

# *Monitoring of Non-conventional abdominal myoelectrical recordings: intestinal (EEnG) and uterine activity (EHG)*

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UNIVERSIDAD  
POLITECNICA  
DE VALENCIA

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  - Surface EEnG.
    - Interference cancellation: Software
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  - Uterine dynamics monitoring
  - Enhancing and characterization of EHG in pregnancy and labor

# Presentation

- Gbio-e tiene has more than 20 years of experience on Biomedical Engineering. Now is part of I3BH-UPV, Valencia
- Formed by 24 researchers (15 PhD)
- Principal Areas of R+D+I
  - Biomedical Systems and Devices for Diagnosis and Therapy
    - Development of sensors and biosensors
    - Development of Ad hoc monitoring systems
    - Advanced signal processing and decision support systems
  - Modelling and Simulation of Cells and Tissues
    - Cardiac electrical activity models
    - Signal simulation for diagnosis
- Collaborates with private companies, hospitals and international research groups.



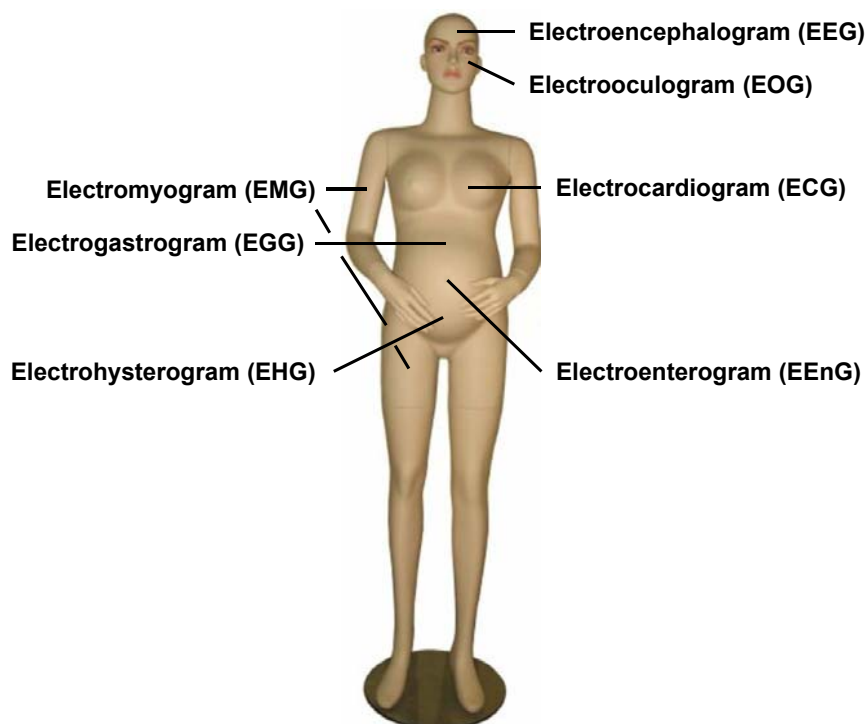
GE Healthcare



**Non-conventional abdominal signals: EEnG & EHG**



## ○ Bioelectrical signals on body surface



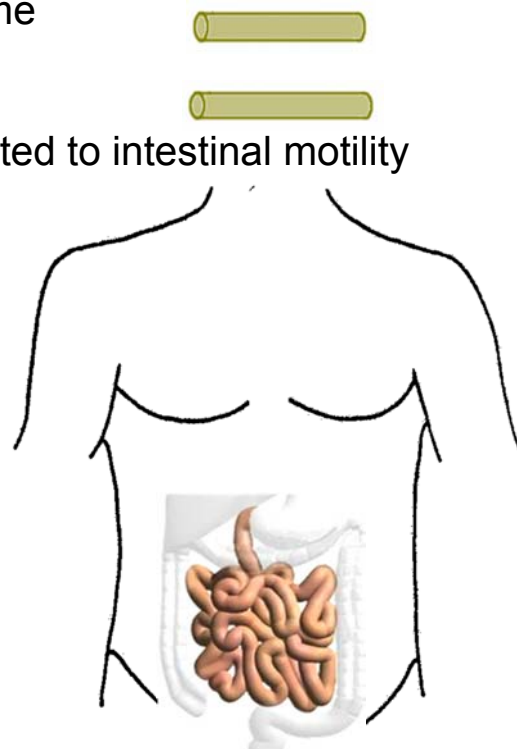
**Non-conventional abdominal signals: EEnG & EHG**



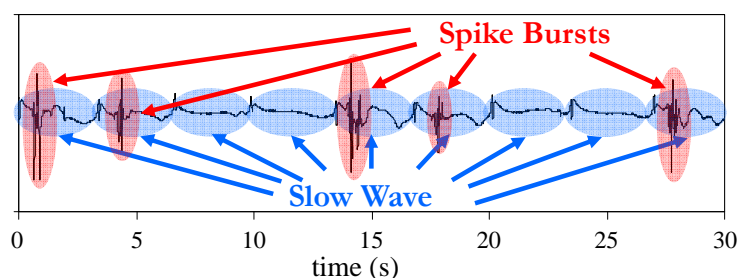
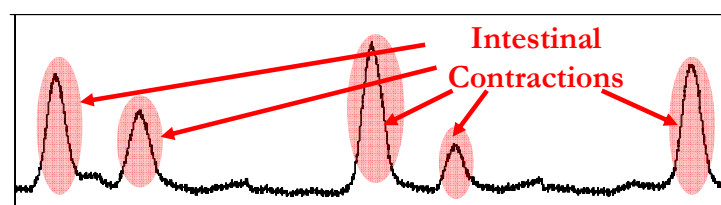
# Intestinal Activity Studies

## ○ Intestinal Motility

- Segmentation and propelling the chyme
- Mix food and enzymes
- Gastrointestinal disorders are associated to intestinal motility dysfunctions
  - Intestinal ischemia
  - Intestinal obstruction
  - Duodenal distention
  - Myopathic disorders
  - Paralytic ileum
  - Thyroid abnormalities
  - Etc.

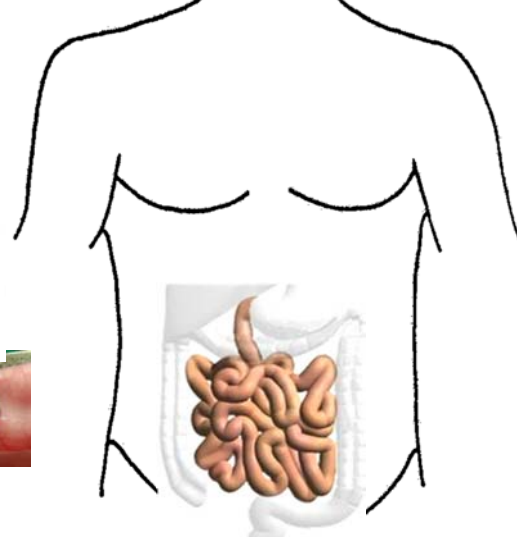


# Intestinal Activity Studies

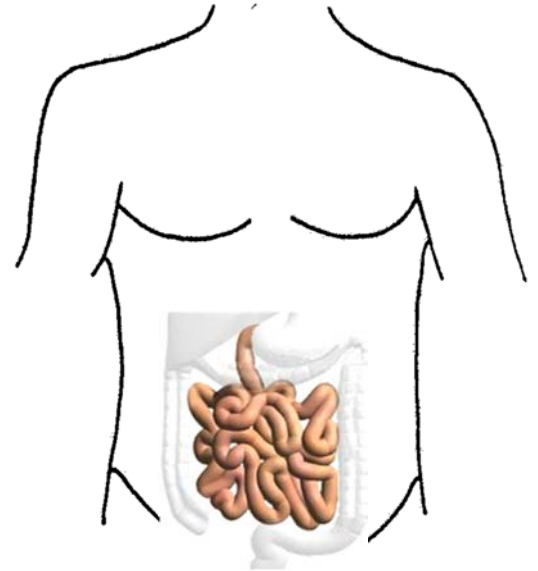
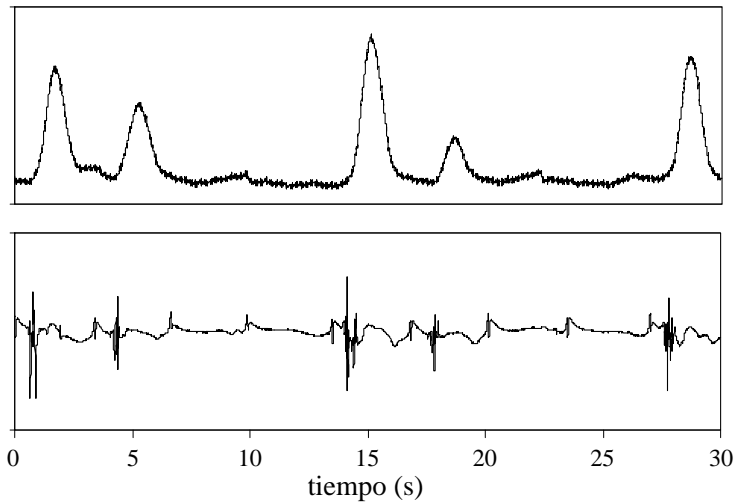


Electroenterogram (EEnG)

- Pressure Recordings
- Myoelectrical Recordings



# Intestinal Activity Studies



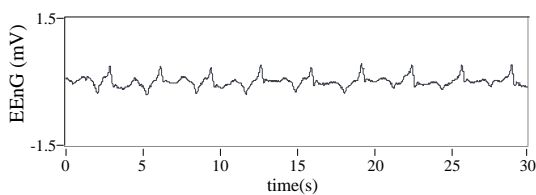
## Objetives

- Characterize internal EEnG
- Relate it with Gold Standard (Pressure)

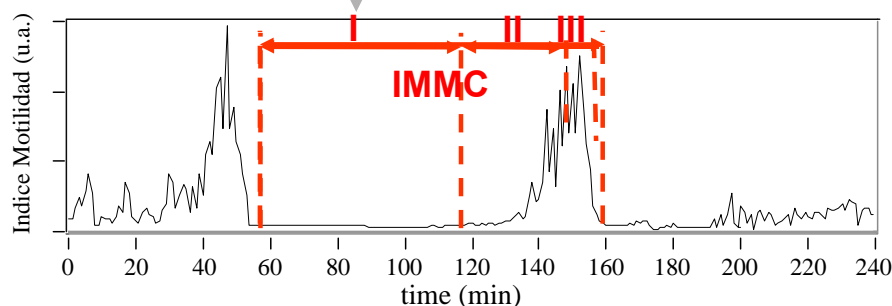
# Intestinal Activity Studies

## Activity Pattern in Fast State

### Interdigestive Migratory Motor Complex (IMMC)



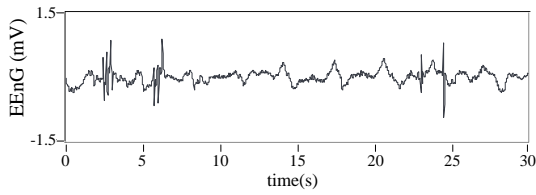
- Phase I: Inactivity  $\approx 50$ min
- Phase II: Irregular Activity  $\approx 30$ min
- Phase III: Maximum Activity  $\approx 6$ min



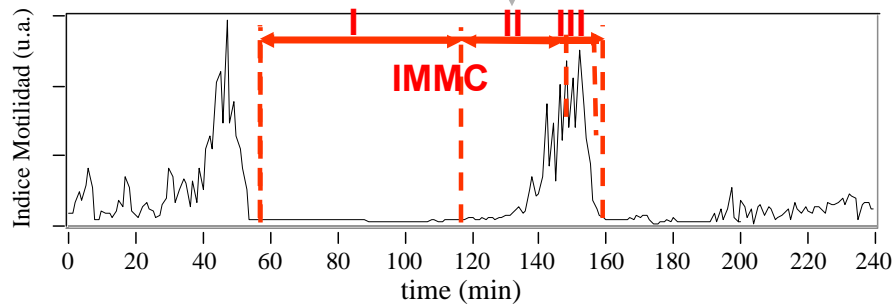
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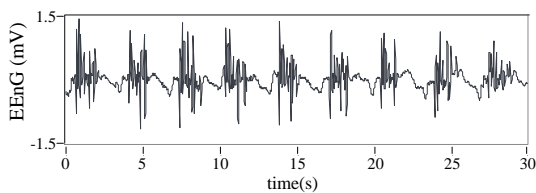
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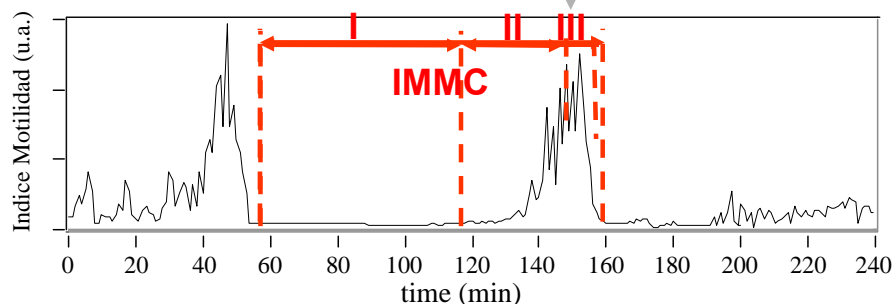
# Intestinal Activity Studies

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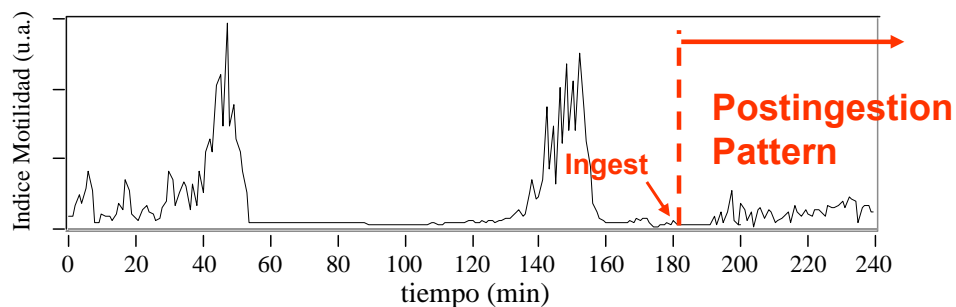
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# Intestinal Activity Studies

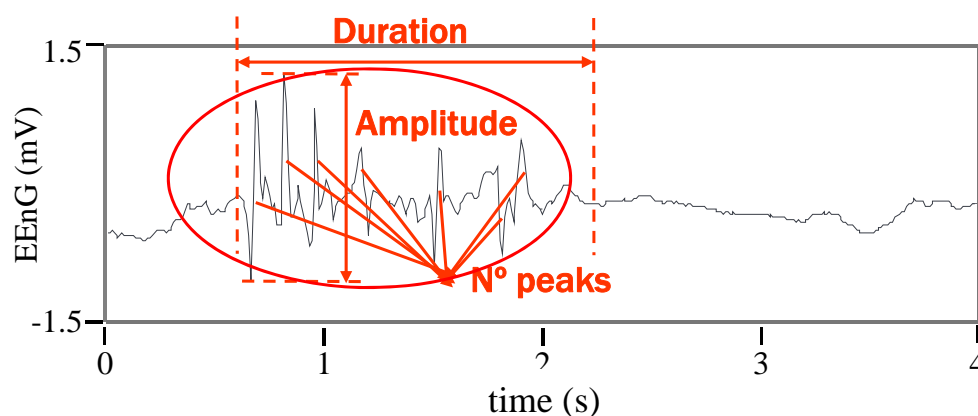
## ○ Activity Pattern in Postingestion

- After breath intake till the return of Phase III
- Irregular contractile activity
- Duration and intensity depend on the quantity and composition of ingested food



# Intestinal Activity Studies

## ○ Intestinal Motility Parameters

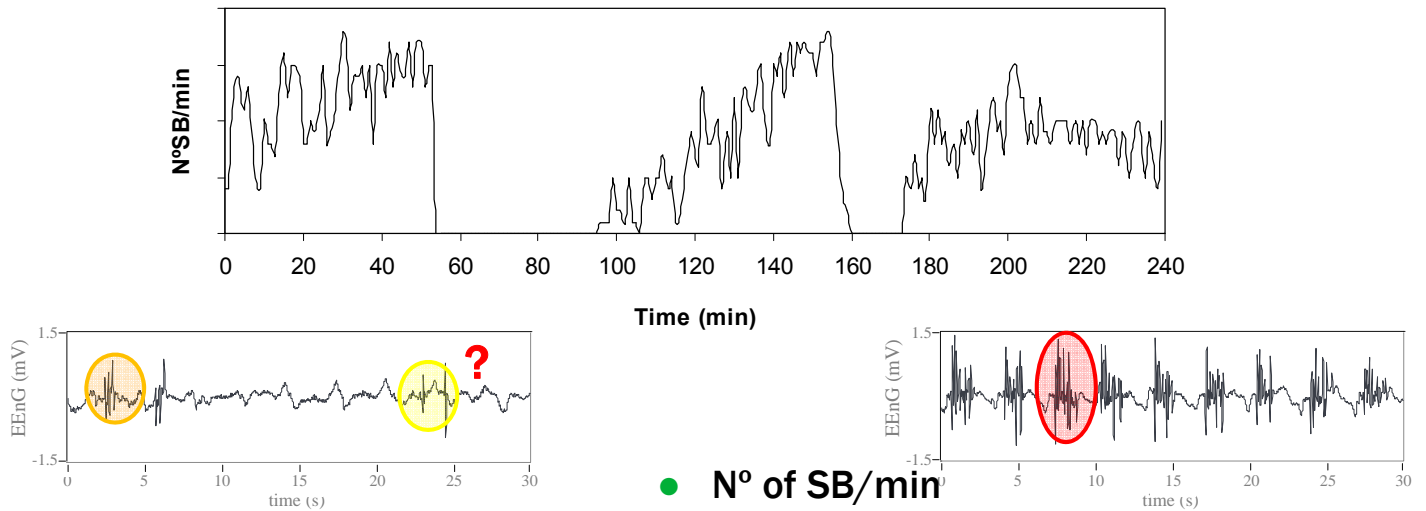


- Amplitude SB
- Duration SB
- N° of peaks/min
- N° of SB/min

# Intestinal Activity Studies

## ○ Intestinal Motility Parameters

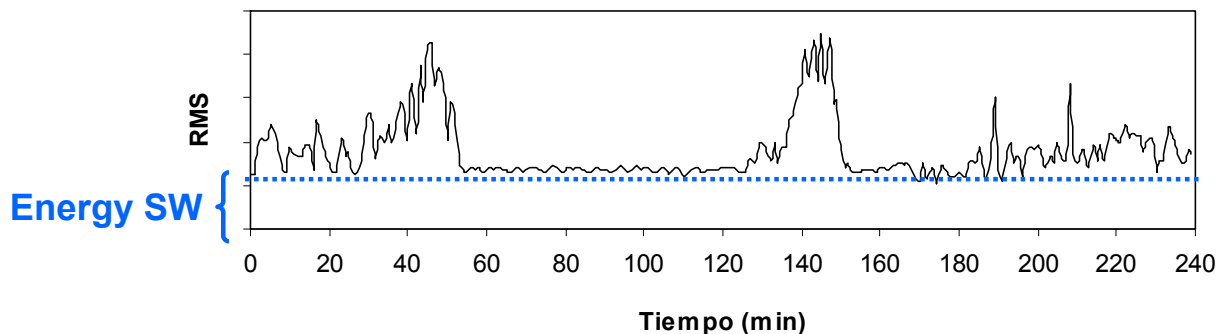
- Does not include information about the INTENSITY of the contractions



