

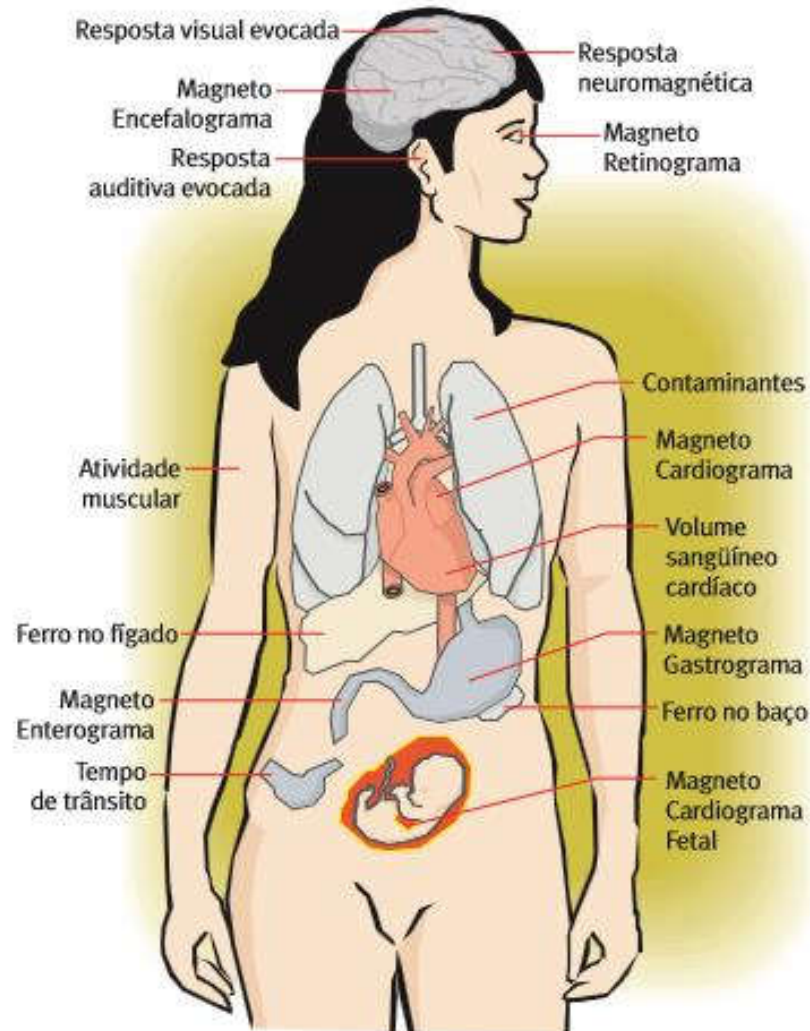
# Biomagnetism

*An alternative to study biological systems*

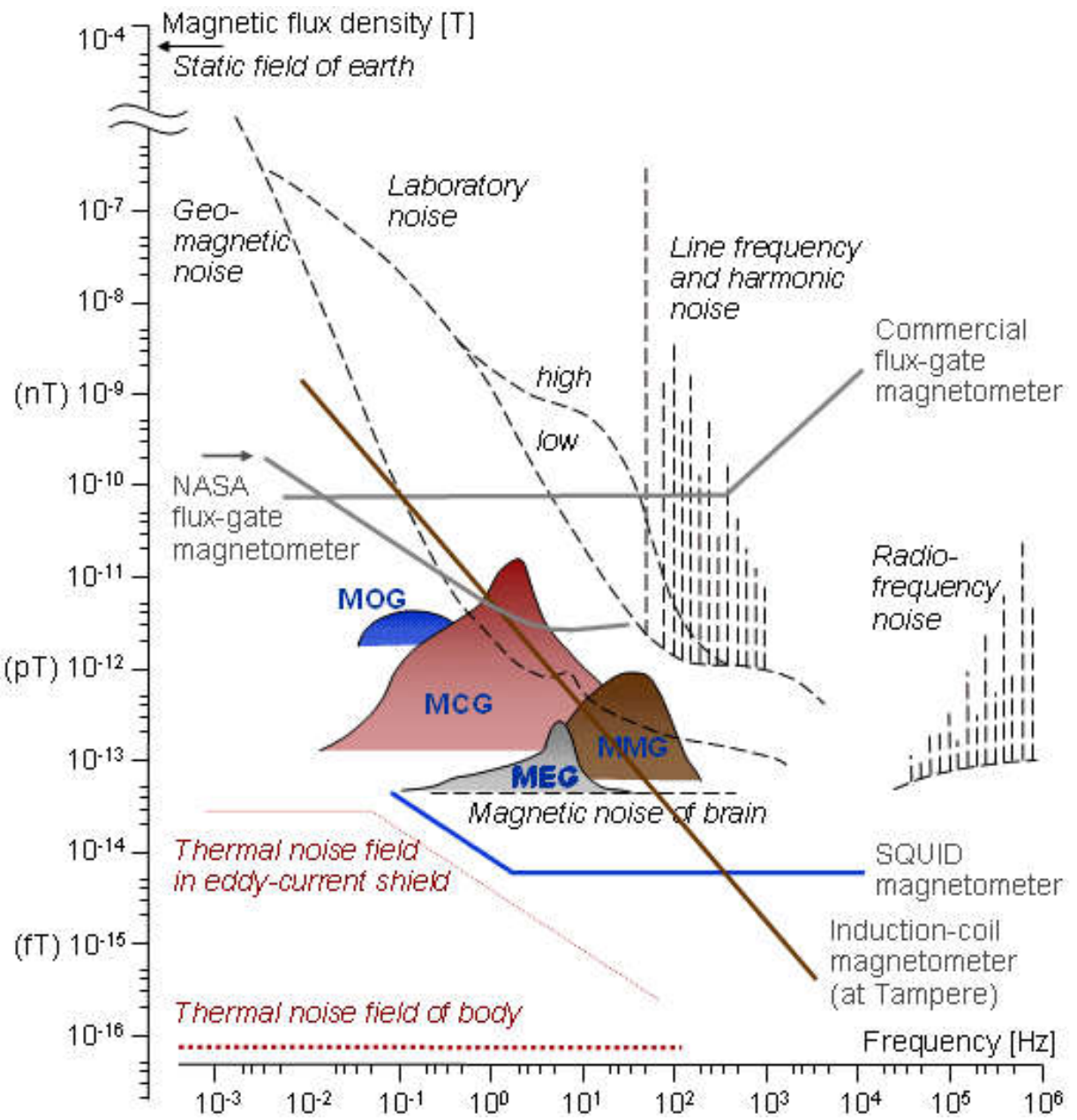


Oswaldo Baffa  
USP-Ribeirão Preto-SP Brazil  
*baffa@usp.br*

# Sources of Magnetic Fields in the Human Body



# Typical intensity and spectral distribution of magnetic fields and sensors sensitivity

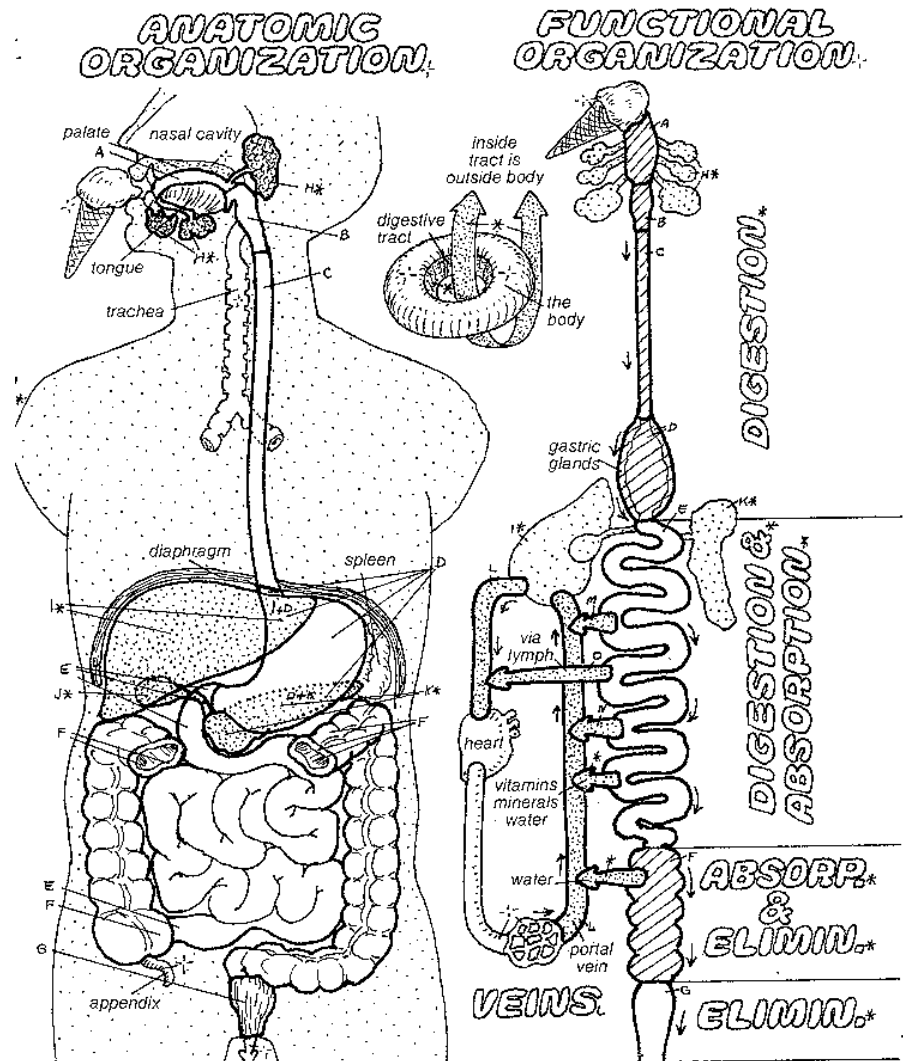


# Gastrointestinal Motility and Drug Delivery

Ricardo Brandt de Oliveira-FMRP-USP/ Luiz E.A. Troncon-FMRP-USP/ José Ricardo de Arruda Miranda-IBB-UNESP-Botucatu/ Fabiano Carlos Paixão-UNIFESP-S.J. Campos/ Antonio Adilton Oliveira Carneiro/ Charlie A Miquelin/ José G. Guasti Jr./ João Borin/ Marcelo Moreira/ Marcello Rodrigues/ Nasser Daghasanli/ Paulo Loureiro Sousa/ Theodoro Cordova/ Agostinho Ferreira

# Motivation-1

- Digestion requires that the food passes through the GI tract at an appropriate speed and time.
- Enzymes
- Motility
- Blood Irrigation
- Electric Signals



# Motivation-2

- Gastrointestinal motility assessment can give useful information to gastroenterologists for the understanding of the pathophysiology of several diseases
- New methods are necessary to cope with some of the drawbacks present in:
  - X-rays
  - Scintigraphy
  - Hydrogen
  - Intubation

# Sources of Magnetic Fields

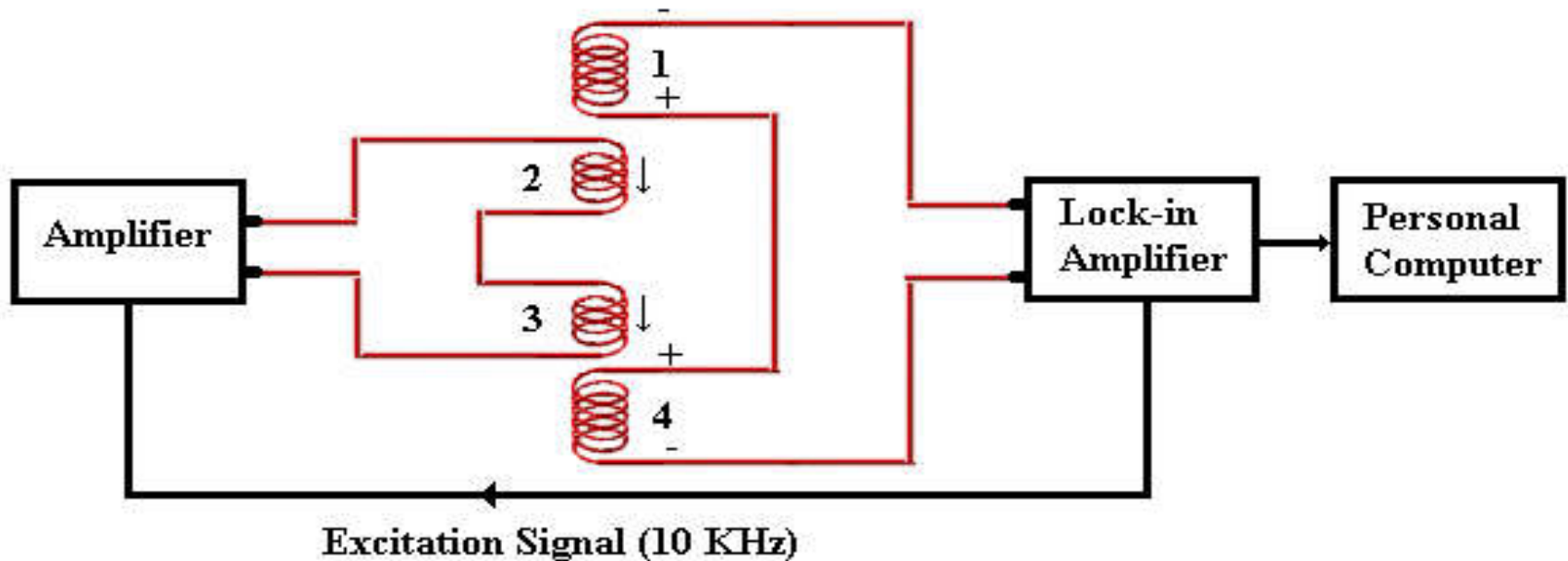
- Magnetic Fields produced by depolarizing currents- *Intrinsic Fields*
  - SQUIDs ( fento-tesla sensitivity)
- Inert magnetic markers and tracers can be ingested in small quantities. A [test meal](#) containing magnetic tracers or markers. Ferrite powder or magnetite are used in concentrations of 1-4% weight *Extrinsic Fields*
  - Fluxgate magnetometers (~nano-tesla)
  - AC biosusceptometer
  - Magnetoresistive sensors.

# GI Motility Studies with Magnetic Markers and Tracers

- Gastric emptying time
- Orocaecal transit time
- Pharynx clearance and transit time
- Esophagus transit time
- Stomach mix
- Gastrocolic reflex
- Colon motility
- Total transit time
- Drug delivery
  
- Bowel ischemia (SQUIDs)

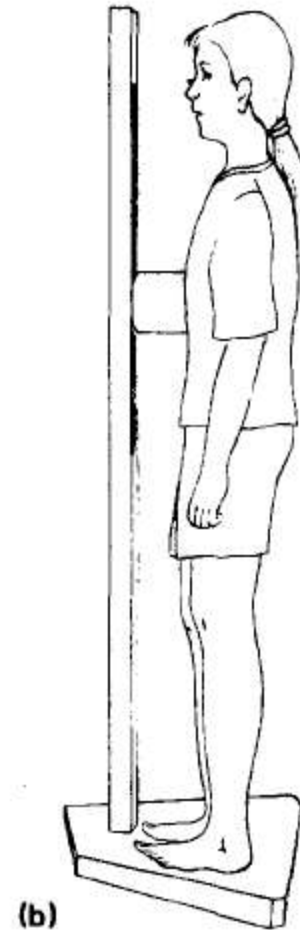
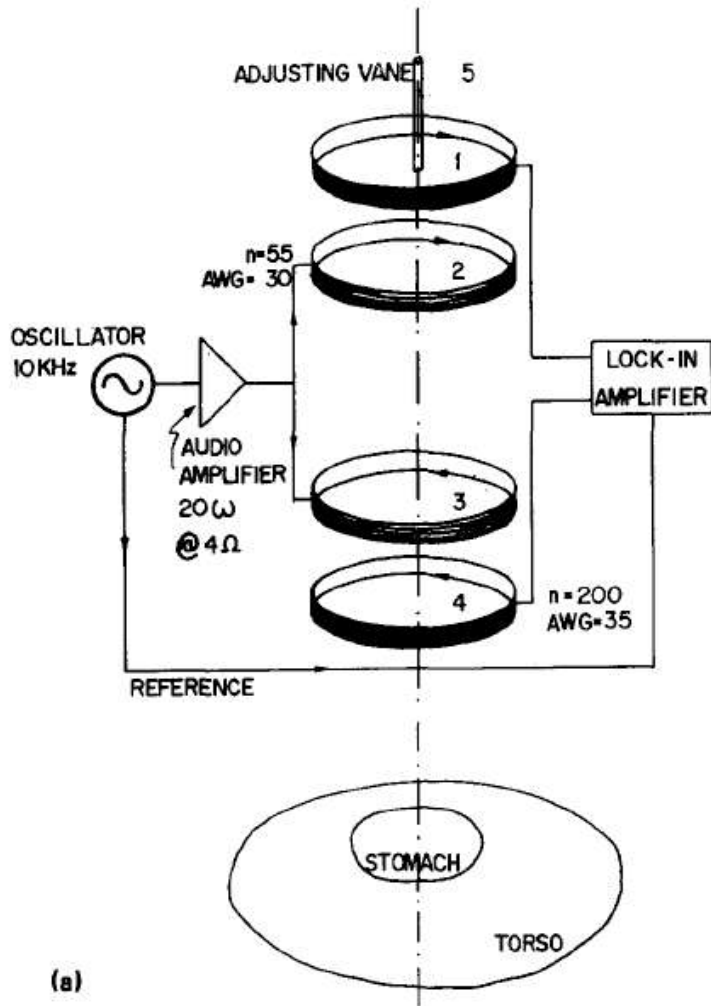


# The AC Biosusceptometer (Our Workhorse)



- A set of coils (2,3) generate a signal that is detected by a lock-in amplifier. When properly balanced no voltage is detected at the lock-in. However when a magnetic substance is near one pair of coils a net voltage is detected.

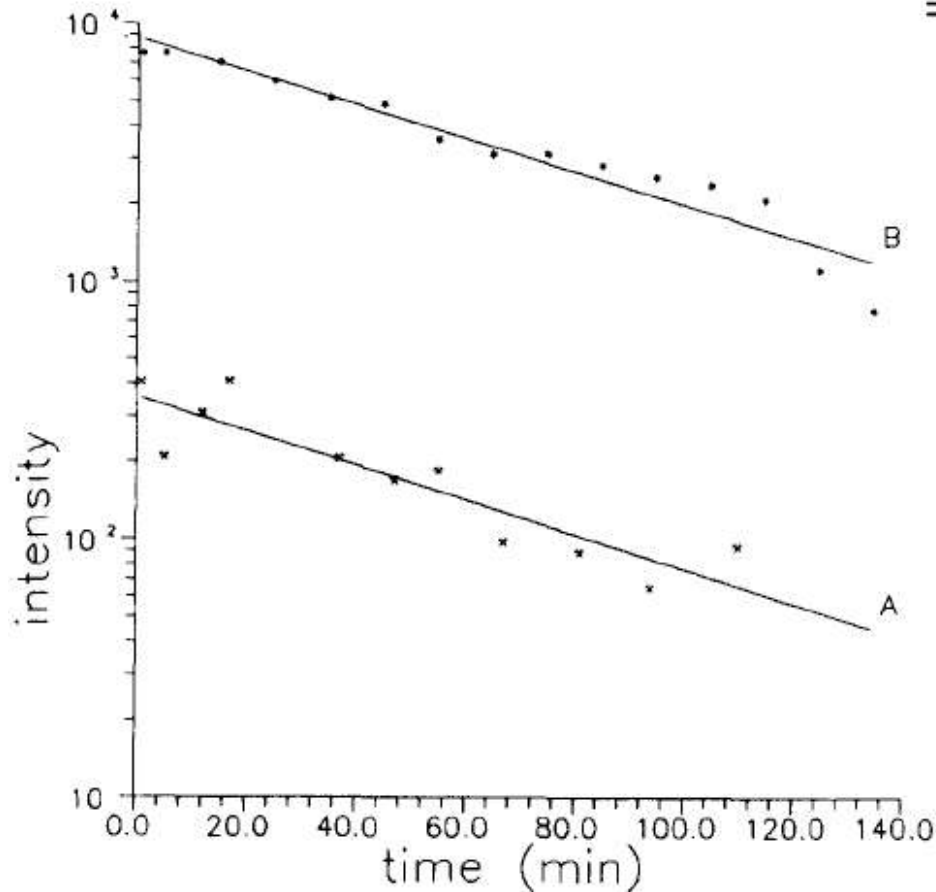
# Gastric Emptying sensor (a) and positioning (b)



# Gastric Emptying

TABLE I. Gastric emptying times (minutes) with standard deviations.

