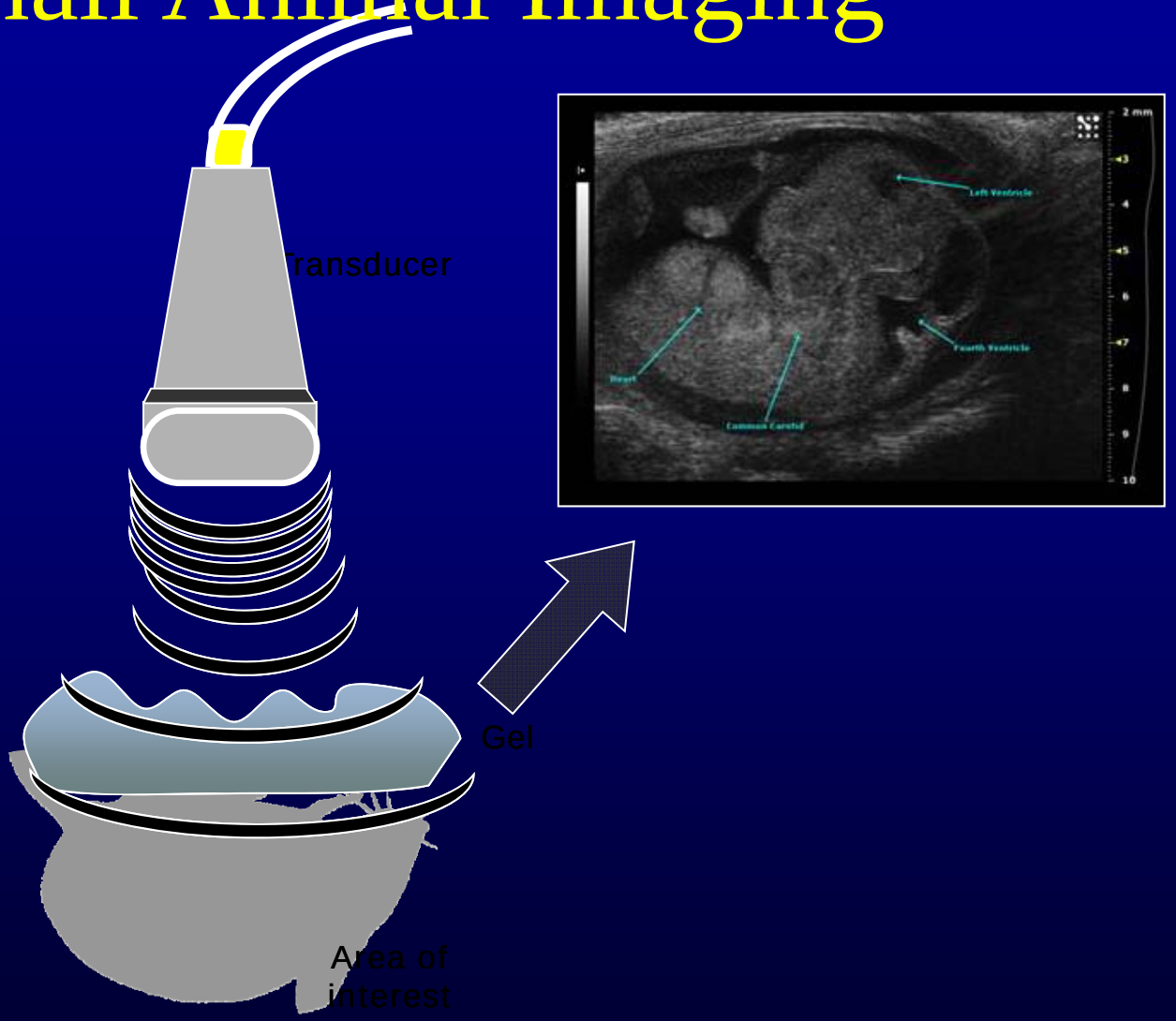




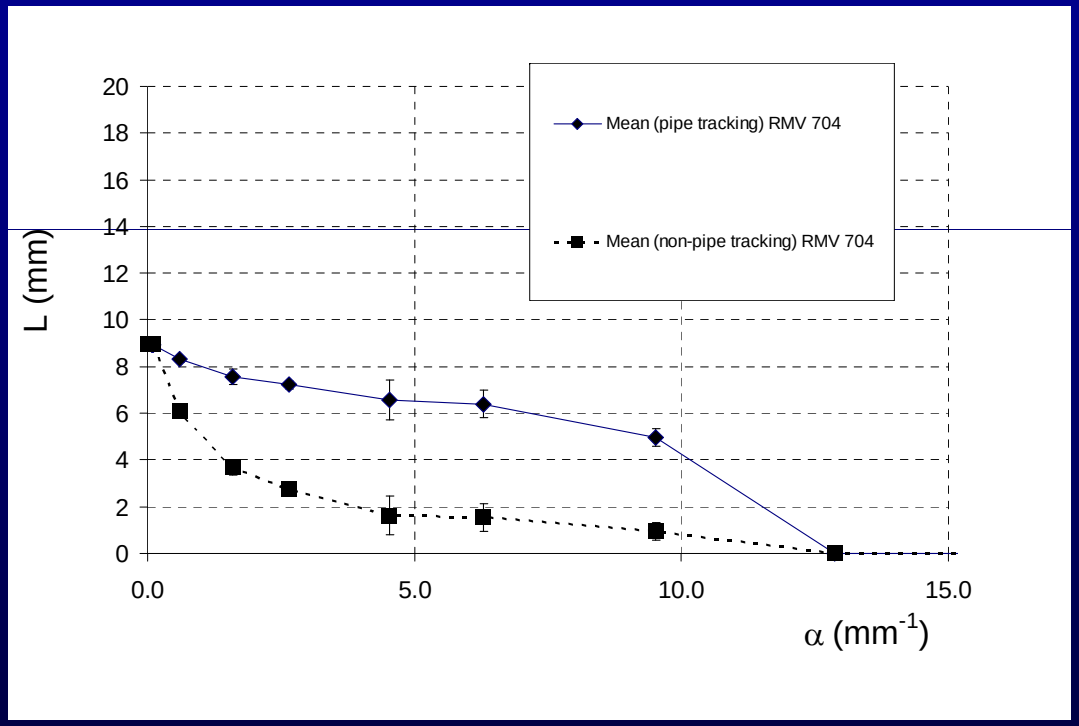


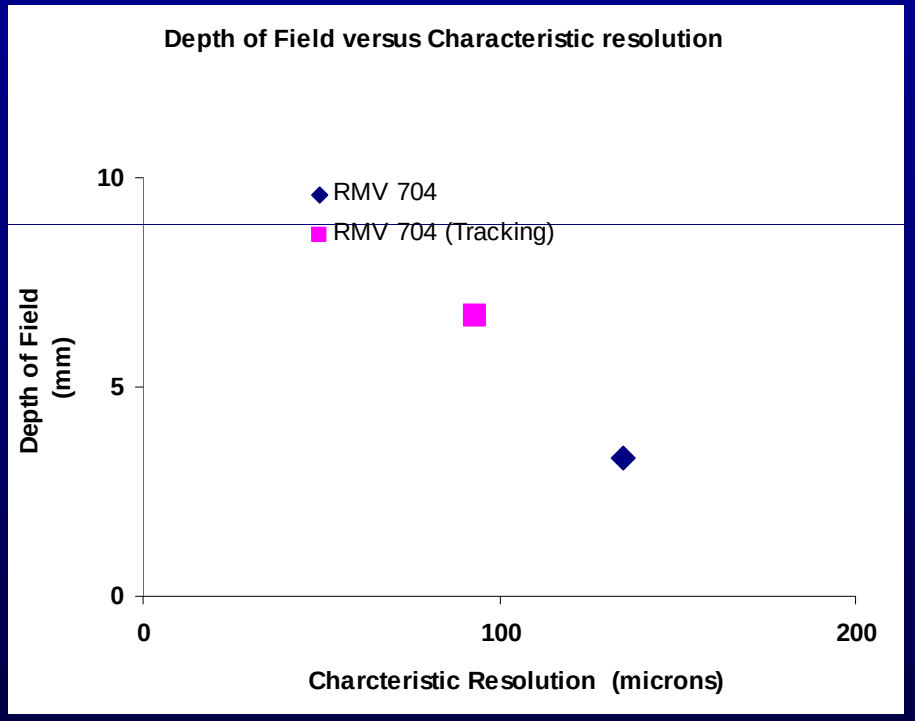
139 micron pipe

Small Animal Imaging