Threshold levels: subjective criteria

# Intestinal Activity Studies

## ○ Intestinal Motility Parameters

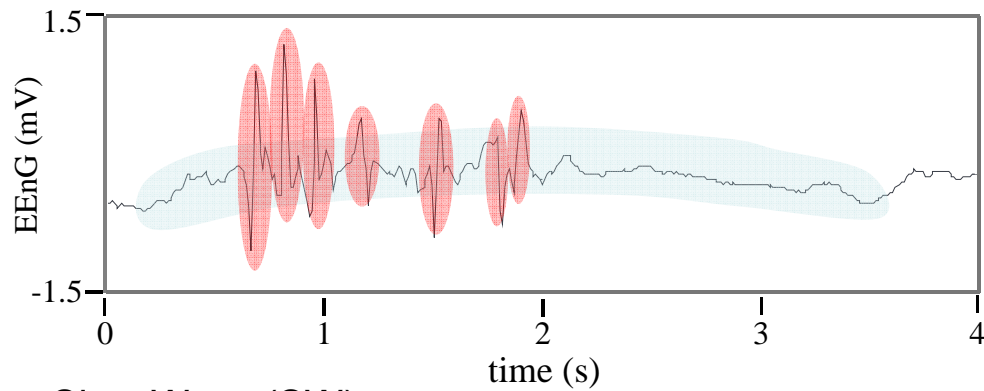


- Root Mean Square (RMS)

$$RMS = \sqrt{\frac{\sum_{i=1}^N x_i^2}{N}}$$

# Intestinal Activity Studies

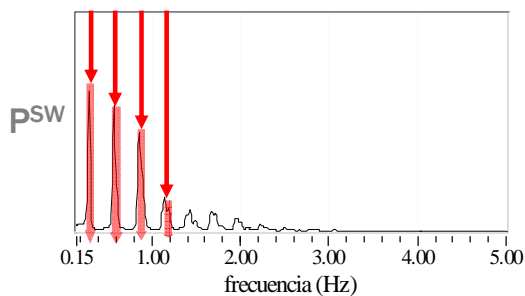
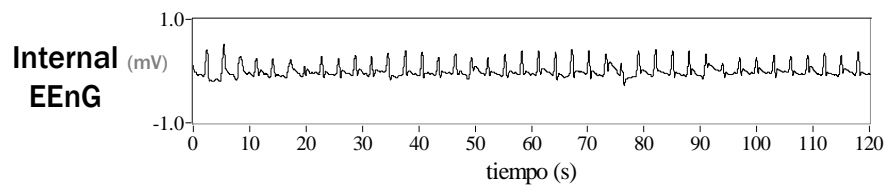
## Multicomponent Signal



- Slow Wave (SW)
    - Slow oscillation of potential
  - Spike Bursts (SB)
    - Rapid changes of potential
- ⇒ Low Frequency
- ⇒ High Frequency

# Intestinal Activity Studies

## ○ Spectral Analysis of the SW



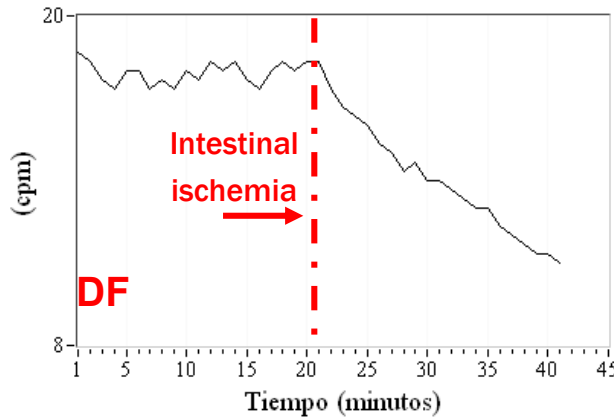
- Decreasing amplitude peaks
- At multiples of the SW repetition frequency ( $\approx 0.3\text{Hz}$ , 18 cpm dog)



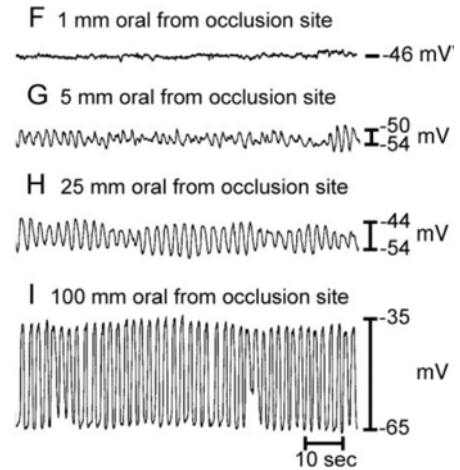
# Intestinal Activity Studies

## ○ Spectral Analysis of the SW

- The application of this technique to **monitor** EEnG dominant frequency (**freq. SW**) can detect **pathologies** such as intestinal ischemia



- At multiples of the SW repetition frequency ( $\cong 0.3\text{Hz}$ , 18 cpm dog)



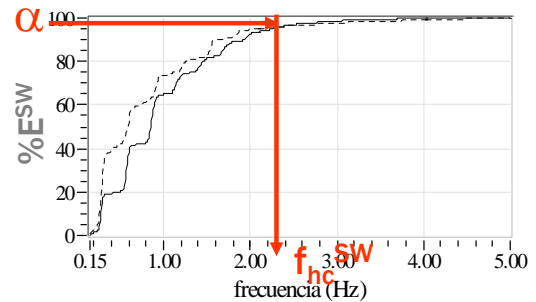
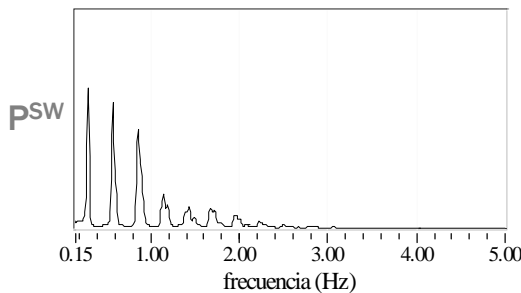
# Intestinal Activity Studies

## ○ Spectral Analysis of the SW

$$\%E(f_0, f_1, f) = \frac{E(f_0, f)}{E(f_0, f_1)} \cdot 100 = \frac{T \cdot \int_{f_0}^f P_w(f) \cdot df}{T \cdot \int_{f_0}^{f_1} P_w(f) \cdot df} \cdot 100$$

**1.95 ± 0.60 Hz**

$$f_{hc}^{SW} \quad \left| \quad \%E^{OL}(f_{hc}^{SW}) = 97.5\% \right.$$

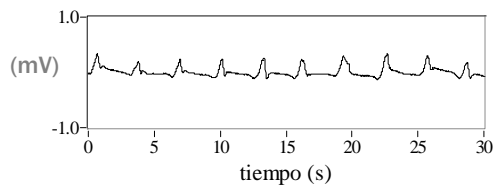


- Where is concentrated the energy of the SW?  $\Rightarrow$
- Up to what frequency does it extend?  $\Rightarrow$
- %Energy accumulated in frequency of the SW:  $\%E^{SW}(f)$
- High limit in freq. of SW:  $f_{hc}^{SW}$
- Residual energy tail  $\alpha = 2.5\%$

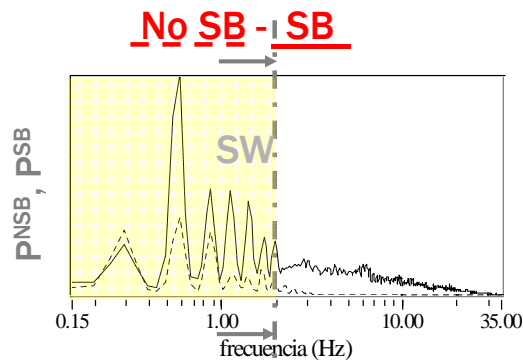
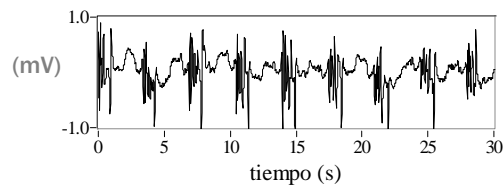
# Intestinal Activity Studies

## ○ Spectral Analysis of the SW+Spike Bursts

contractile inactivity (**No SB**)



maximum contractile activity (**SB**)

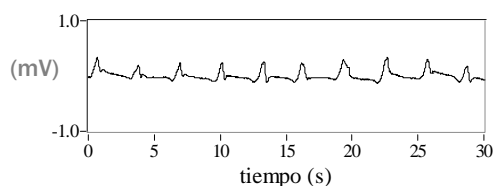


- Power spectral density in range SW >> amplitude than higher frequencies

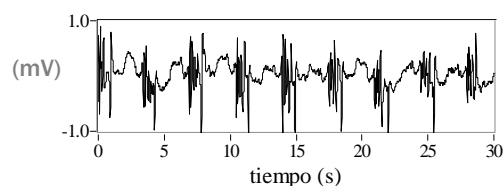
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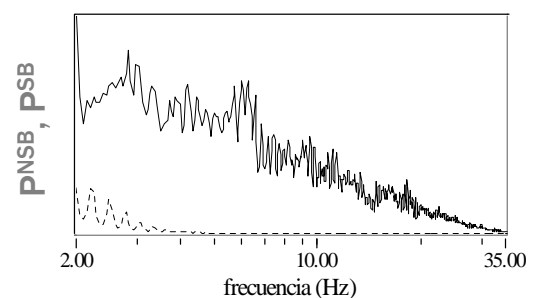


maximum contractile activity (**SB**)



No SB - SB

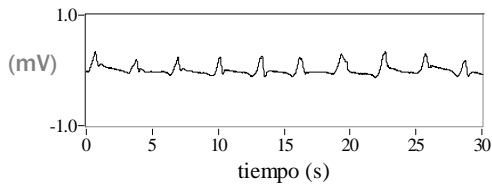
- Power spectral density above 2 Hz increases significantly during periods of contractile activity



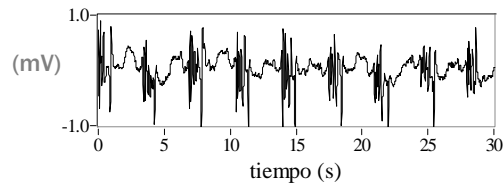
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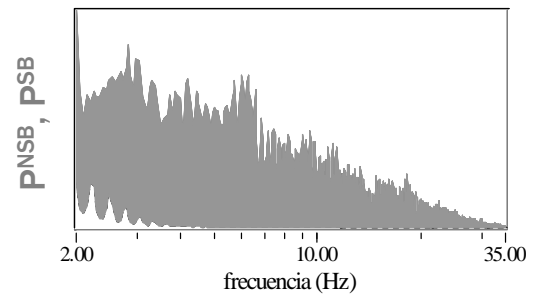
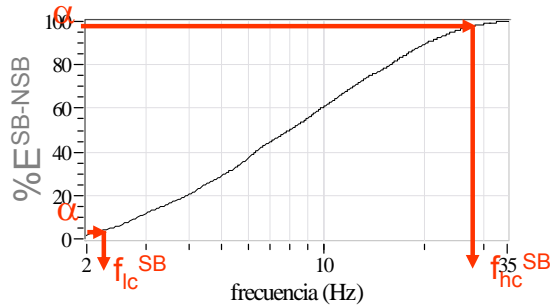


### Energy Limits of SB?

$2,25 \pm 0.07$  Hz

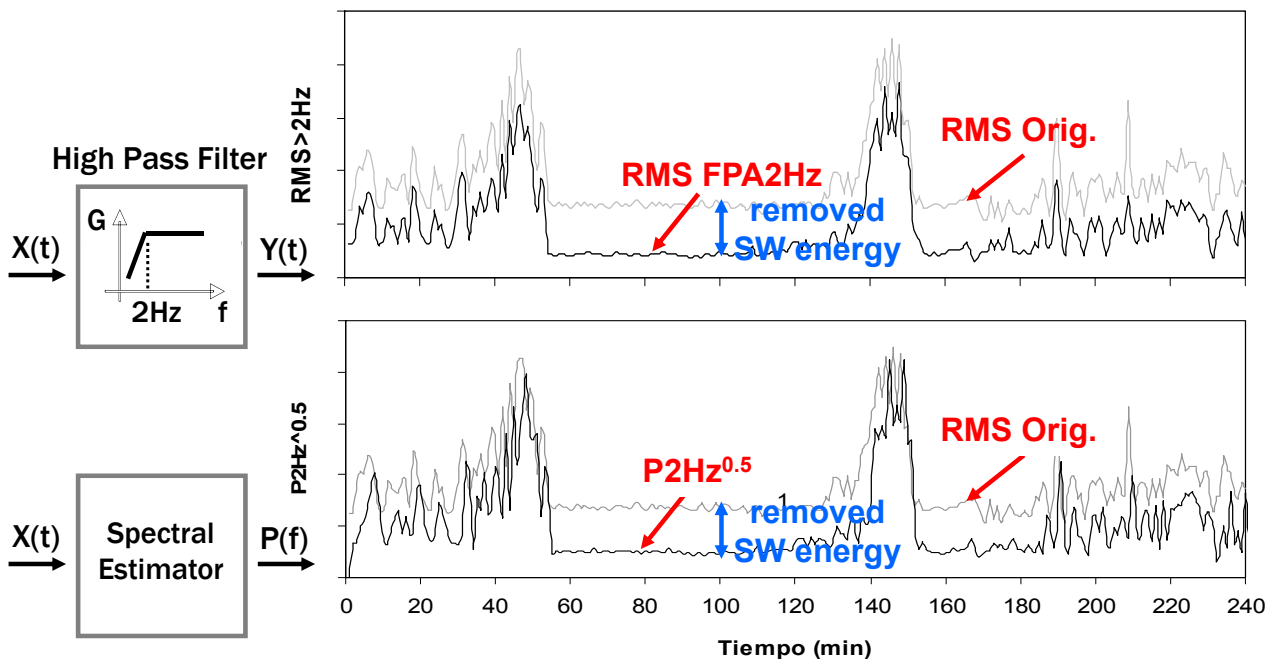
$27,25 \pm 1.30$  Hz

- Increment in signal energy: contractile activity-inactivity
- Higher frequencies than SW range:  $f > 2$  Hz



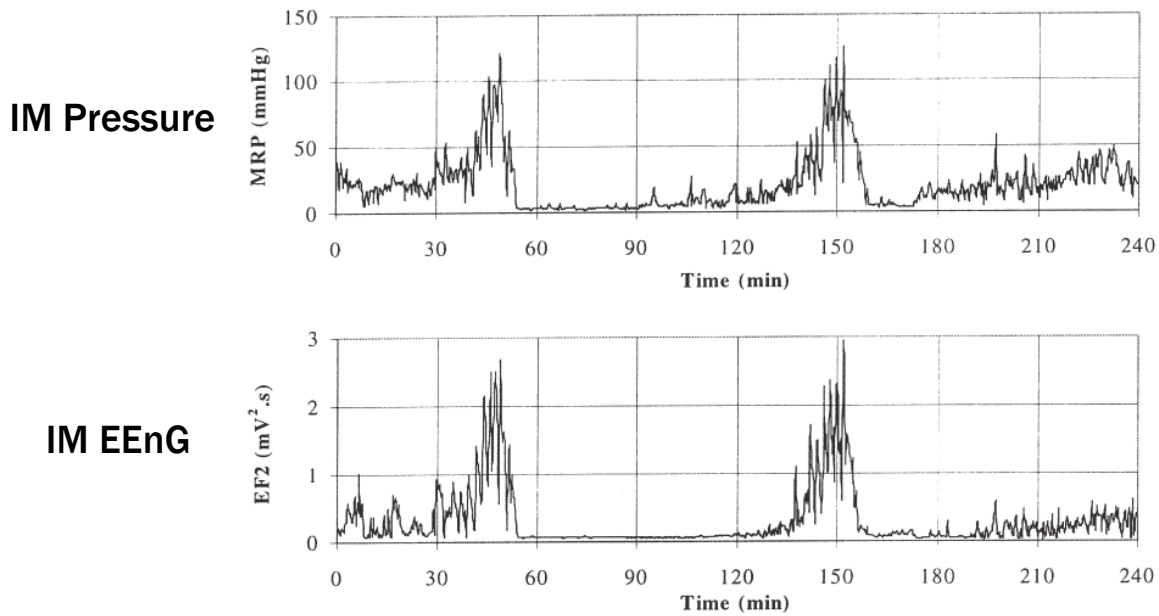
# Intestinal Activity Studies

## Intestinal Motility Parameters



# Intestinal Activity Studies

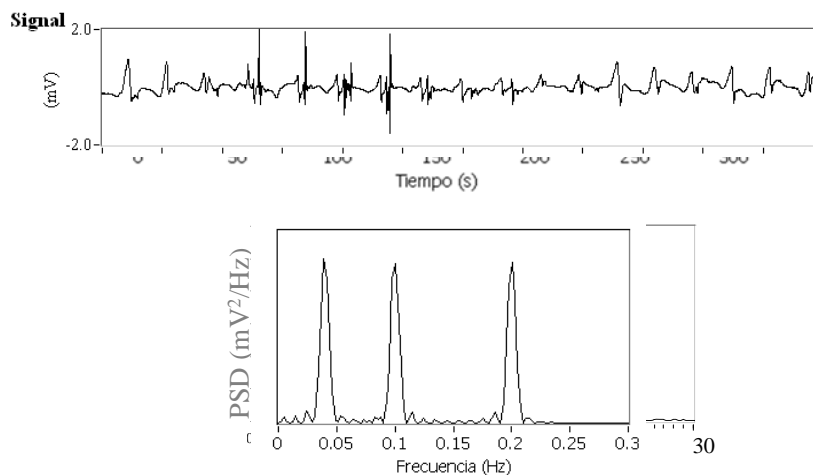
## ○ Intestinal Motility Parameters



# Intestinal Activity Studies

## ○ Spectral Analysis

- Requires signals to be **stationary**
- Lost of temporal information



**Solution: Time-Frequency Analysis**

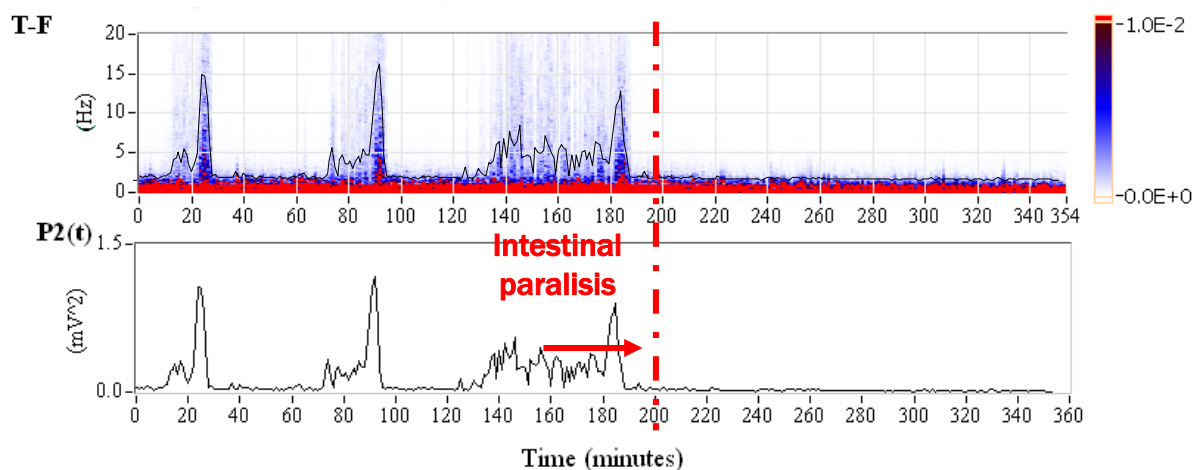
# Intestinal Activity Studies

- Time-Frequency Analysis: T-F generalized (Cohen)
  - Permits independent resolution for T and F
  - The kernel function determines the properties of the distribution