Subject	Susceptometry	Gamma camera
JRM	$61 \pm 19$	$61 \pm 17$
MA	$45 \pm 18$	$47 \pm 12$
JVS	$80 \pm 20$	$70 \pm 21$



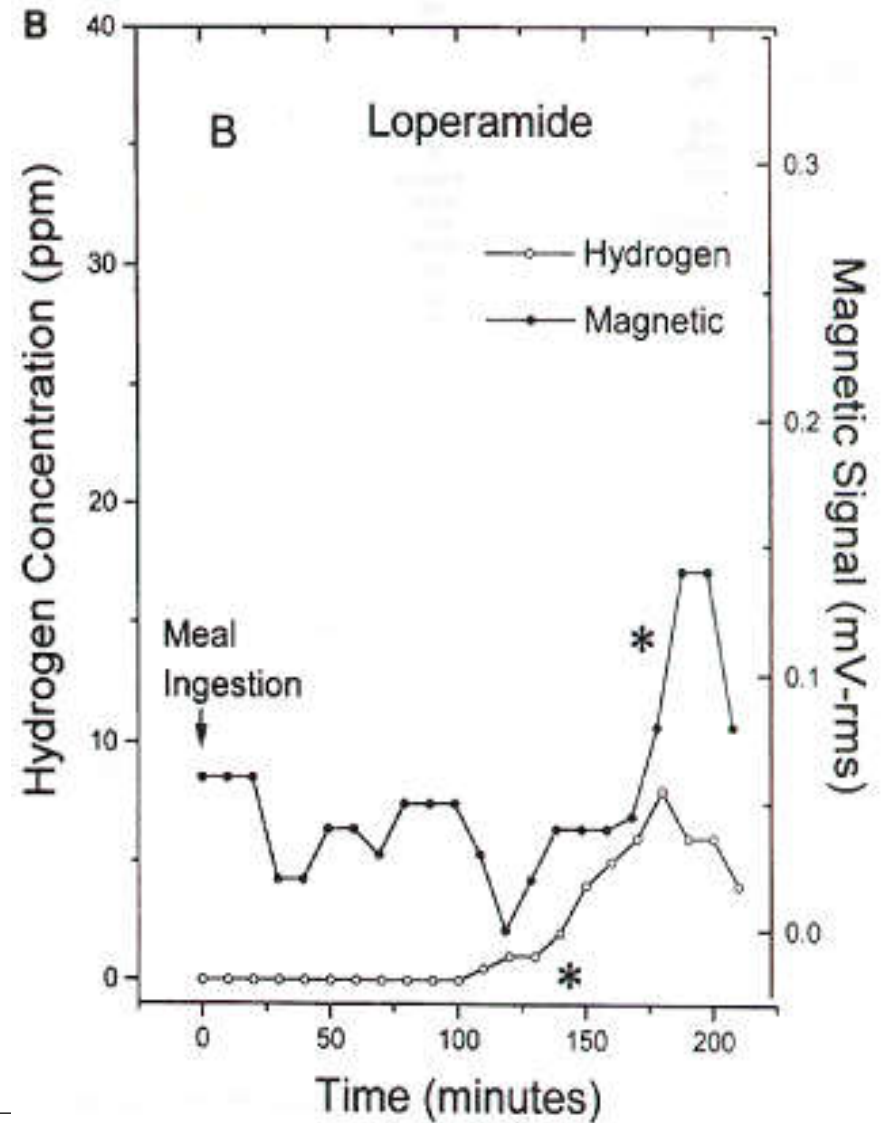
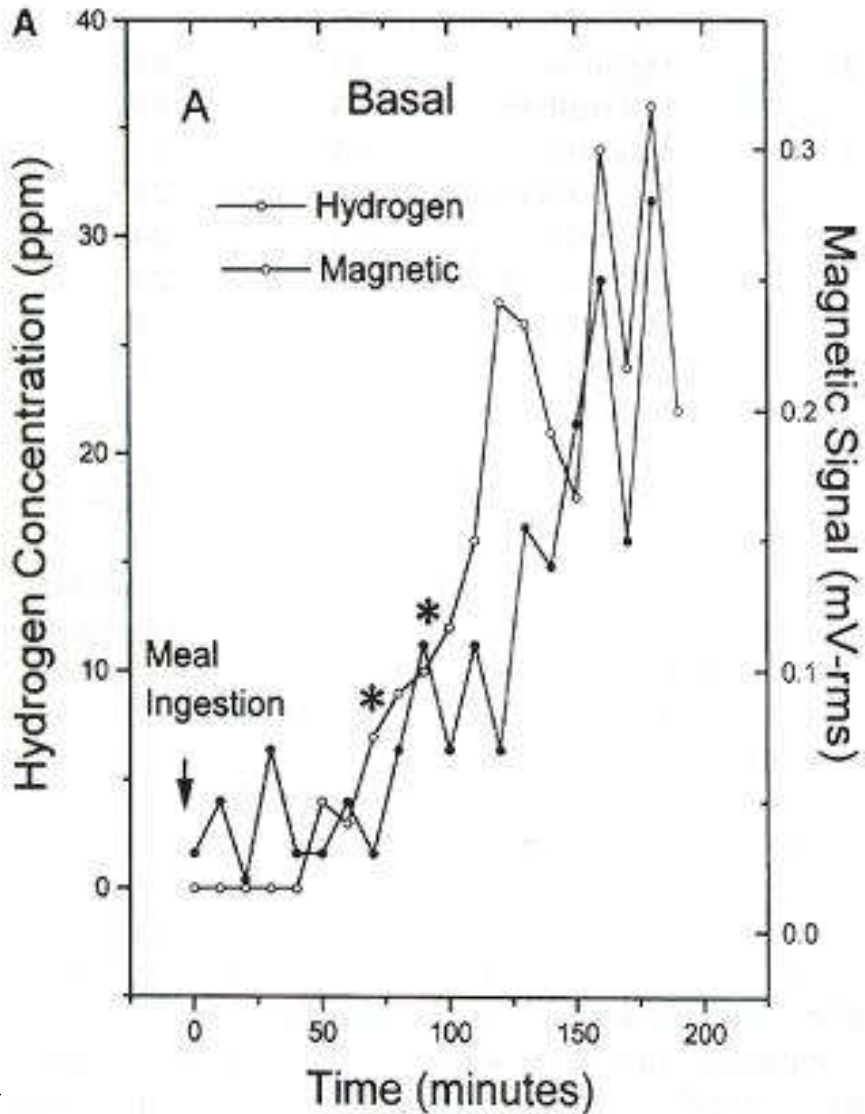
MIRANDA, J. R., BAFFA, O.,  
OLIVEIRA, R. B., MATSUDA, N. M. An  
AC Biosusceptometer to Study Gastric  
Emptying. Medical Physics. , v.19, n.2,  
p.445 - 448, 1992.

# Oroceacal Transit Time Measurements

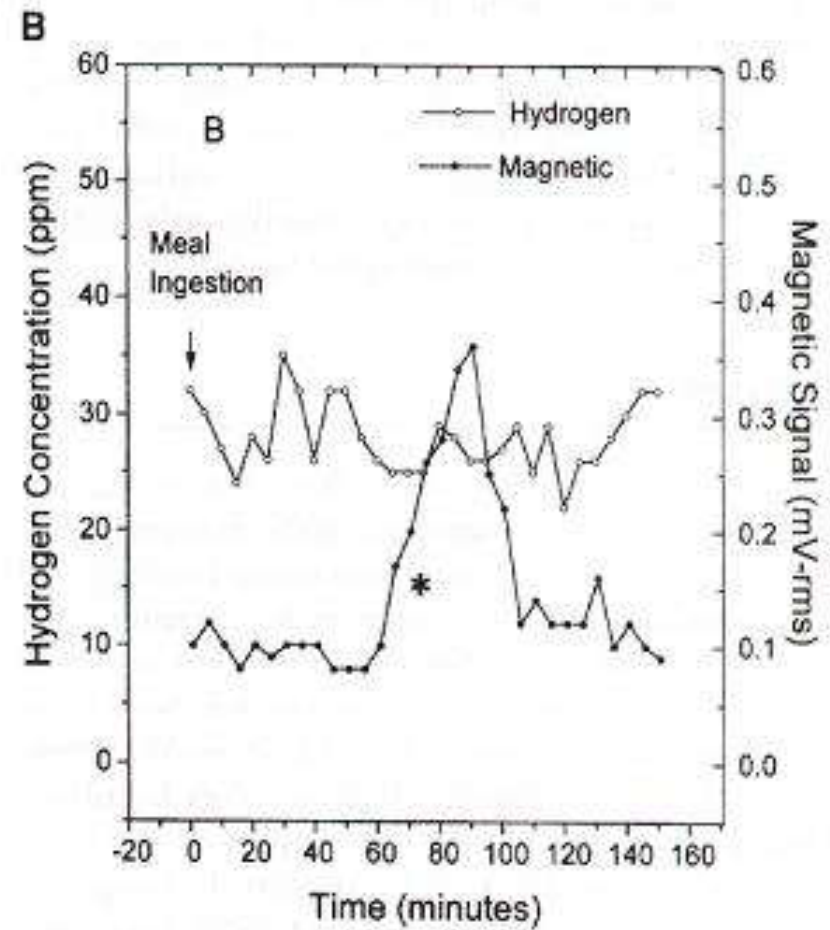
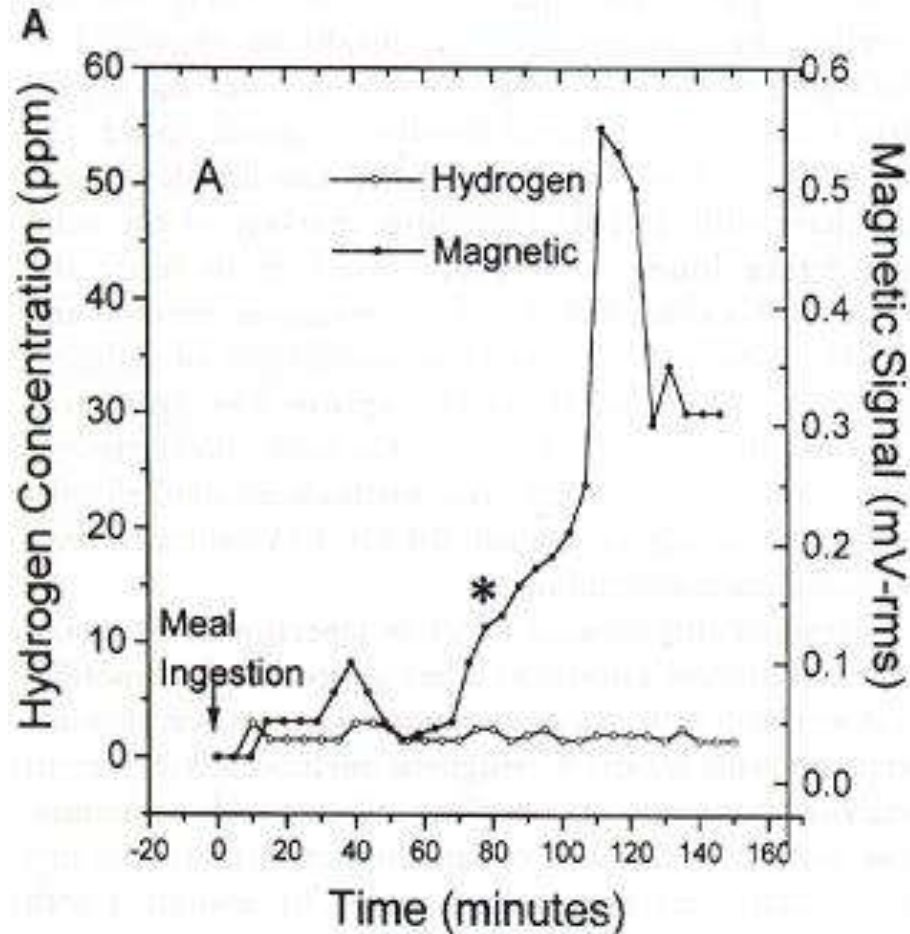
- OCTT was measured by biomagnetic methods and the results were compared with the hydrogen breath test.
- A magnetic test meal was given containing lactulose and the expired hydrogen was analyzed by gas chromatography.

OLIVEIRA, R. B., BAFFA, O., TRONCON, L. E. A., MIRANDA, J. R. A., CAMBREA, C. R. Evaluation of a Biomagnetic Technique for Measurement of Orocaecal Transit Time. *European Journal Of Gastroenterology Hepatology.* , v.8, p.491 - 496, 1996.

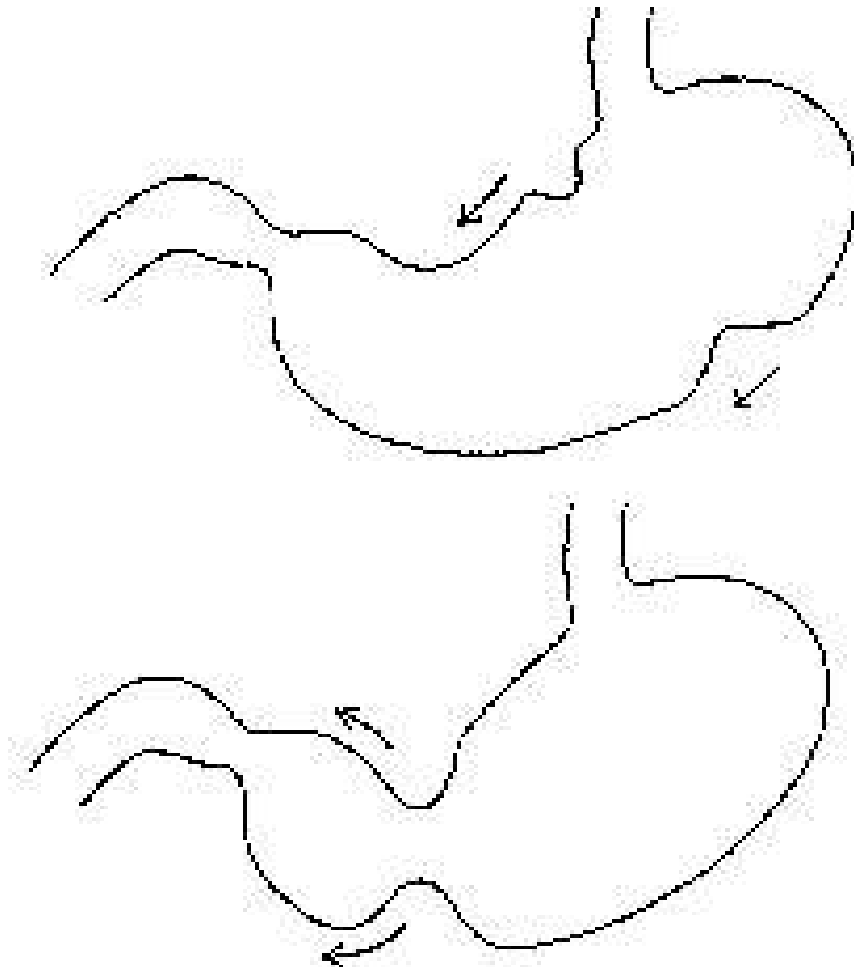
# OCTT Plots in the Same Subject Before and After Loperamide Administration



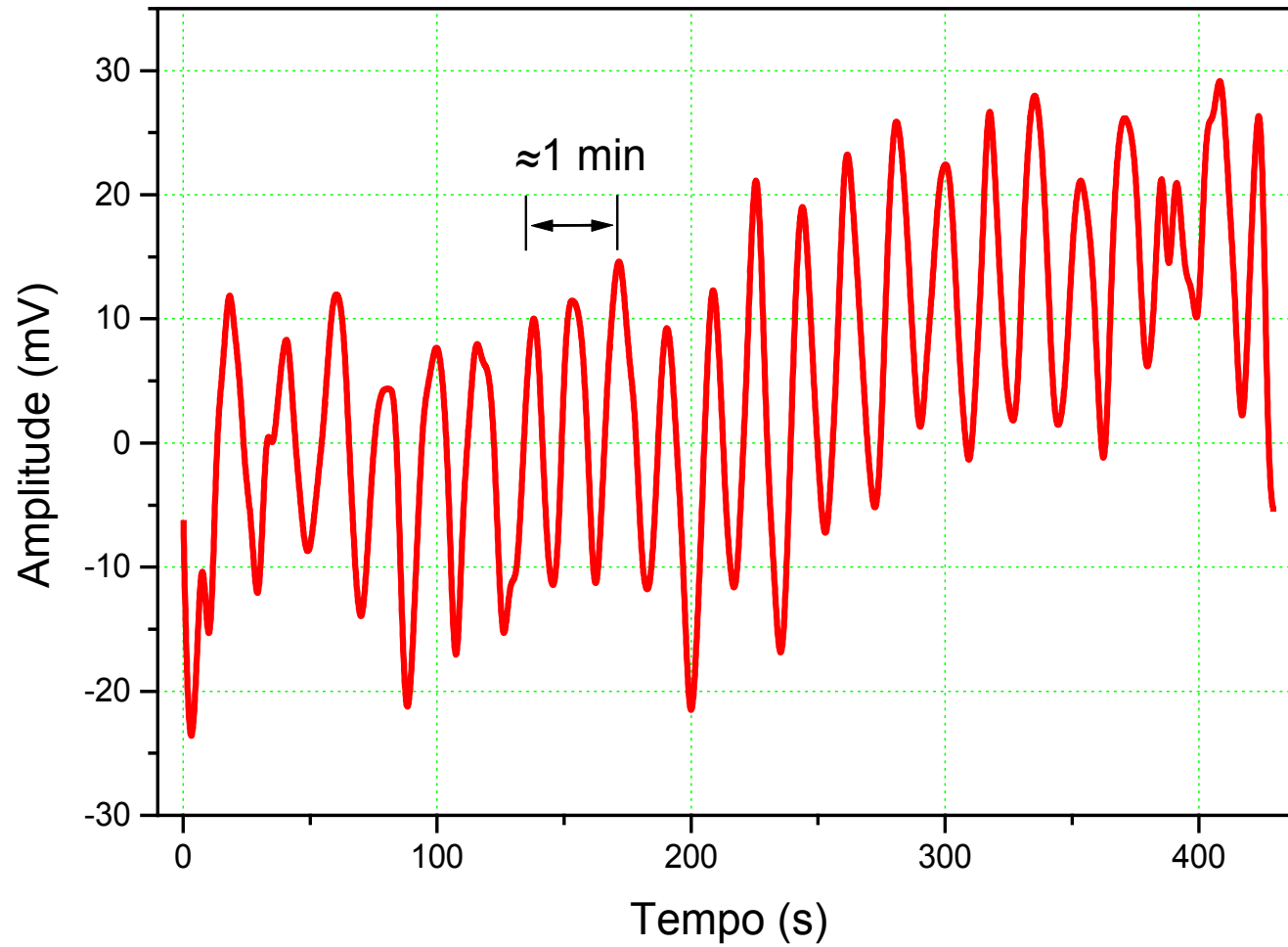
# OCTT Plot for a Hydrogen Non-Producer and High Fasting Producer Subjects in Comparison with the Magnetic Method



# Assesment of Stomach's Mechanical Activity

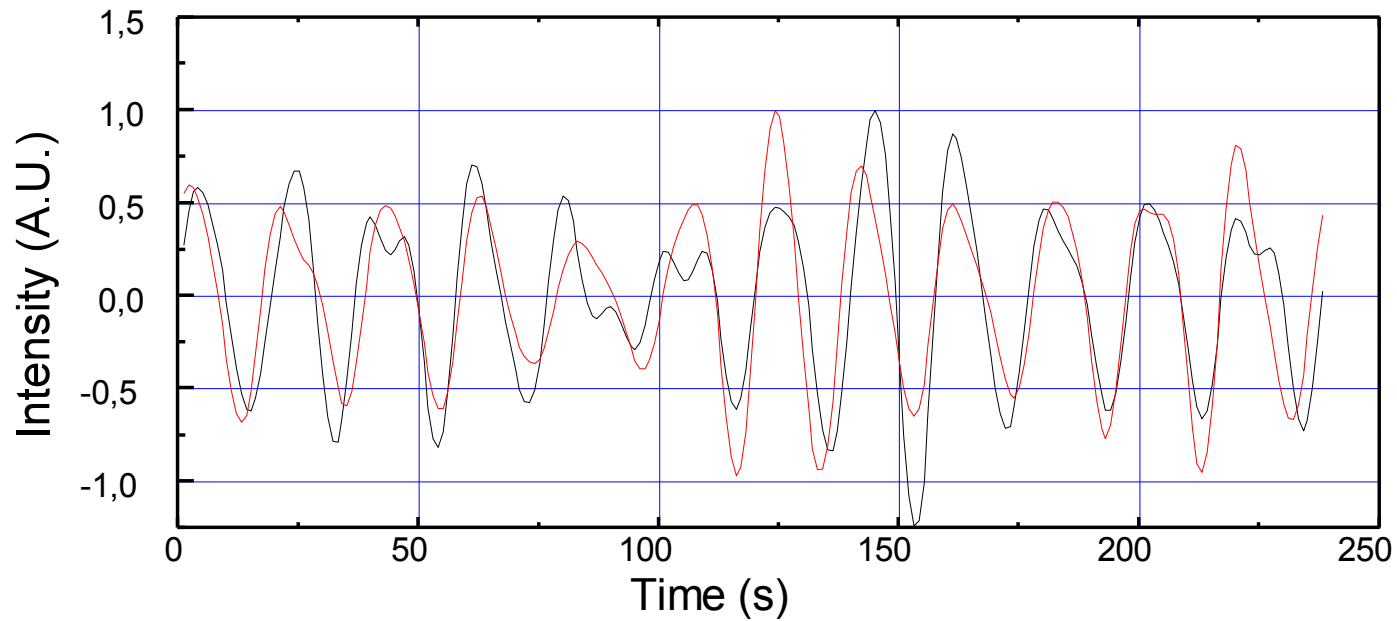


# Gastric Contractions





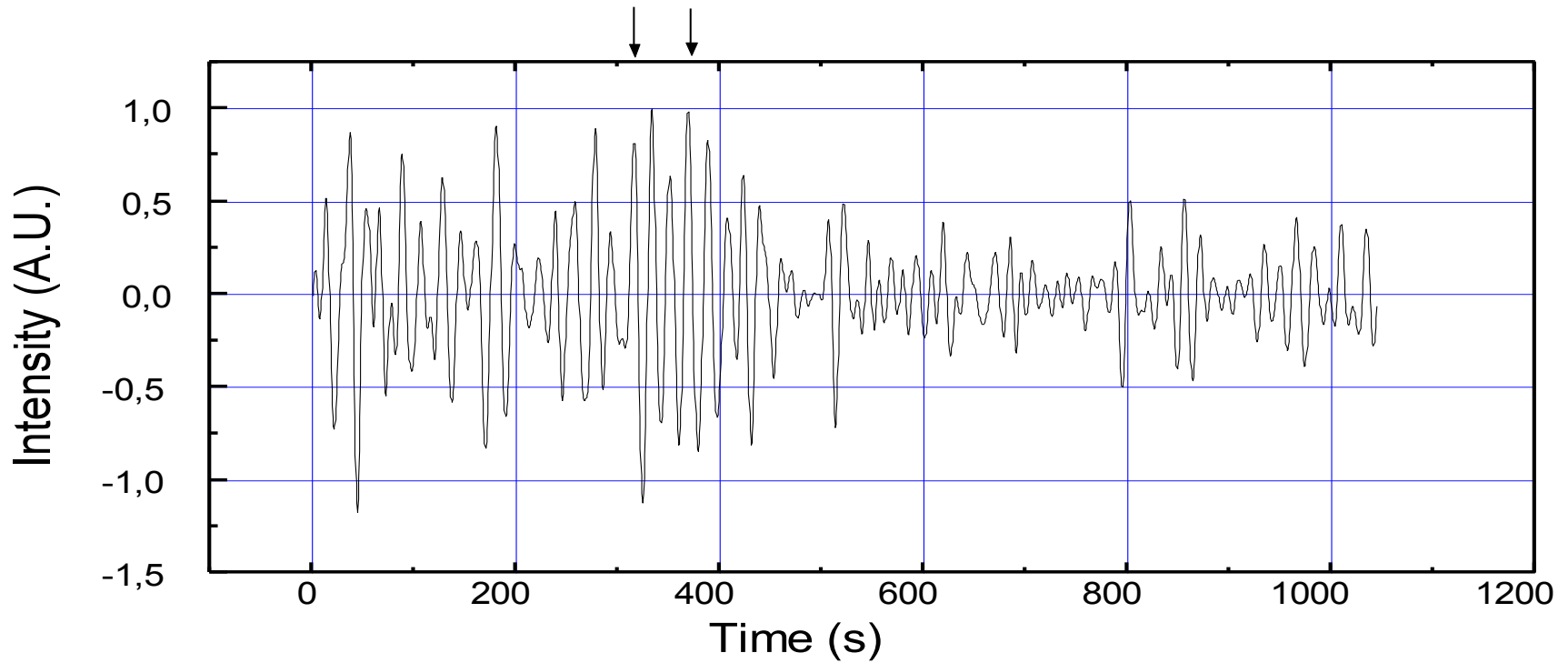
# Simultaneous Recording of Susceptometry & Scintigraphy GAC