Results from Vevo 770- RMV704 probe using tracking technique





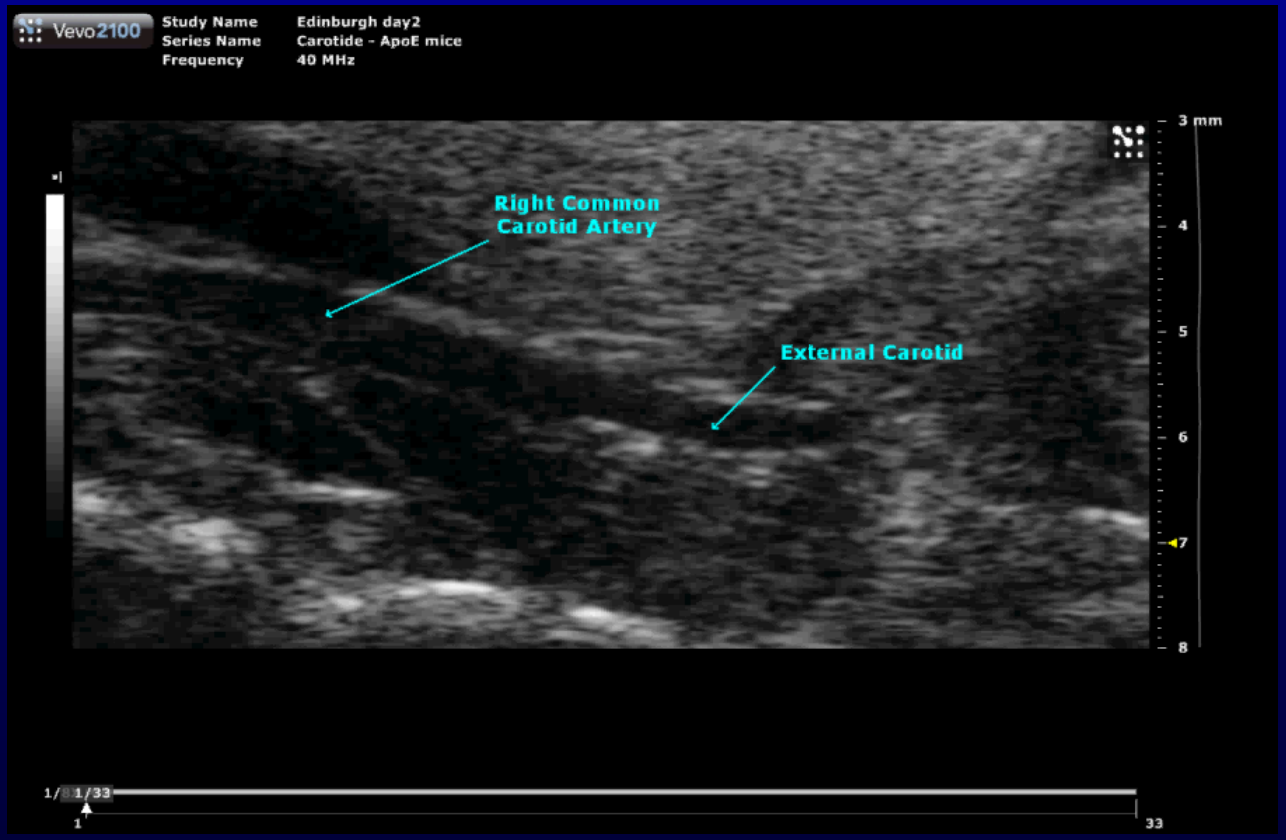
Visualsonics Vevo 2100
Linear Array Technology