# Intestinal Activity Studies

- Time-Frequency Analysis: Marginals
  - Similarly to quantifying parameters from PSD, marginals in T and F can be defined
  - Detection of Gastrointestinal Pathologies



# Intestinal Activity Studies

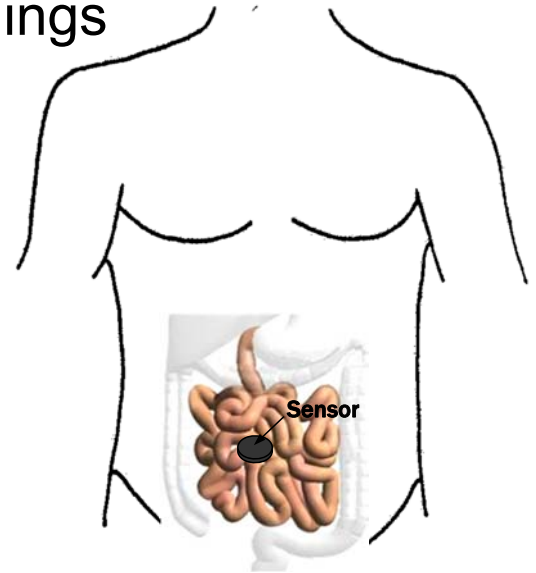
- Internal Myoelectrical Recordings

- Require surgical intervention
- No clinical application ❌



- Surface Myoelectrical Recordings

- Non Invasive
- Low Cost



- Objectives

- Characterize Surface EEnG
- Relate it with Internal EEnG

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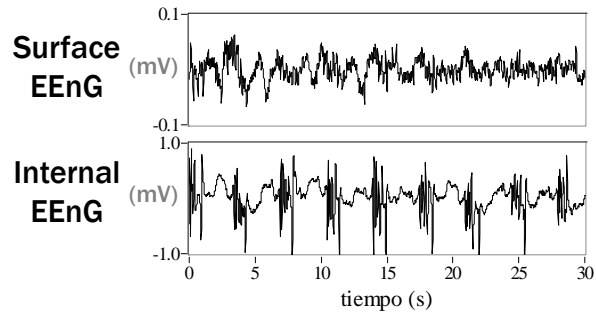
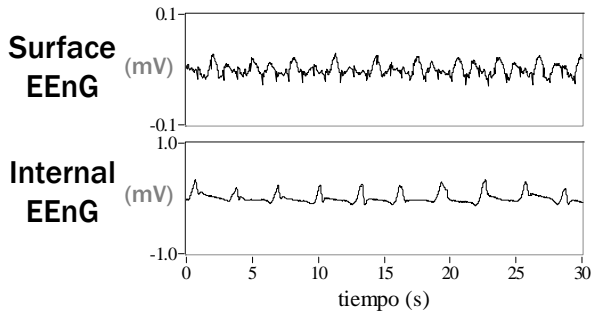
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# Intestinal Activity Studies

## ○ Surface EEnG

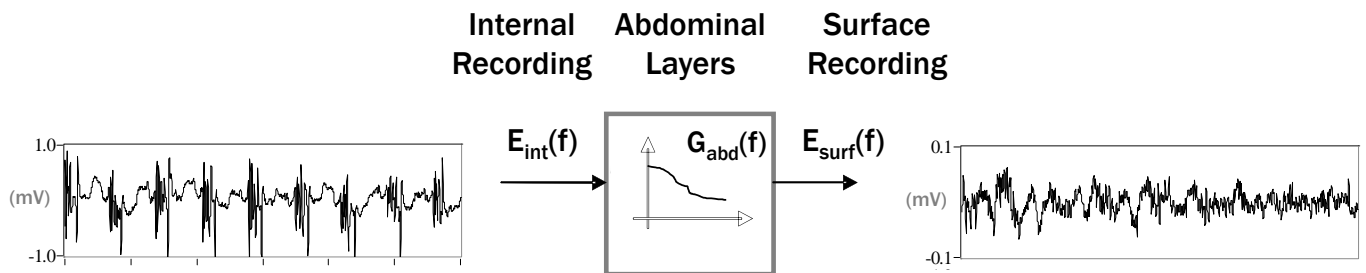
- Very **attenuated** signal, specially in ↑freq. (SB)
- contractile inactivity (No SB)      maximum contractile activity (SB)



# Intestinal Activity Studies

## ○ Surface EEnG

- Very **attenuated** signal, specially in ↑freq. (SB)



- Estimation of the transfer function of abdominal layers for each freq.
  - Energy ratio surface / internal in bands of 1 Hz

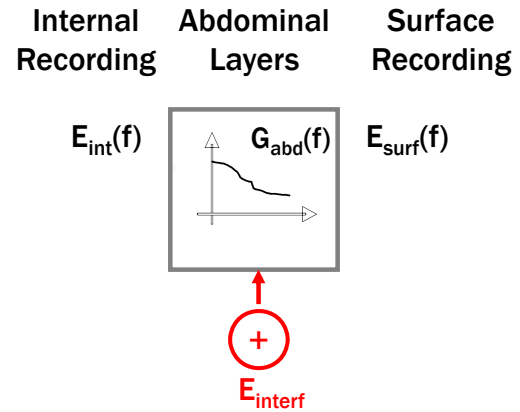
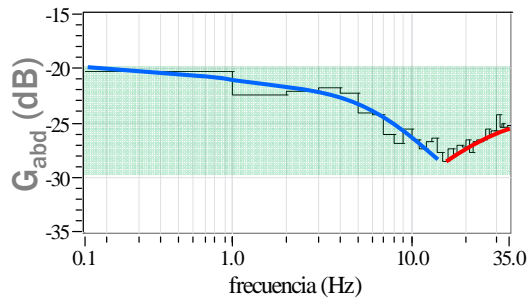
$$G_{abd}(f) = \frac{E_{surf}^{SB}(f-1, f)}{E_{int}^{SB}(f-1, f)}$$

for  $f=1,2,\dots,35$  Hz

# Intestinal Activity Studies

## ○ Surface EEnG

- Very **attenuated** signal, specially in ↑freq. (SB)



- 1<sup>st</sup> segment: ↑ f → higher attenuation  
Low pass filter of EEnG energy
- 2<sup>nd</sup> segment: ↑ f → lower attenuation  
additional energy in surface EEnG?

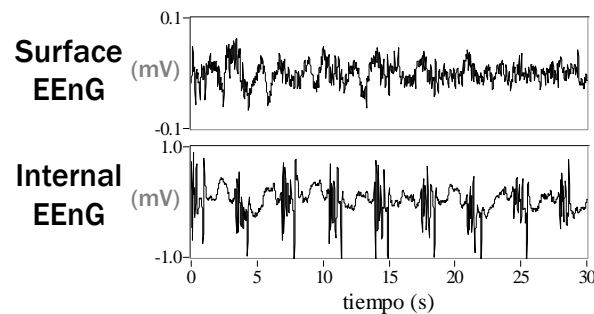
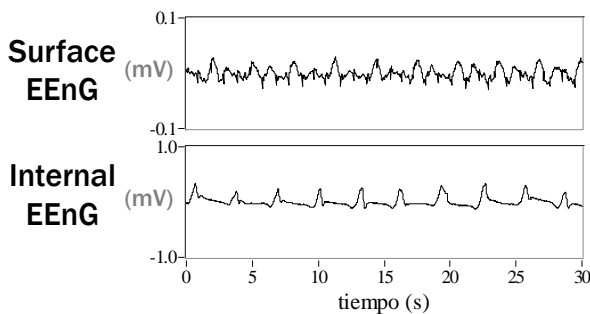
Most studies focus on the SW (low frequency)

**INTERFERENCE**  
in high frequency

# Intestinal Activity Studies

## ○ Surface EEnG

- Very **attenuated** signal, specially in ↑freq. (SB)
- contractile inactivity (No SB)      maximum contractile activity (SB)



- Presents **interferences**:

- Contact potential
- EGG
- Respiration
- ECG
- Movement artifacts

Low Freq.

High Freq.

**Cancellation?**



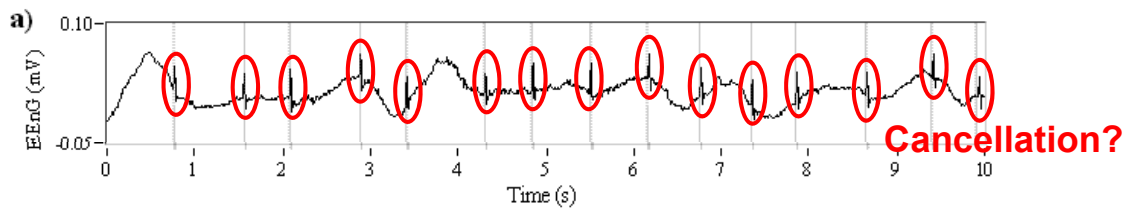
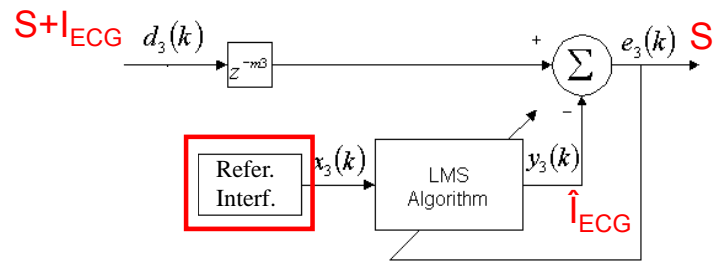
'Software'

'Hardware'



# Intestinal Activity Studies

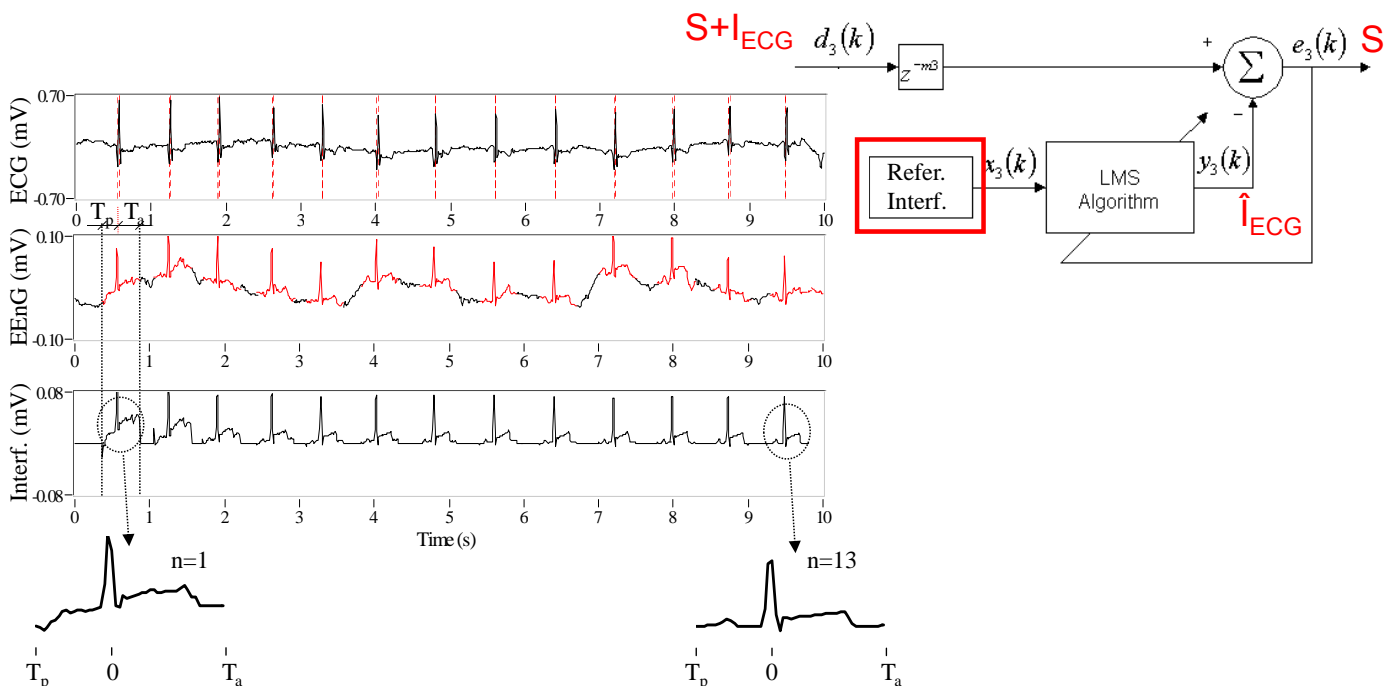
- Interference Cancellation: 'Software'
  - Adaptive Filtering ECG



'Software'

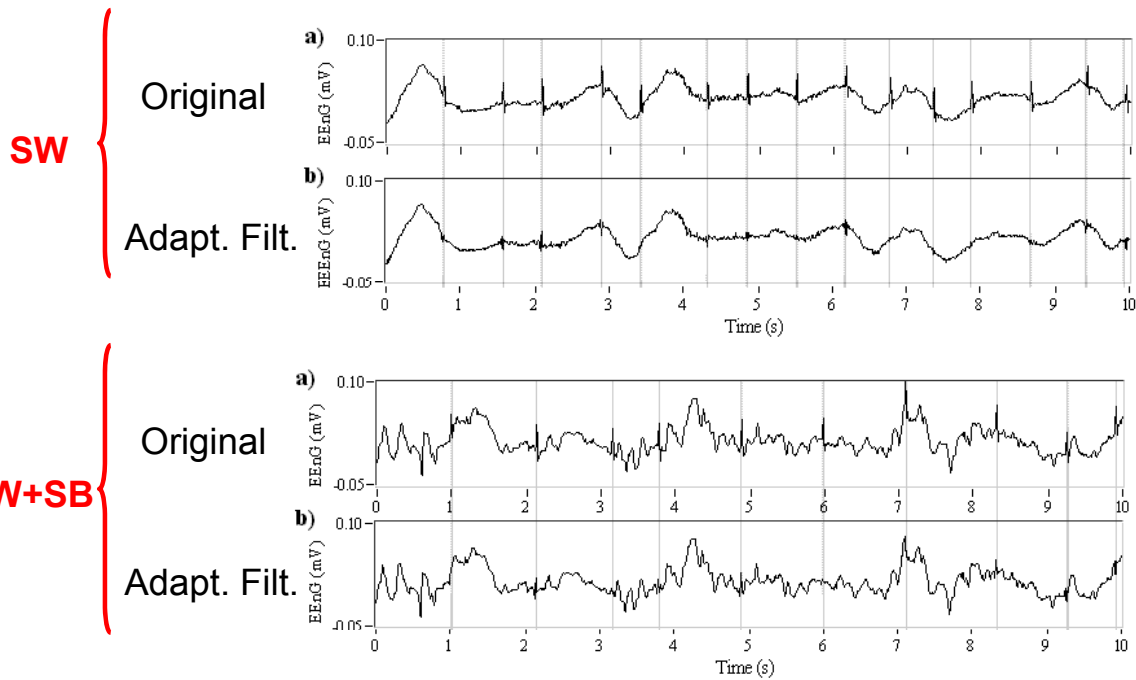
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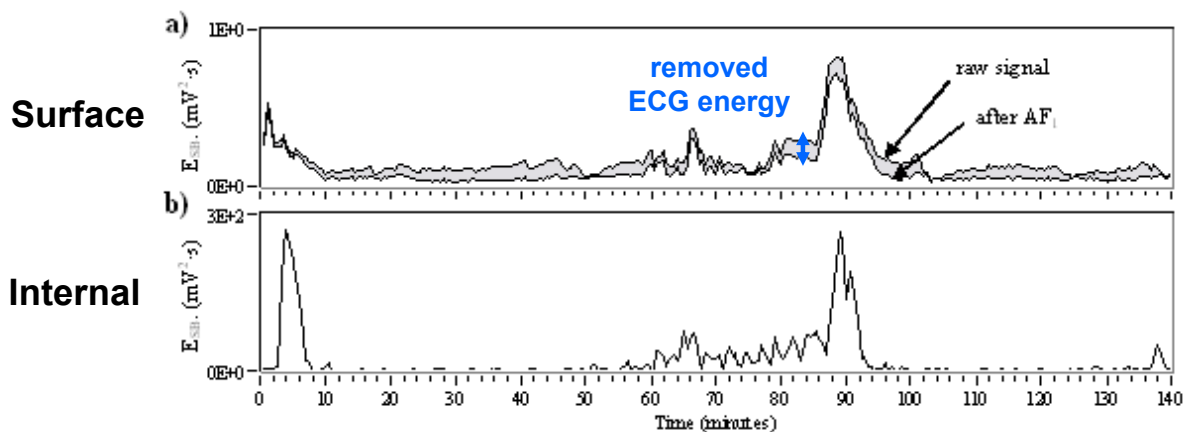
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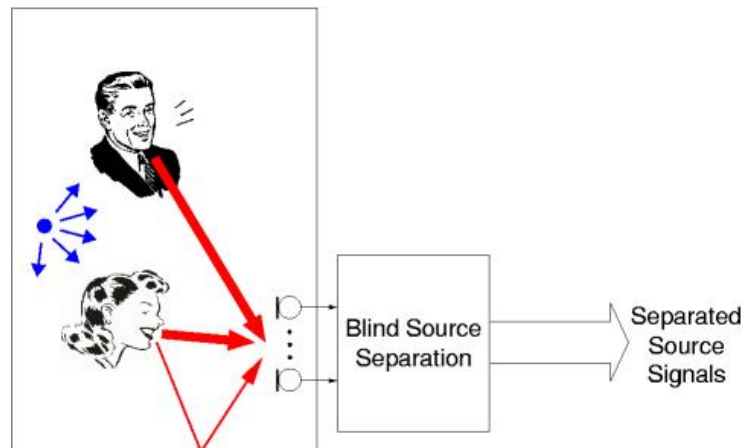
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## Effect on intestinal motility parameters



# Intestinal Activity Studies

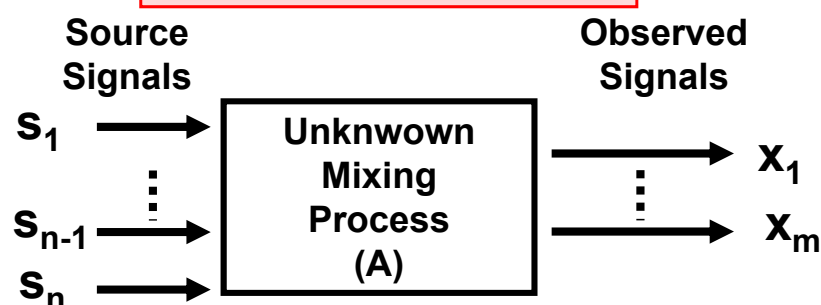
- Interference Cancellation: 'Software'
  - Independent Component Analysis (ICA)
- It's a subgroup (the +powerful and +employed) of the *Blind Source Separation* (BSS) techniques



# Intestinal Activity Studies

- Interference Cancellation: 'Software'
  - Independent Component Analysis (ICA)
- It's a subgroup (the +powerful and +employed) of the *Blind Source Separation* (BSS) techniques
- Consists on **extracting** a set of statistically **independent components** from a set of **observed signals** without prior knowledge of the signal sources and the mixing matrix.