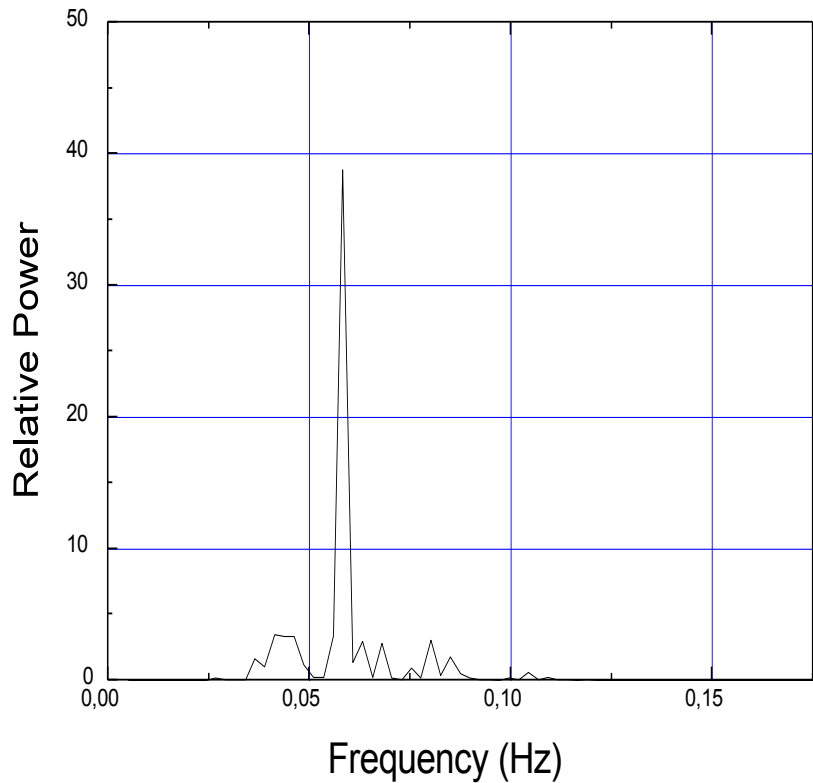
# Drug Effect Assessed by the Susceptometric Measurements

- 8 Normal Volunteers
- Hyoscine N-butylbromide (Buscopan-IV 40 mg)
- 87 % of measurements showed significant amplitude variations

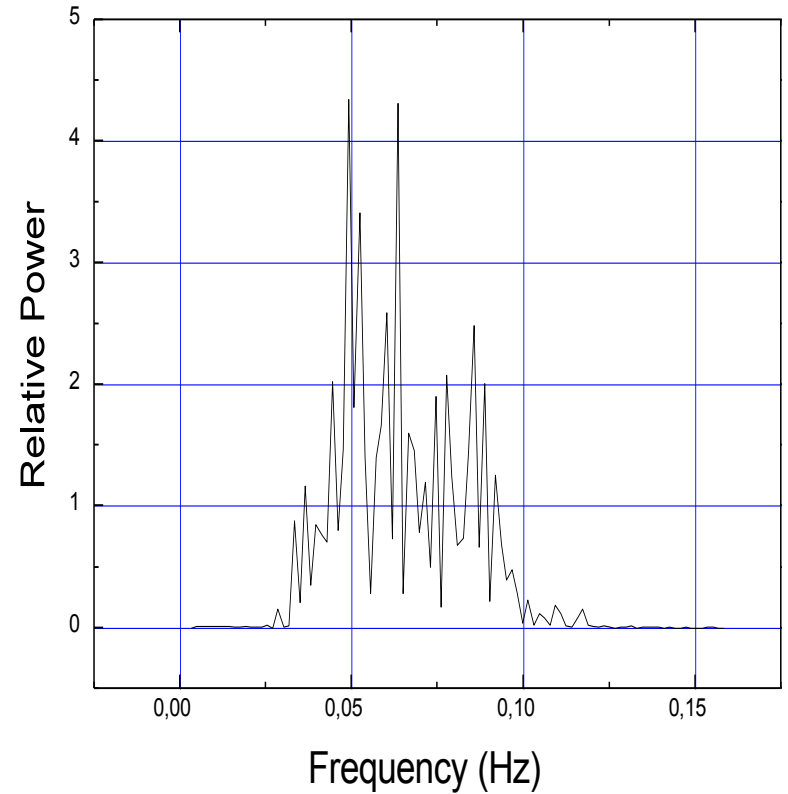
# Effect of the Drug on the Signal



# Signal Fourier Transforms



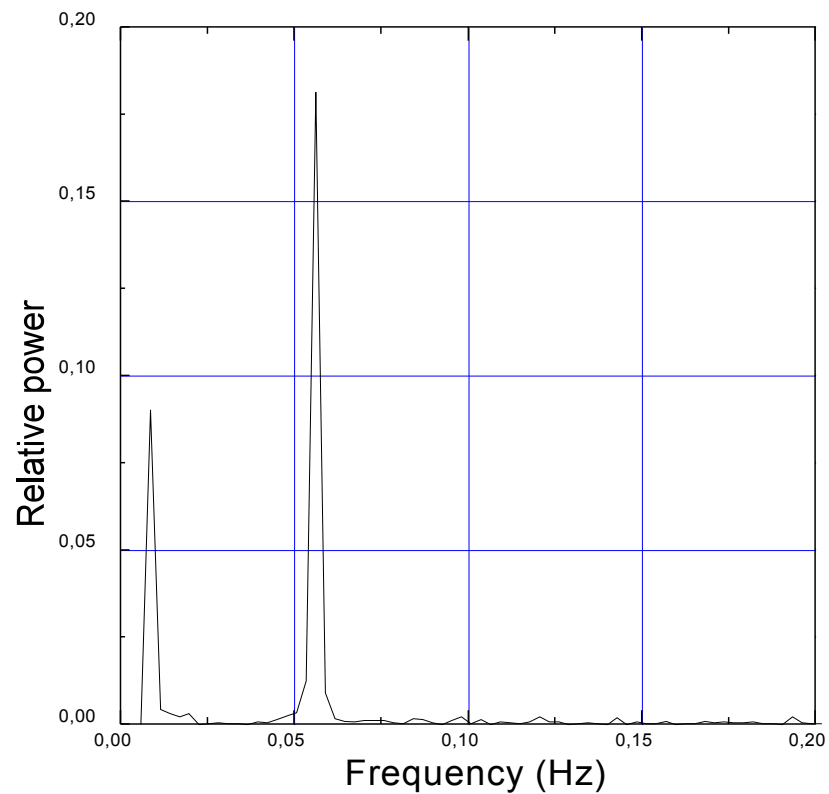
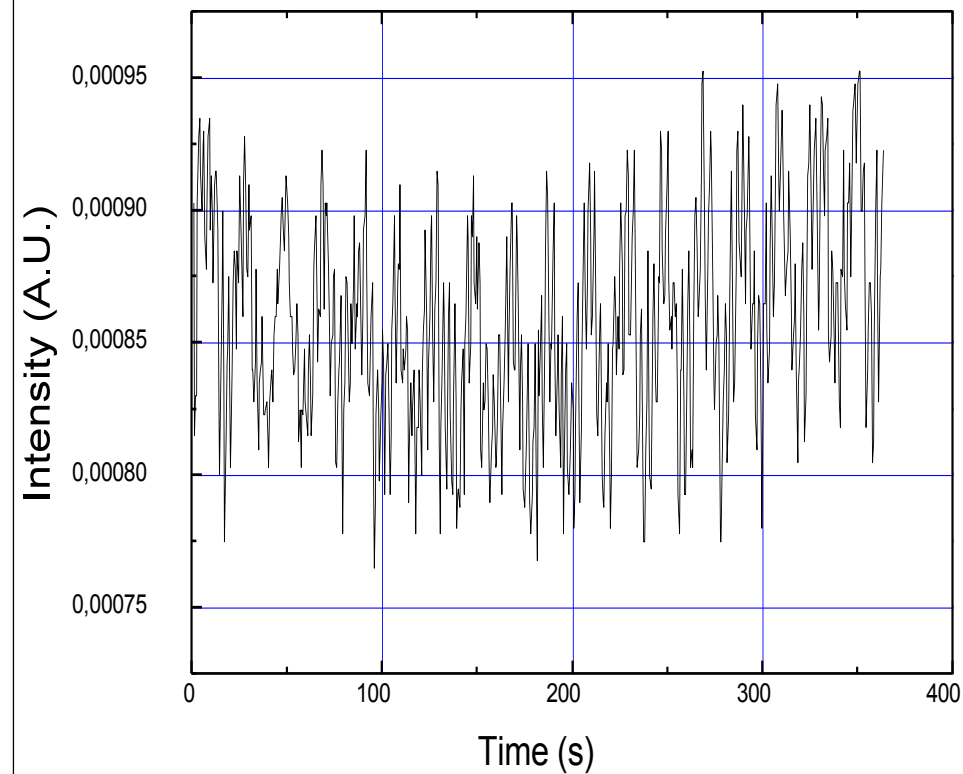
**Before**



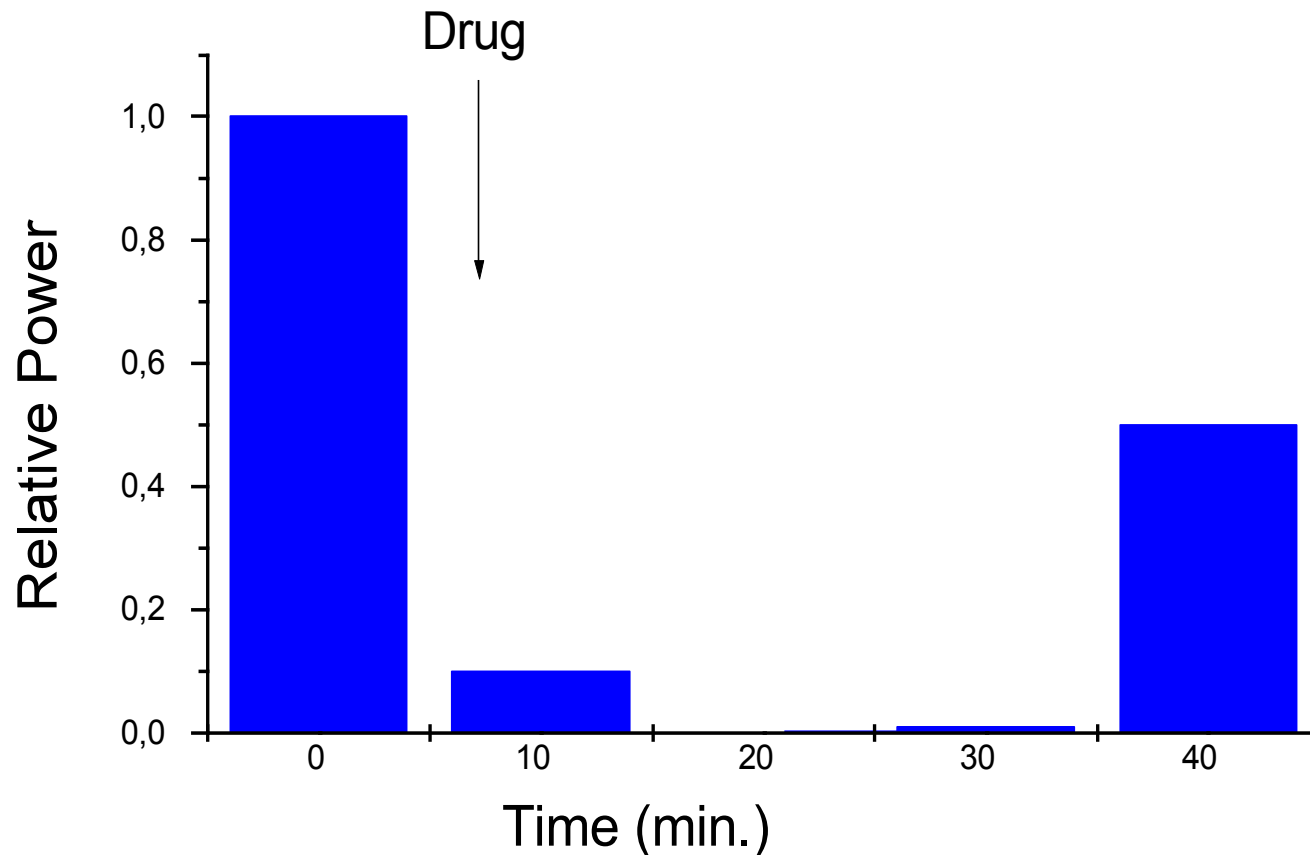
**After**

Scale 10 X

# 28 minutes after...

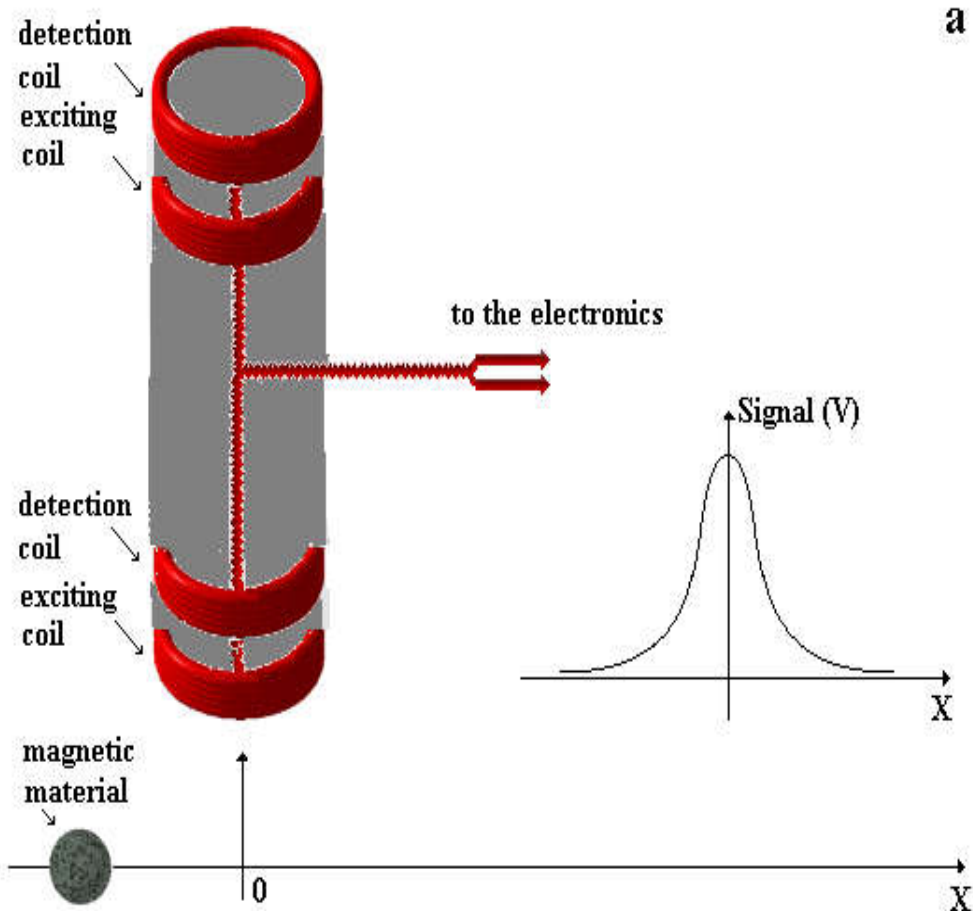


# Signal Amplitude Versus Time Due to the Effect of Drug



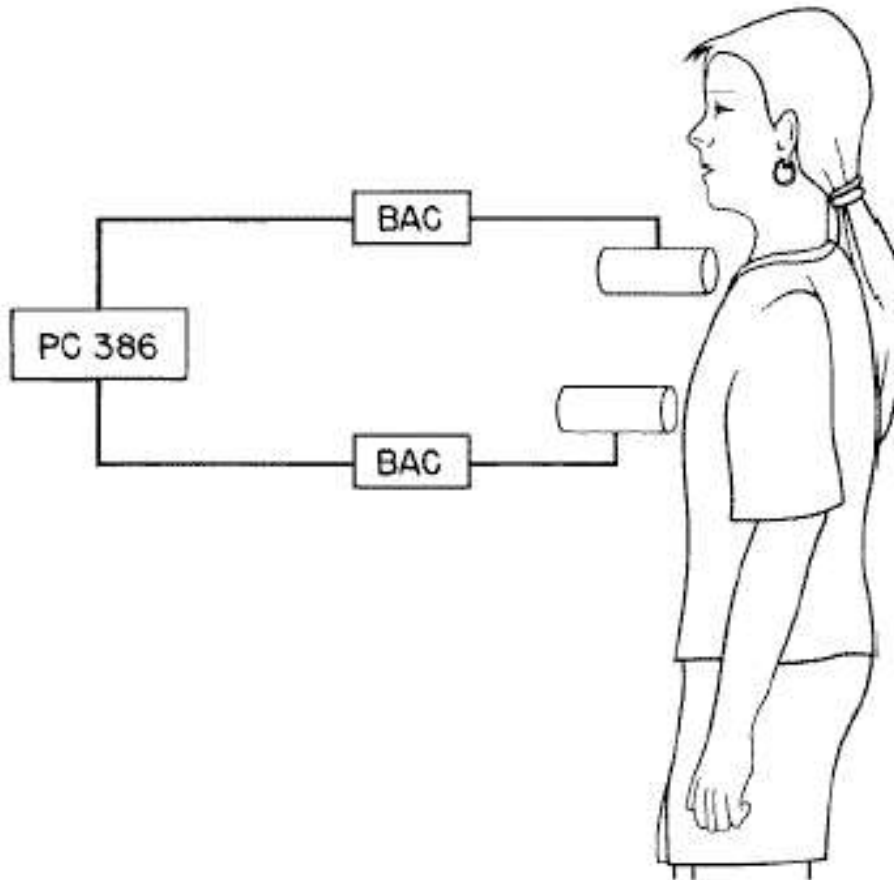
MIRANDA, J. R. A., OLIVEIRA, R. B., SOUSA, P. L., BRAGA, F. J. H. N., BAFFA, O. A Novel Biomagnetic Method to Study Gastric Antral Contractions. *Physics in Medicine and Biology*. , v.42, n.9, p.1791 - 1799, 1997.

# Esophagus Transit Time (ETT) Sensor Configuration



- The biosusceptometer is in an axial configuration
- The passage of the magnetic test meal near one of its extremities produces a signal as shown

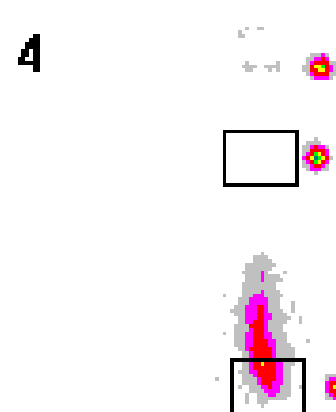
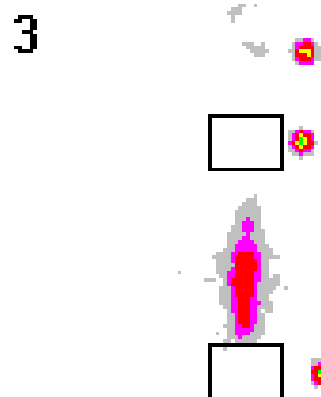
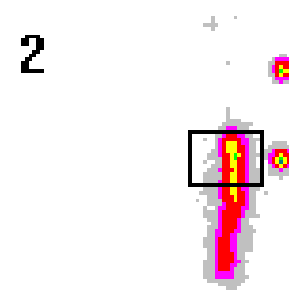
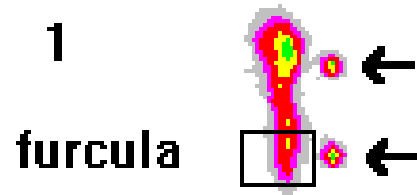
# Sensor Positioning



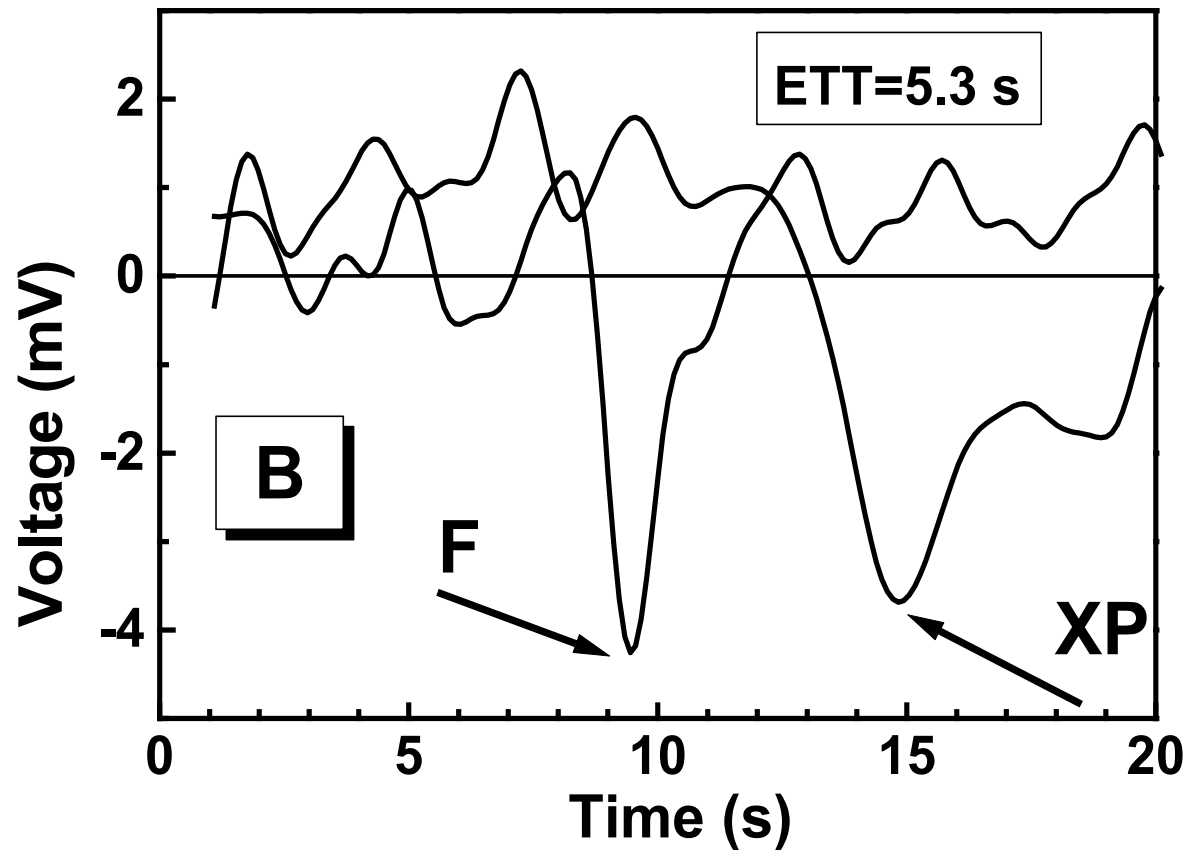
- DAGHASTANLI, N. A., BRAGA, F. J. H. N., OLIVEIRA, R. B., BAFFA, O. Oesophageal Transit Time Evaluated by a Biomagnetic Technique. Physiological Measurements v.19, n.3, p.413 - 420, 1998