- Linear array technology
- Colour Doppler
- Wide field of view

Visualsonics Vevo 2100 - transducers

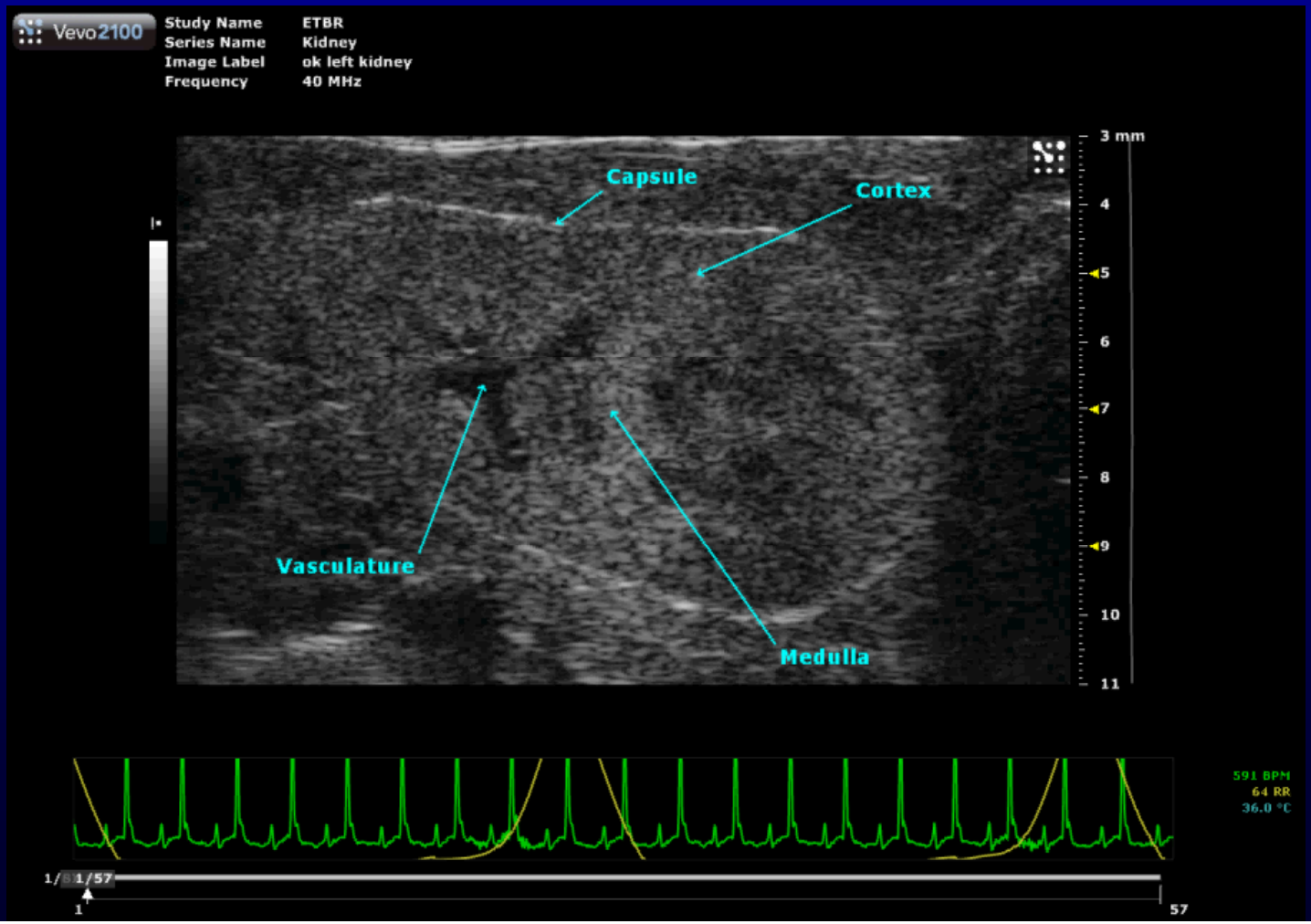
Transducer	Centre Frequency (MHz)	Frequency Bandwidth (MHz)	FOV (mm)
MS200	15	9-18	36
MS250	21	13-24	30
MS400	30	18-38	20
MS550S	40	32-56	11
MS550D	40	22-55	7