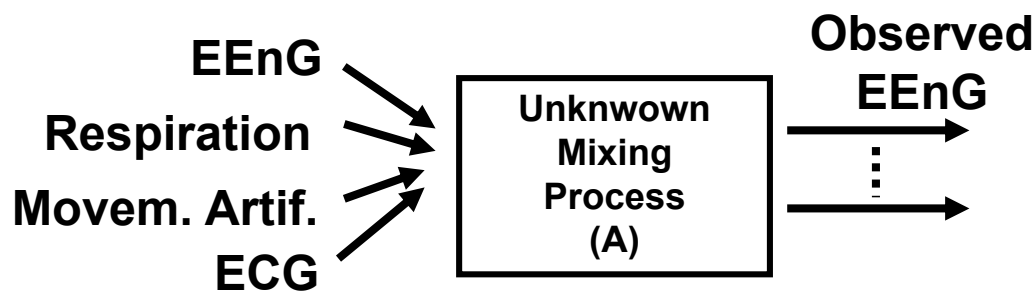
$$x(t) = A \cdot s(t) + n(t)$$



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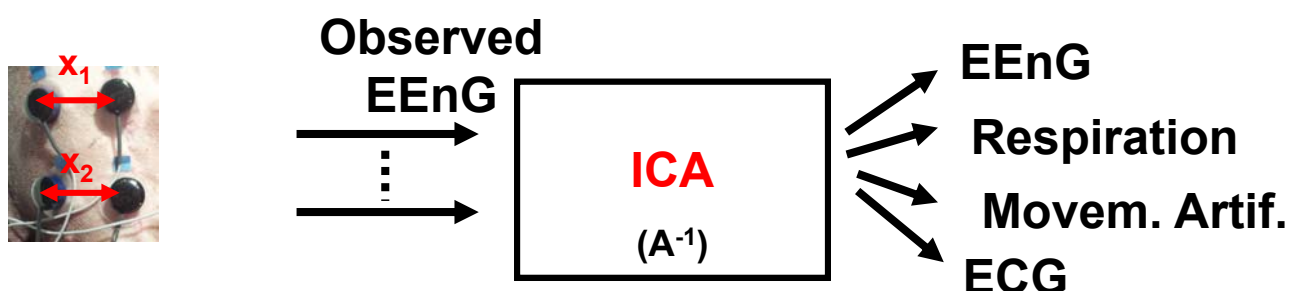
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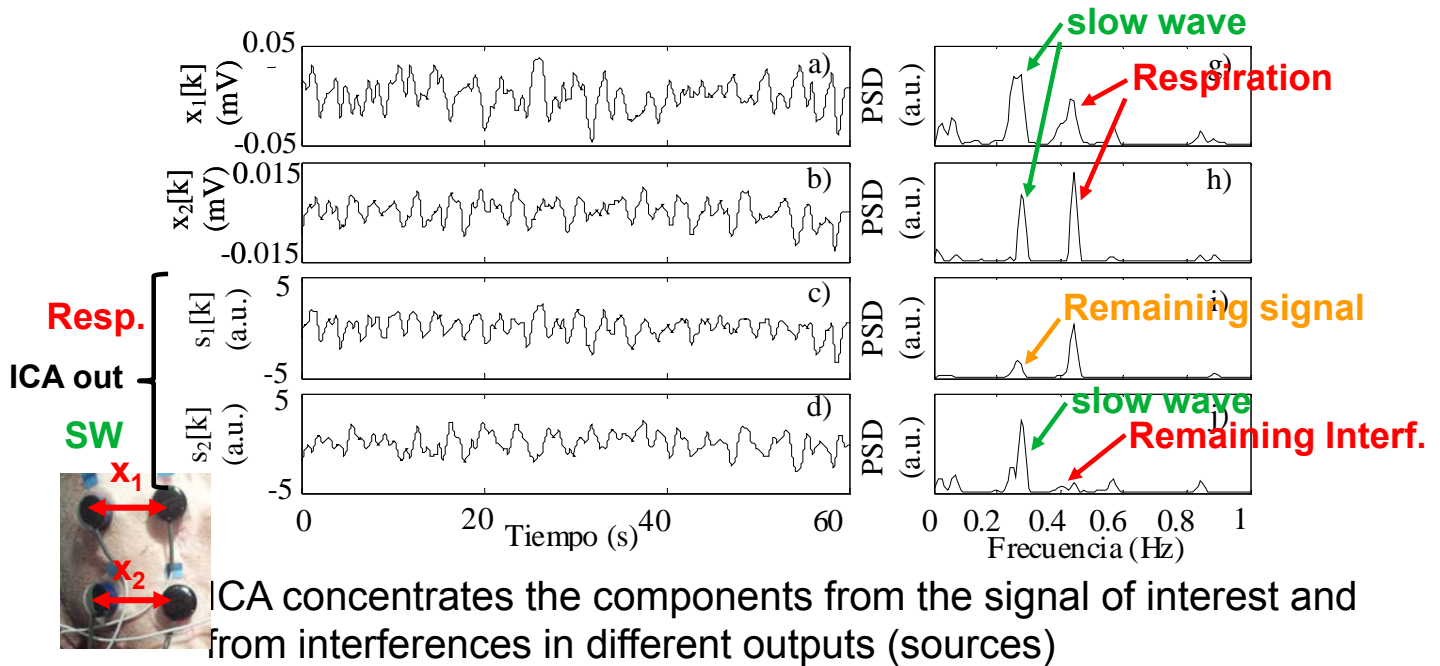


# Intestinal Activity Studies

- Interference Cancellation: 'Software'

SW+interf. ↓ f

- Independent Component Analysis (ICA)

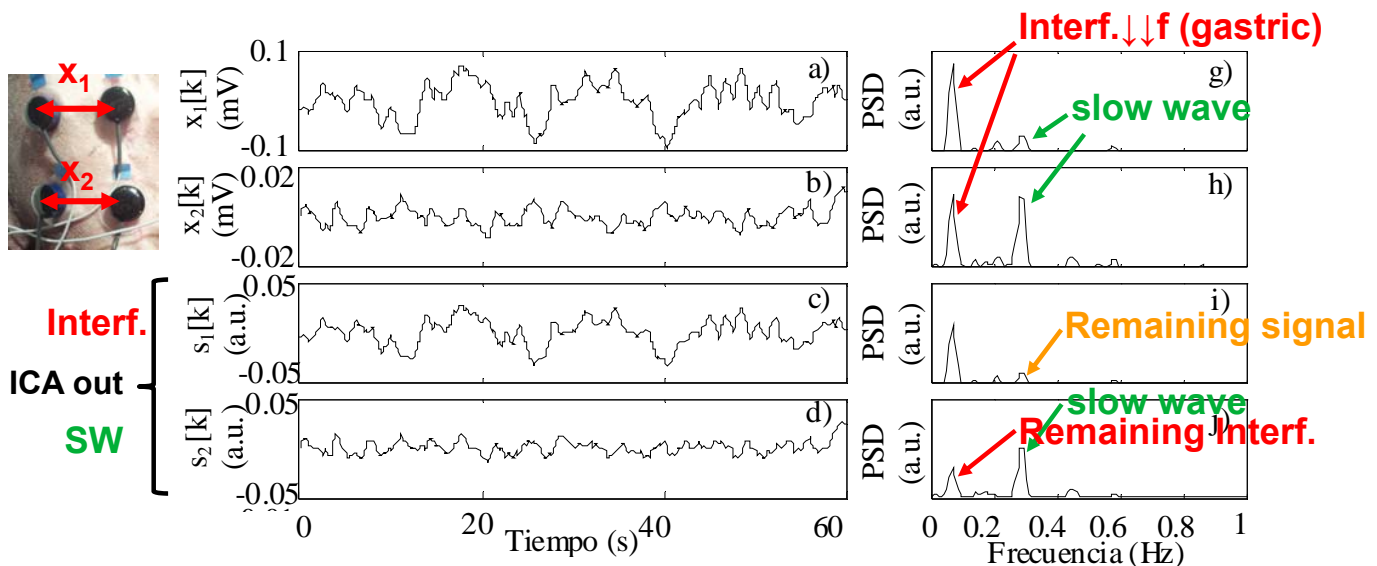


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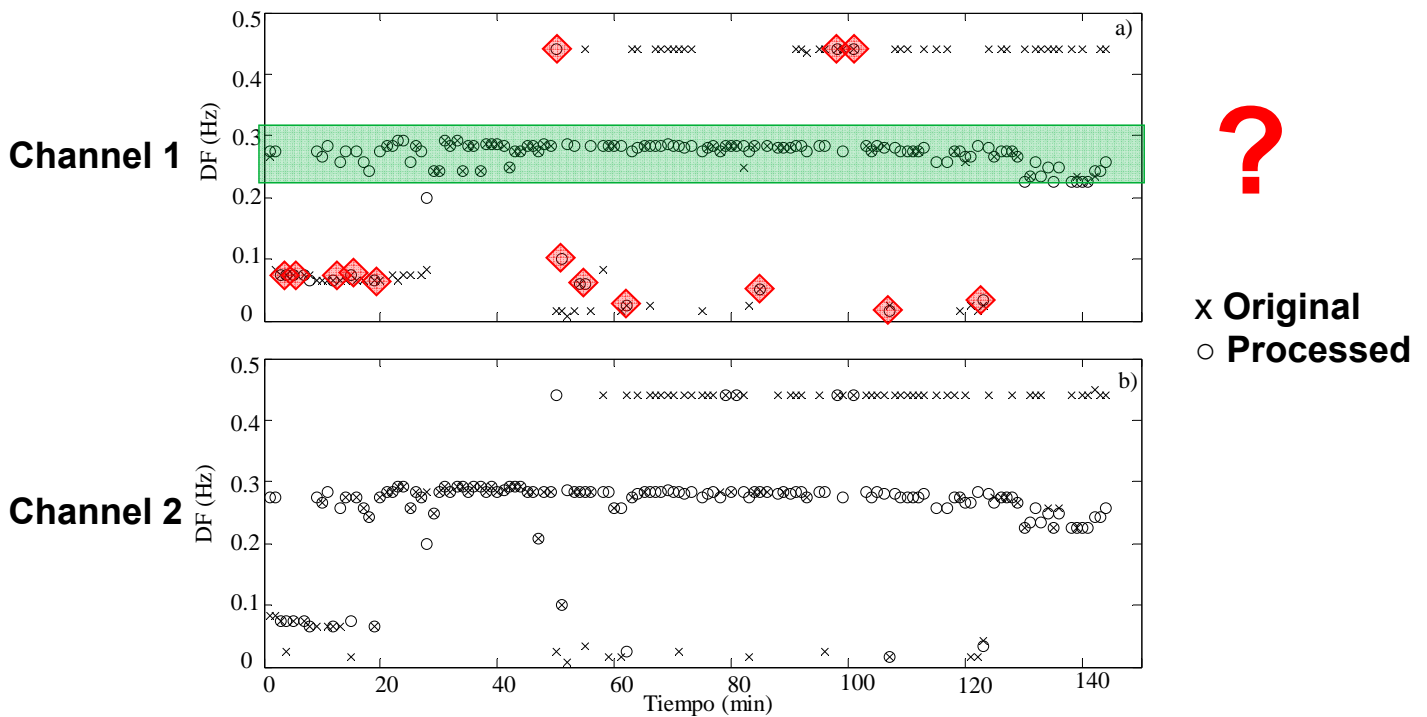
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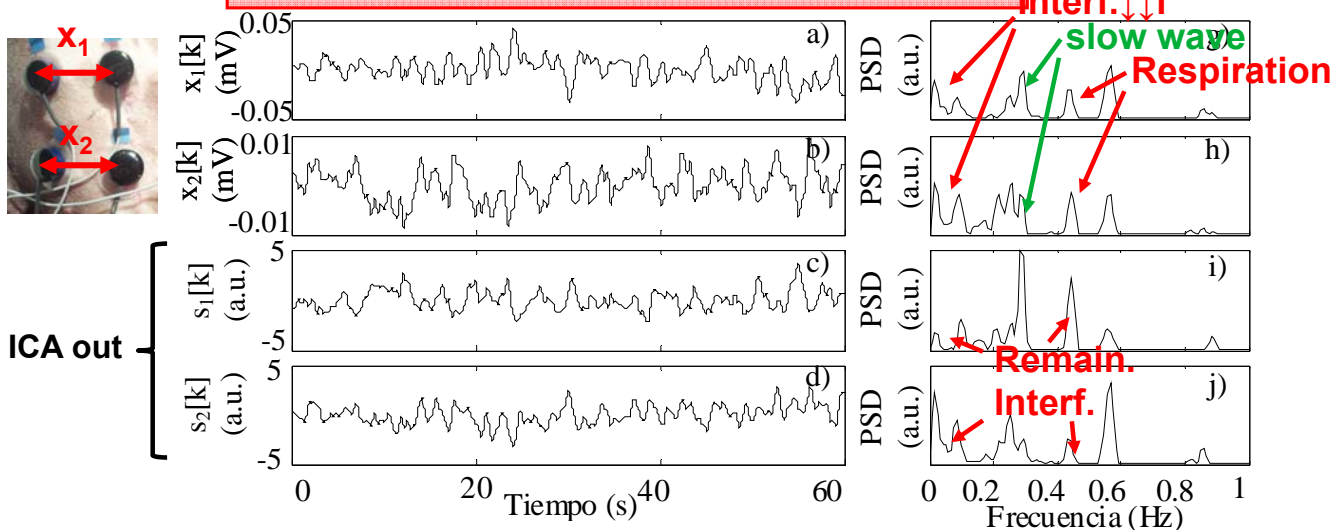
# Intestinal Activity Studies

○ Interference Cancellation: 'Software'

SW+interf. ↓ f

□ Independent Component Analysis (ICA)

Nº Channels must be greater than Nº sources



■ If there is more than 1 source of interference, ICA cannot separate the sources correctly.