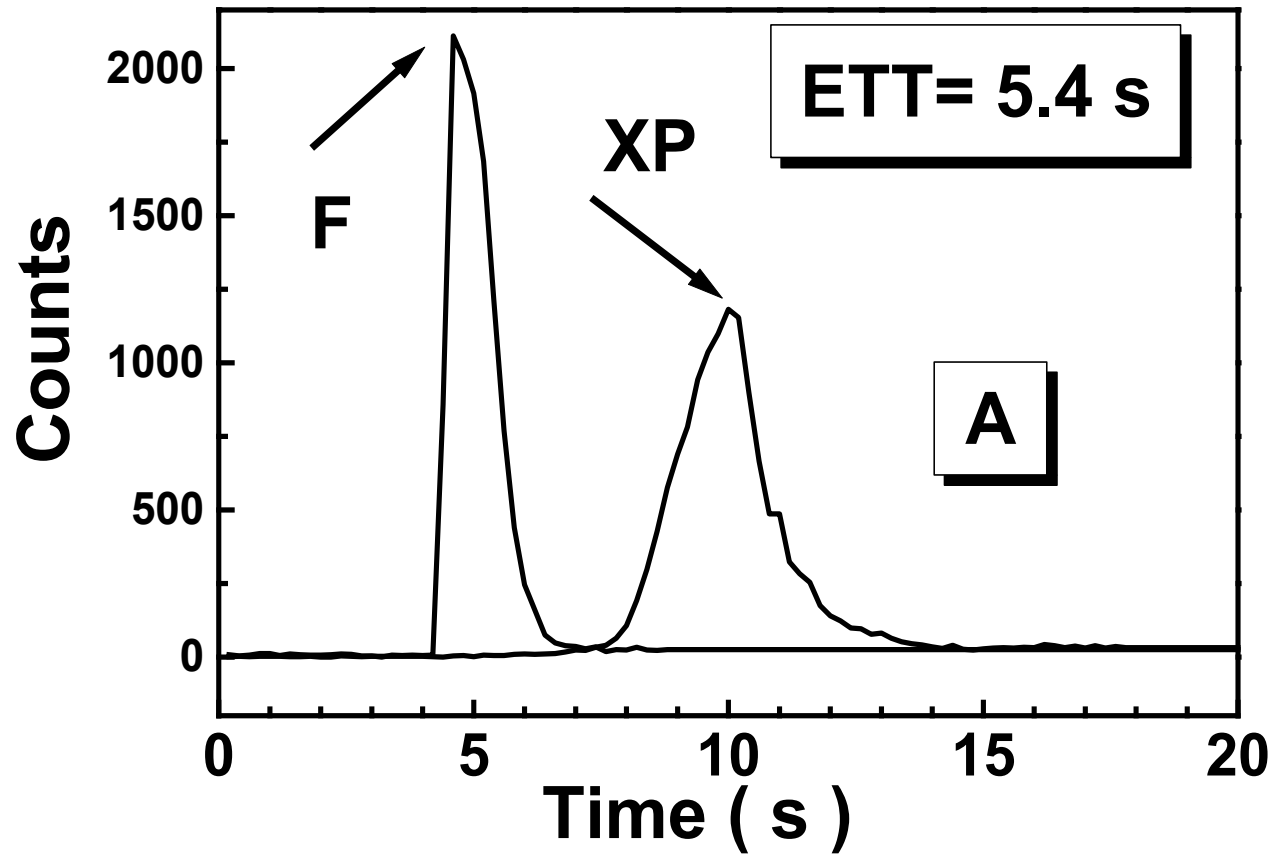
# ETT as Seen by Scintigraphy



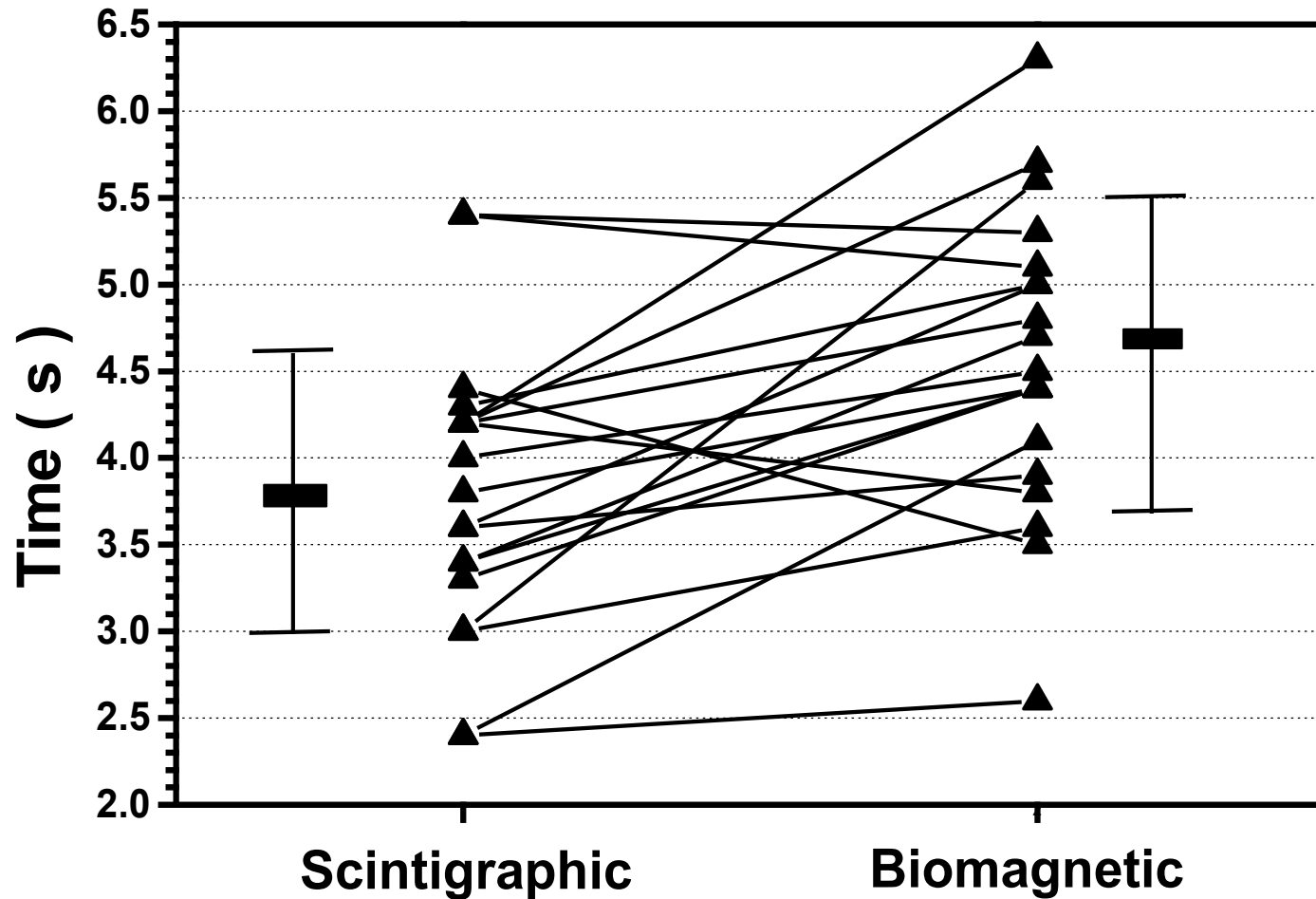
# ETT-Biomagnetic Measurement



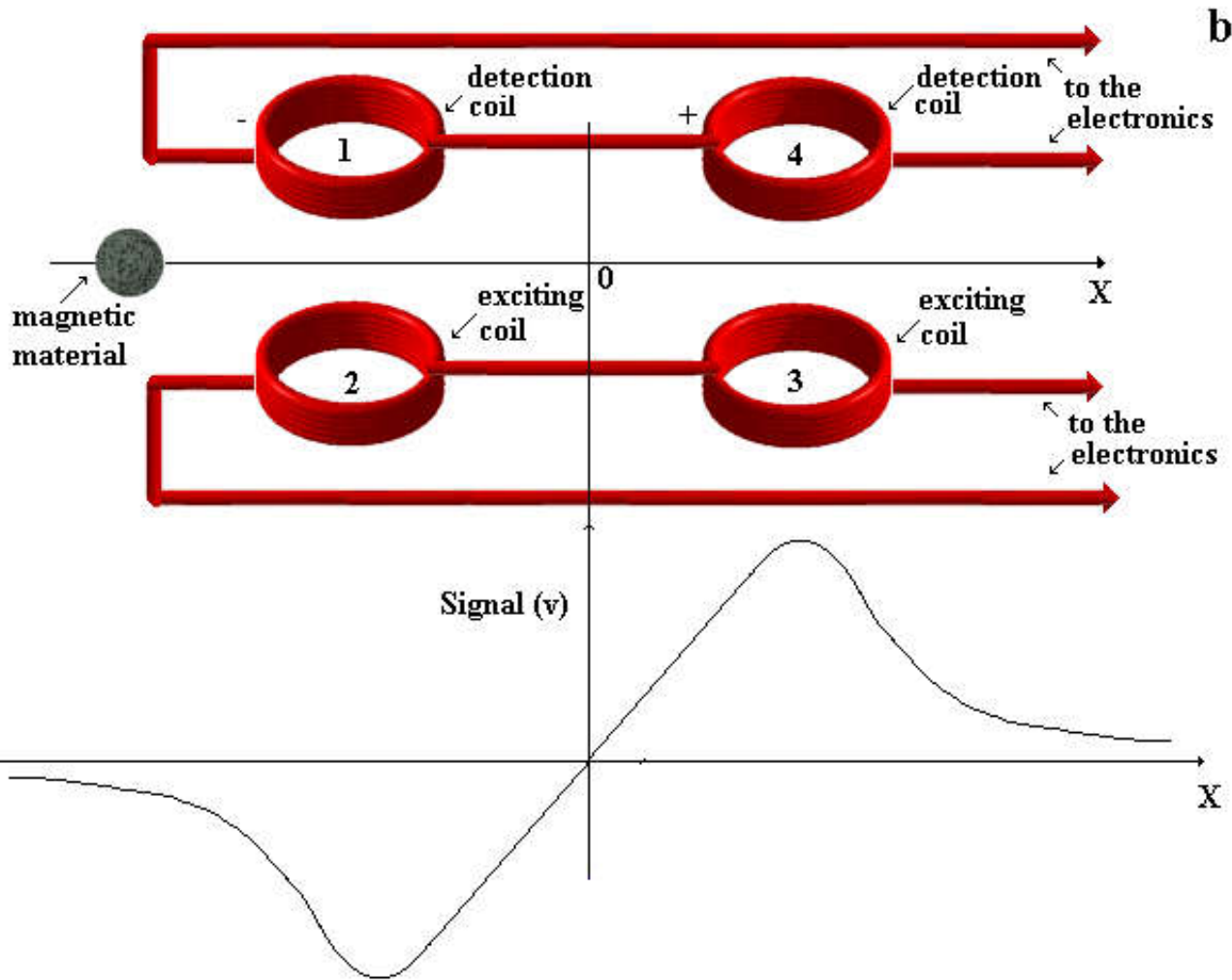
# ETT-Scintigraphy Measurement



# Comparison Between the Biomagnetic and Scintigraphic Methods

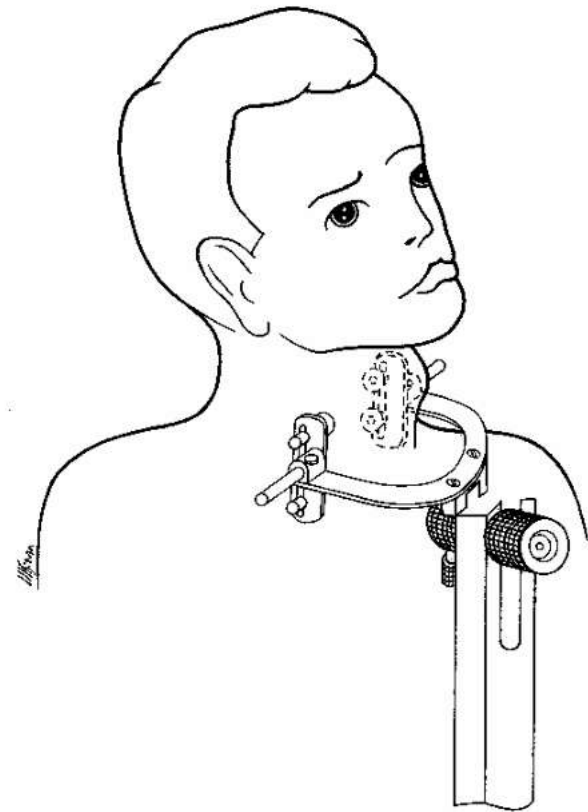
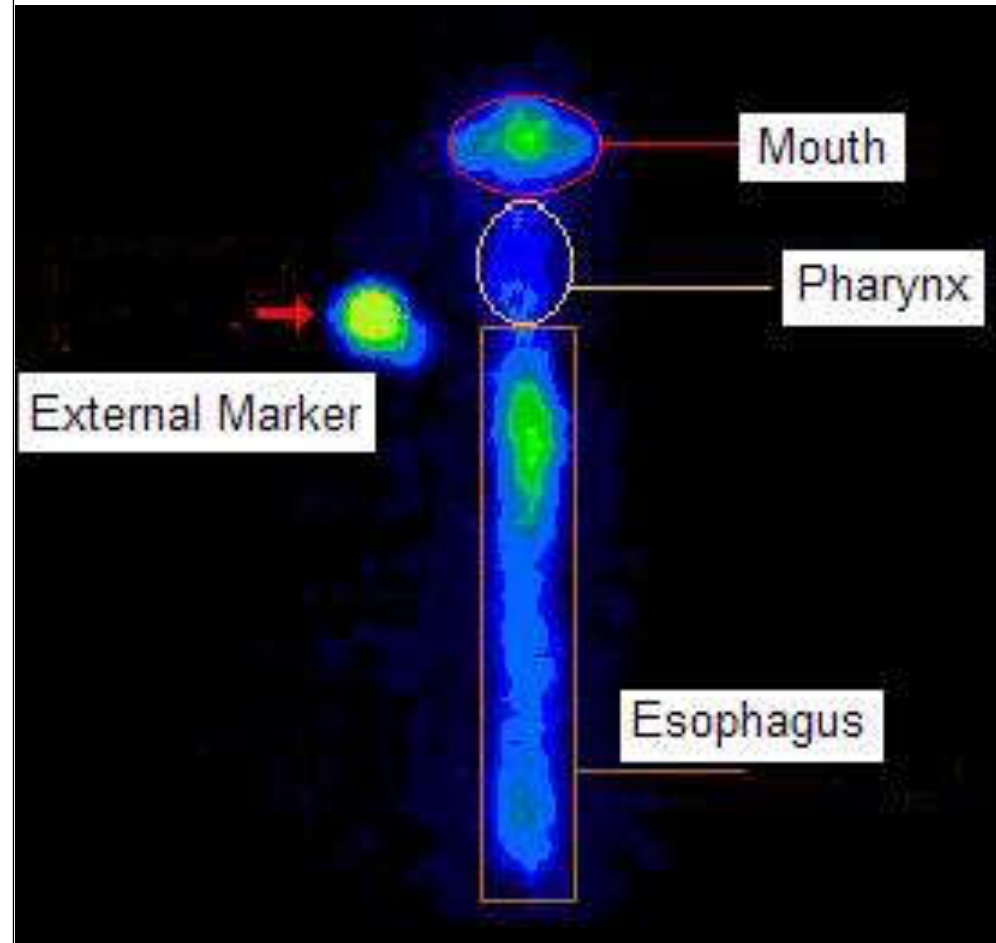


# Clearance and Pharynx Transit Time Measurement

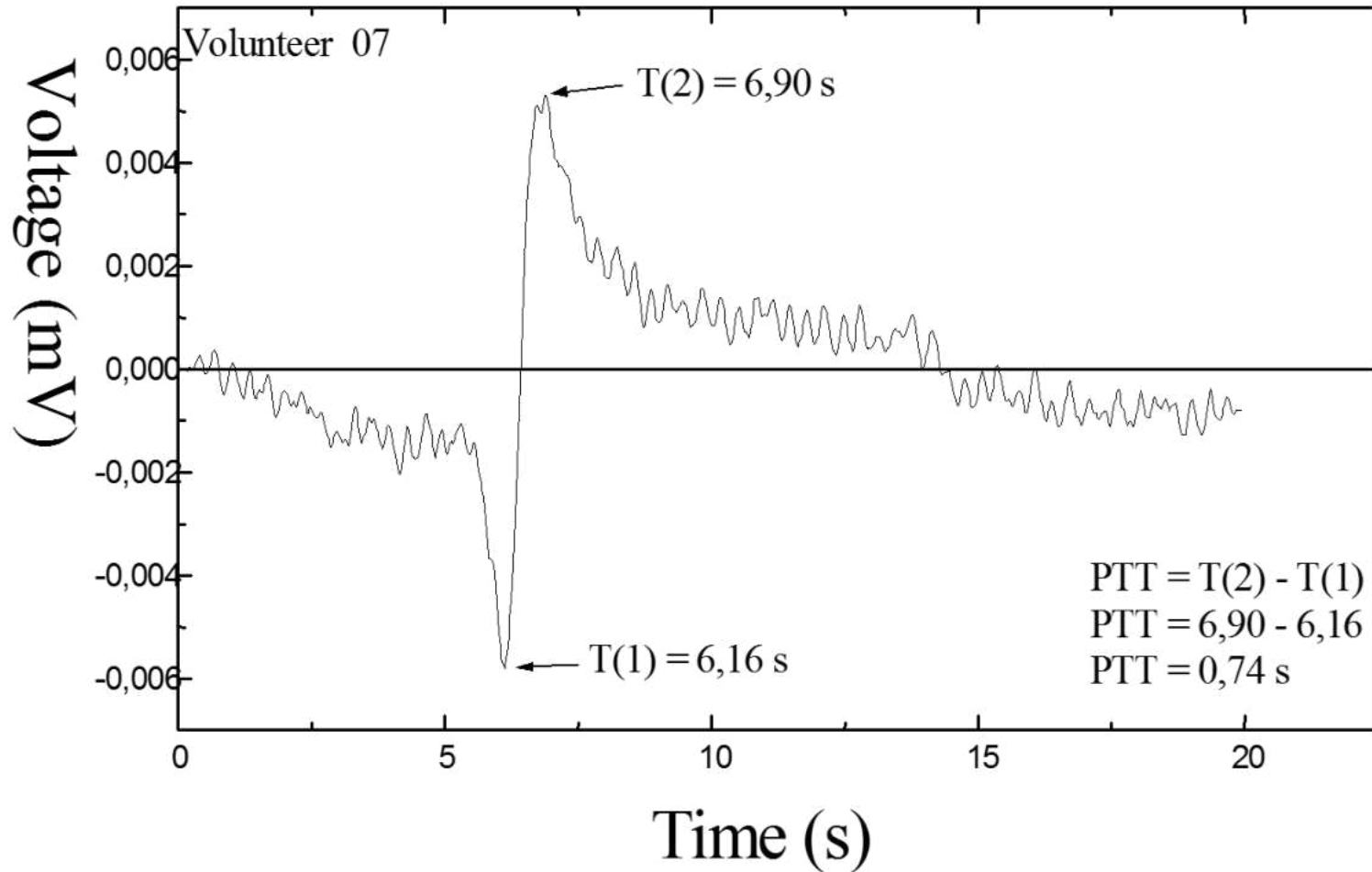


MIQUELIN, C. A.,  
BRAGA, F. J. H. N.,  
DANTAS, R. O.,  
OLIVEIRA, R. B.,  
BAFFA, O.  
Pharyngeal  
clearance and  
pharyngeal transit  
time determined by  
a biomagnetic  
method in normal  
humans.  
Dysphagia. , v.16,  
p.308 - 312, 2001.

