RAGNAR GRANIT INSTITUTE
TAMPERE UNIVERSITY OF TECHNOLOGY

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General Solution for the Clinical Application of Magnetocardiography

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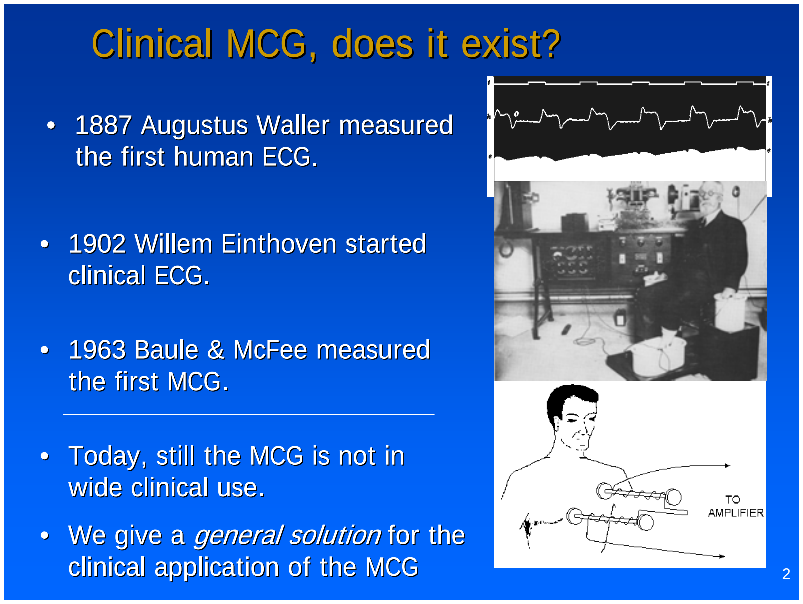
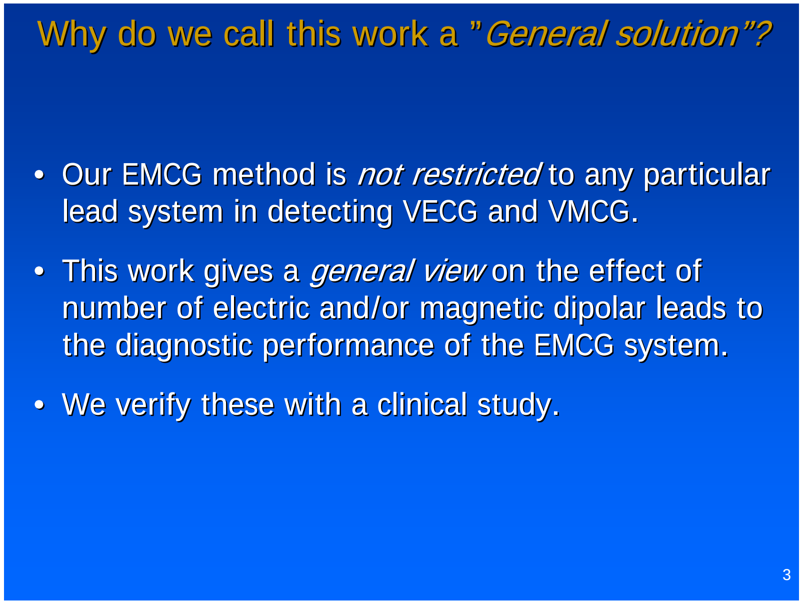


Clinical MCG, does it exist?

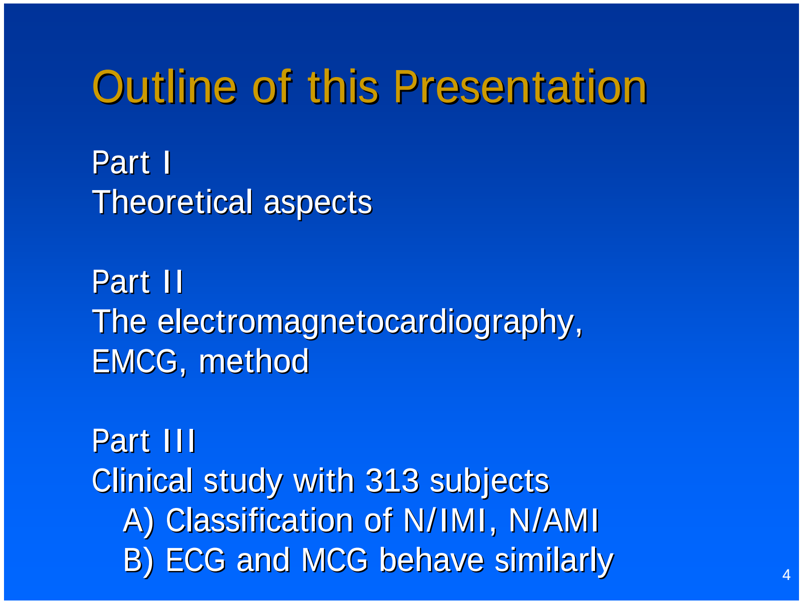
- 1887 Augustus Waller measured the first human ECG.
- 1902 Willem Einthoven started clinical ECG.
- 1963 Baule & McFee measured the first MCG.