Small Animal Imaging
Vevo 2100



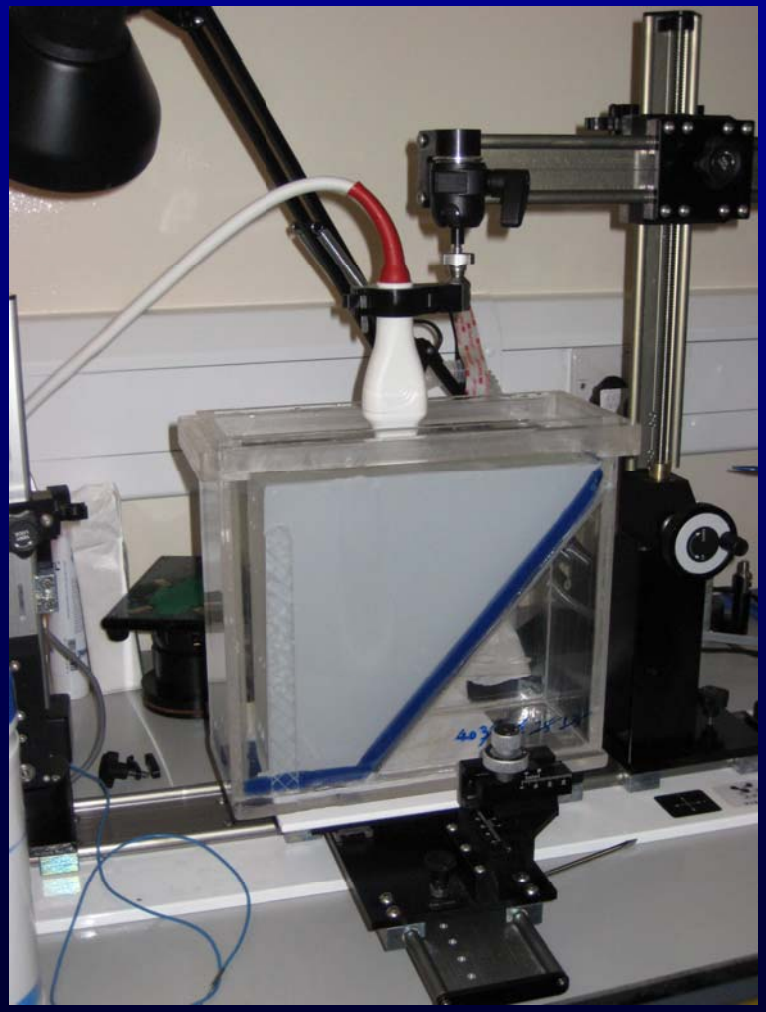
MS550S – 40MHz

Small Animal Imaging
Vevo 2100

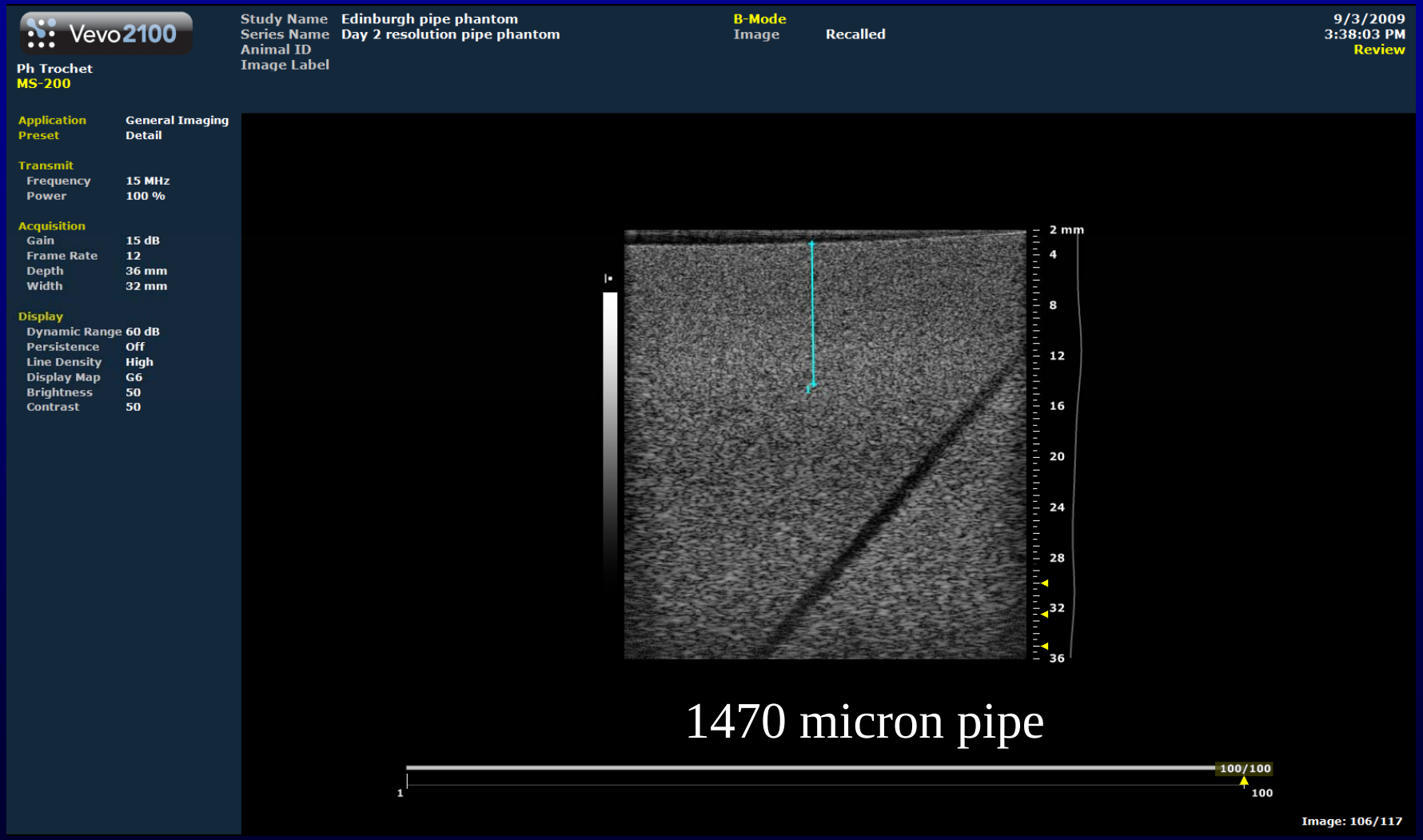


MS550D – 40MHz