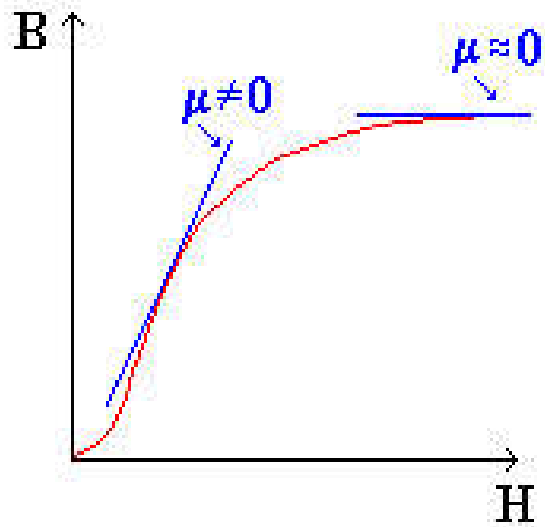
# Scintigraphic Image and Sensor Positioning



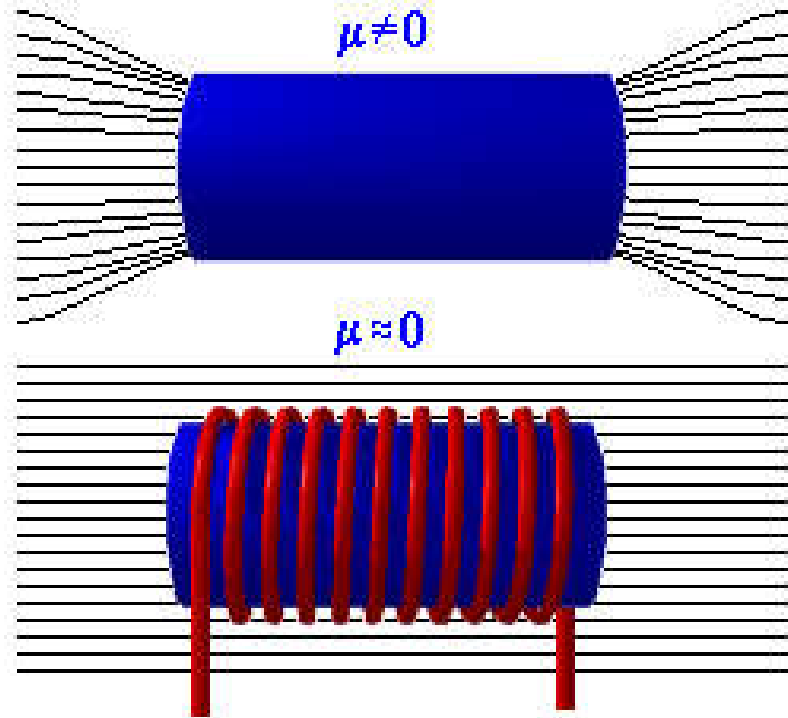
# PTT Typical Signal



# Fluxgate Magnetometer- $10^{-9}$ T



(a)



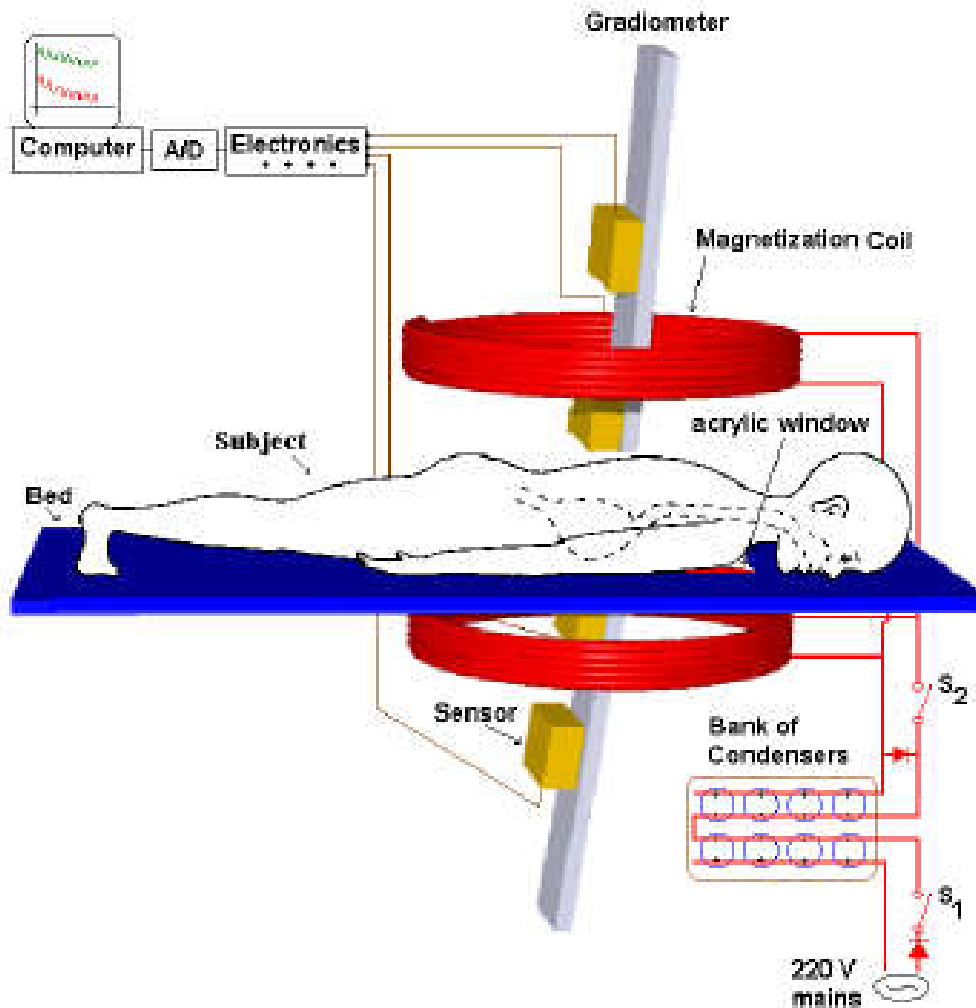
(b)



# Fluxgate with a Toroidal Nucleus

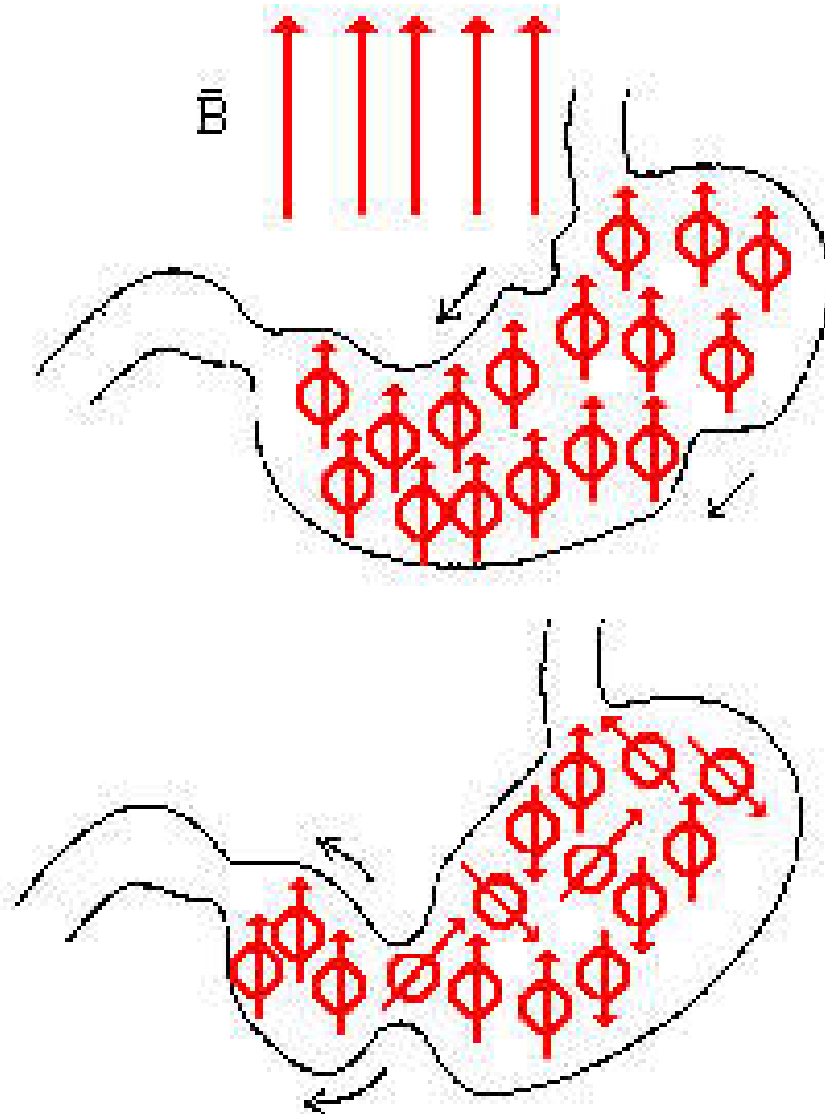


# Experimental Set-up for Magnetization Measurement



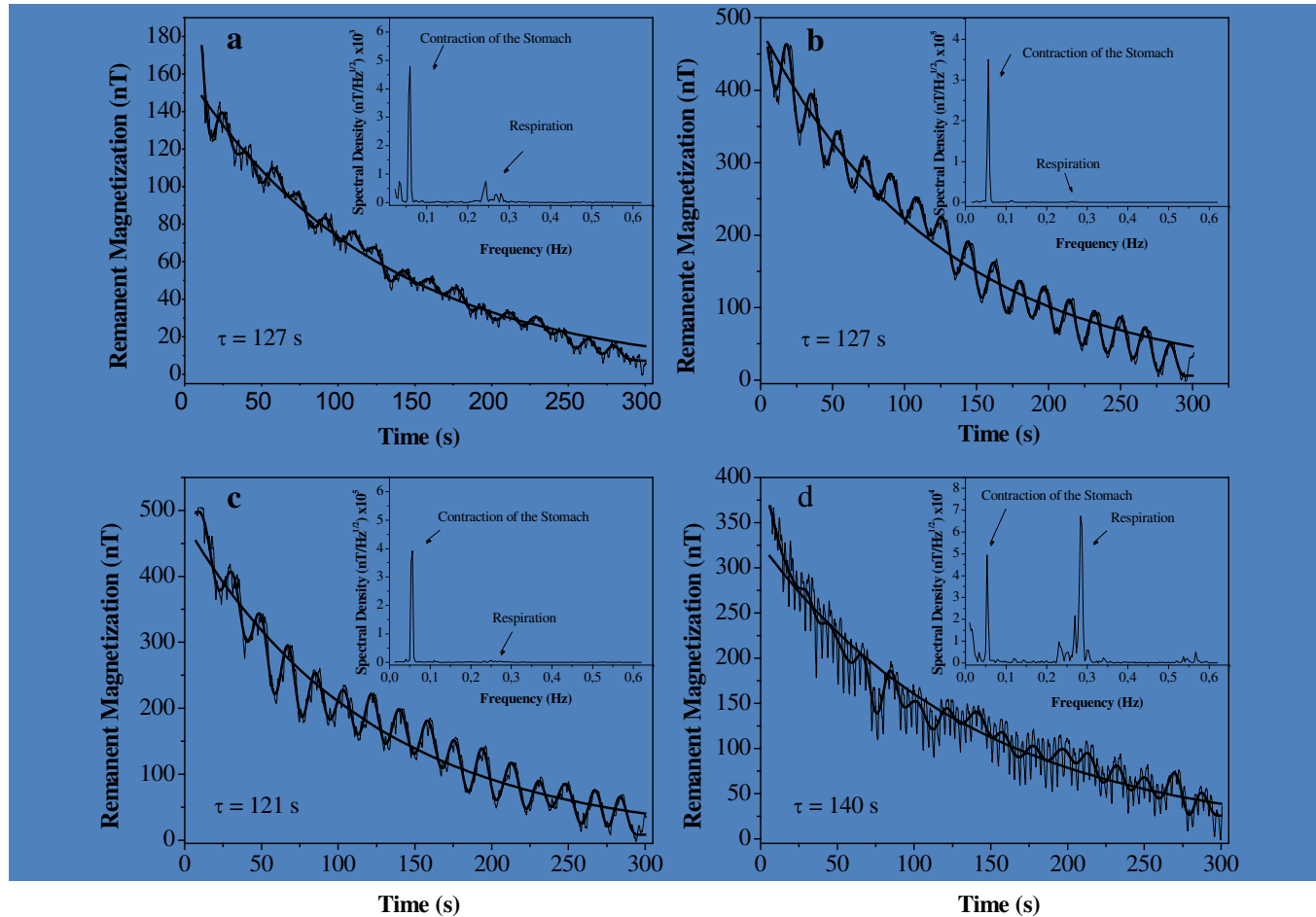
CARNEIRO, A. A. O.,  
BAFFA, O., OLIVEIRA,  
R. B.  
Study of Stomach  
Motility Using Magnetic  
Tracers. *Physics in  
Medicine and Biology*,  
v.44, p.1691 - 1697,  
1999.

# Relaxation Process Induced by the Stomach Motor Activity



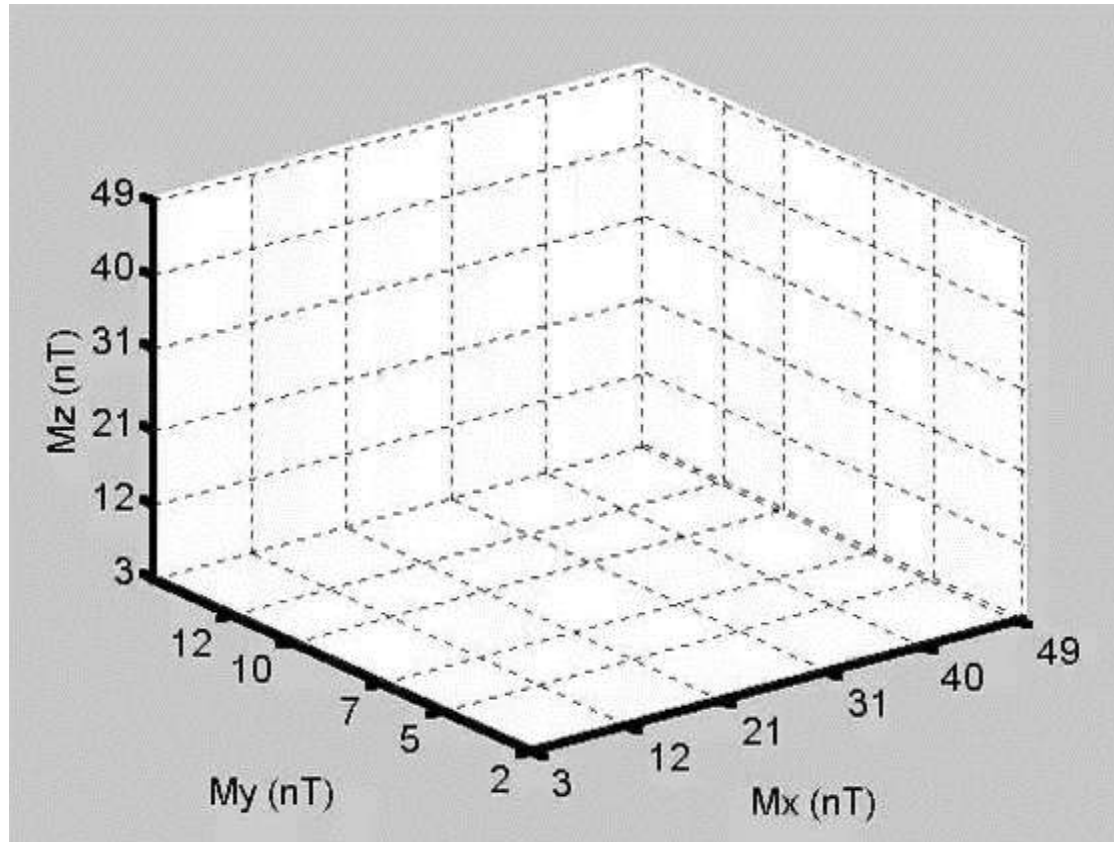
**Z component of  
the remanent  
magnetization  
 $M_z$  is measured**

# Magnetization Decay Due to Stomach's Mechanical Activity



Sequence of RM decay curves obtained from a volunteer within the 40 min period immediately after ingestion of the test meal.

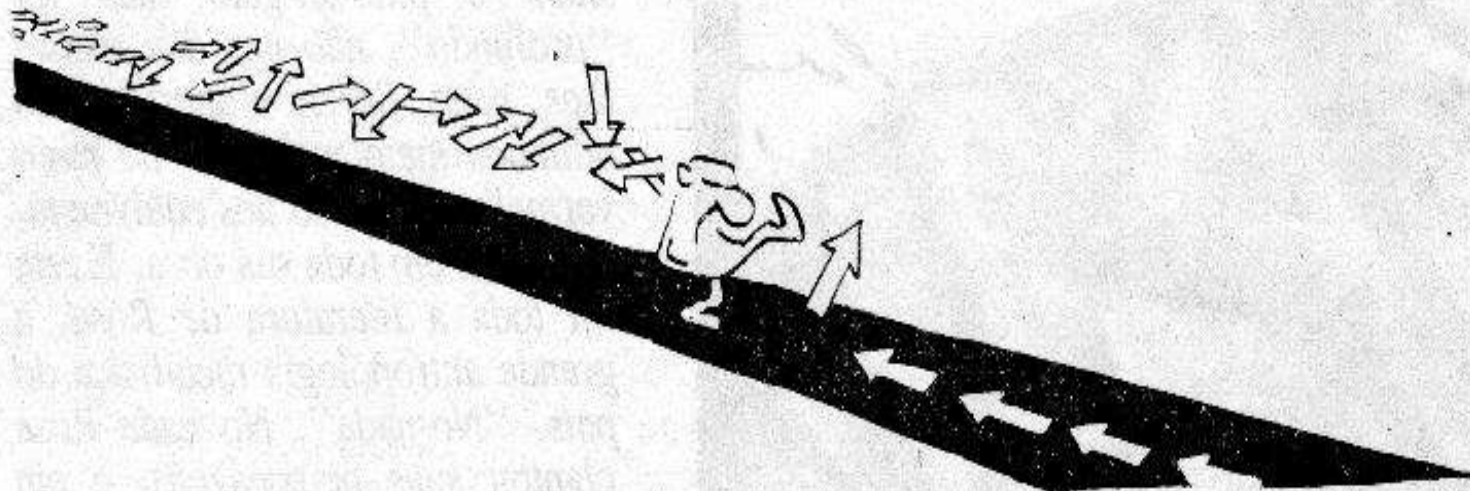
# Remanent Magnetization – Time course



# M<sub>Z</sub>-Decay: a possible mechanism

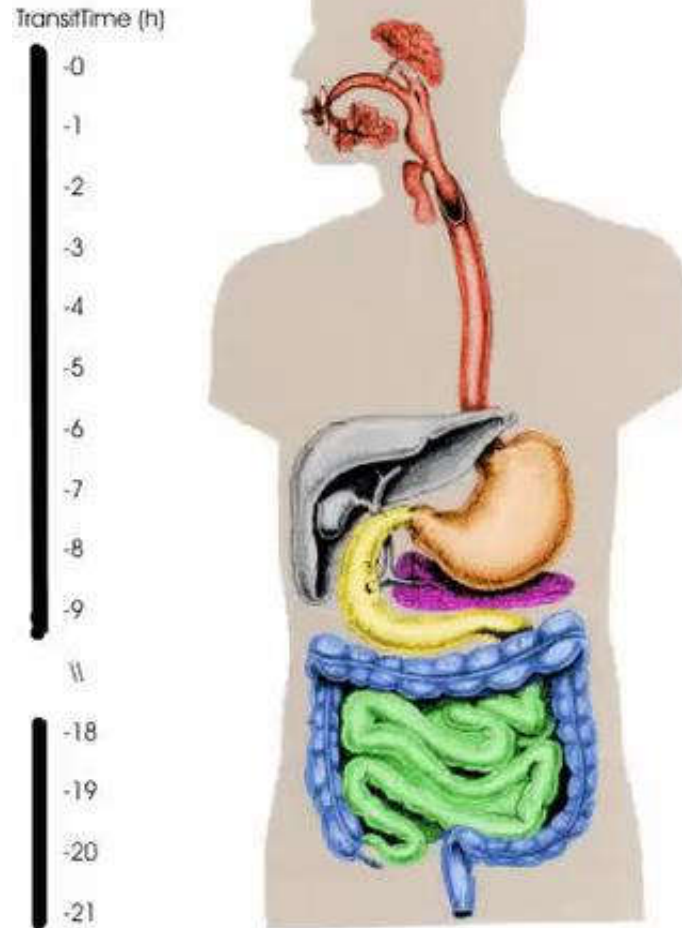
PIRATAS DO TIETÊ

LAERTE

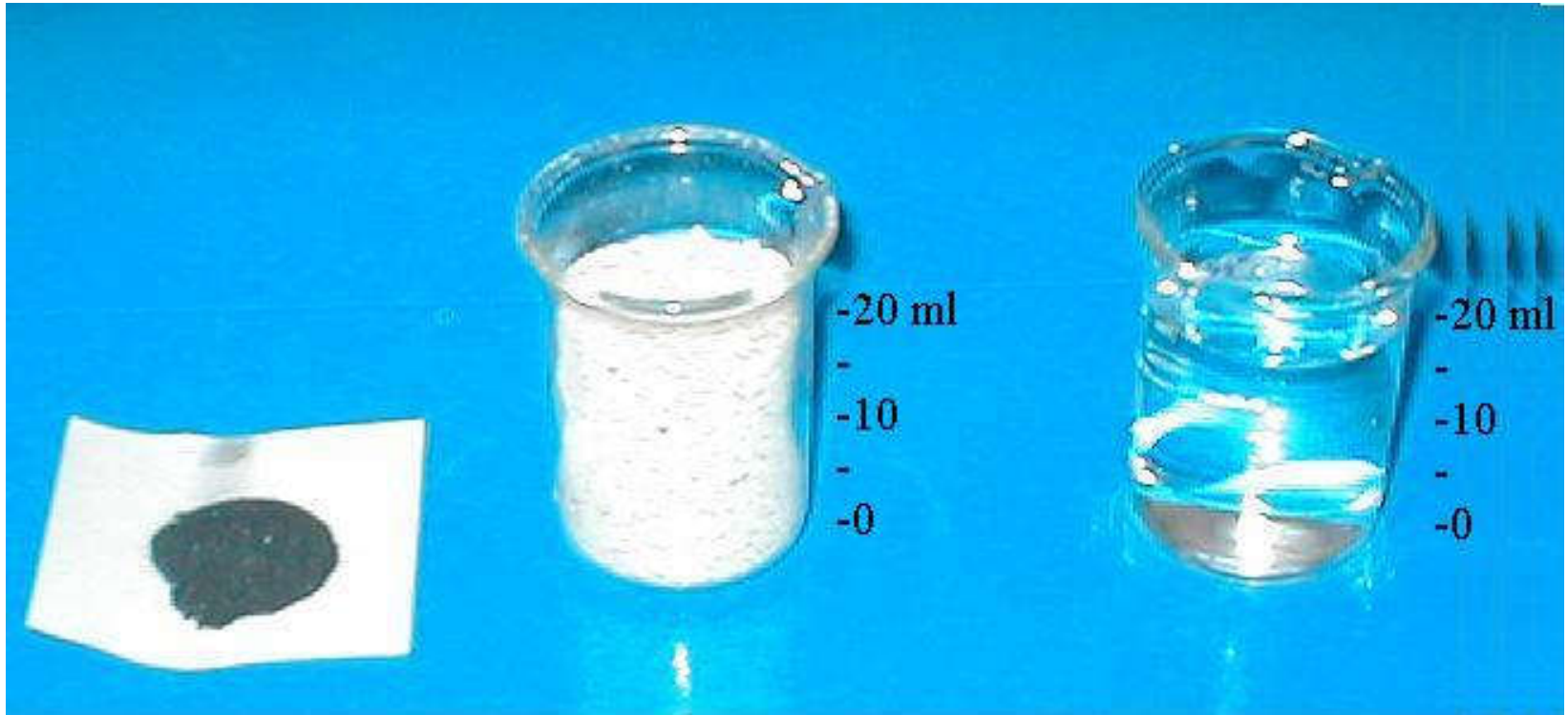


LAERTE

# Gastrocolic Reflex



# Test Meal



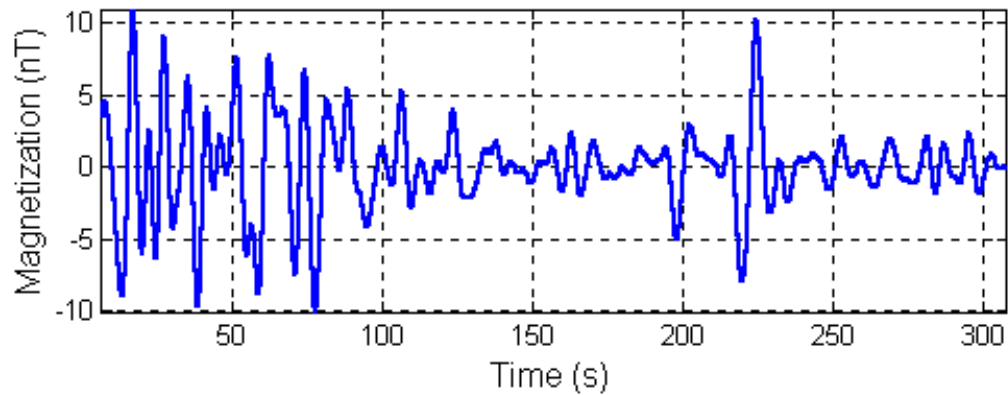
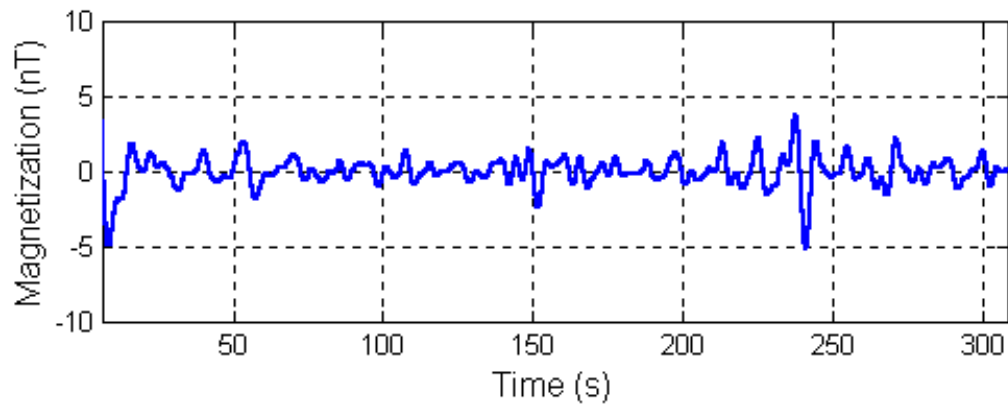
3 g magnetite ( $\text{Fe}_3\text{O}_4$ )