- Today, still the MCG is not in wide clinical use.
- We give a *general solution* for the clinical application of the MCG



Why do we call this work a ”*General solution”?*

- Our EMCG method is *not restricted* to any particular lead system in detecting VECG and VMCG.
- This work gives a *general view* on the effect of number of electric and/or magnetic dipolar leads to the diagnostic performance of the EMCG system.
- We verify these with a clinical study.



Outline of this Presentation

Part I
Theoretical aspects

Part II
The electromagnetocardiography, EMCG, method

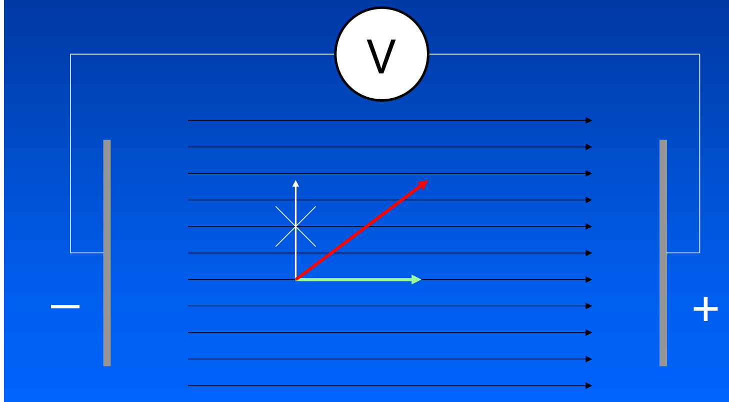
Part III
Clinical study with 313 subjects
A) Classification of N/IMI, N/AMI
B) ECG and MCG behave similarly

PART I

THEORETICAL ASPECTS

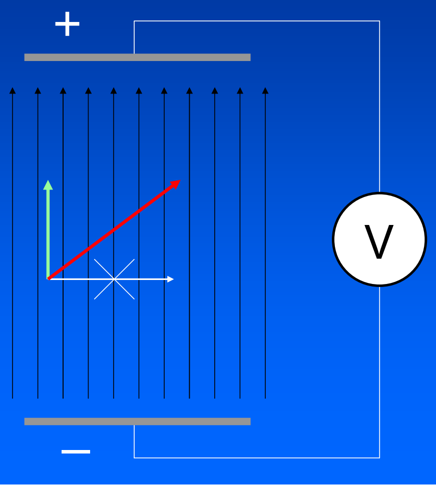
To obtain maximum amount of
additional information from the source,
such a lead must be used,
which detects such component
of the volume source,
which is not detected
by the existing leads.

One dipolar lead detects one component of the elementar electric sources

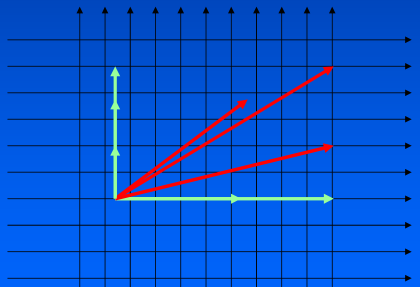


Another component is detected by a lead which is normal to the first one

This lead is independent on the previous one



Even though these orthogonal leads detect orthogonal components of the source, the signals are not fully independent, because changes in the amplitude or angle of the source affect to both signals.



In the rare occasion that only one component of the source changes, the signal changes only in that lead.

All this holds also within magnetic leads.

And it will be just now shown that:
All this also holds between
electric and magnetic leads
on volume source level.

The fundamental issue in the clinical application of biomagnetism is:

Do the biomagnetic signals include information independent on that of the bioelectric signals?

This issue is discussed with the help of the Helmholtz Theorem.

Helmholtz's theorem:

A general vector field which vanishes at infinity, can be represented as a sum of two *independent* vector fields, one that is irrotational and another which is solenoidal

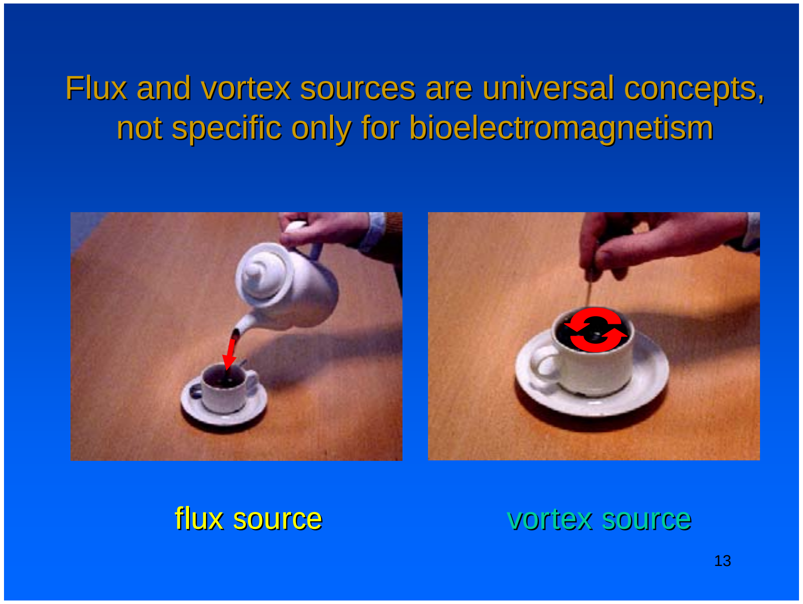
$$J^i = J^i_F + J^i_V$$

These vector fields are referred to as
FLUX source and VORTEX source

$$\overline{J^i}_F = -\nabla \bullet \overline{J^i} \qquad V_{LE} = \int_v \Phi_{LE} \nabla \bullet \overline{J^i} dv$$