Clinical Pipe Phantom with Vevo 2100 probe

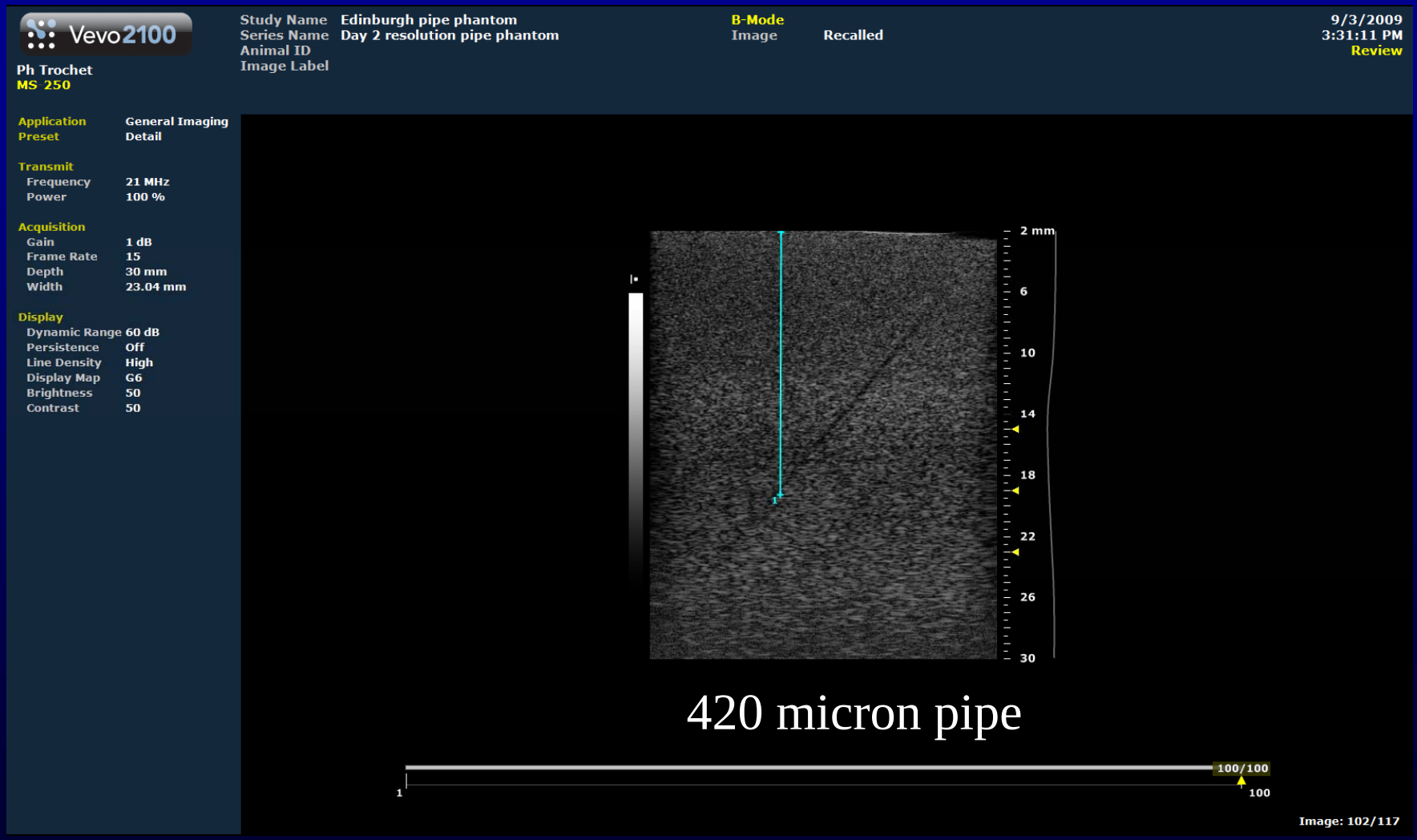


Example images of Clinical Pipe Phantom Vevo 2100, MS200, 15MHz



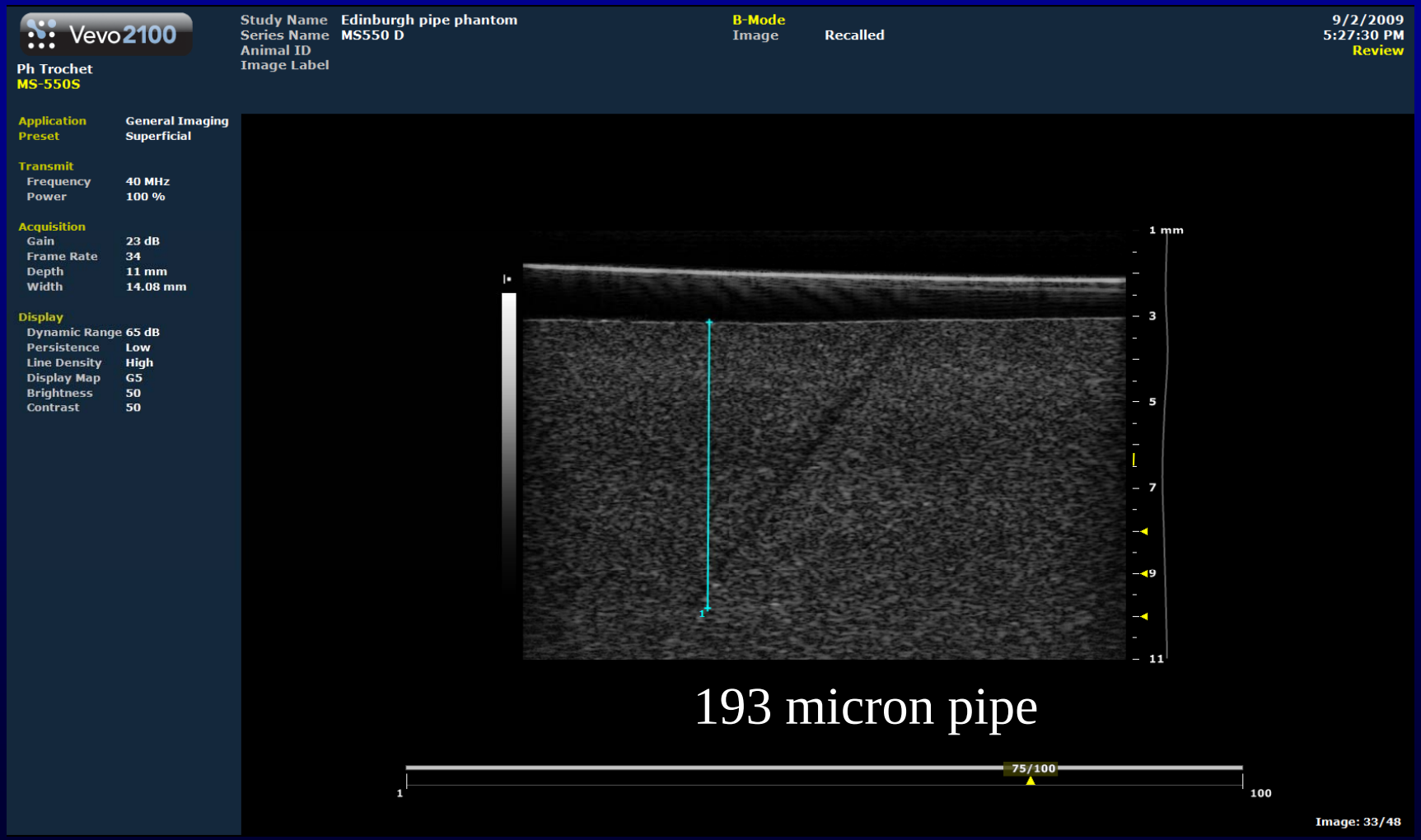
1470 micron pipe