15 g Oat Flour

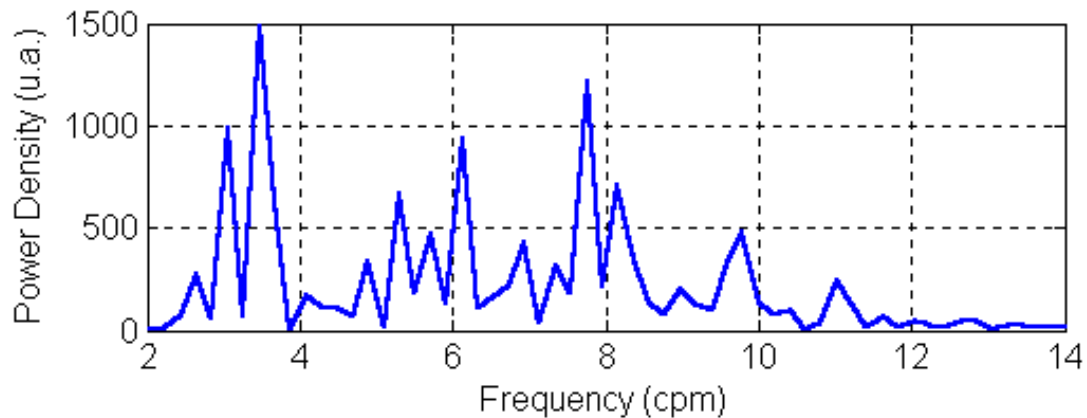
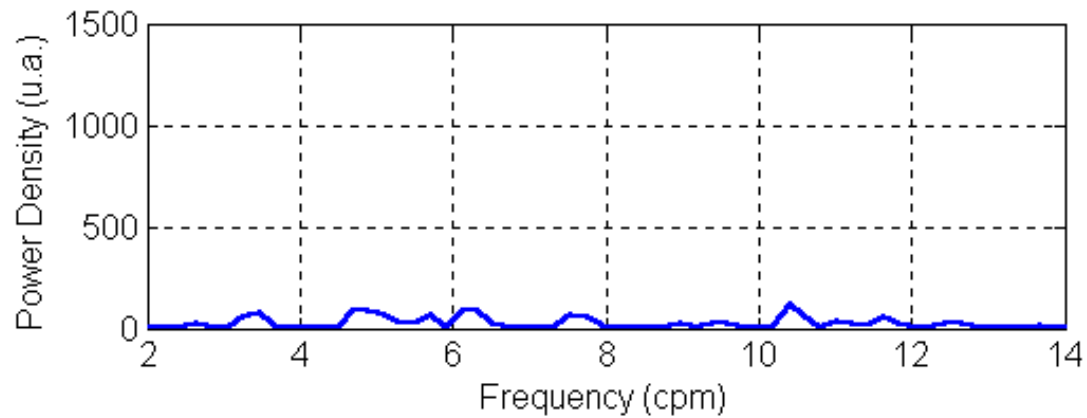
Water



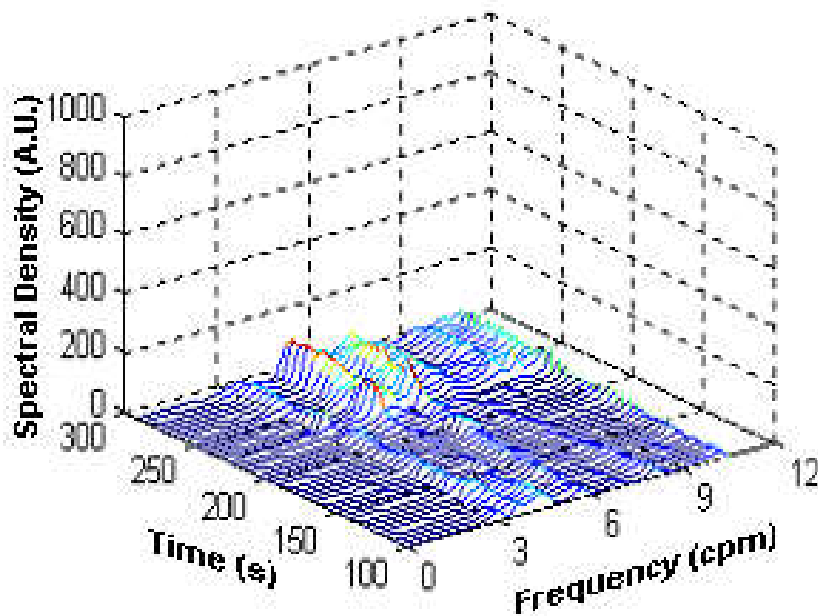
# Magnetic Signal of Cecum Region



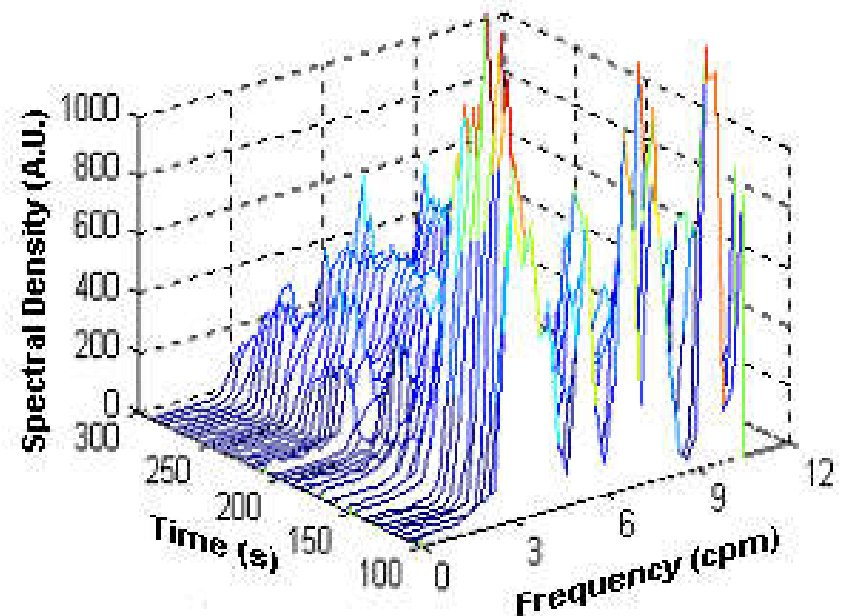
# Magnetic Signal Fourier Transform



# Evolution of the B<sub>2</sub> component



Before Meal

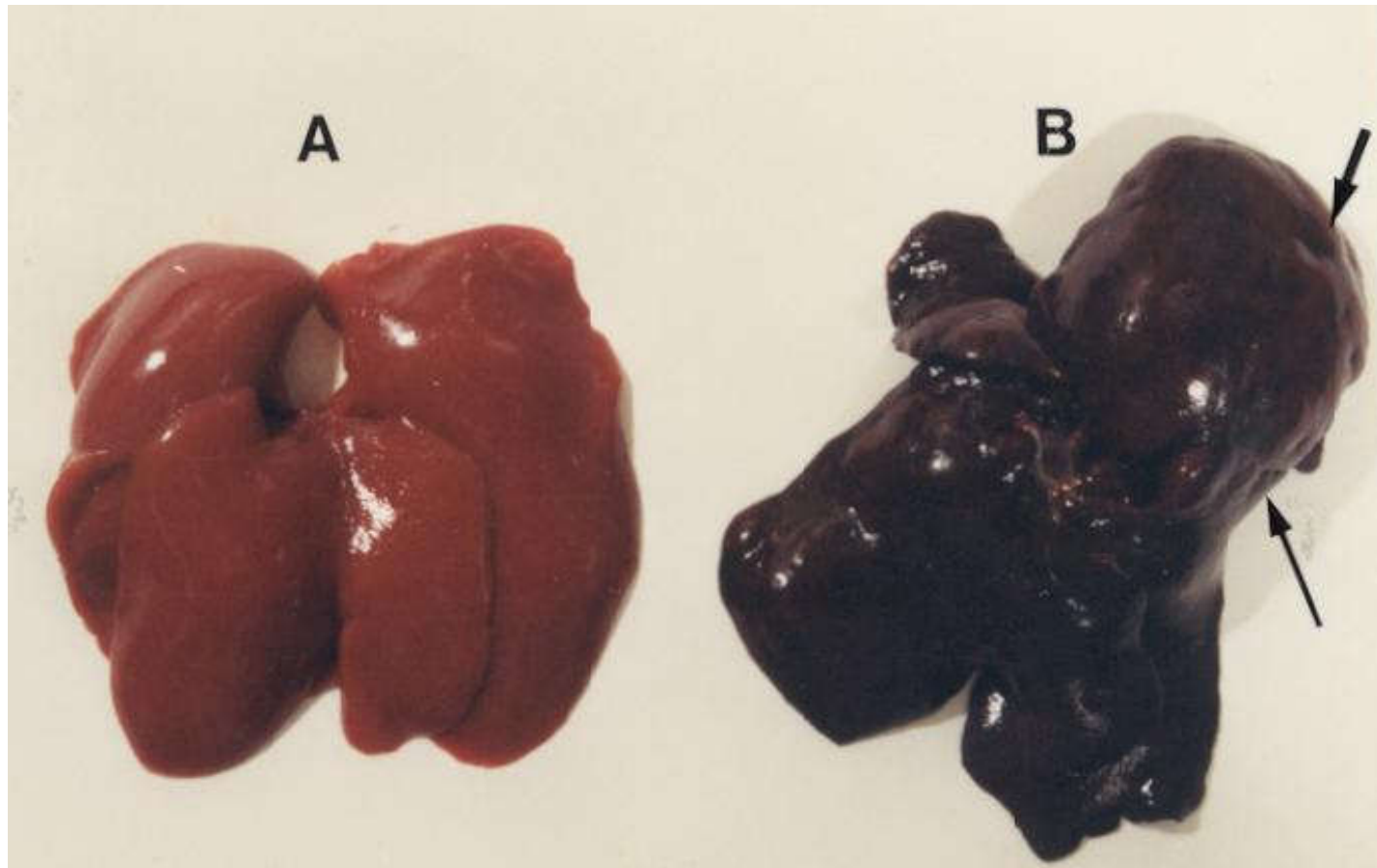


After Meal

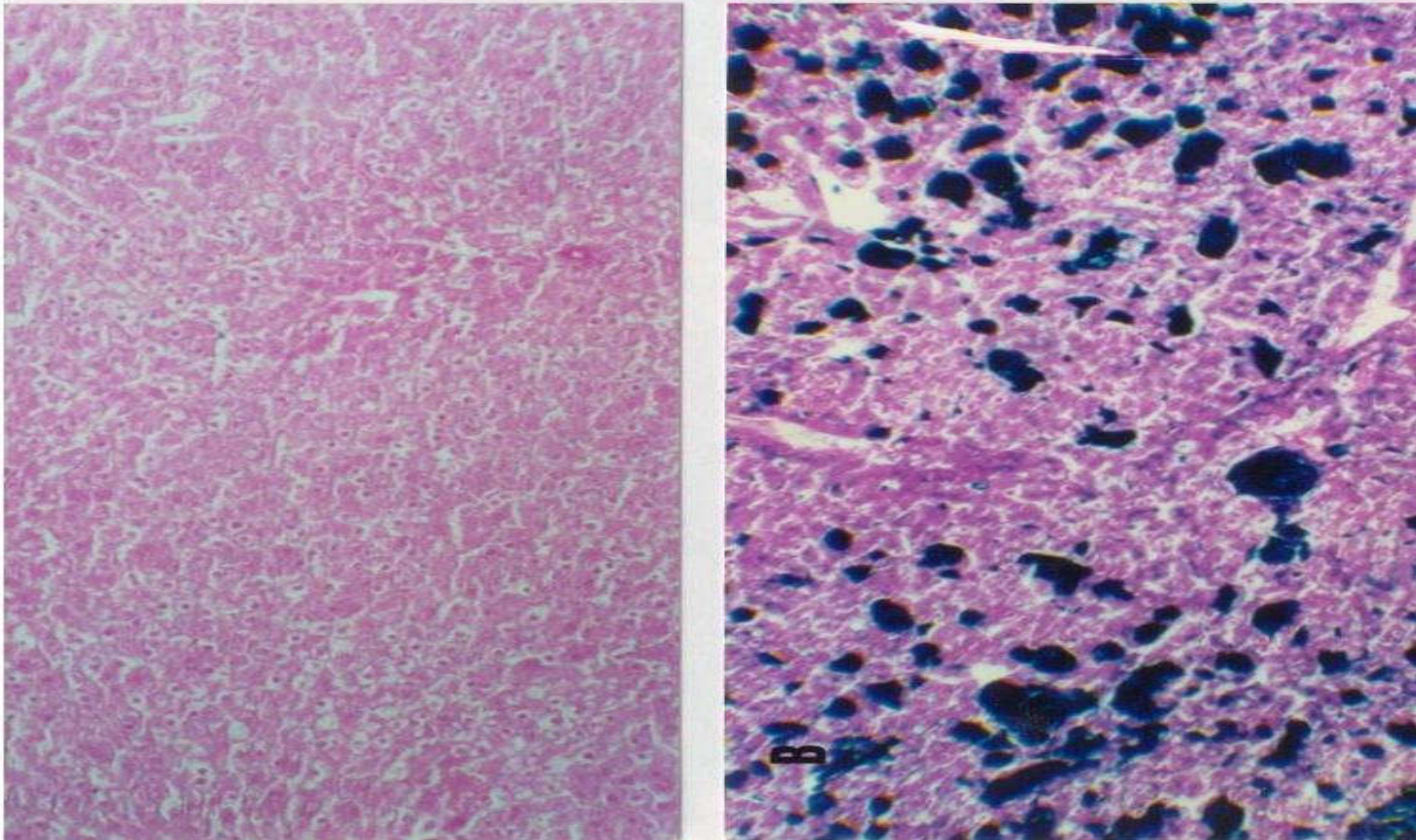
# Liver Susceptometry

Zeev Gidon Kipervaser Sapiro  
Antonio Adilton Oliveira Carneiro  
Geraldo dos Santos Neto  
Eduard Hincapie

# Macroscopic aspects of the iron overloaded liver



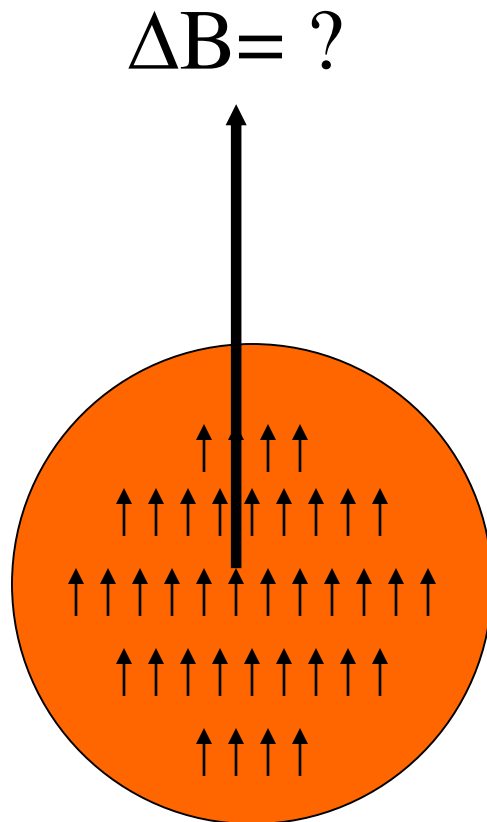
# Microscopic aspects of the iron overloaded liver



# Methods for iron overload assessment

- Needle Biopsy (*gold standard?*)
- Serum ferritin concentration
- **Magnetic Resonance Imaging**
- **Magnetic Susceptibility**

# Magnetic Field Some estimates



The magnetic field produced by a sphere of radius  $r$  is given by: 
$$\Delta B = \frac{\mu_0}{2\pi} \left( \frac{m_d}{r^3} \right)$$

But:  $\chi = \frac{M}{H}$  and  $M = \frac{m_d}{V}$

Thus:  $m_d = MV = \chi HV$

But:  $\chi \approx 10^{-5}$   $B = \mu_0(1 + \chi)H \approx \mu_0 H$

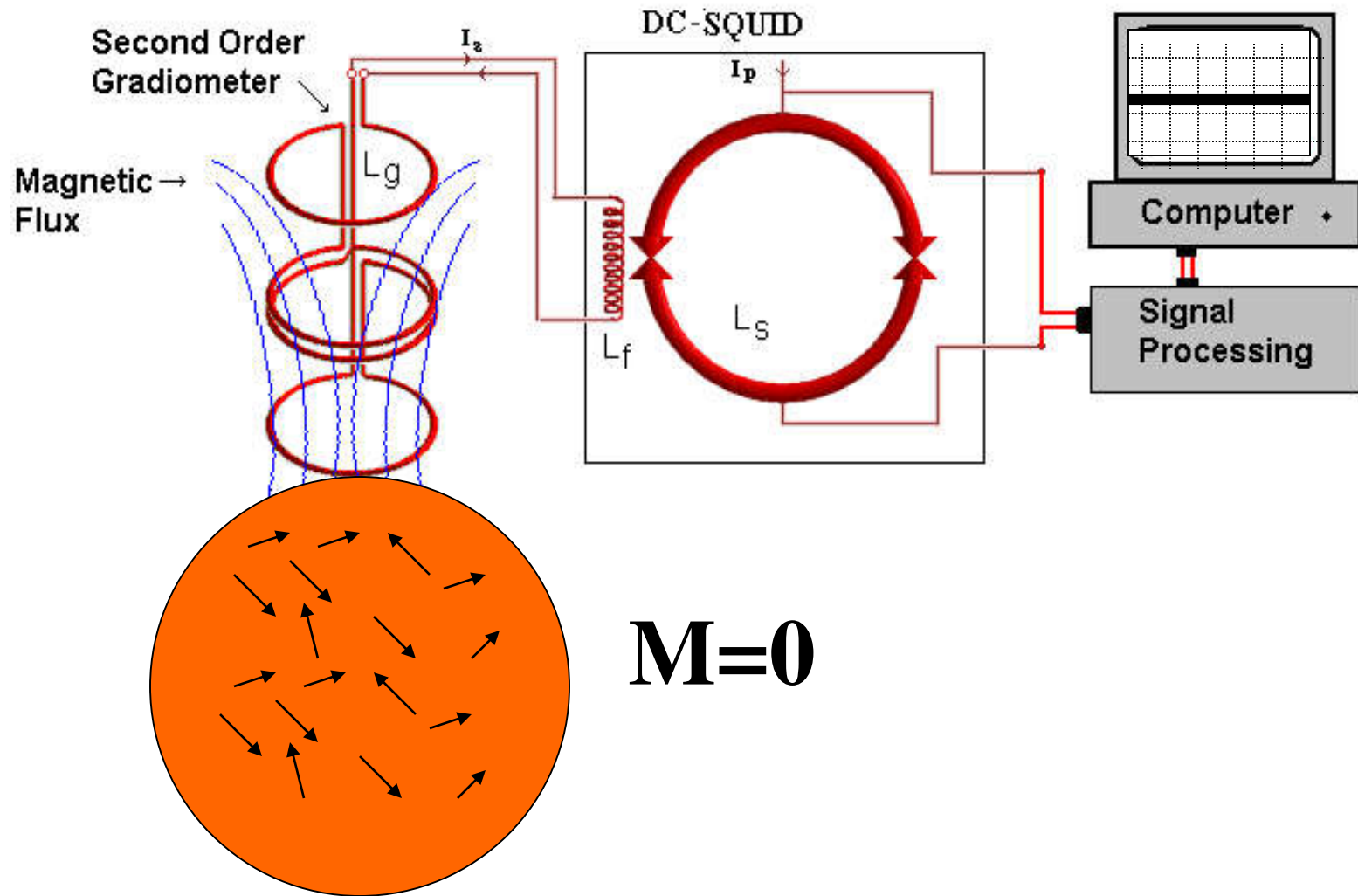
Thus: 
$$m_d = \frac{\chi VB}{\mu_0}$$

$$\Delta B = \frac{\mu_0}{2\pi} \left( \frac{\chi VB}{\mu_0 r^3} \right) = \frac{\mu_0}{2\pi} \left( \frac{4\pi r^3}{3\mu_0 r^3} VB \right) = \frac{2}{3} \chi B$$