$$\overline{J^i}_V = -\nabla \times \overline{J^i} \quad V_{LM} = \frac{\mu}{2} \int_v \Phi_{LM} \bar{r} \bullet \nabla \times \overline{J^i} dv$$

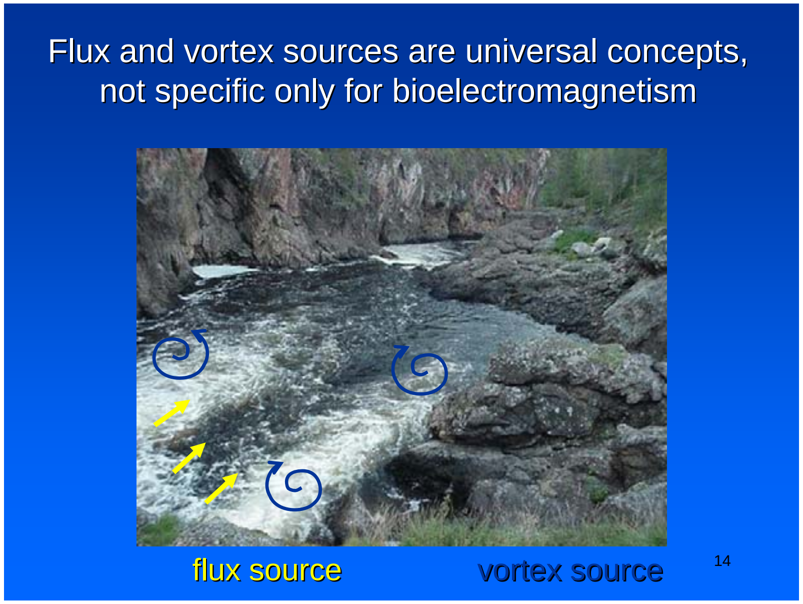
Bioelectric signals originate from the FLUX source	Biomagnetic signals originate from the VORTEX source



Flux and vortex sources are universal concepts, not specific only for bioelectromagnetism

flux source

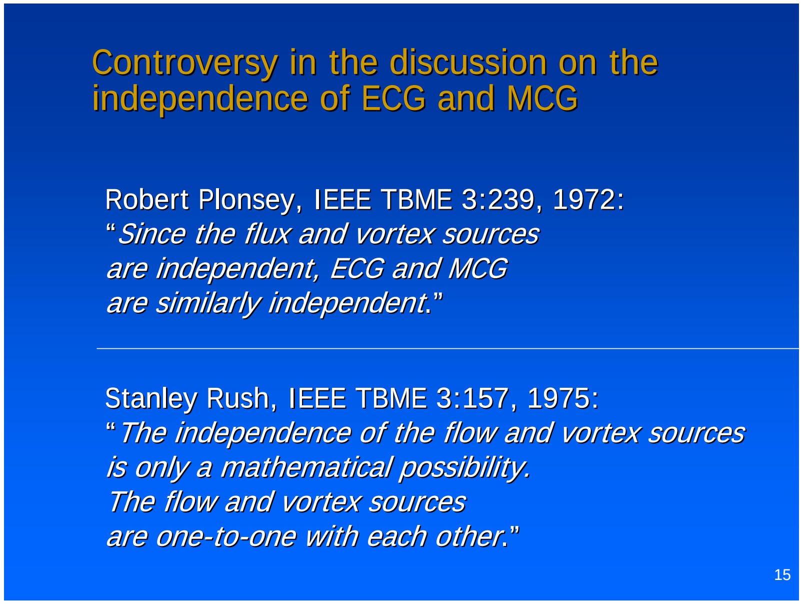
vortex source



Flux and vortex sources are universal concepts, not specific only for bioelectromagnetism