Example images of Clinical Pipe Phantom Vevo 2100, MS250, 21MHz



420 micron pipe

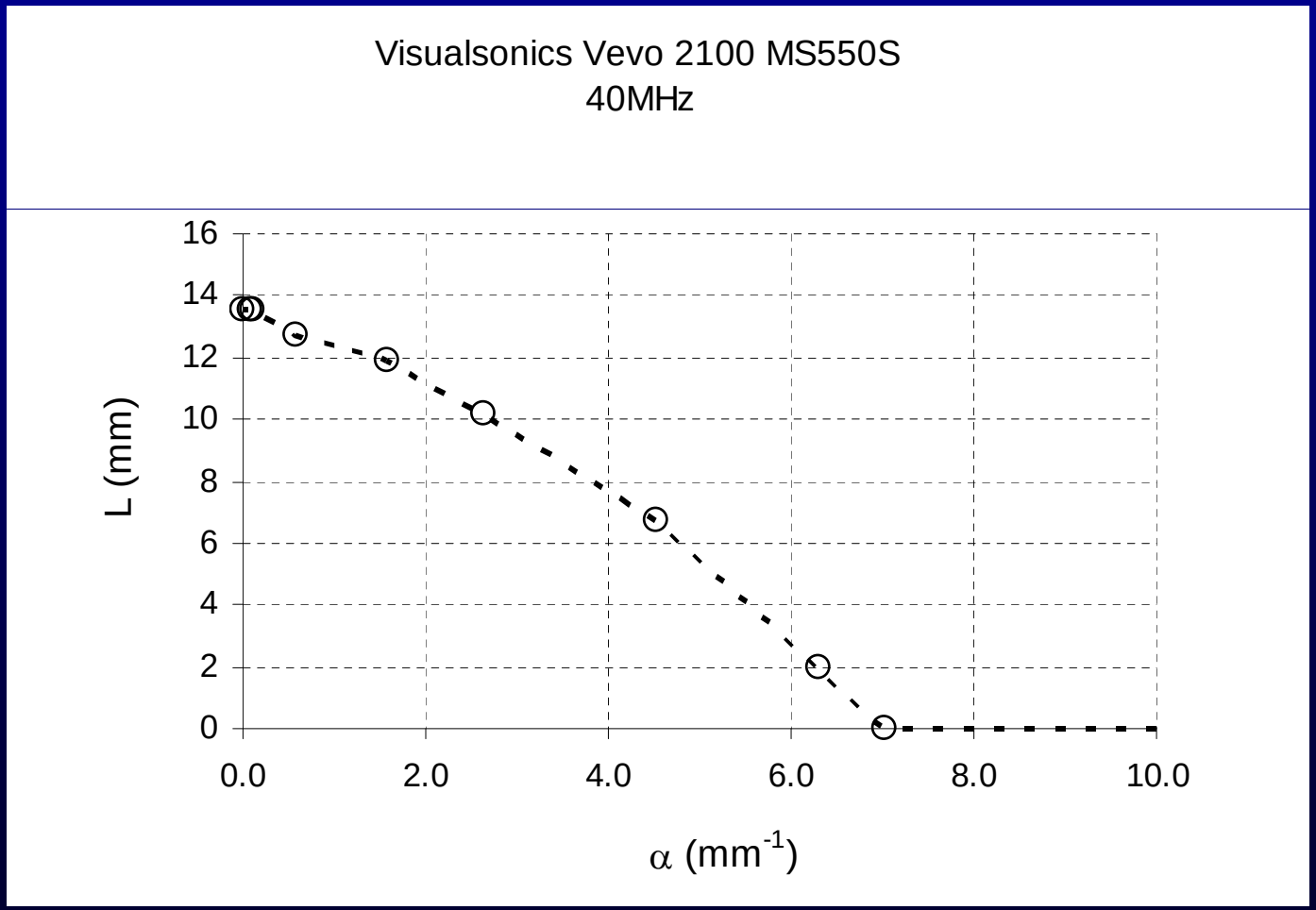
Example images of Pre-clinical Pipe Phantom Vevo 2100, MS550D, 40MHz