# Intestinal Activity Studies

- Interference Cancellation: ‘Software’
  - Empirical Mode Decomposition (EMD)
- The *Empirical Mode Decomposition* (EMD) consists on **decomposing a signal** or temporal series in a finite number of Intrinsic Mode Functions (IMF)

$$x(t) = \sum_{j=1}^n IMF_j(t) + r_n(t)$$

- The IMF are non linear oscillatory functions that are directly extracted from the data. They must satisfy 2 conditions:
  - the n° of extrema and the n° of zero crossing differ by one at most
  - the average of the upper and lower envelope must be sufficiently close to zero according to some criterion
- The decomposition **process** is **adaptive** and **data driven**. Empiric method, NO explicit equations.
- The technique is applicable to **non-stationary and non-linear signals**

# Intestinal Activity Studies

- Interference Cancellation: ‘Software’
  - Empirical Mode Decomposition (EMD)

Method \ Data	Stationary	Non-stationary	Linear	Non-linear	Theory
Fourier	✓	✗	✓	✗	✓
Wavelets	✓	✓	✓	✗	✓
Time-series	✓	✗	✓	✓	✓
EMD	✓	✓	✓	✓	✗

# Intestinal Activity Studies

## ○ Interference Cancellation: 'Software'

SW+interf. ↓ f

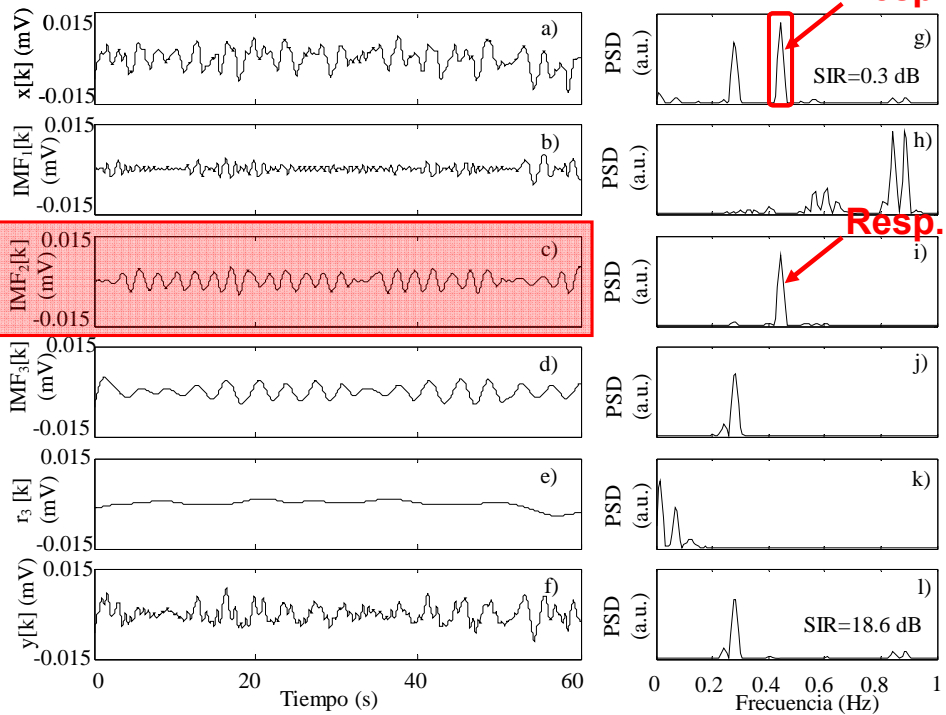
## □ Empirical Mode Decomposition (EMD)

Original

Resp. →

EMD out

Processed



# Intestinal Activity Studies

## ○ Interference Cancellation: 'Software'

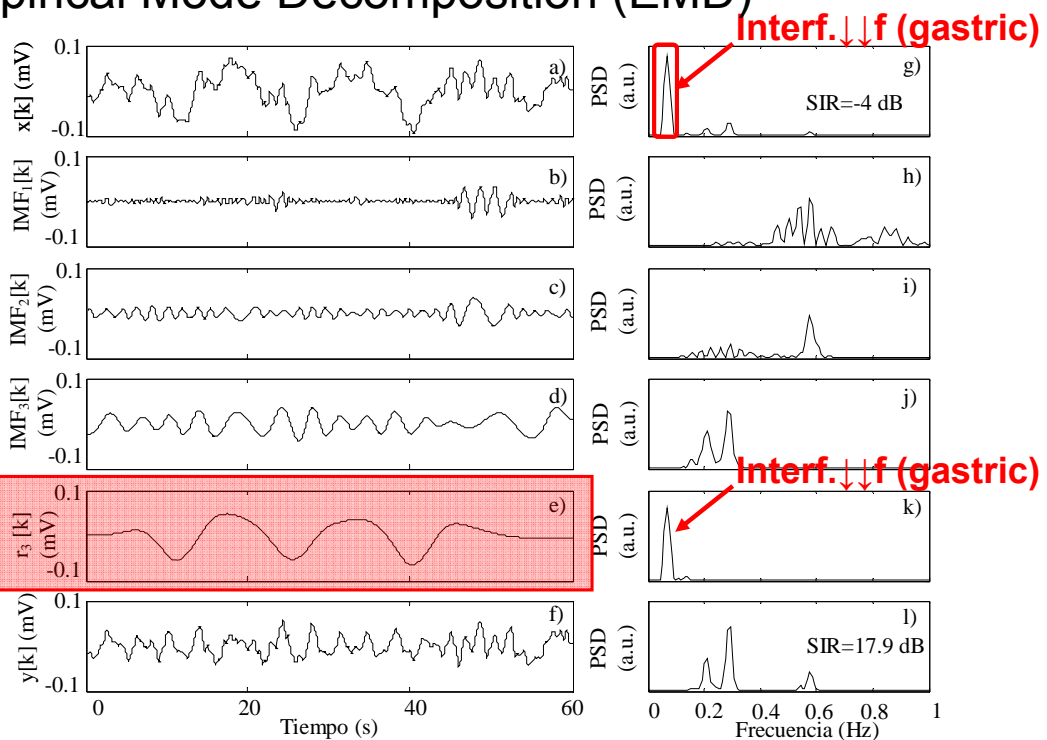
SW+interf. ↓ f

## □ Empirical Mode Decomposition (EMD)

EMD out

Interf. ↓ f →

Processed



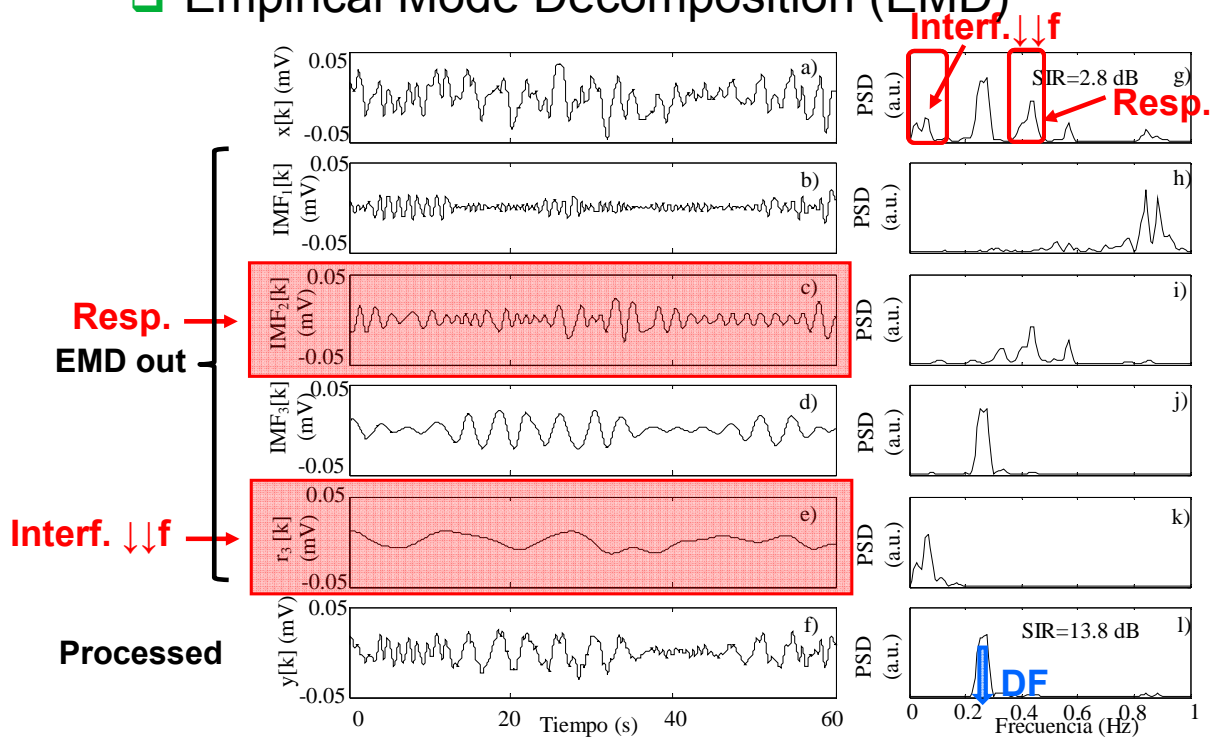


# Intestinal Activity Studies

- Interference Cancellation: 'Software'

SW+interf. ↓ f

- Empirical Mode Decomposition (EMD)

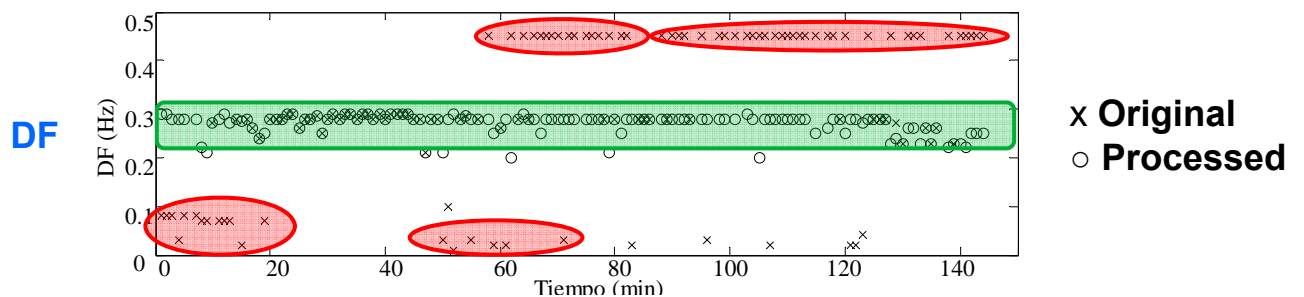


# Intestinal Activity Studies

- Interference Cancellation: 'Software'

SW+interf. ↓ f

- Empirical Mode Decomposition (EMD)



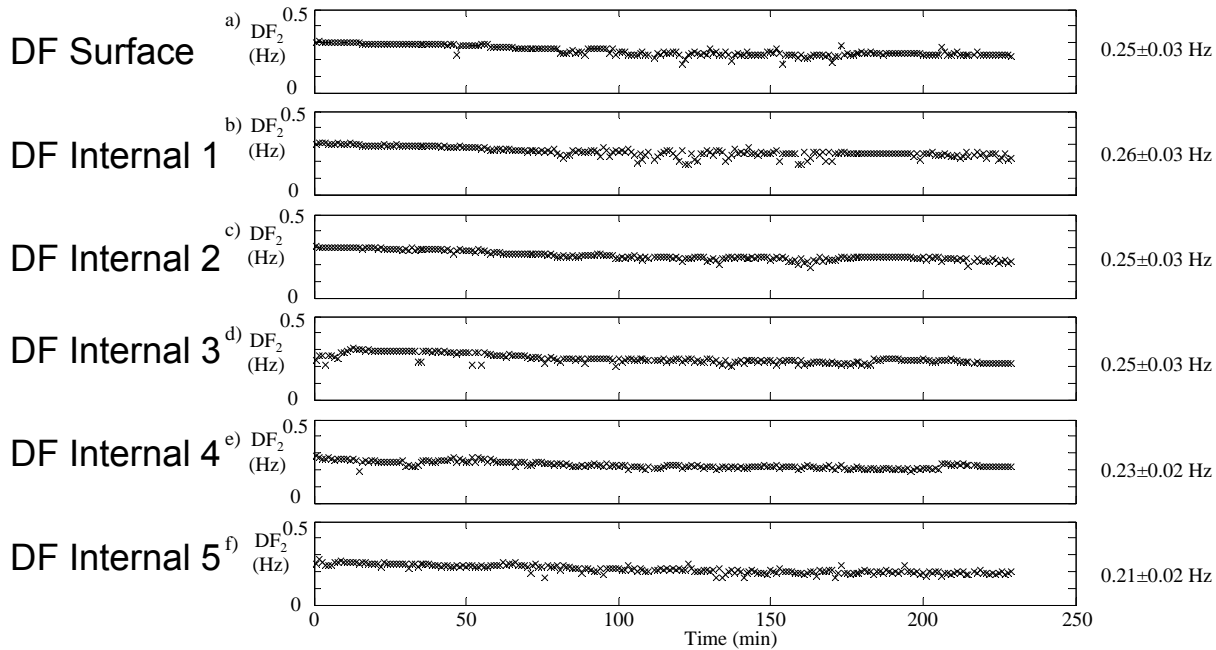
x Original  
o Processed

# Intestinal Activity Studies

## ○ Interference Cancellation: 'Software'

SW+interf. ↓ f

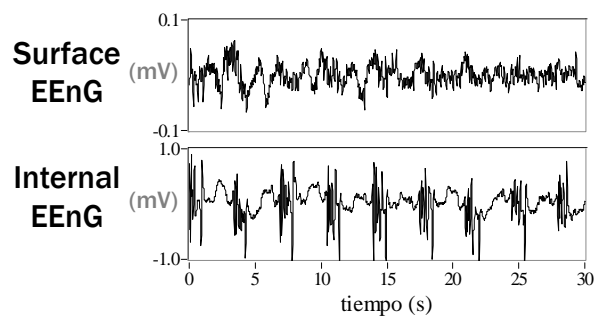
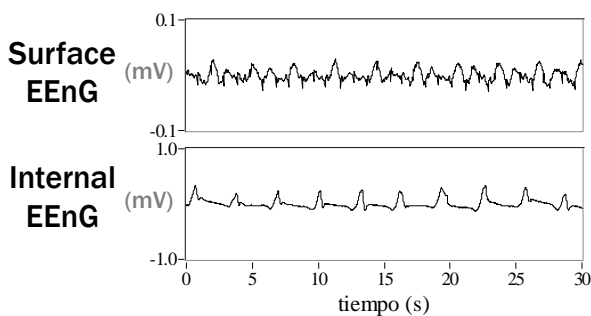
### □ Empirical Mode Decomposition (EMD)



# Intestinal Activity Studies

## ○ Surface EEnG

- Very **attenuated** signal, specially in ↑freq. (SB)
- contractile inactivity (No SB)      maximum contractile activity (SB)



### □ Presents **interferences**:

- Contact potential
- EGG
- Respiration
- ECG
- Movement artifacts

Low Freq.

High Freq.

Cancellation?

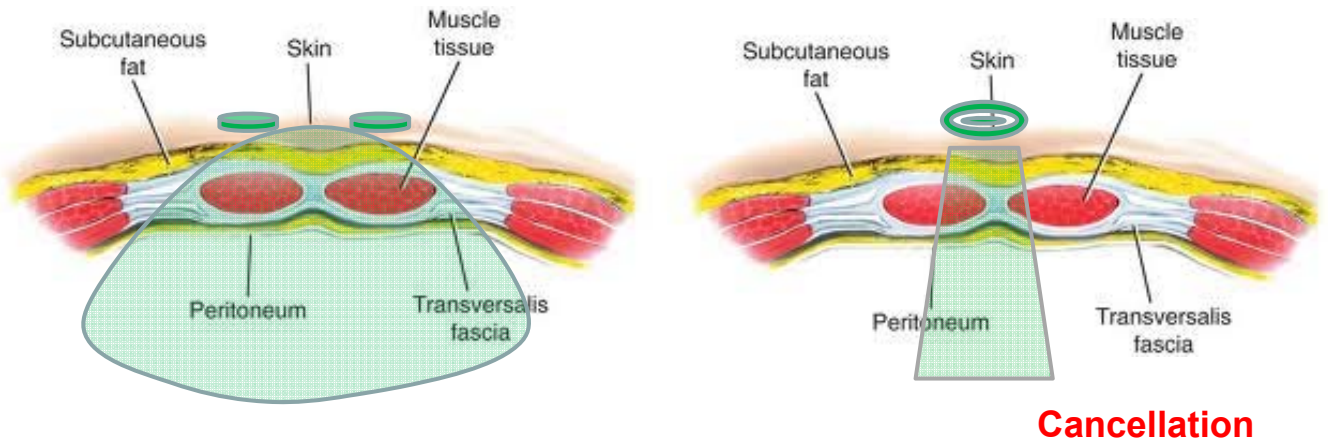


'Software'

'Hardware'

# Intestinal Activity Studies

- Interference Cancellation: 'Hardware'
  - Electrodes in Laplacian configuration

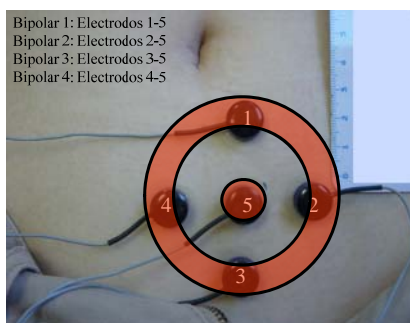


'Hardware'

# Intestinal Activity Studies

- Interference Cancellation: 'Hardware'
  - Electrodes in Laplacian configuration

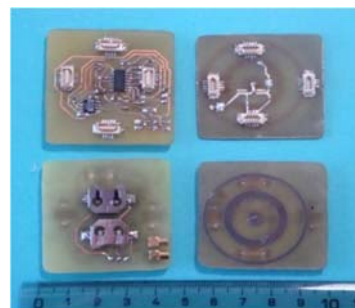
**Discrete approximation**



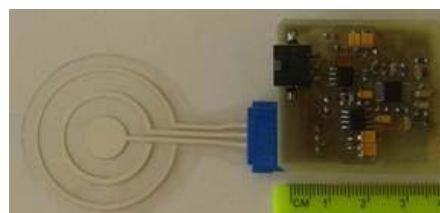
$$L_v \approx \frac{4}{b^2} \left[ V_5 - \frac{1}{4}(V_1 + V_2 + V_3 + V_4) \right]$$

**Continuous approximation**

Rigid Electrodes

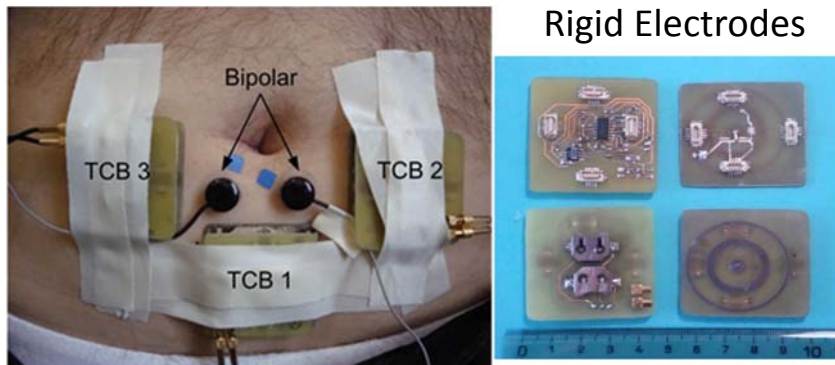


Flexible Electrodes



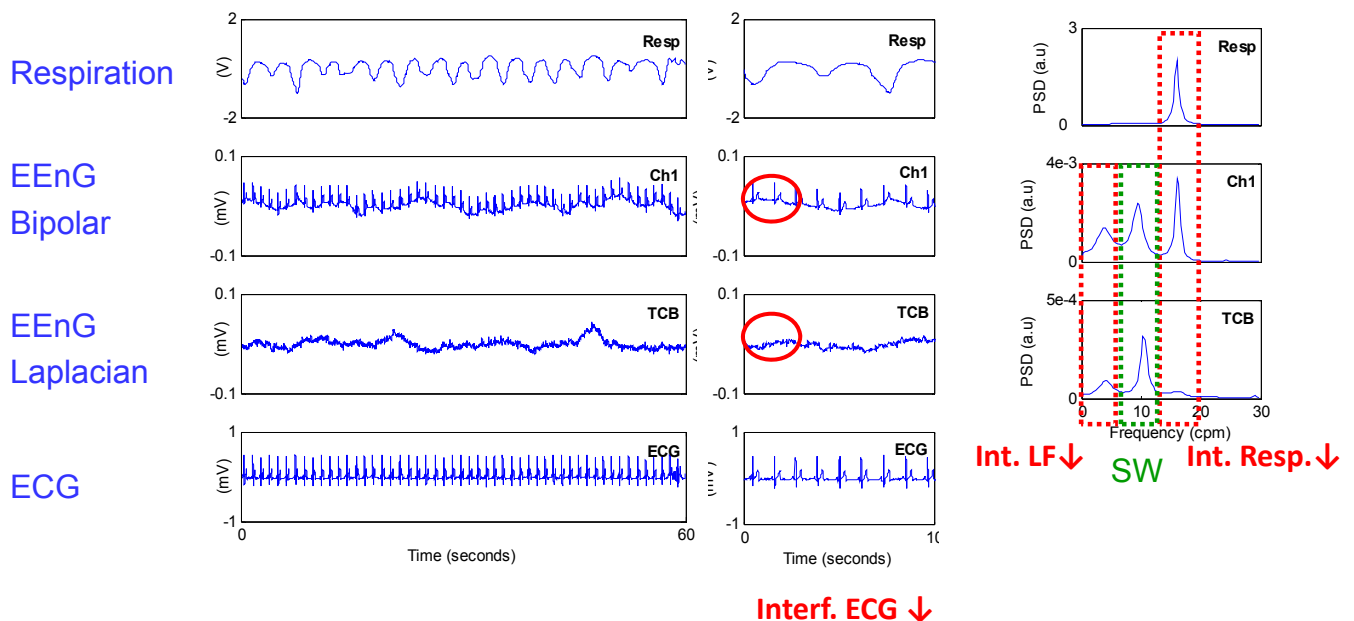
# Intestinal Activity Studies

- Interference Cancellation: 'Hardware'
  - Electrodes in Laplacian configuration