flux source

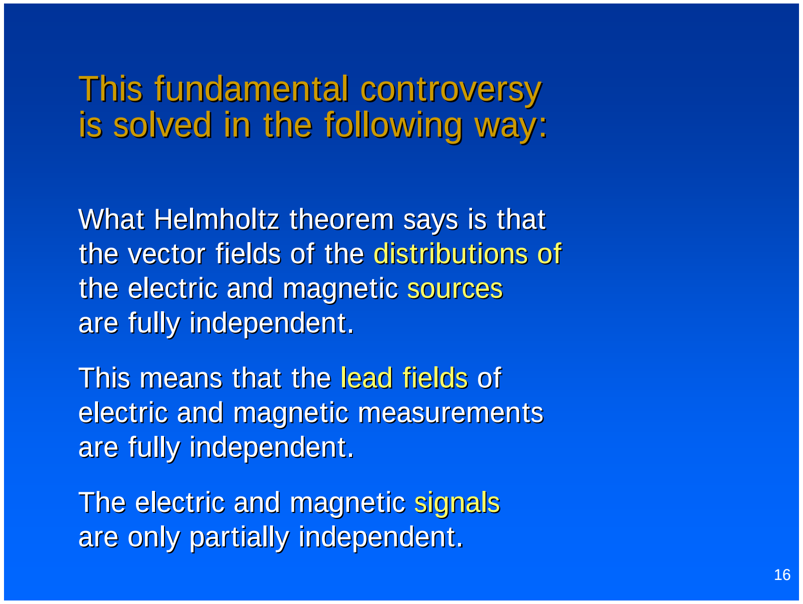
vortex source



Controversy in the discussion on the independence of ECG and MCG

Robert Plonsey, IEEE TBME 3:239, 1972:
"*Since the flux and vortex sources*
are independent, ECG and MCG
are similarly independent."

Stanley Rush, IEEE TBME 3:157, 1975:
"*The independence of the flow and vortex sources*
is only a mathematical possibility.
The flow and vortex sources
are one-to-one with each other."



This fundamental controversy is solved in the following way:

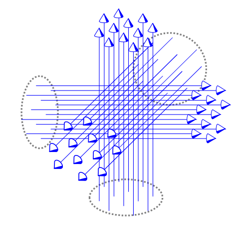
What Helmholtz theorem says is that the vector fields of the distributions of the electric and magnetic sources are fully independent.

This means that the lead fields of electric and magnetic measurements are fully independent.

The electric and magnetic signals are only partially independent.

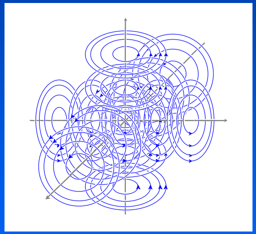
Lead fields of leads detecting the electric and magnetic dipole moments (flux and vortex sources)

ECG



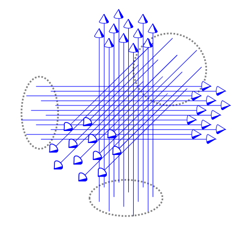
Three orthogonal linear lead fields. Sensitivity is homogeneous.

MCG

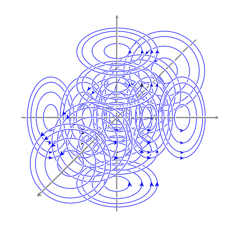


Three orthogonal tangential lead fields. Sensitivity is proportional to the radial distance.

The three electric lead fields are mutually independent



The three magnetic lead fields are mutually independent



On the basis of the Helmholtz Theorem, the electric and magnetic lead fields are mutually independent.

Therefore, none of the six components of the electric and magnetic lead fields is a linear combination of the other five.

Conclusion

Because all the 6 dipolar electric and magnetic lead fields are independent,
recording all these leads
gives the maximum amount of information
on the dipolar volume source.

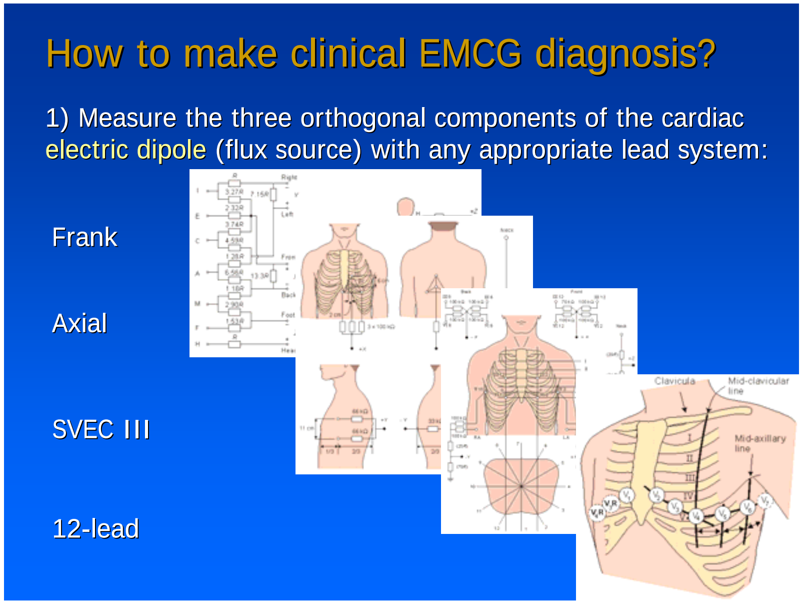
All this holds also on quadrupolar, octupolar, etc. level.

PART II

General Solution for the Clinical Application of Magnetocardiography:

The Electromagnetocardiography method (EMCG)

Part III Clinical study



How to make clinical EMCG diagnosis?