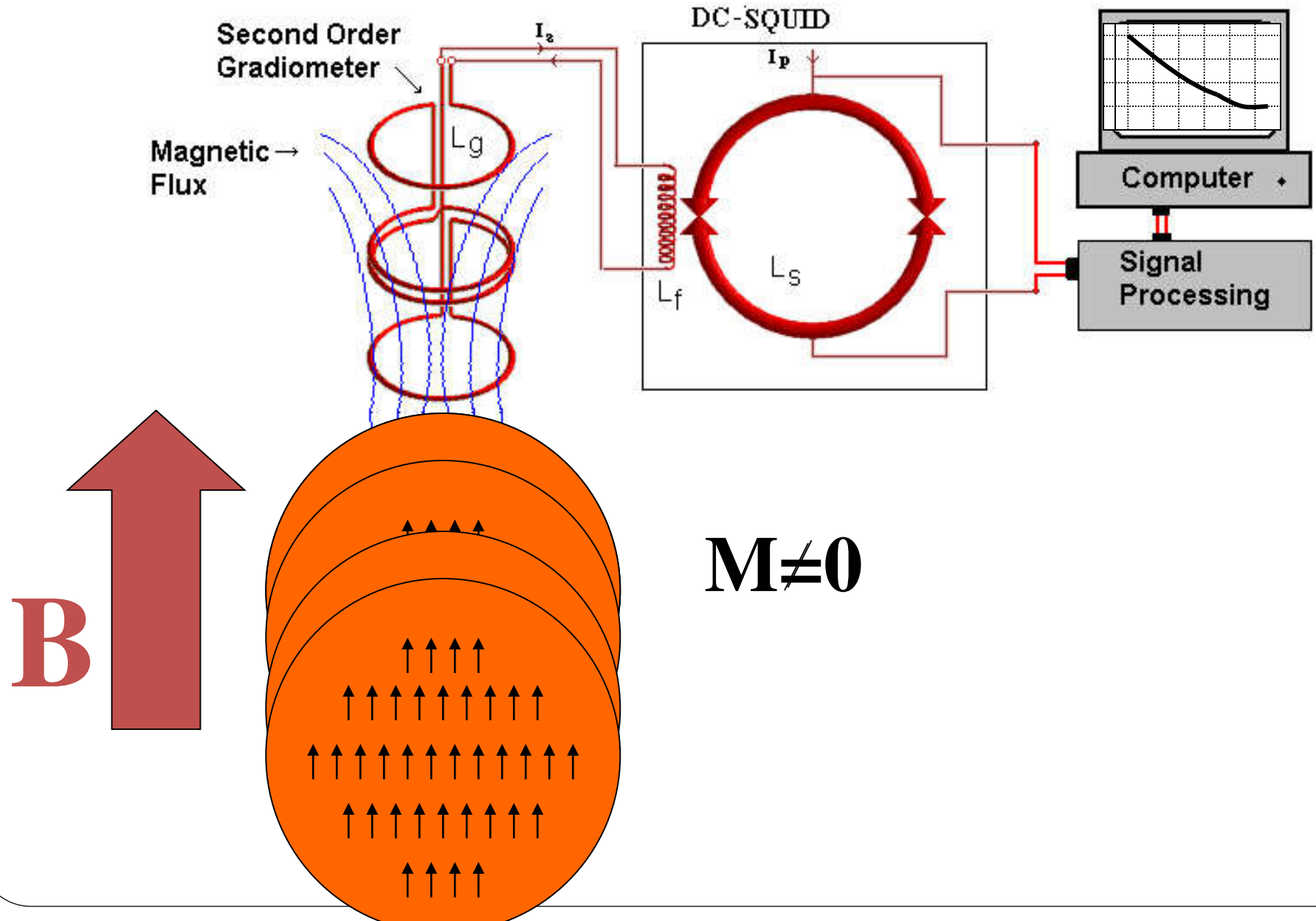
Using a magnetic field of  $60\mu\text{T}$  a variation of  $100\text{pT}$  will be produced.



# Procedure of measurement



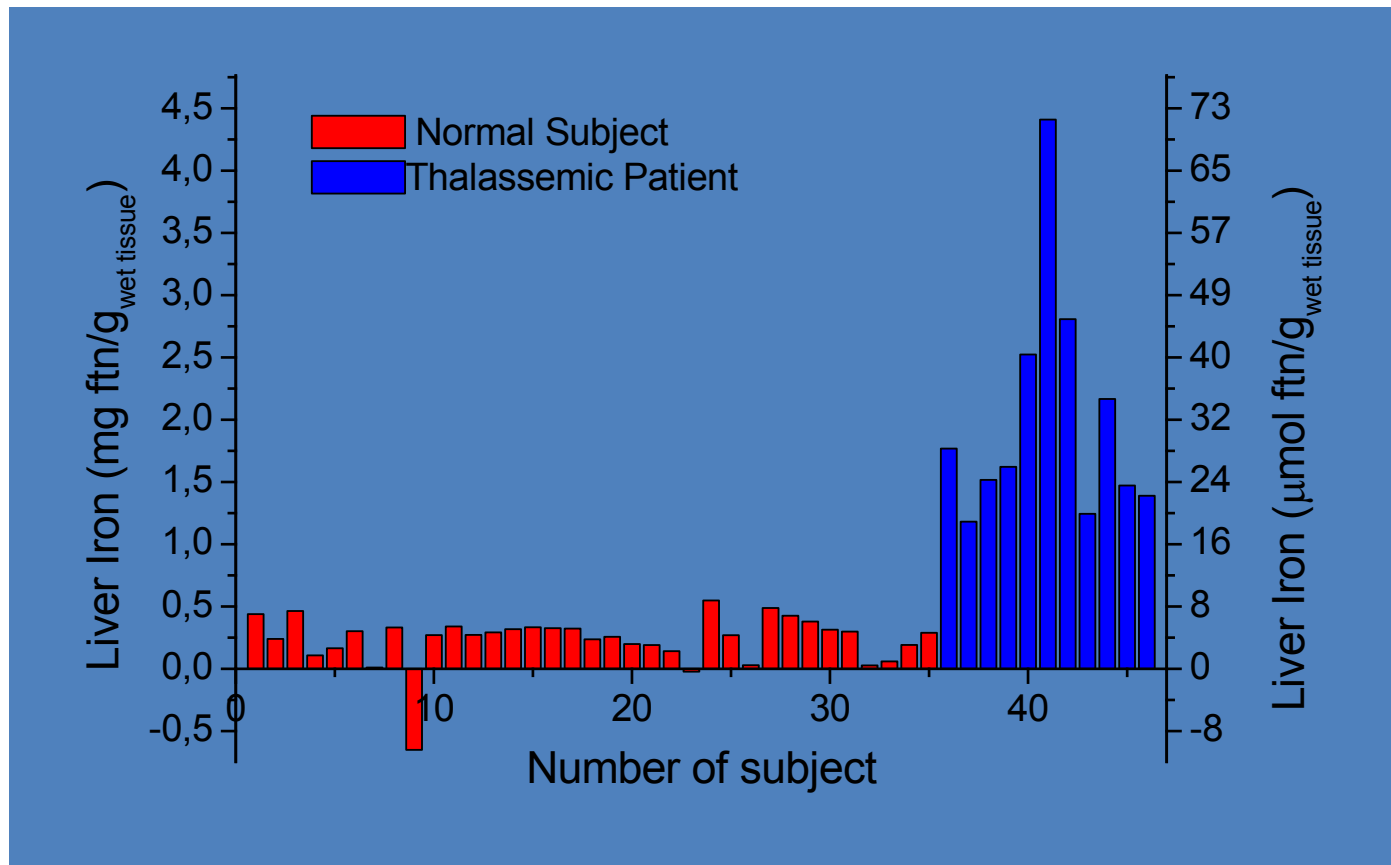
# Procedure of measurement



# *In vivo* measurements



# Results of in vivo measurements

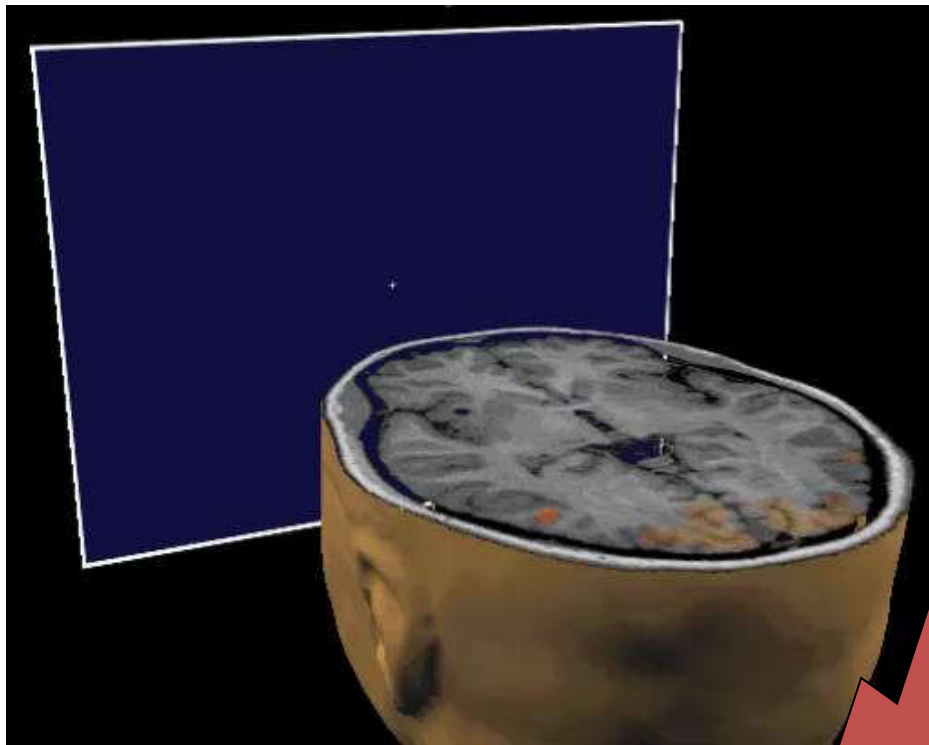


# MEG

Draulio Barros de Araujo

Ronald Wakai

# Noninvasive methods to study and localize neuronal activity: fMRI, EEG e MEG



Belliveau et al. Science 1991

**MEG e EEG**

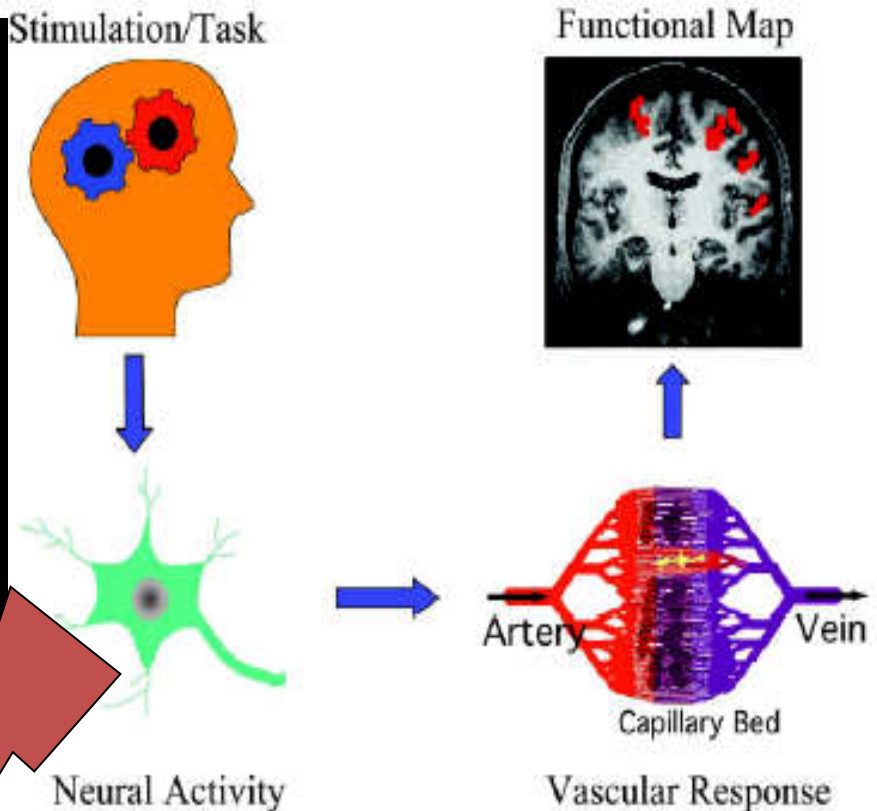
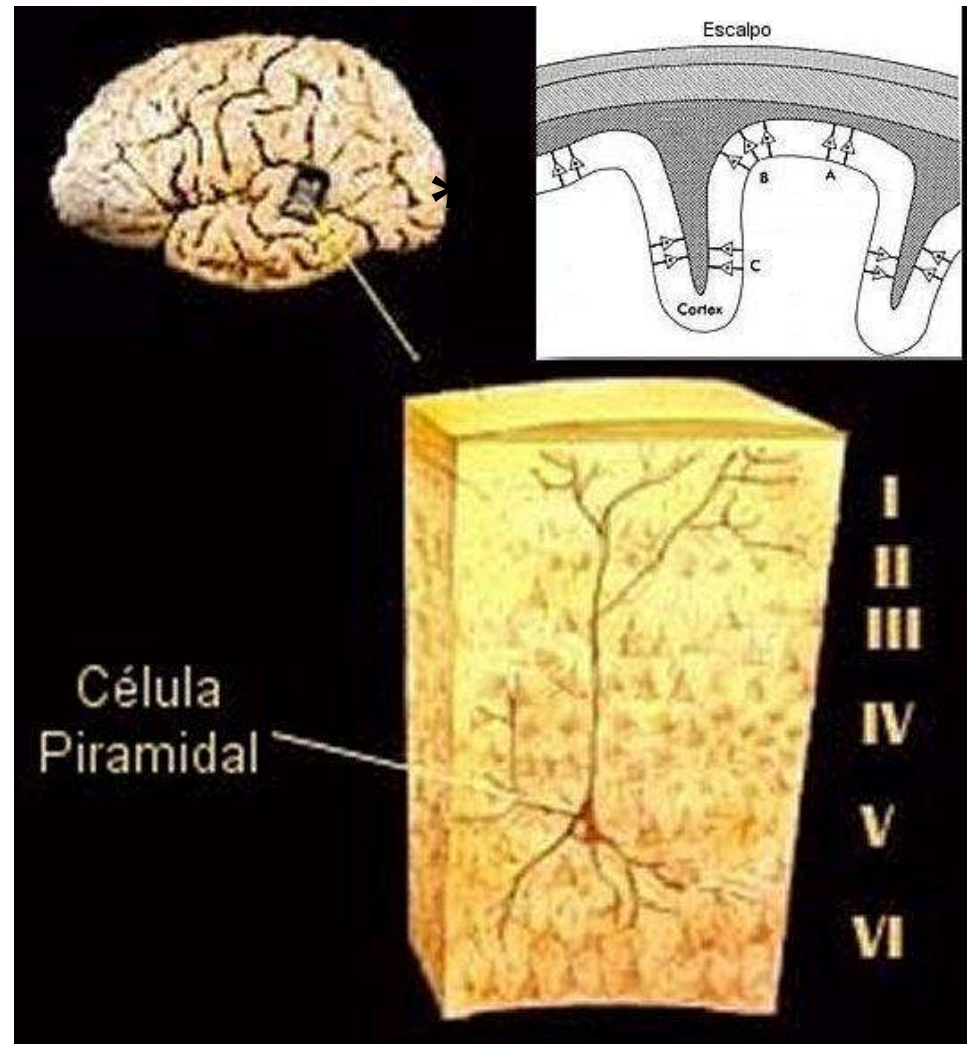
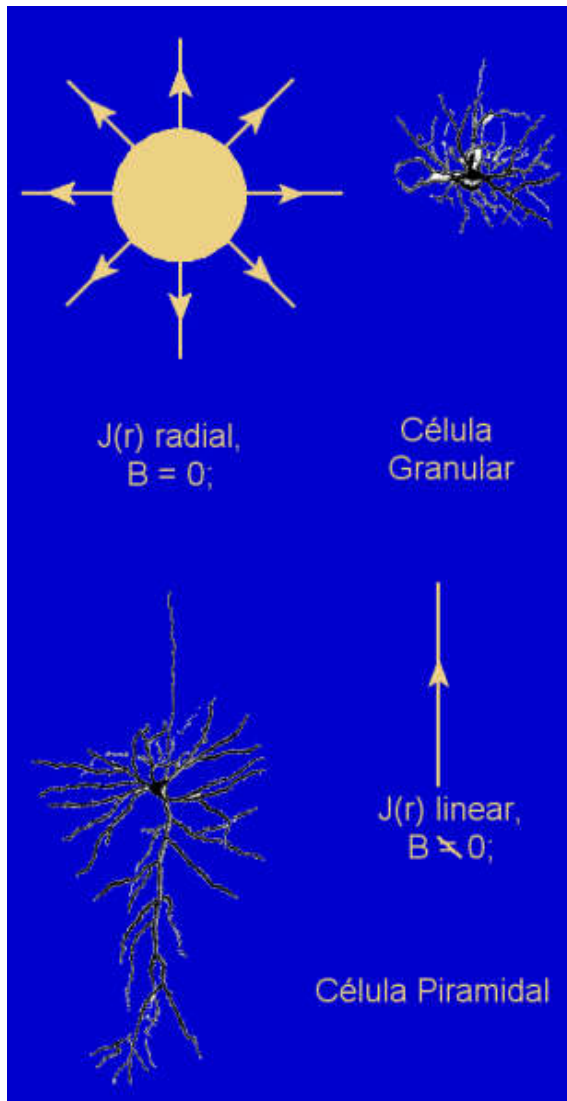


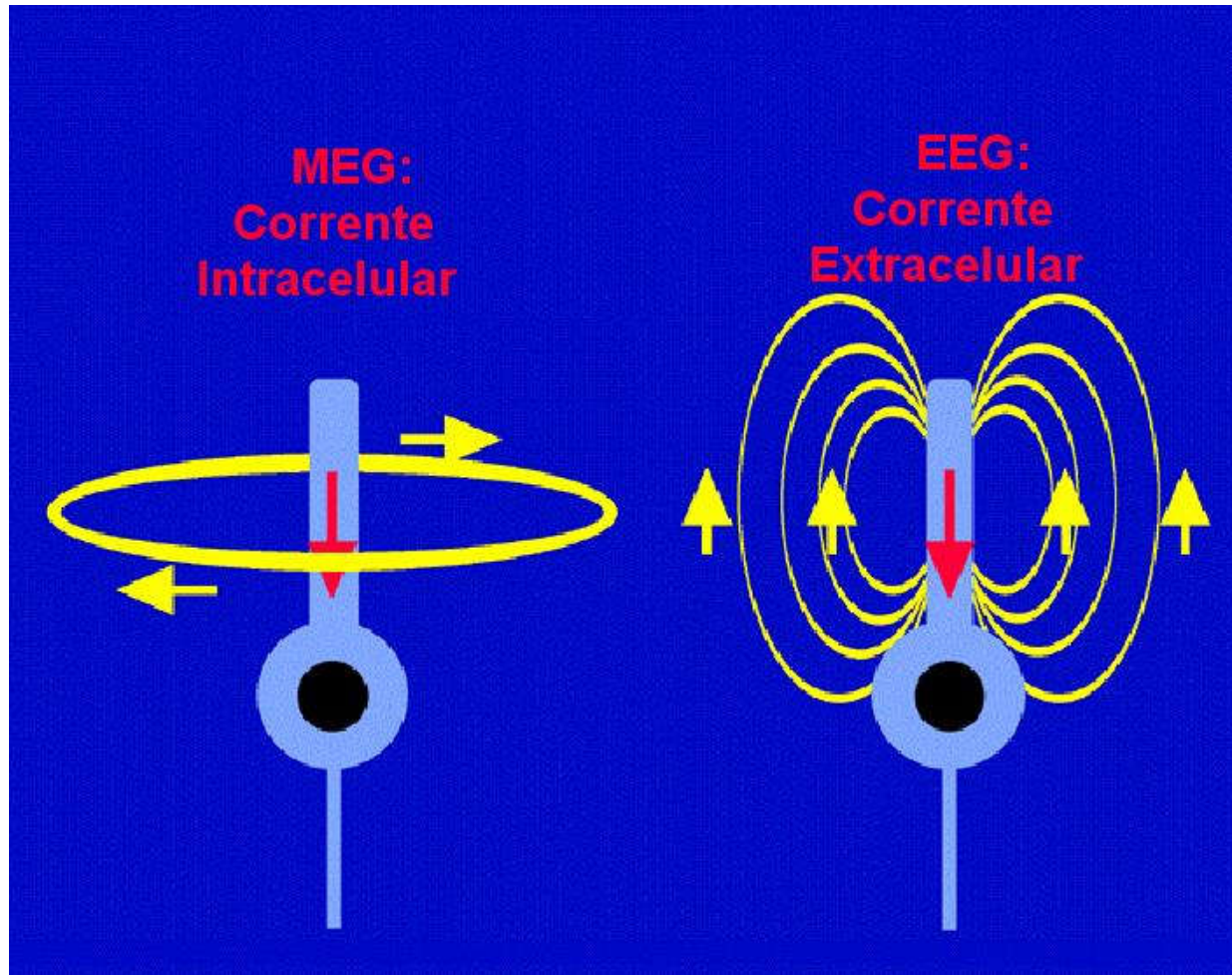
Fig. 1. Schematic chain of processes from behavior to functional mapping.