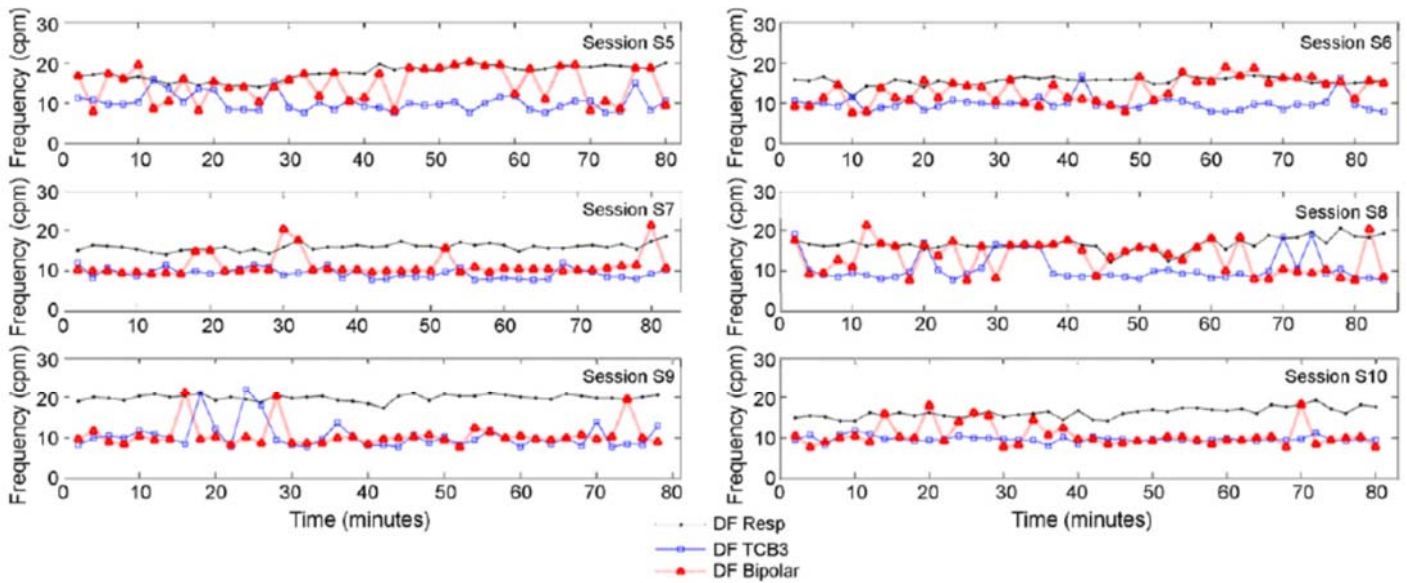
# Intestinal Activity Studies

- Interference Cancellation: 'Hardware'
  - Electrodes in Laplacian configuration



# Intestinal Activity Studies

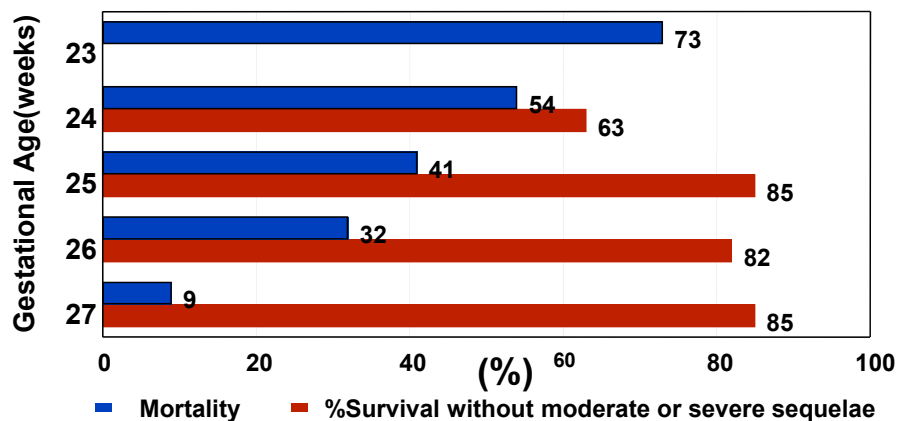
- Interference Cancellation: 'Hardware'
- Electrodes in Laplacian configuration



Int. Resp. ↓

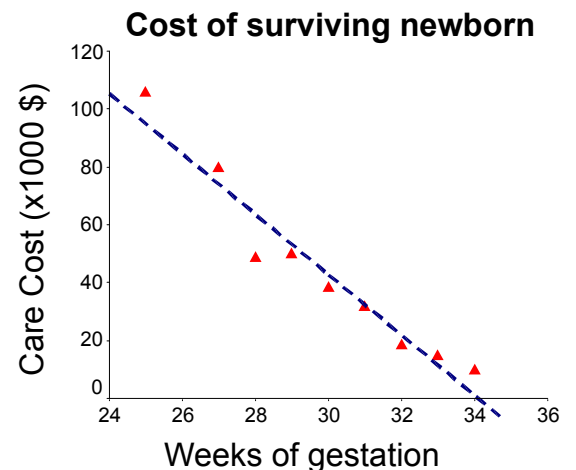
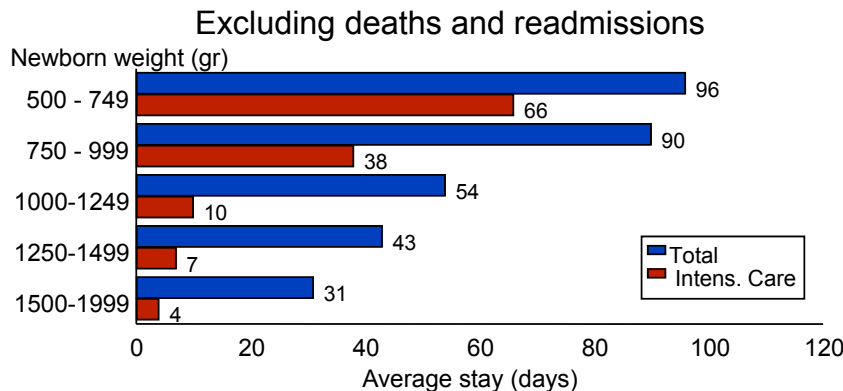
# Uterine Activity Studies

- Preterm birth (<37 wog)
  - 5-10% of total births
  - Main cause of perinatal deaths (85%); 1/5 mental retardation; 1/3 visual impairment; 1/2 cerebral palsy



# Uterine Activity Studies

- Preterm birth (<37 wog)
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  - Main cause of perinatal deaths (85%); 1/5 mental retardation; 1/3 visual impairment; 1/2 cerebral palsy
  - It involves prolonged hospital stays and a high economic cost



# Uterine Activity Studies

- Preterm birth (<37 wog)
  - 5-10% of total births
  - Main cause of perinatal deaths (85%); 1/5 mental retardation; 1/3 visual impairment; 1/2 cerebral palsy
  - It involves prolonged hospital stays and a high economic cost
  - The effectiveness of tocolytic and lung maturation agents is subject to the early initiation of therapy
  - Reliable prediction of true labor

↓  
understanding the mechanisms that initiate labor

↓  
study of uterine contractions.

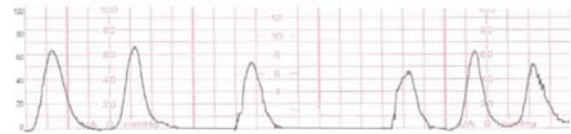
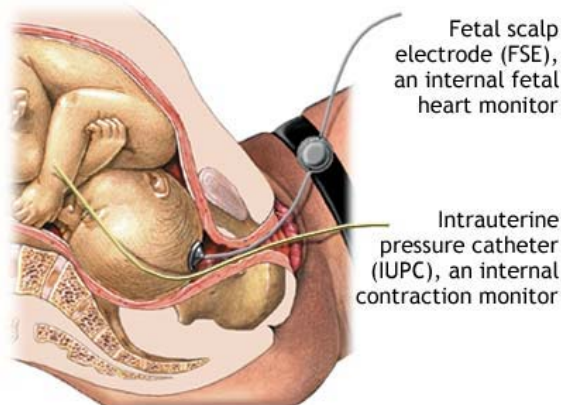
# Uterine Activity Studies

## ○ Monitoring of Uterine Contractions

### □ Intrauterine Pressure (IUP)

- Direct and accurate measurement
- 'Free' of artifacts and interferences
- 'Only' mechanical information
- Requires membrane rupture

**Gold Standard**

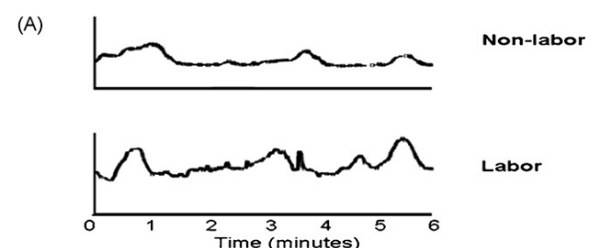
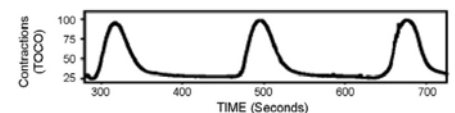


# Uterine Activity Studies

## ○ Monitoring of Uterine Contractions

### □ External Tocography (TOCO)

- Non invasive measurement
- Provides approximate duration and frequency of contractions
- Inaccurate measurement
  - Influence of probe location and pressure
  - Subjectivity of the examiner
- Use of tight straps
- No information about *efficiency* of the contractions

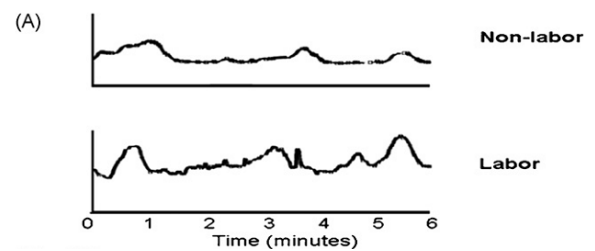
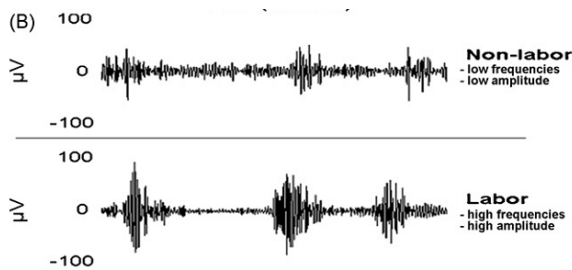
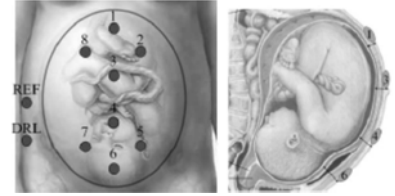
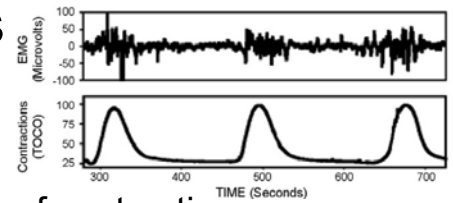


# Uterine Activity Studies

## Monitoring of Uterine Contractions

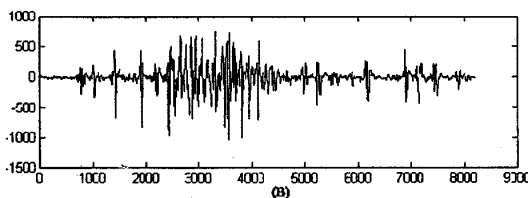
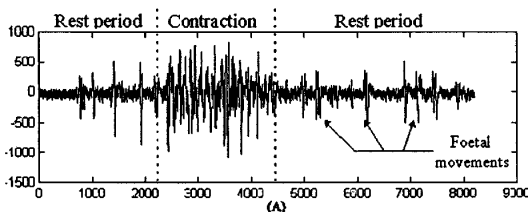
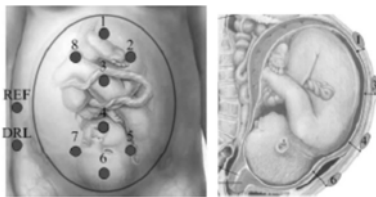
### Electrohysterography (EHG)

- Non invasive measurement
- Provides approximate duration and frequency of contractions
- Inaccurate measurement ?
  - Amplitude depends on recording conditions
  - Influence of body fat (less than TOCO)
- Use of tight straps is NOT needed
- information about *efficiency* of the contractions

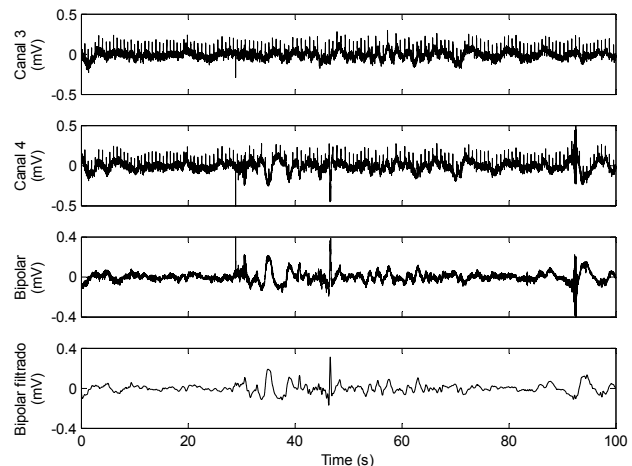


# Uterine Activity Studies

## EHG Recordings



## Monopolar vs Bipolar



### Presents interferences from:

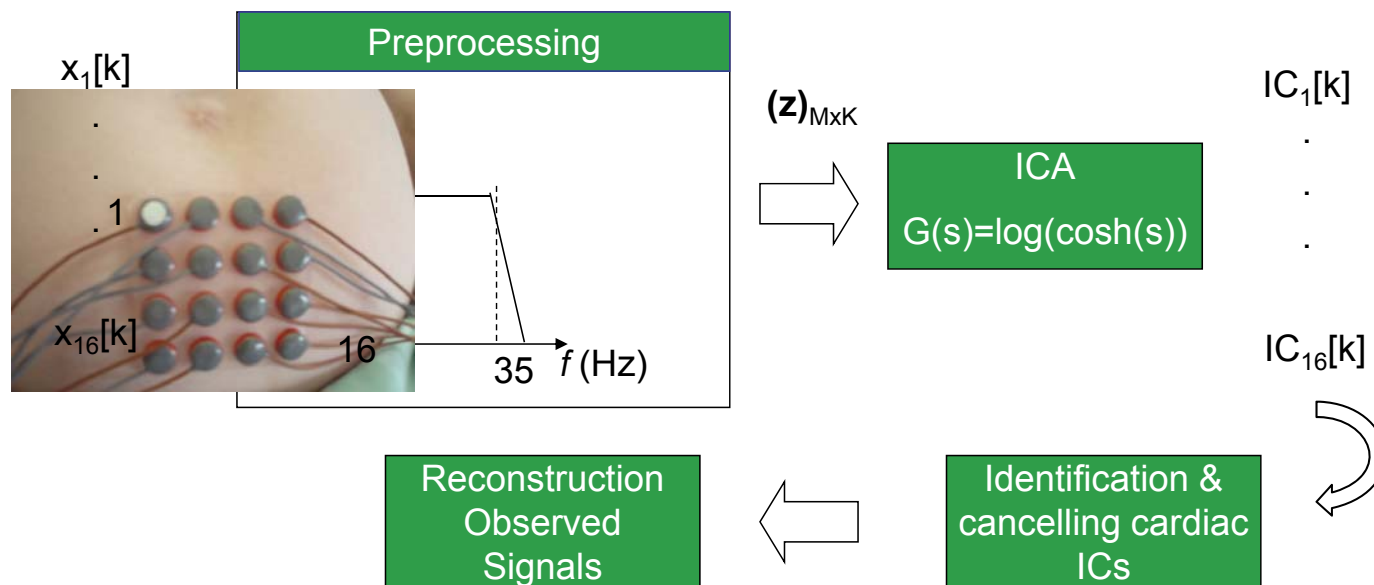
- Contact potential
- Respiration
- ECG
- Movt. Artifacts

Cancellation? ↔ 'Software'  
↔ 'Hardware'