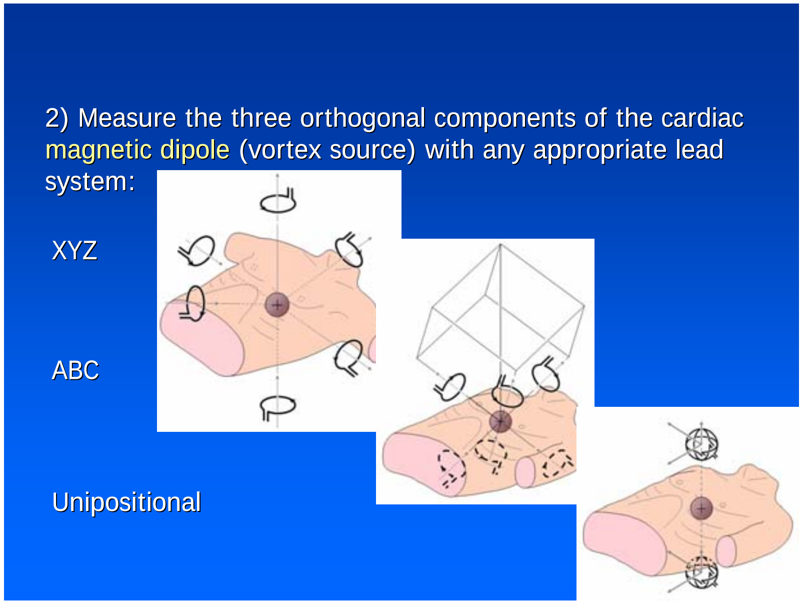
1) Measure the three orthogonal components of the cardiac electric dipole (flux source) with any appropriate lead system:

Frank

Axial

SVEC III

12-lead

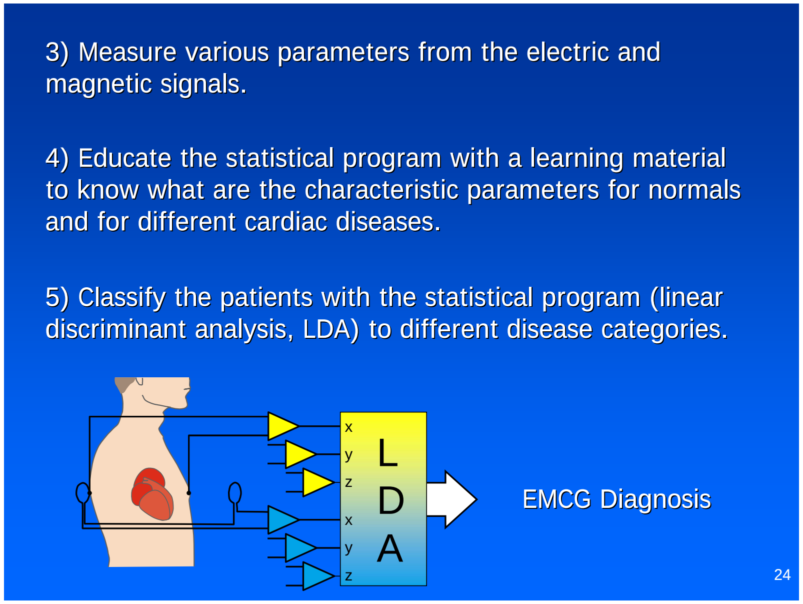


2) Measure the three orthogonal components of the cardiac magnetic dipole (vortex source) with any appropriate lead system:

XYZ

ABC

Unipositional



3) Measure various parameters from the electric and magnetic signals.

4) Educate the statistical program with a learning material to know what are the characteristic parameters for normals and for different cardiac diseases.

5) Classify the patients with the statistical program (linear discriminant analysis, LDA) to different disease categories.

EMCG Diagnosis

Computerized EMCG diagnosis

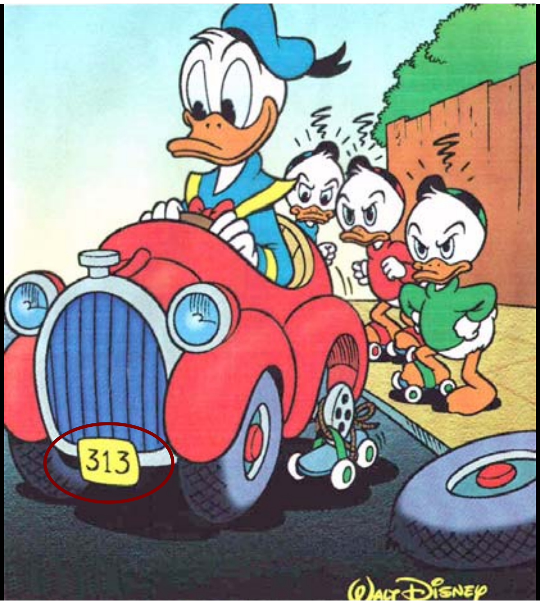
Electric x, y and z leads and Magnetic x, y and z leads