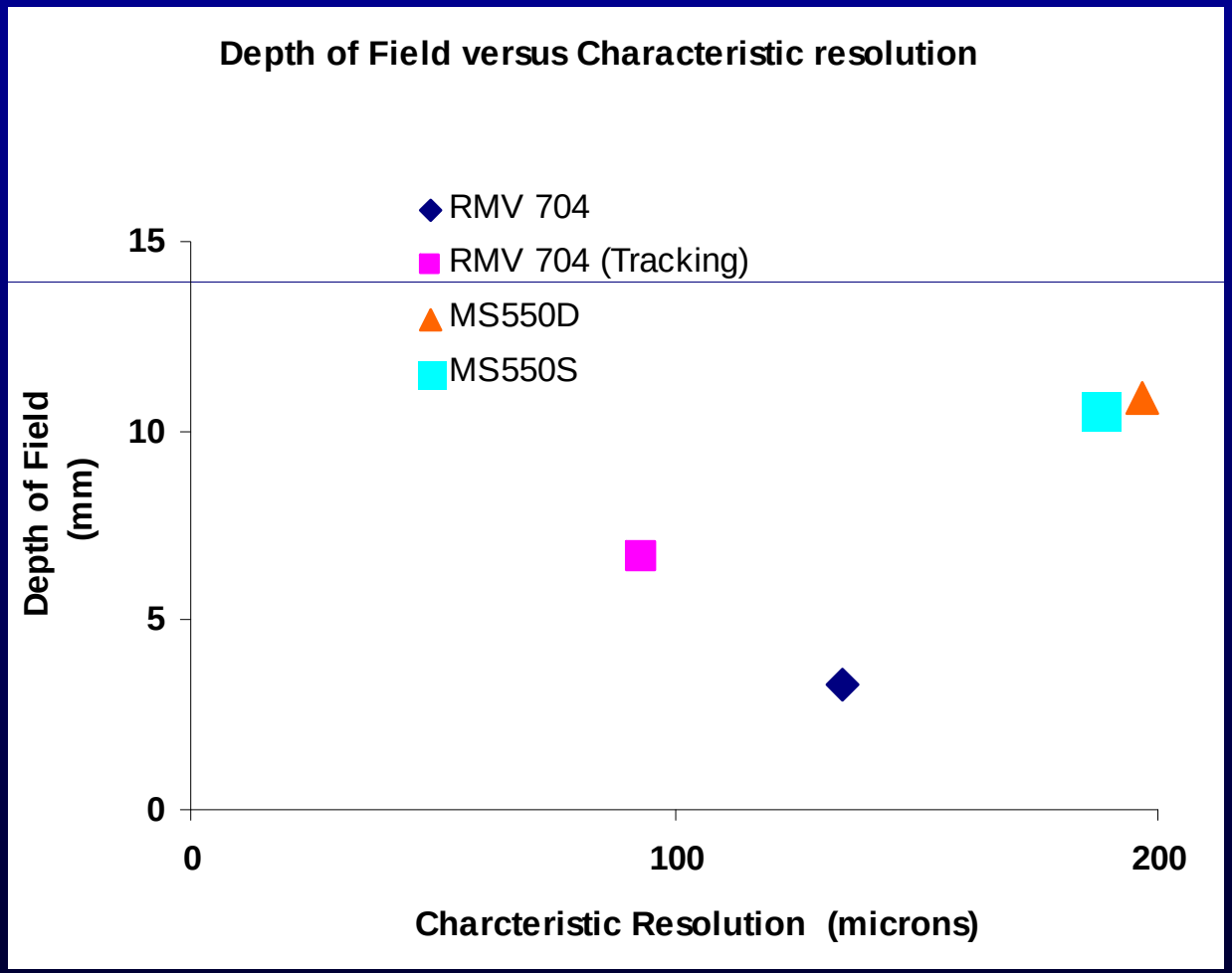
193 micron pipe

Example images of Pre-Clinical Pipe Phantom Vevo 2100, MS550S, 40MHz

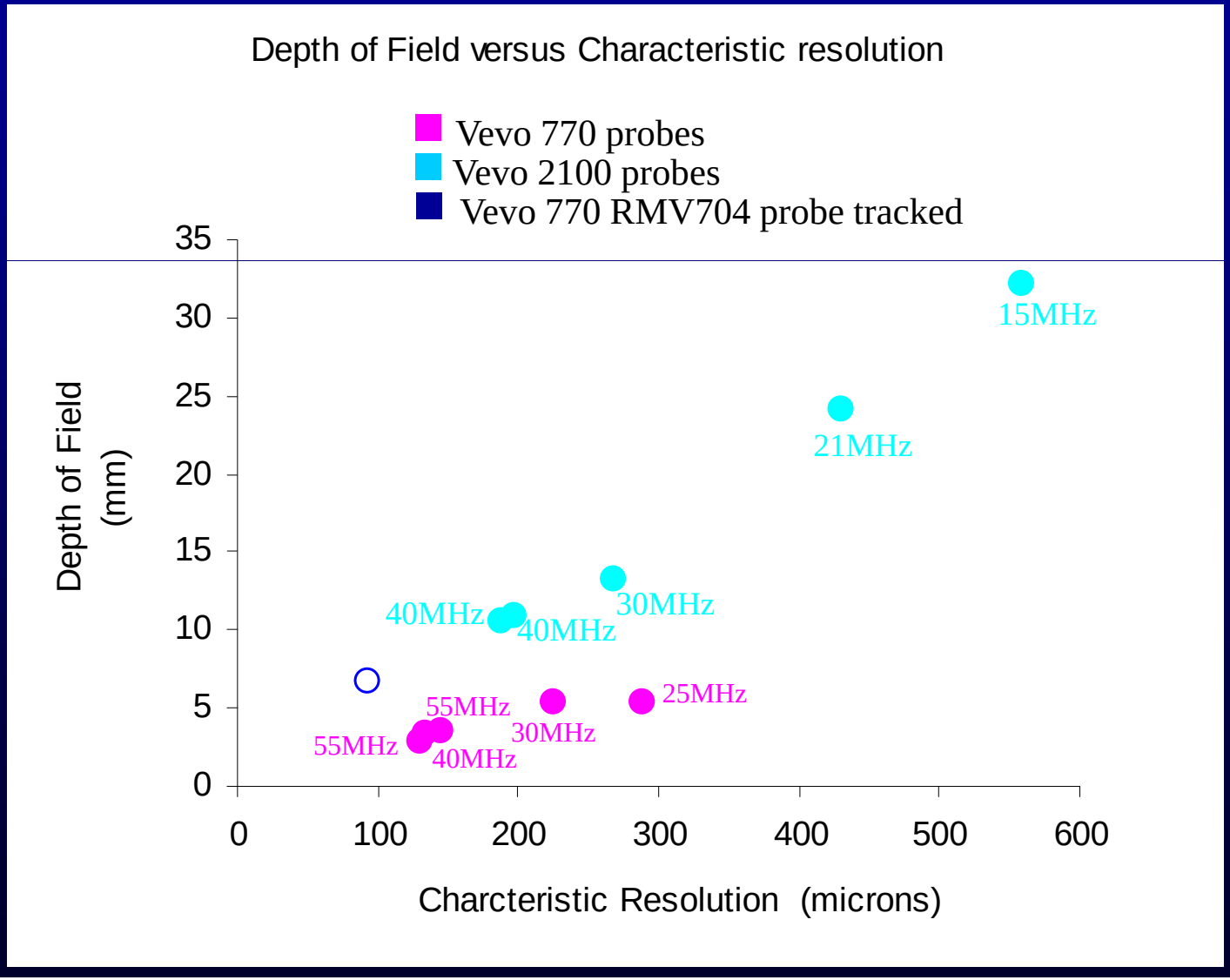
Results from Vevo 2100 using Pre-clinical Pipe Phantom