Kim, PNAS, 2003

# Cellular Architecture → Sources

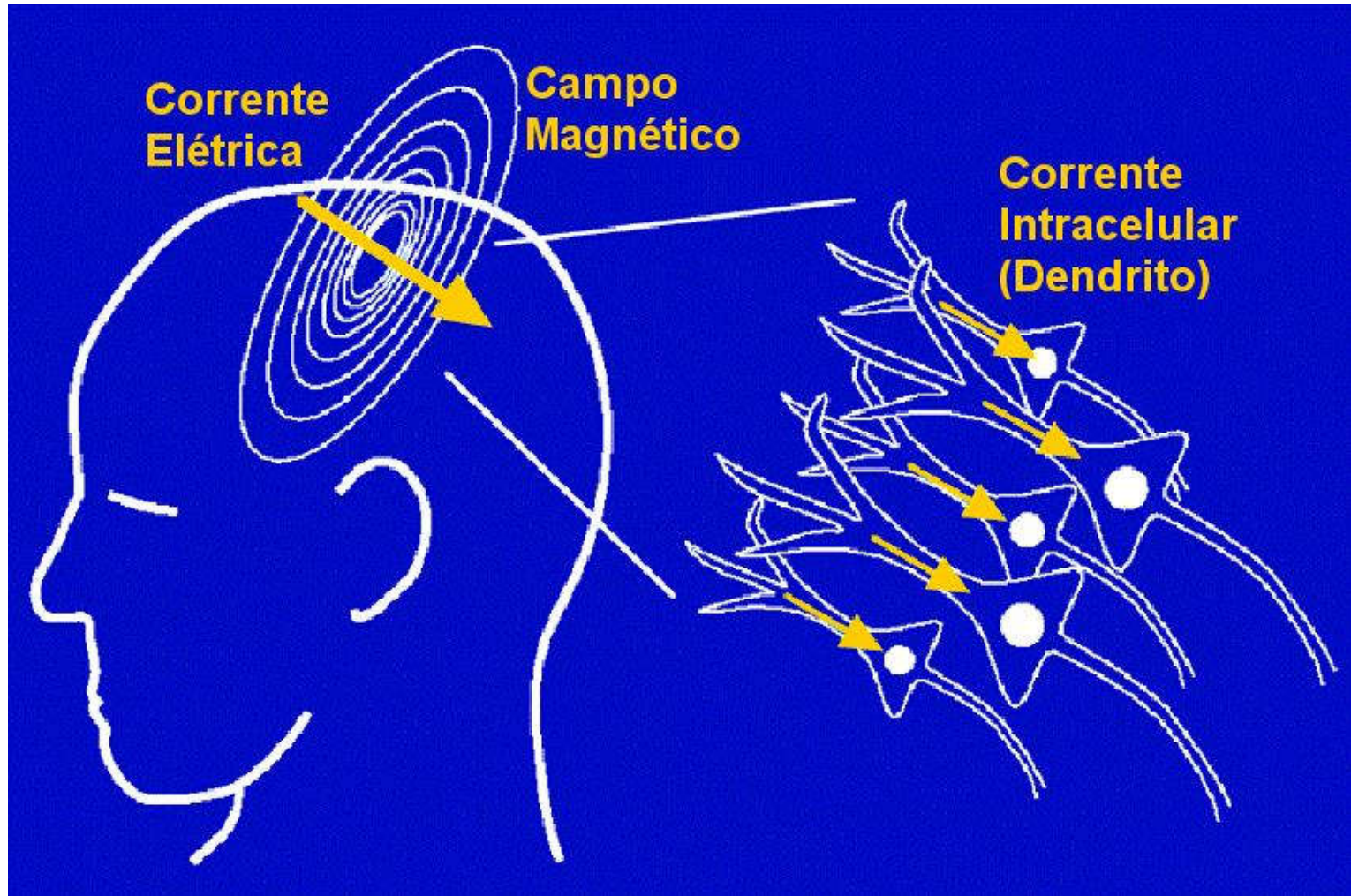


# MEG e EEG Current sources



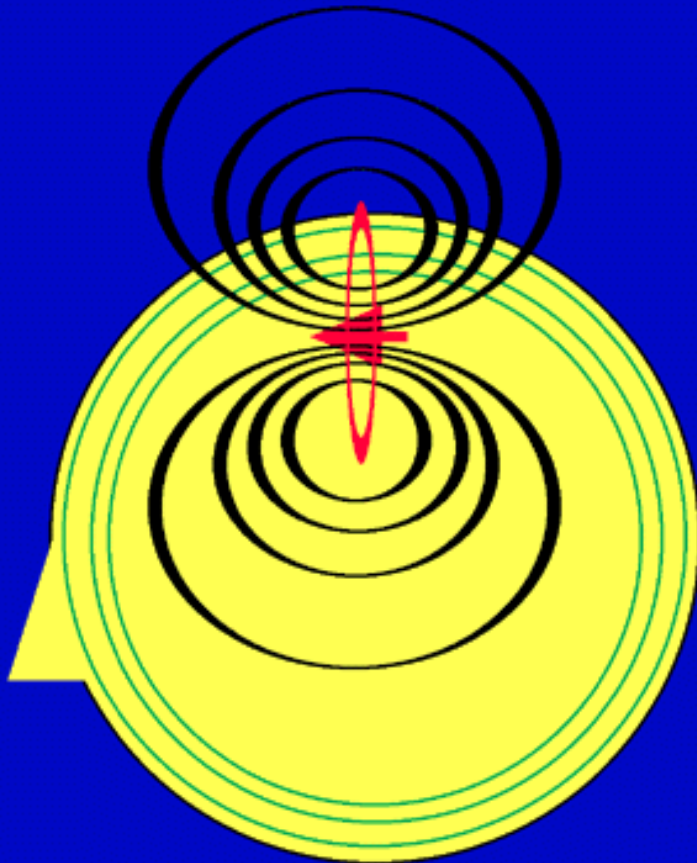


# Magnetoencefalography (MEG)

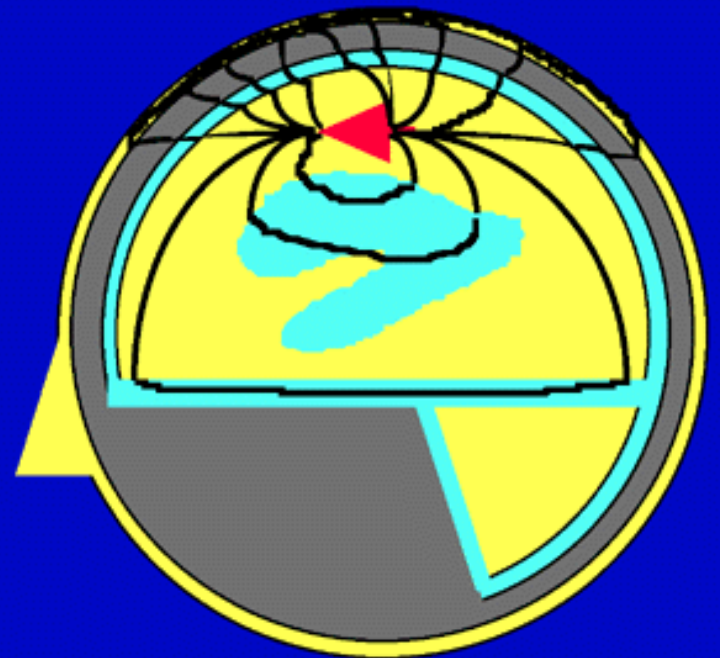


# The effect of electrical conductivity on the EEG

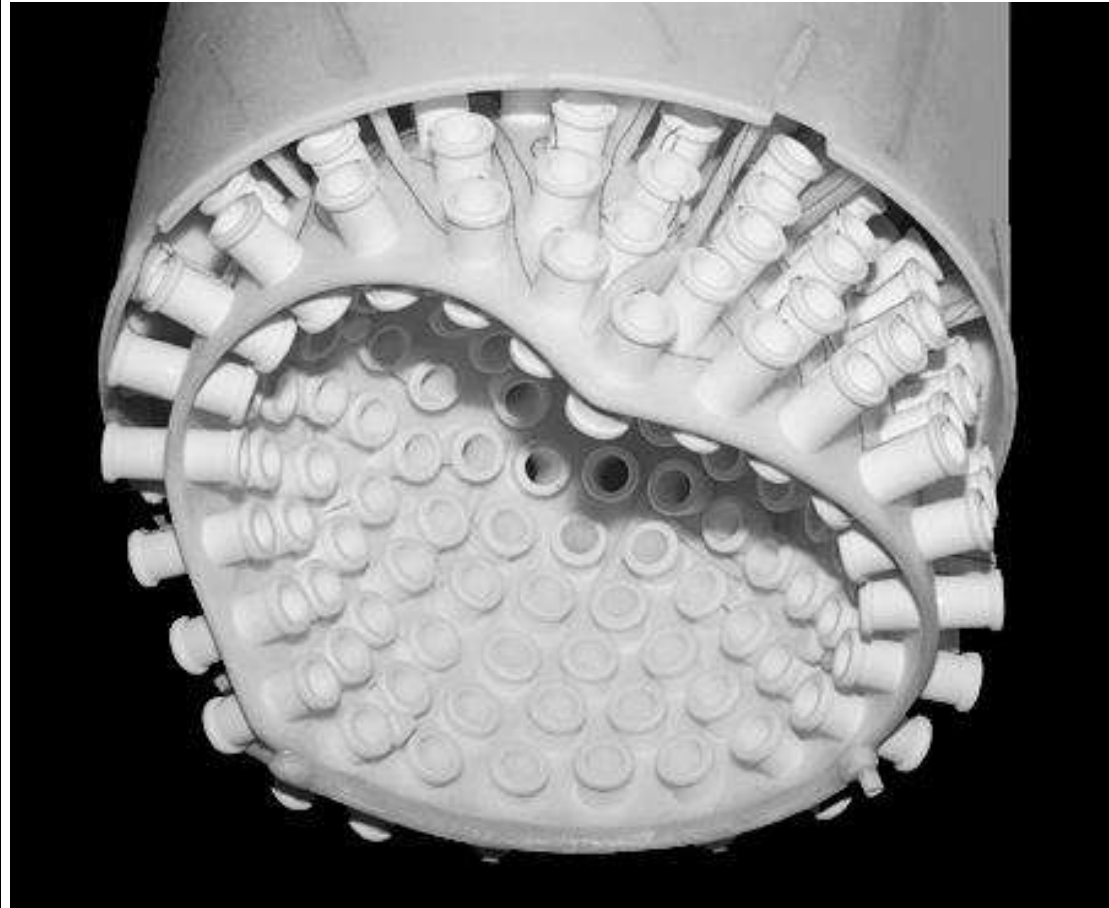
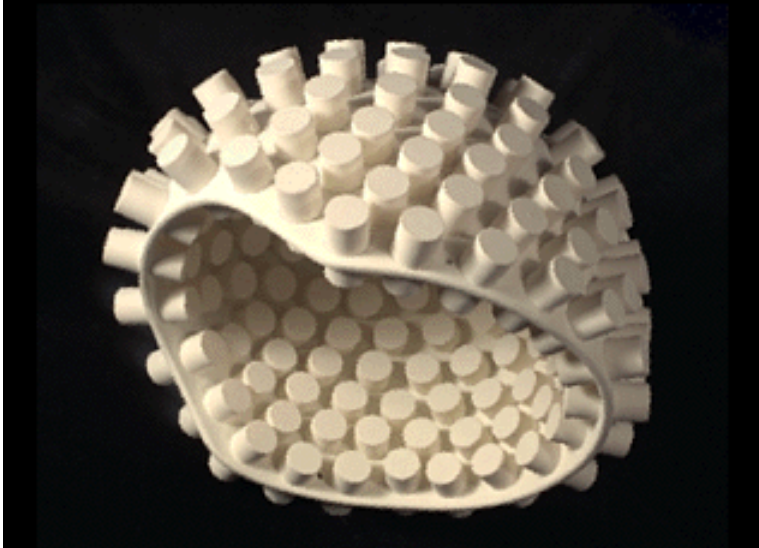
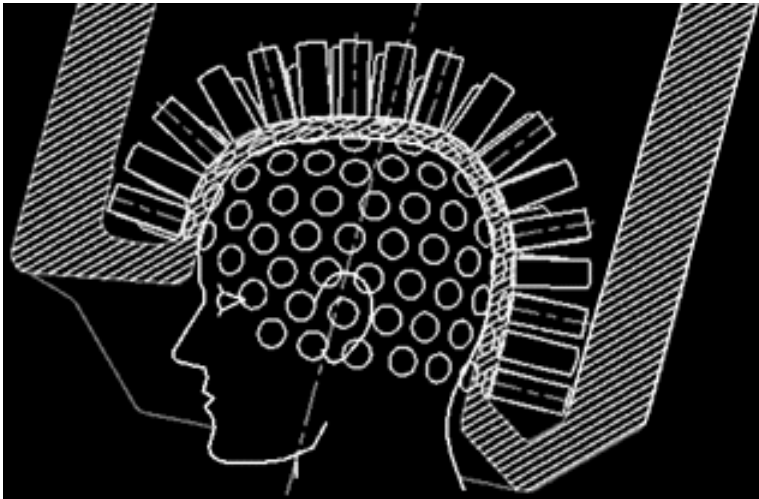
**MEG**



**EEG**



# Sensor Array



# CTF and Neuromag Systems

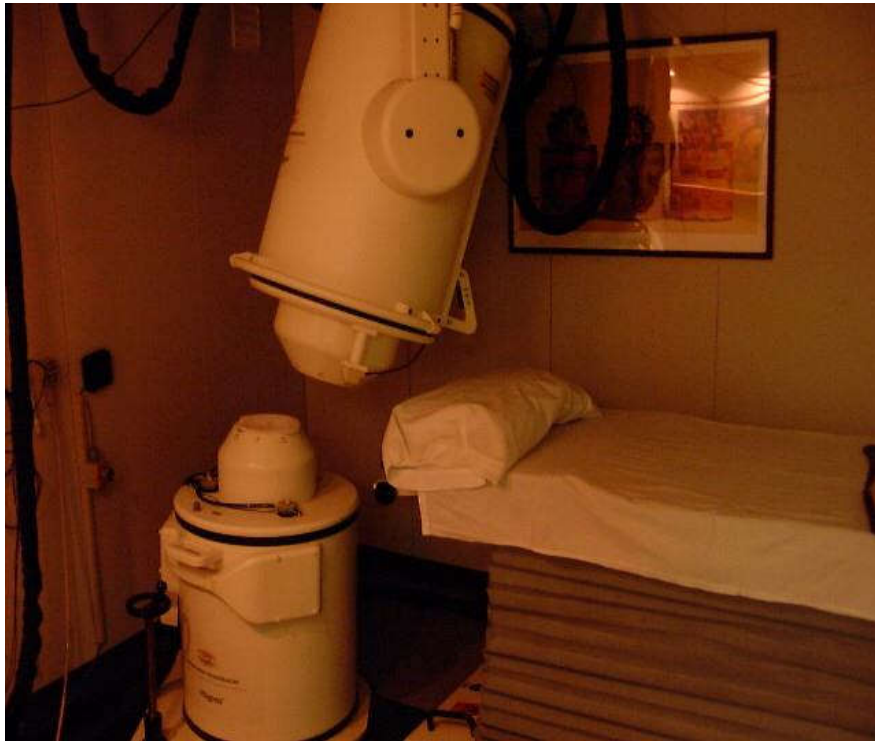


# System inside a MSR

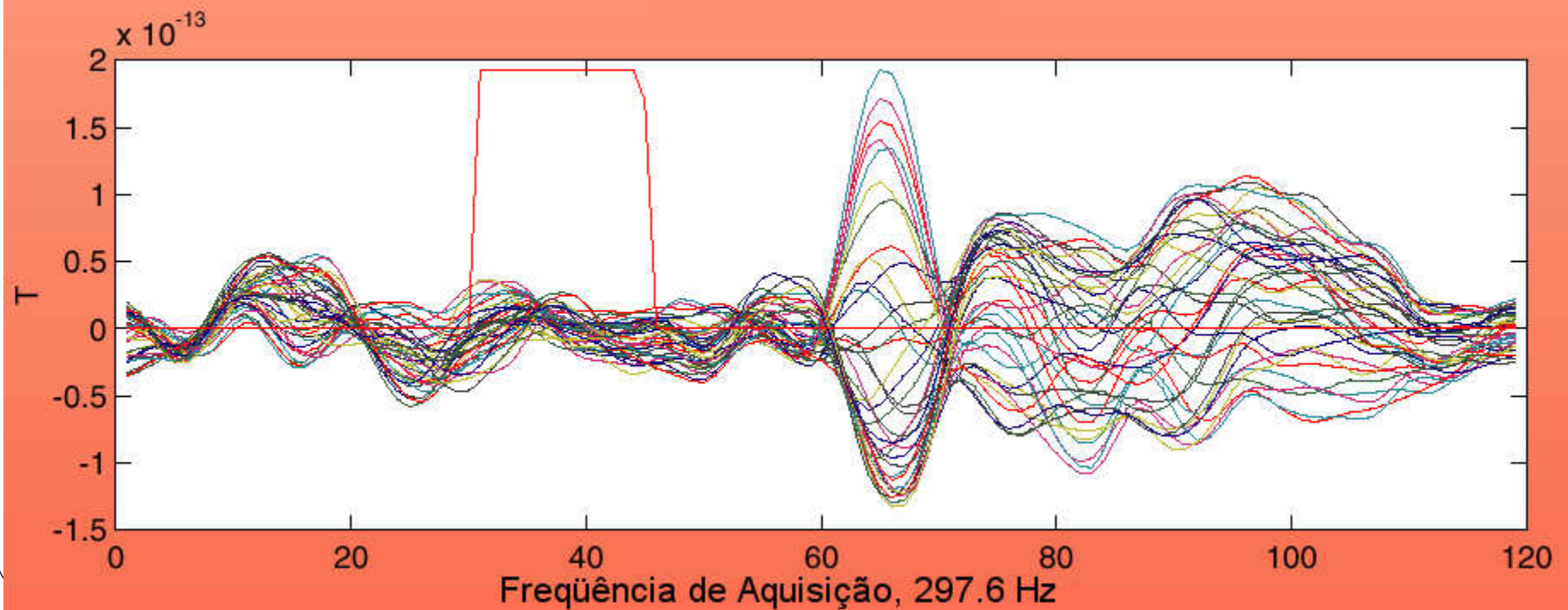
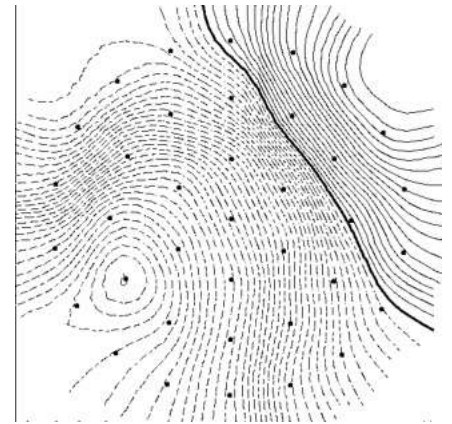
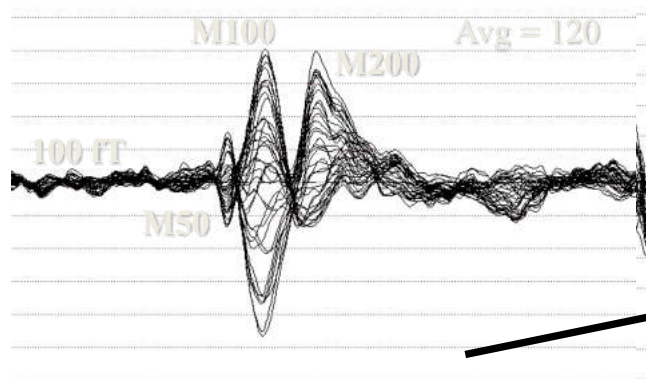


# Magnes II – Sistema Bti

Sensor Dual Magnes II, Bti - 2 x 37 Channels  
Inside a magnetically shielded room

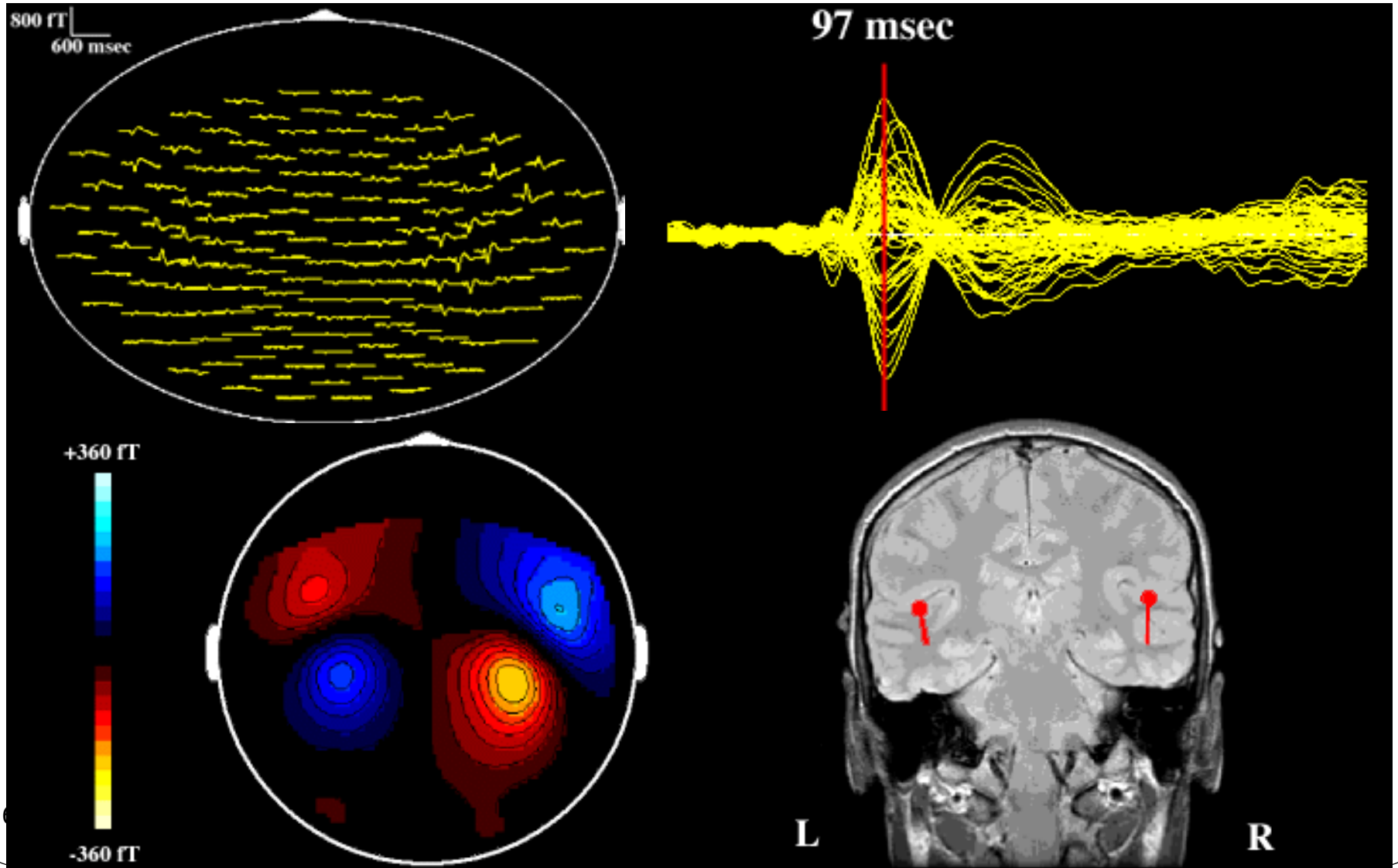


# Evoked magnetic fields



# Data Interpretation

normal response to a bilateral audio stimuli





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