PART III

CLINICAL STUDY

Patient material in the clinical study

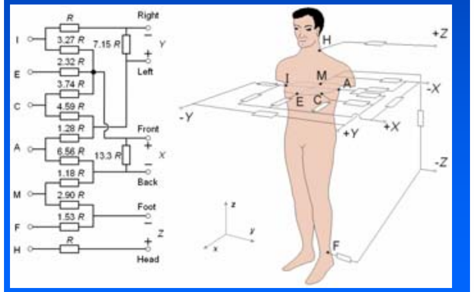
Old inferior myocardial infarction (IMI) 73 male and 17 female, 59 +/- 19 years	90
Old anteroseptal myocardial infarction (AMI) 59 male and 12 female, 59 +/- 5 years	71
Normal healthy persons 85 male and 67 female, 54 +/- 11years	152
Total number of persons	313

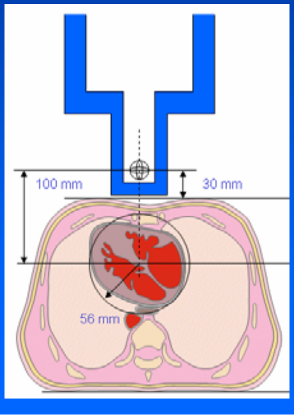


We measured

the VECG with the Frank lead system

the VMCG with the Unipositional lead system





From the 6
electric and magnetic
dipolar signals
different parameters
were measured

Definition of some parameters

Amplitudes:

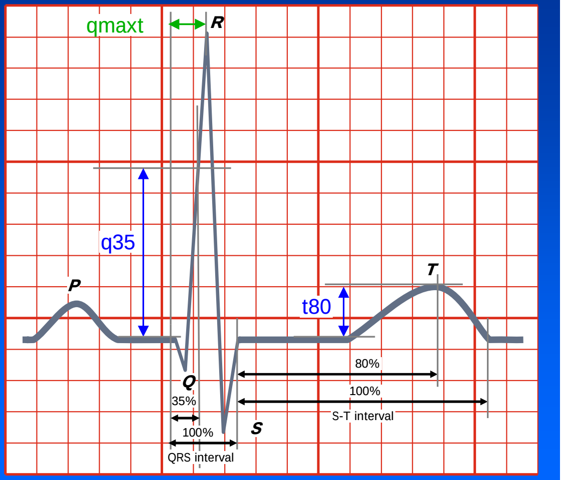
**q35

**t80

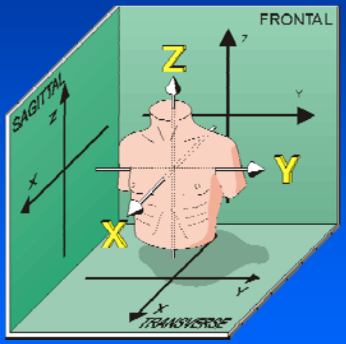
Times:

**qmaxt

(Altogether
over 130
parameters)



Results (A)



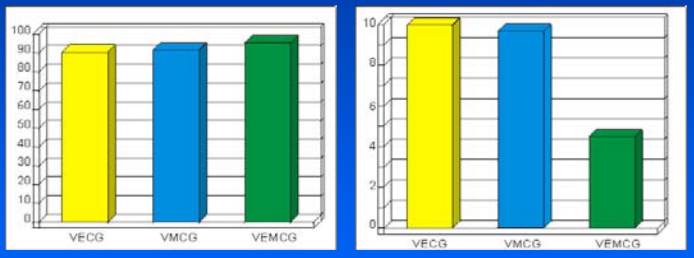
Consistent coordinate system

Correct jackknifed classification rates (%) in linear discriminant analysis (LDA) between N/IMI patients with increasing (cumulative) number of parameters

ECG		MCG		EMCG		p
Param	Corr%	Param	Corr%	Param	Corr%	
Ez t80	80.2	Mz t80	74.0	Ez t80	80.2	
Ez q15	86.8	My q10	83.9	Ez q15	86.8	
Ey q15	88.8	Mx q85	86.8	My q5	92.1	
Ey q50	88.4	My q35	87.6	Mx q95	92.6	
Ez qmin	90.1	My qmin	91.7	Ex q5	93.0	
Ez q95	89.7	Mz q5	91.7	Mz t90	94.6	
Ex q5	89.3	Mz qmaxt	91.3	Ez q55	95.5	0.019
Ex q10	88.0	My qmint	91.7	Ex q10	95.5	

Correct classification N/IMI

152 normals / 90 IMI



Correct classification %

Incorrect classification %

Conclusion

When combining the ECG and the MCG to electromagnetocardiography, EMCG,
the number of incorrectly diagnosed patients may decrease even 50%
compared to either ECG or MCG.

Adding more dipolar ECG leads, instead of dipolar MCG leads, would not improve the diagnostic performance, because they are linear combinations of the three orthogonal dipolar electric leads.