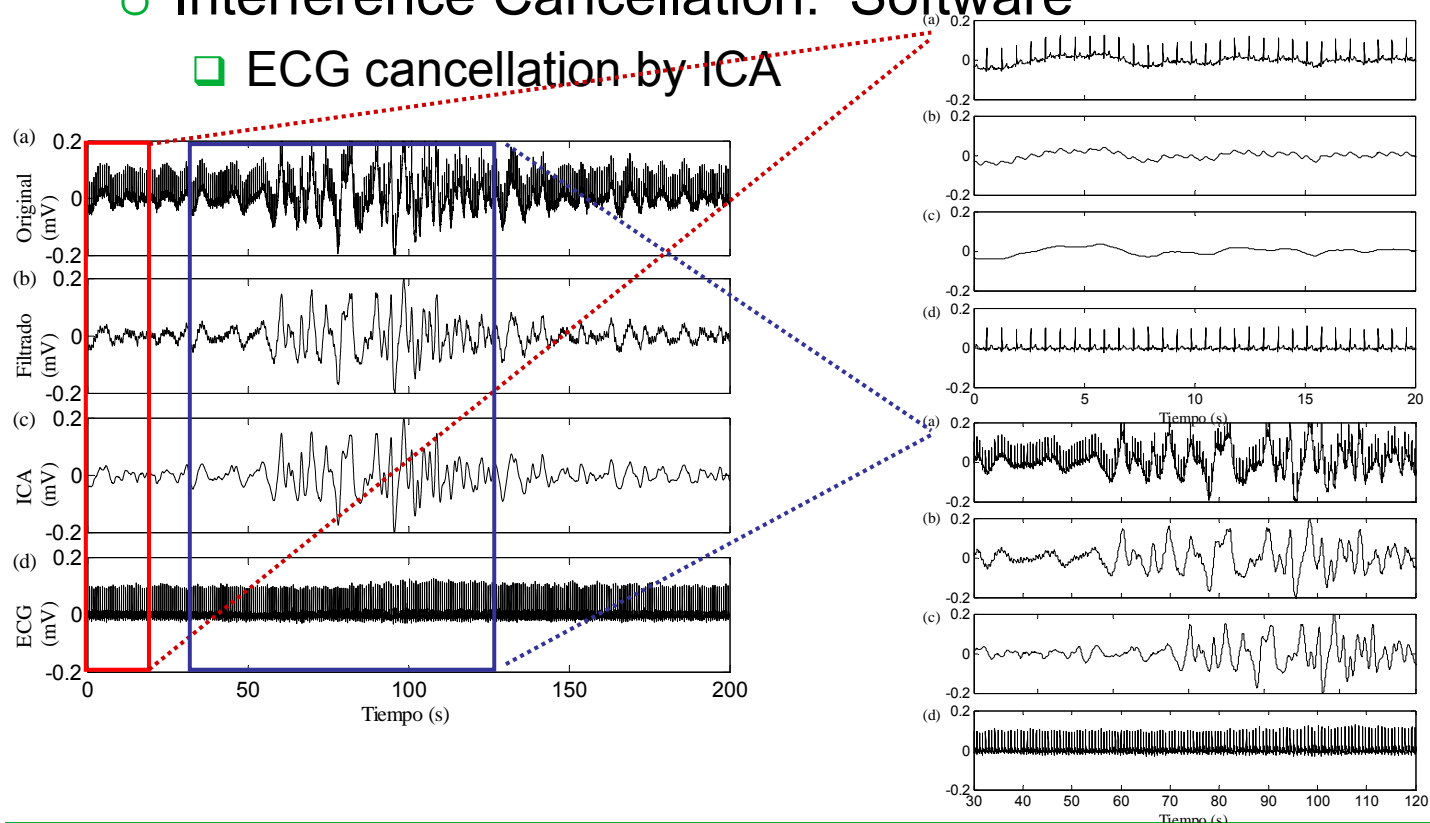
# Uterine Activity Studies

- Interference Cancellation: 'Software'
- ECG cancellation by ICA



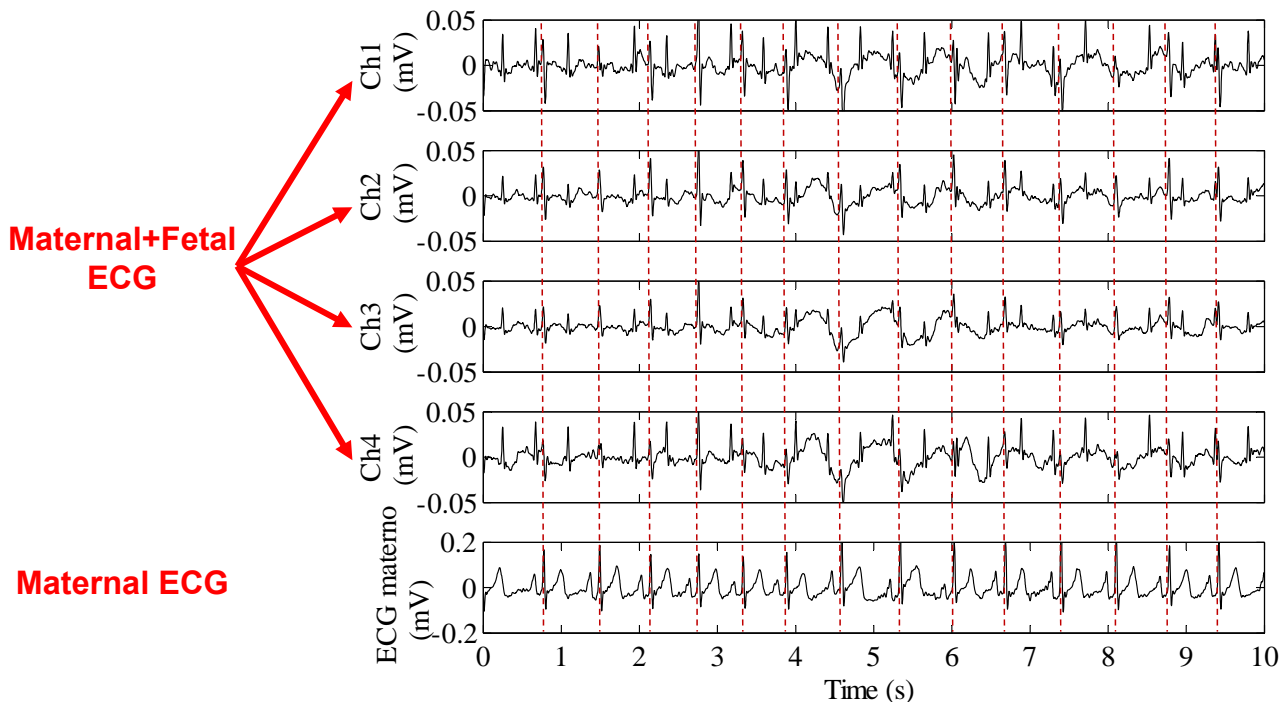
# Uterine Activity Studies

- Interference Cancellation: 'Software'
- ECG cancellation by ICA



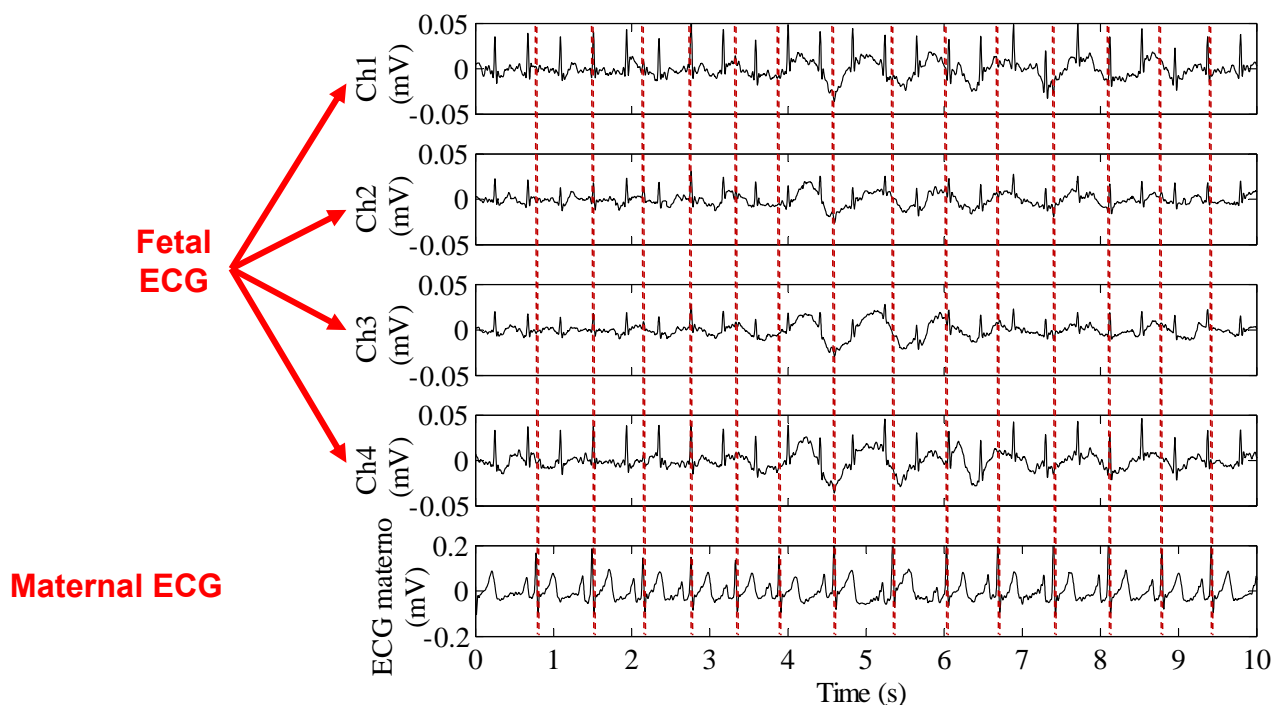
# Uterine Activity Studies

- Interference Cancellation: 'Software'
- ECG cancellation by Adaptive Filtering



# Uterine Activity Studies

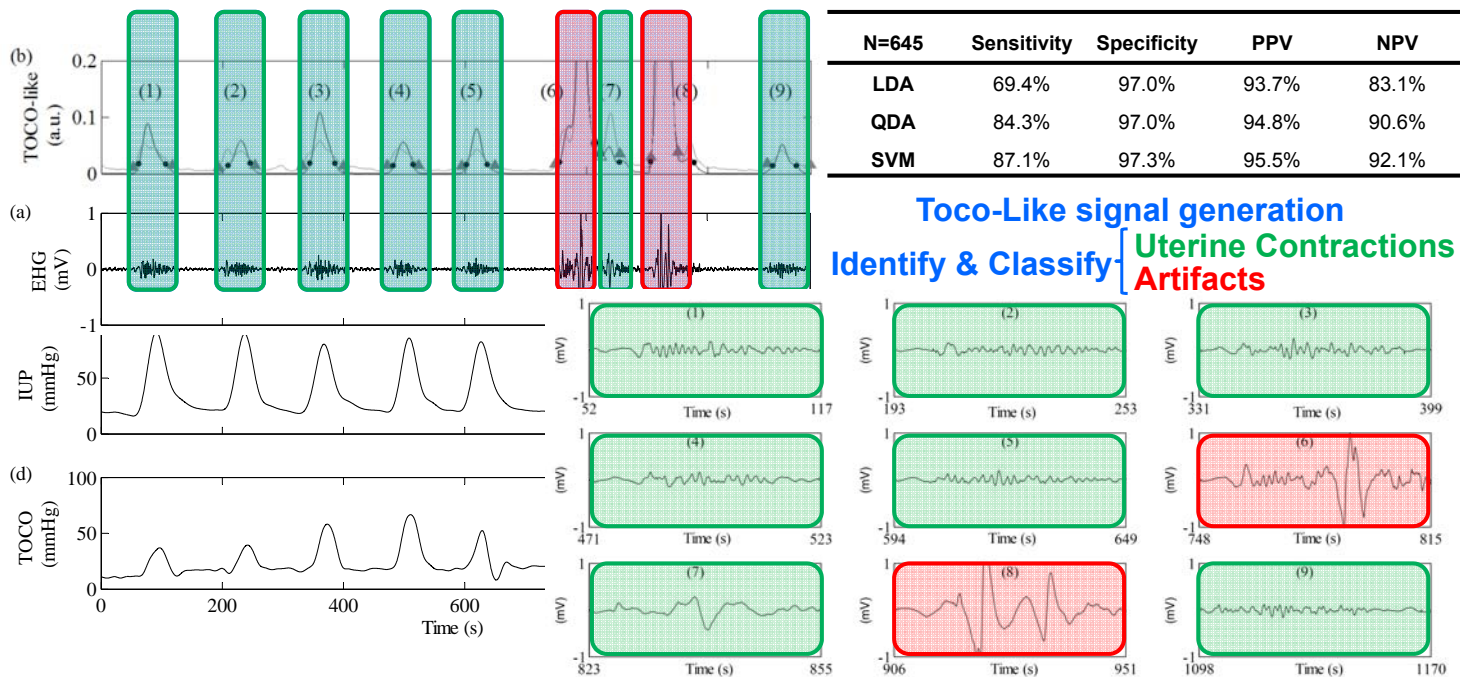
- Interference Cancellation: 'Software'
- ECG cancellation by Adaptive Filtering



# Uterine Activity Studies

## ○ Interference Cancellation: 'Software'

### □ Artif. cancel. & contraction detection by expert system



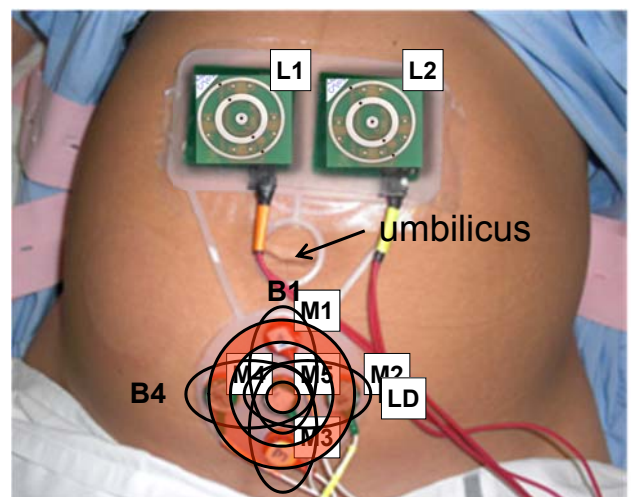
# Uterine Activity Studies

## ○ Contraction detection: monitoring uterine dynamics contraction detection

### ○ Signals

#### □ EHG

- 5 Monopolar
- 4 Bipolar
- 1 Laplacian Discrete
- 2 Laplacian Continuous



**Cancellation?** → 'Software'  
 → 'Hardware'

# Uterine Activity Studies

- Contraction detection: monitoring uterine dynamics

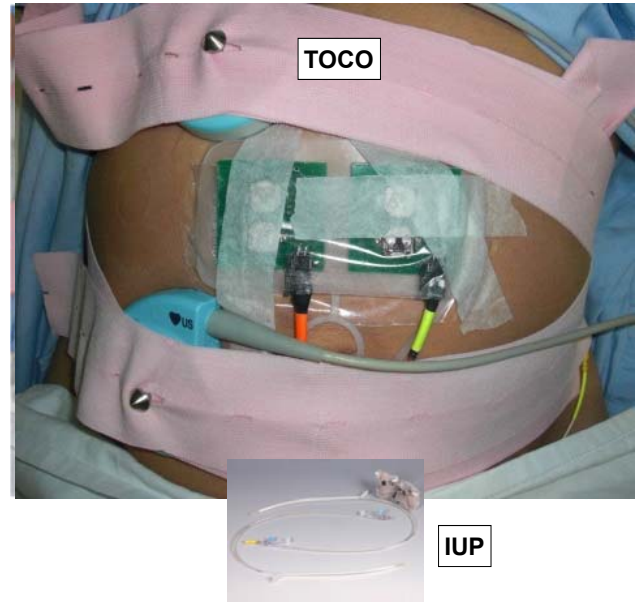
- Signals

- EHG

- 5 Monopolar
    - 4 Bipolar
    - 1 Laplacian Discrete
    - 2 Laplacian Continuous

- TOCO

- IUP

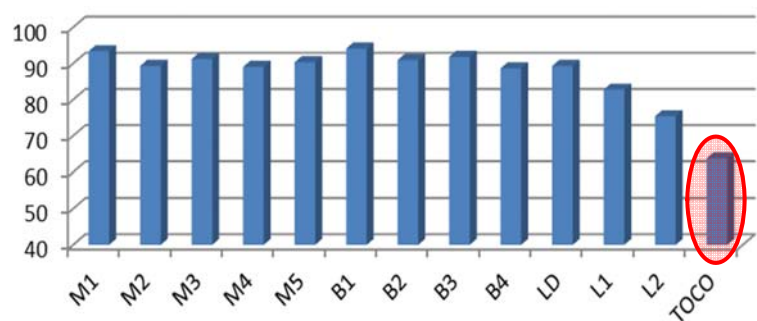


# Uterine Activity Studies

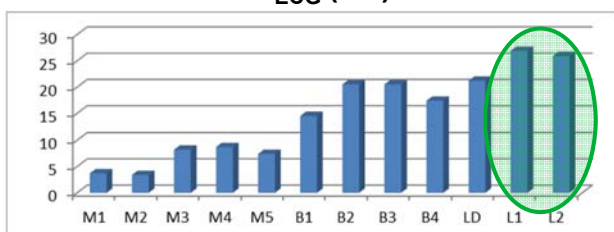
- Contraction detection: monitoring uterine dynamics

$$CCI = \frac{N_C}{\frac{1}{2}(N_T + N_E)}$$

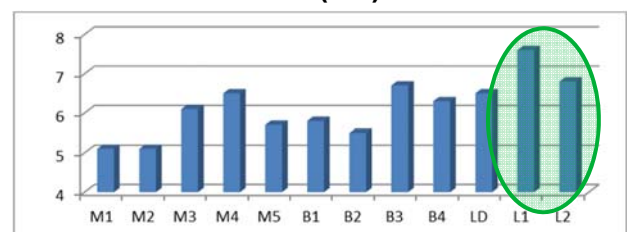
- $N_C$  n° consistant contract.
- $N_T$  n° contract. IUP
- $N_E$  n° contract. EHG (o toco)



S/I<sub>ECG</sub> (dB)



S/N (dB)



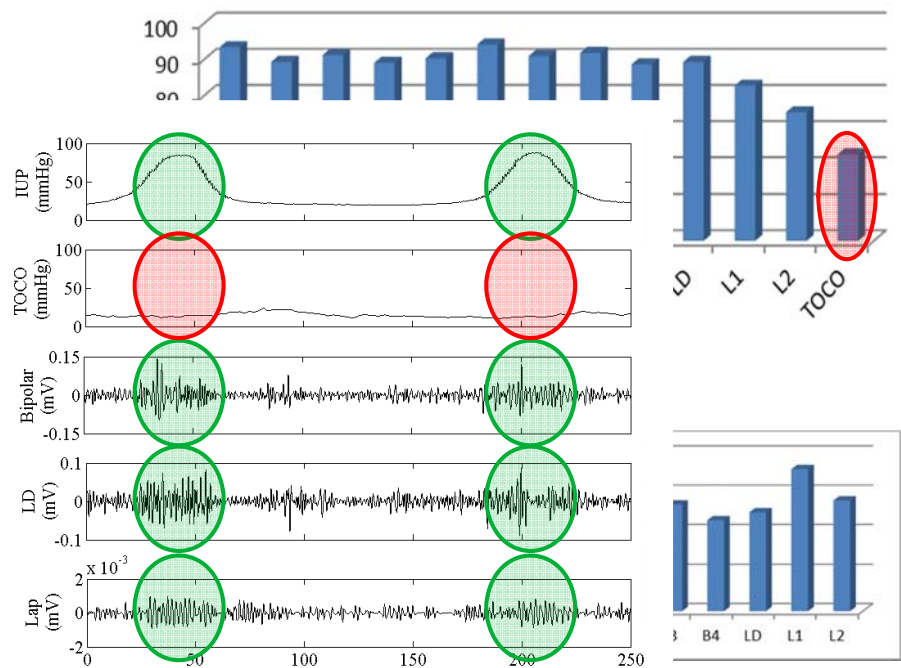
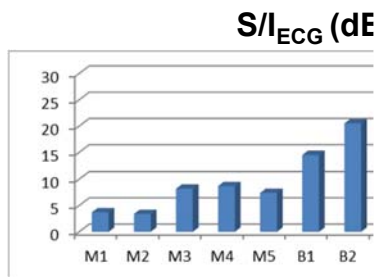
Cancellation? → 'Hardware'