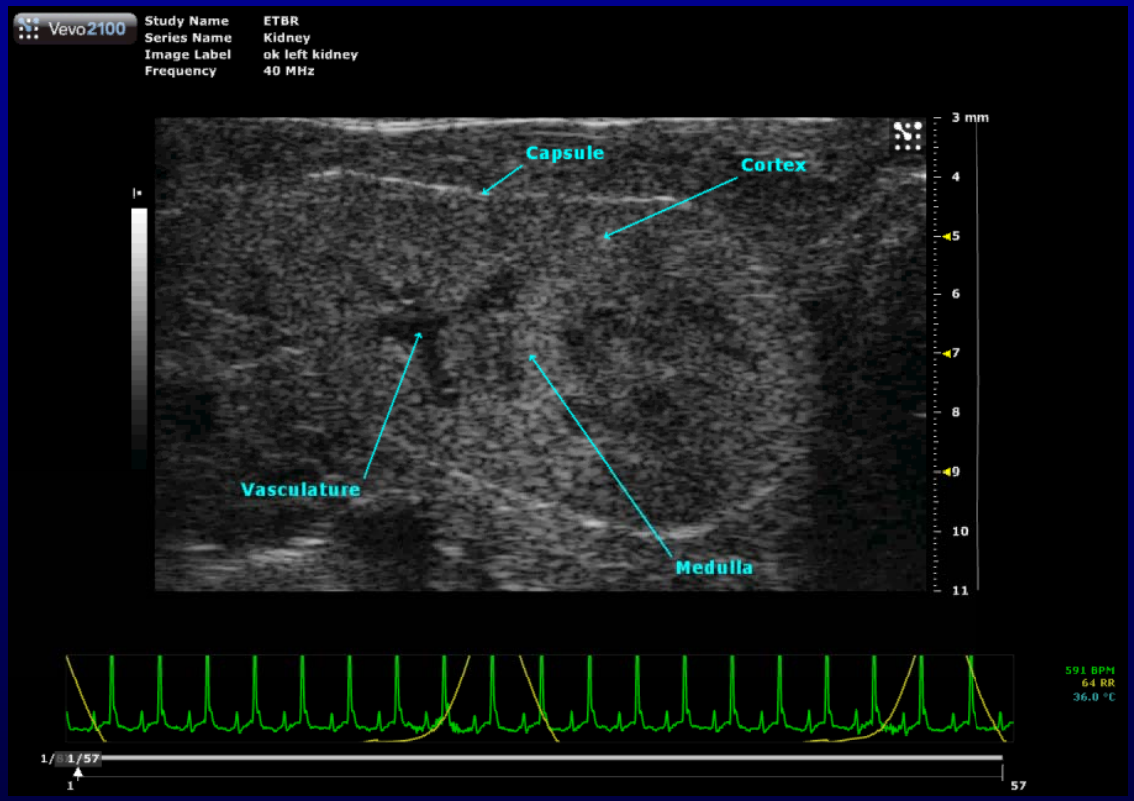
Comparison of results from Vevo 2100 and Vevo 770



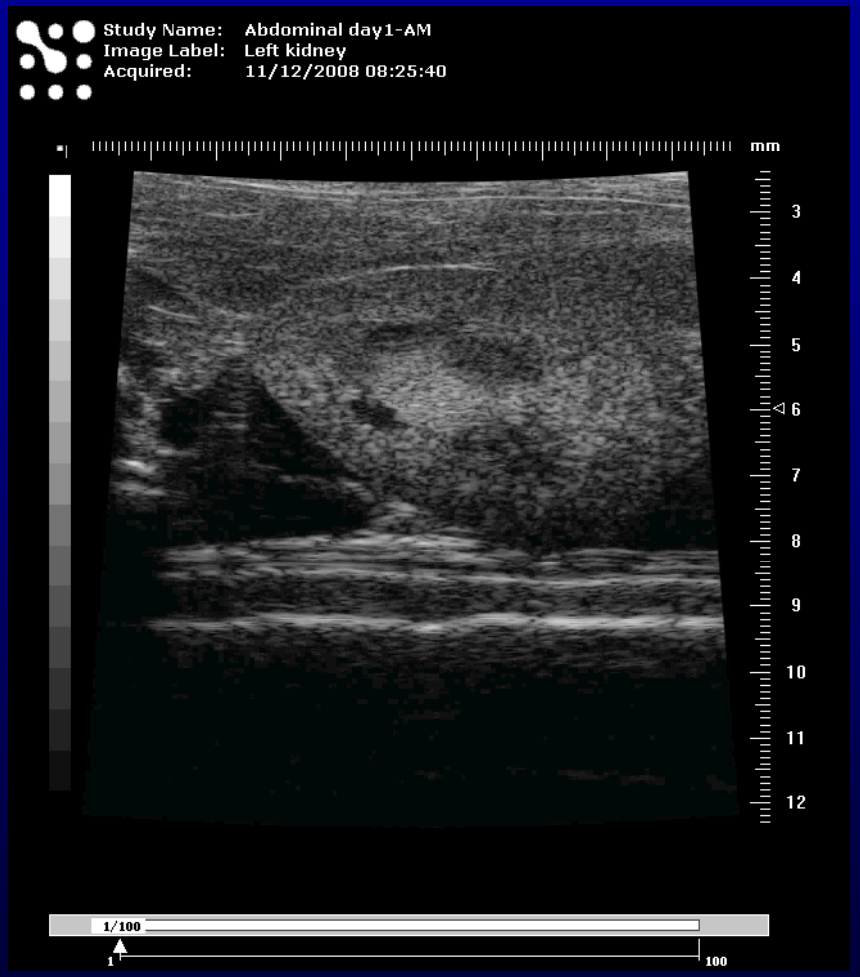
Results from Vevo 2100 using High Resolution Pipe Phantom



Example images from Vevo 2100 and Vevo 770 40MHz probes



Vevo 2100 MS550S



Vevo 770 RMV704

Conclusions

- Using the Edinburgh Pipe Phantom we are able to quantify the performance of clinical and high resolution, pre-clinical ultrasound scanners.

Advantages as Experimental Subjects

- Mice are easy to look after
  - Inexpensive
  - Large numbers – small space
- Short life cycle
  - High reproduction rate
    - Sexual maturity 6 weeks
    - Gestation 19 days
    - Disease often appears within 4-6 weeks

Many Differences

- Mouse
  - Small
  - 4 legs & a tail
  - Whiskers
  - Communicate in ultrasonic range
  - Naturally athletic
    - Can jump 1m
    - Climb almost anything
  - Relatively short life
    - 1-3yrs

Looks can be Deceiving

- Similarities
  - Eyes
  - Ears
  - Hair
  - Internal organs
- Genes
  - Only 150 of 30,000 not in common

- Genome relatively easy to manipulate