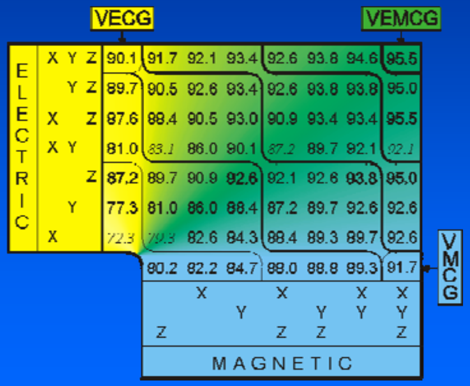
Results (B)

We evaluated the diagnostic performance of each individual electric and magnetic lead and all their combinations

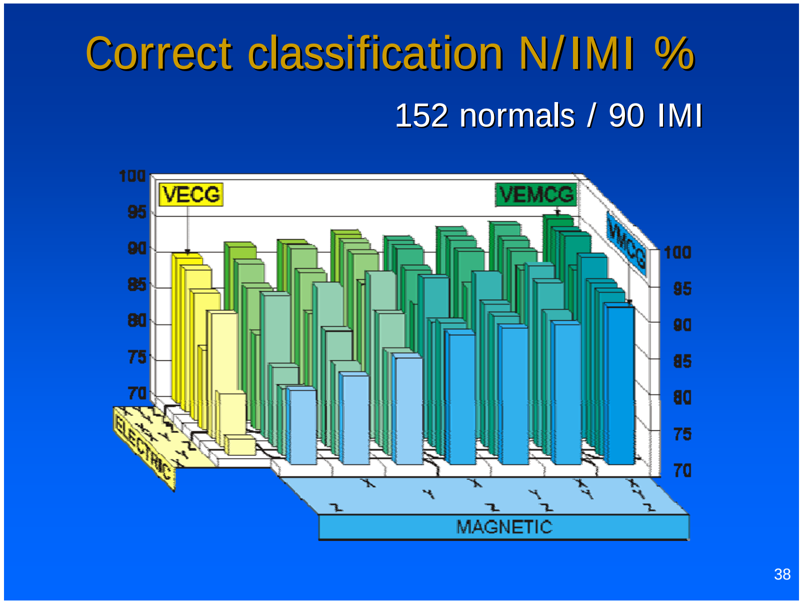
In order to demonstrate that, electric and magnetic leads are of equal value.

Correct classification N/IMI %

152 normals / 90 IMI

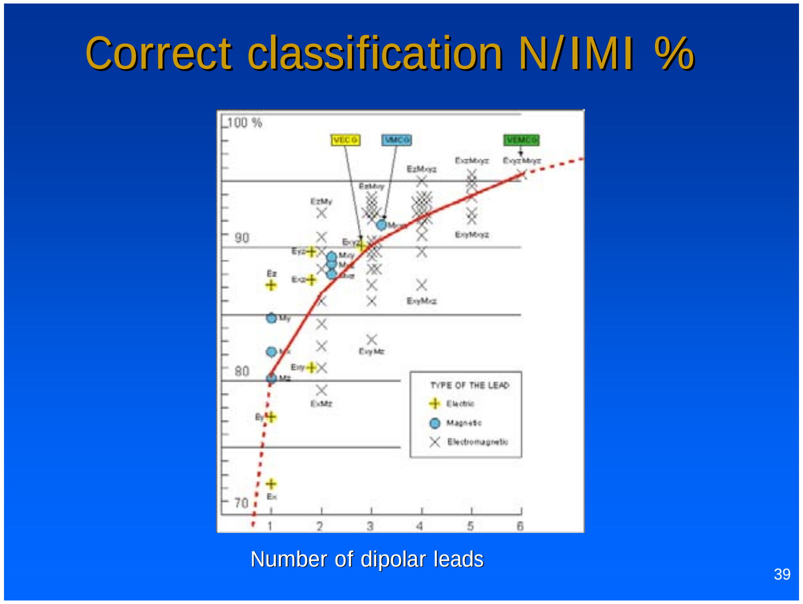


ELECTRIC X Y Z	90.1	91.7	92.1	93.4	92.6	93.8	94.6	95.5
Y Z	89.7	90.5	92.6	93.4	92.6	93.8	93.8	95.0
X Z	87.6	88.4	90.5	93.0	90.9	93.4	93.4	95.5
X Y	81.0	83.1	86.0	90.1	87.2	89.7	92.1	92.1
Z	87.2	89.7	90.9	92.6	92.1	92.6	93.8	95.0
Y	77.3	81.0	86.0	88.4	87.2	89.7	92.6	92.6
X	72.3	79.3	82.6	84.3	88.4	89.3	89.7	92.6
		80.2	82.2	84.7	88.0	88.8	89.3	91.7
		Z	X	Y	X Z	Y Z	X Y	X Y Z
		MAGNETIC						