# Uterine Activity Studies

## ○ Contraction detection: monitoring uterine dynamics

$$CCI = \frac{N_C}{\frac{1}{2}(N_T + N_E)}$$

- $N_C$  n° consisten contr
- $N_T$  n° contract. IUP
- $N_E$  n° contract. EHG (



Cancellation? → 'Hardware'

# Uterine Activity Studies

## ○ Preterm diagnosis

[Garfield & Maner, 2007]



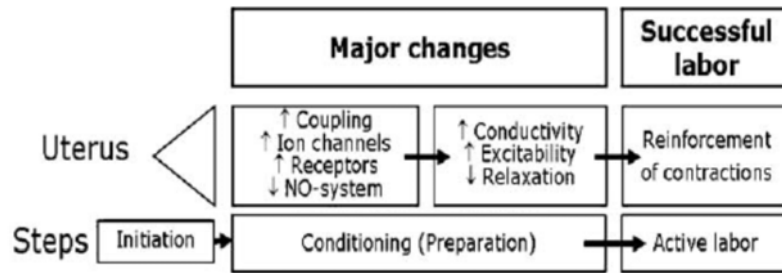
Test	Sens	Spec	PPV	NPV
MPTLS	50.0	63.5	21.4	86.4
Ctx $\geq 4 \text{ h}^{-1}$	6.7	92.3	25.0	84.7
BS $\geq 4$	32.0	91.4	42.1	87.4
Cx $\leq 25 \text{ mm}$	40.8	89.5	42.6	88.8
CFFN+	18.0	95.3	42.9	85.6
<b>EMG</b>	<b>75.0</b>	<b>93.3</b>	<b>81.8</b>	<b>90.3</b>
LIF	59.0	100.0	78.9	80.0

- MPTLS= multiple preterm labor symptoms
- BS= Bishop Score
- Cx=cervical length (ultrasound)
- Ctx=N°contractions (TOCO)
- CFFN+= Cervical fetal fibronectin test
- LIF: Cervical light-induced fluorescence

• **EMG= No-Invasive Uterine Electromiogram (EHG)**

# Uterine Activity Studies

- Evolution throughout pregnancy

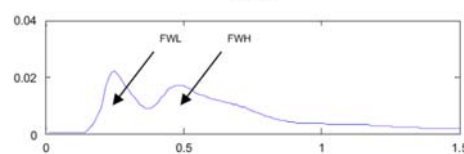
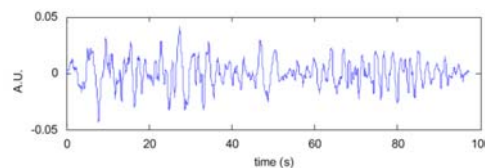


## Physiological changes in EHG parameters:

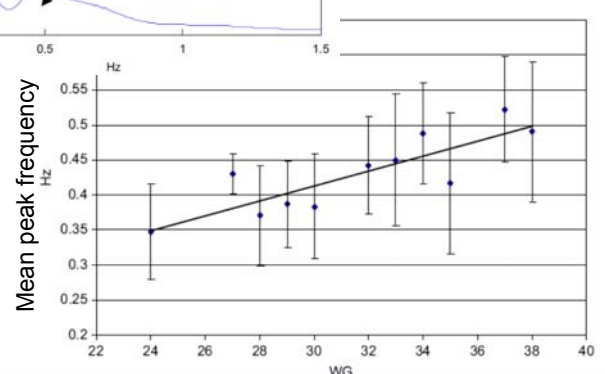
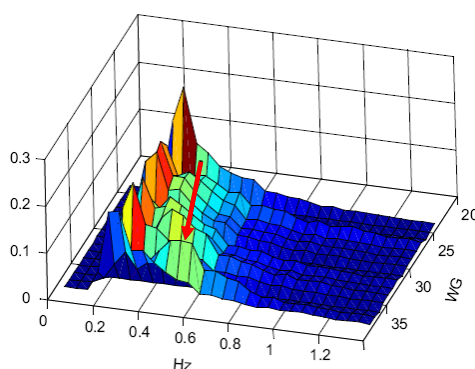
- ↑ Amplitude
- ↓ Duration
- ↑ nº CT/h: 0.5-6 CT/h pregnancy vs. maximum 18 CT/h labor)
- Energy content shifts to higher frequencies
- ↑ relative energy of FWH

# Uterine Activity Studies

- Preterm diagnosis
  - FWH swifts to ↑ frequencies
- Energy content shifts to higher frequencies
- ↑ relative energy of FWH



[Terrien, 2009]

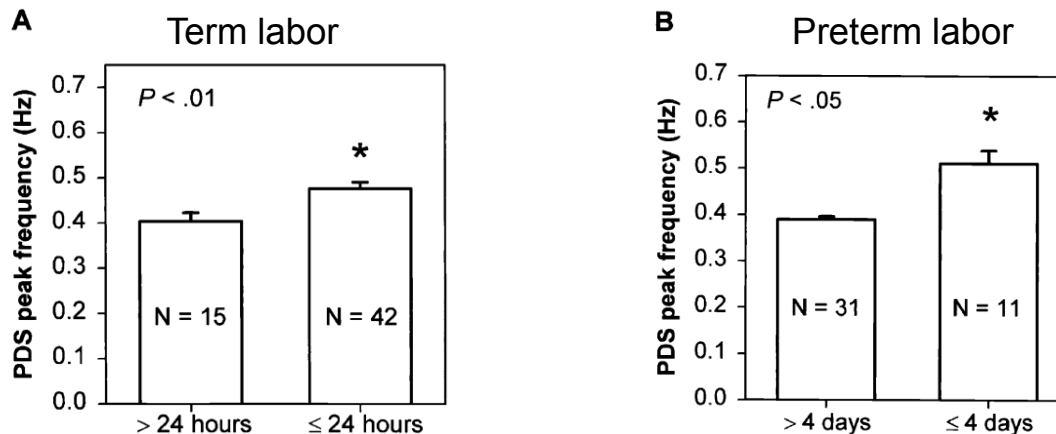


# Uterine Activity Studies

## ○ Preterm diagnosis

### □ Dominant Frequency between [0.34,1] Hz

[Manner, 2003]



**Figure 4.** A) Comparison of average power density spectrum (PDS) peak frequency values for term patients delivering within 24 hours of measurement with those delivering more than 24 hours from measurement. The 24-or-fewer-hours group is statistically higher.  $*P < .01$ . Standard errors shown. B) Comparison of average PDS peak frequency values for preterm patients delivering within 4 days of measurement with those delivering more than 4 days from measurement. The 4-or-fewer-days group is statistically higher.  $*P < .05$ . Standard errors shown.

# Uterine Activity Studies

## ○ Preterm diagnosis

### □ Dominant Frequency between [0.34,1] Hz

[Manner, 2003]

**Table 1.** Predictive Measures and Statistics for Term Patients

MTD interval	PPV	NPV	Sensitivity	Specificity	Cutoff	Z	AUC	$P^*$
48 h	.938	.556	.918	.625	.373	3.00	.783	<.005
24 h	.854	.889	.976	.533	.373	3.03	.760	<.010
12 h	.750	1.000	1.000	.542	.395	3.31	.745	<.001
8 h	.545	1.000	1.000	.394	.395	3.05	.706	<.005

MTD = measurement-to-delivery; PPV = positive predictive value; NPV = negative predictive value; AUC = area under curve.  
 $n = 57$ ;  $P$  significant at <.05.

\*  $P$  value for one-tailed test in receiver operating characteristics analysis.

**Table 2.** Predictive Measures and Statistics for Preterm Patients

MTD interval	PPV	NPV	Sensitivity	Specificity	Cutoff	Z	AUC	$P^*$
6 d	.818	.903	.750	.933	.446	6.79	.890	<.001
4 d	.857	.886	.600	.969	.463	7.01	.906	<.001
2 d	.714	.886	.556	.939	.463	5.86	.884	<.001
1 d	.750	.868	.375	.971	.480	4.74	.851	<.001

Abbreviations as in Table 1.  
 $n = 42$ ;  $P$  significant at <.05.

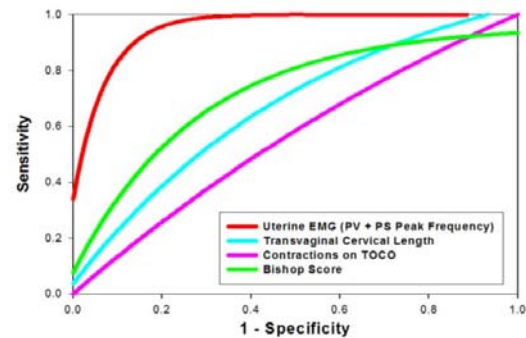
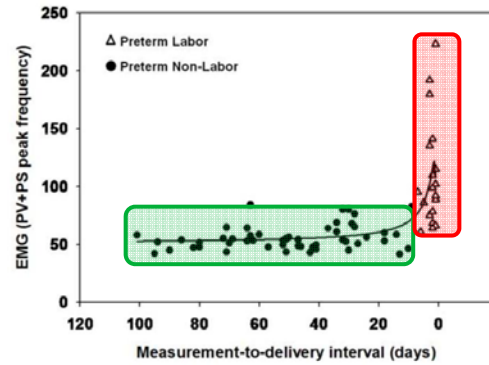
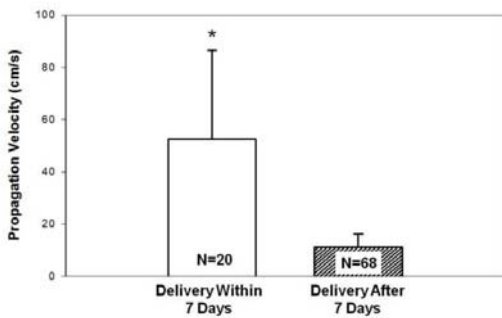
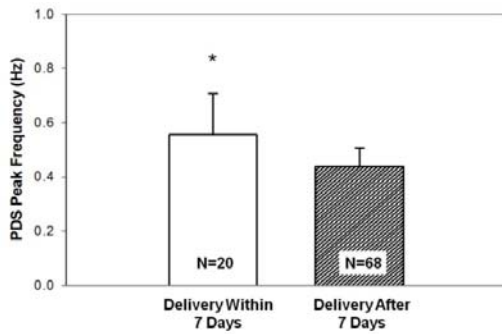
\*  $P$  value for one-tailed test in receiver operating characteristics analysis.

# Uterine Activity Studies

- Preterm diagnosis

- Dominant Frequency + Propagation velocity

[Lukovnik, 2011]

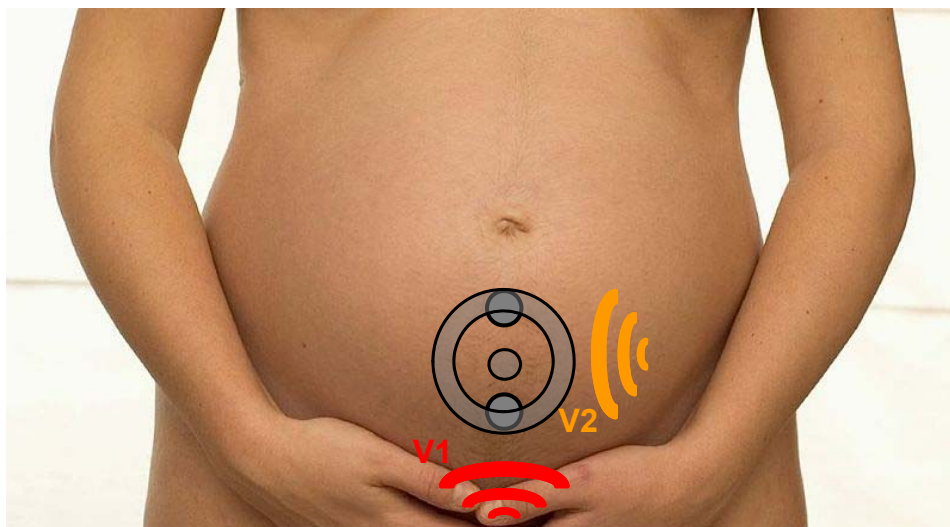


# Uterine Activity Studies

- Preterm diagnosis

- Dominant Frequency + Propagation velocity

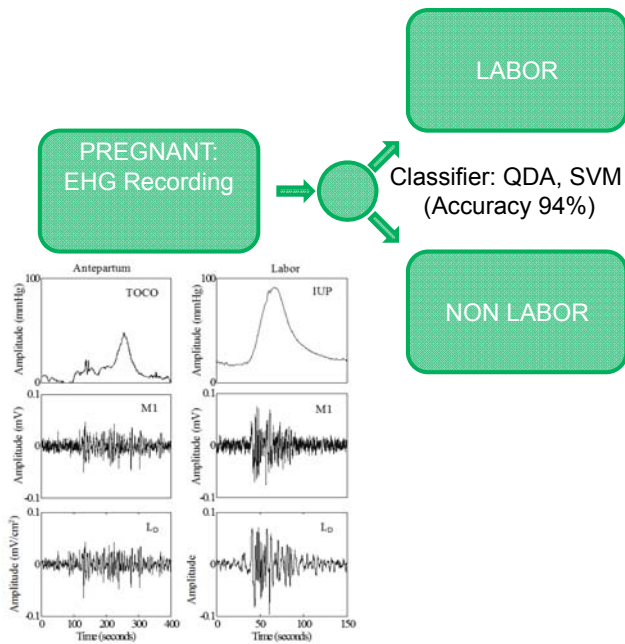
**NOT** Depends on electrode orientation and direction of propagated wavefront





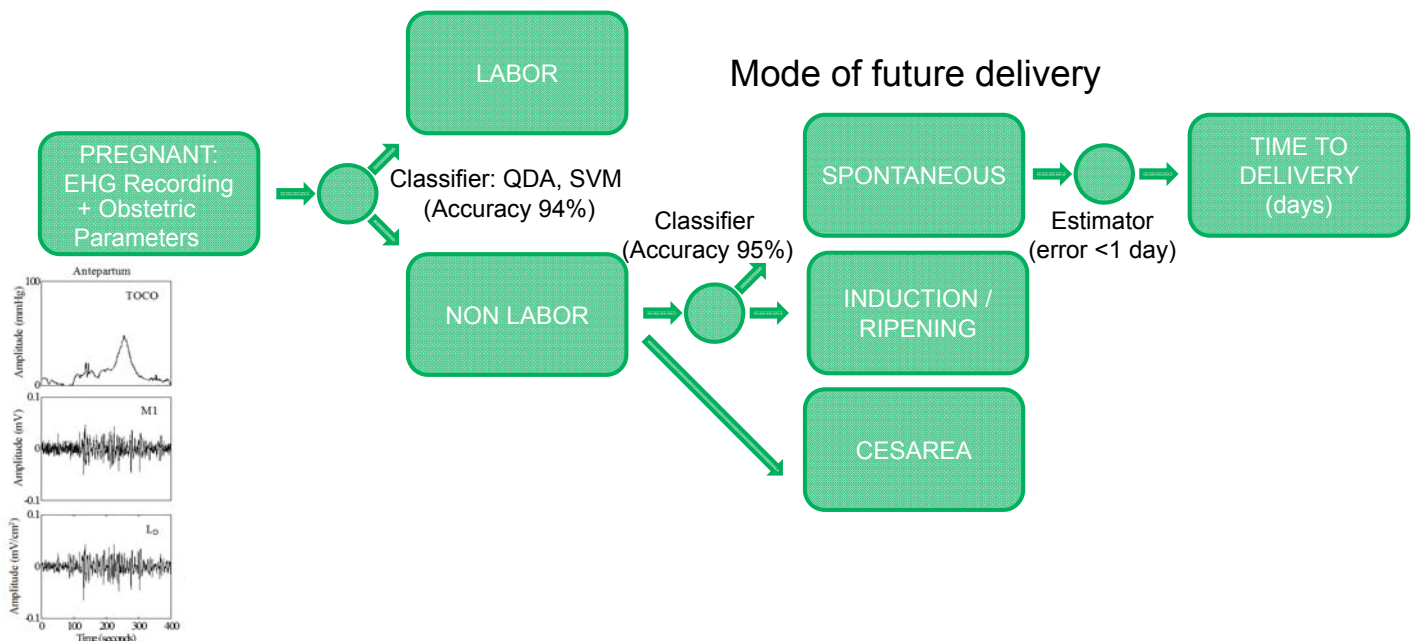
# Uterine Activity Studies

## ○ Predicting Horizon and Mode of Delivery



# Uterine Activity Studies

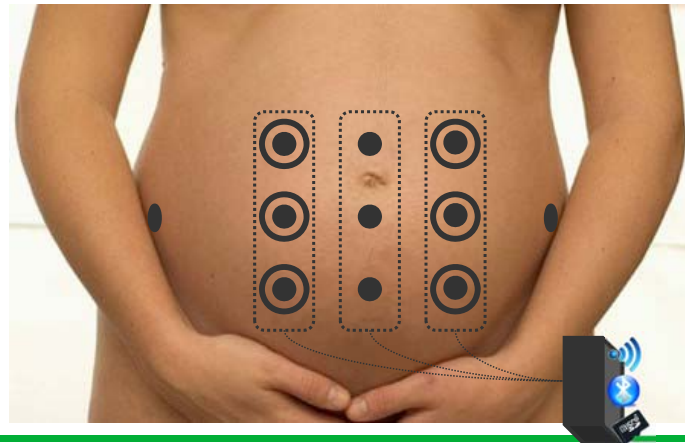
## ○ Predicting Horizon and Mode of Delivery



# Uterine Activity Studies

## ○ Future work

- Enlarge databases
- Study the effect of different cervical ripening drugs
- Individualized follow up of EHG during pregnancy
- Analyze propagation patterns and velocities
- Develop portable EHG, fECG monitoring device
- Aid to predict preterm labor



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# Thanks for your attention