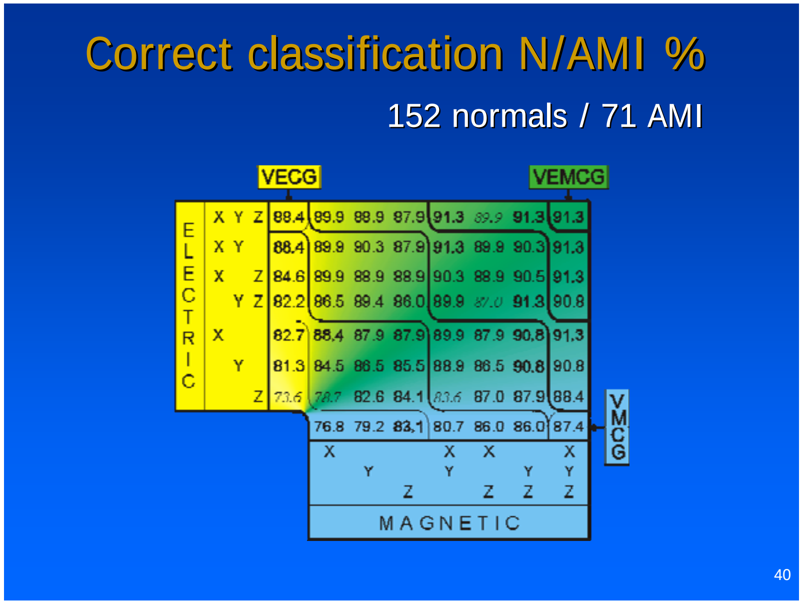
Correct classification N/IMI %

152 normals / 90 IMI



Correct classification N/IMI %

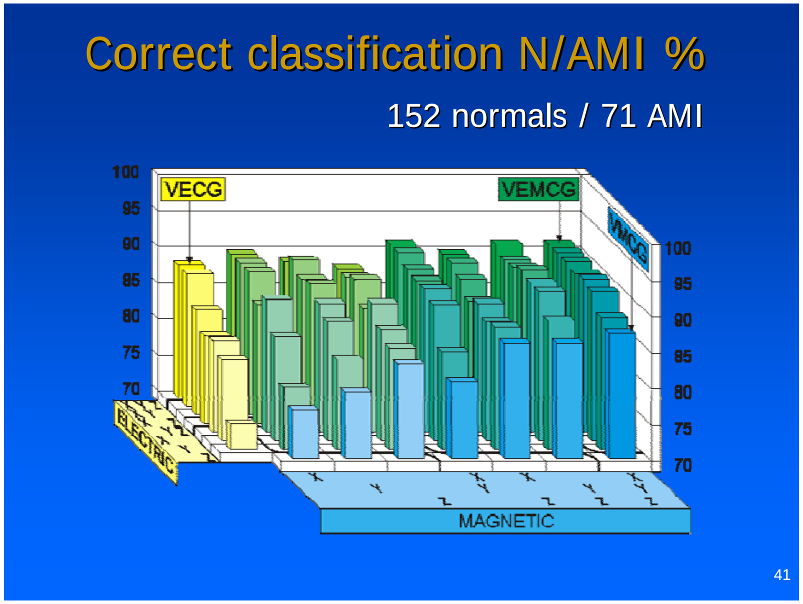
Number of dipolar leads



Correct classification N/AMI %

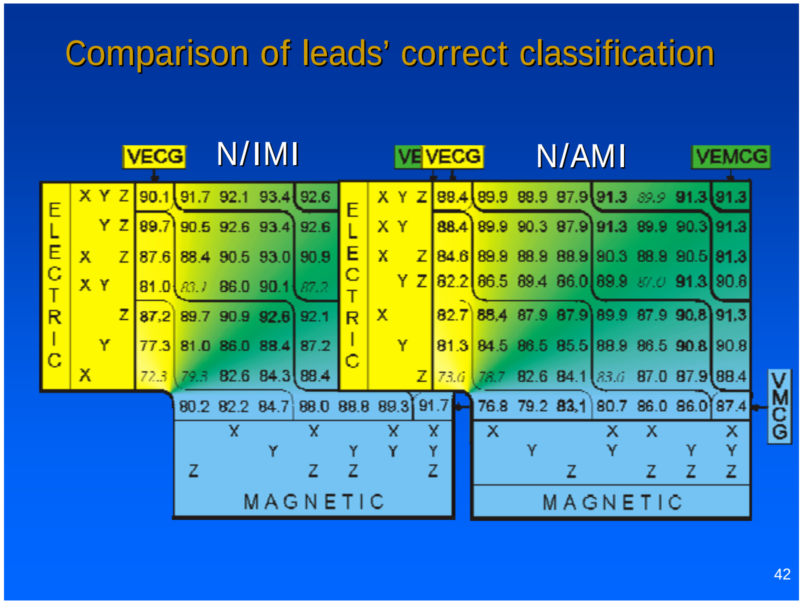
152 normals / 71 AMI

		X	Y	Z	X Y	X Z	Y Z	X Y Z
X Y Z	88.4	89.9	88.9	87.9	91.3	89.9	91.3	91.3
X Y	88.4	89.9	90.3	87.9	91.3	89.9	90.3	91.3
X Z	84.6	89.9	88.9	88.9	90.3	88.9	90.5	91.3
Y Z	82.2	86.5	89.4	86.0	89.9	87.0	91.3	90.8
X	82.7	88.4	87.9	87.9	89.9	87.9	90.8	91.3
Y	81.3	84.5	86.5	85.5	88.9	86.5	90.8	90.8
Z	73.6	78.7	82.6	84.1	83.6	87.0	87.9	88.4
		76.8	79.2	83.1	80.7	86.0	86.0	87.4



Correct classification N/AMI %

152 normals / 71 AMI



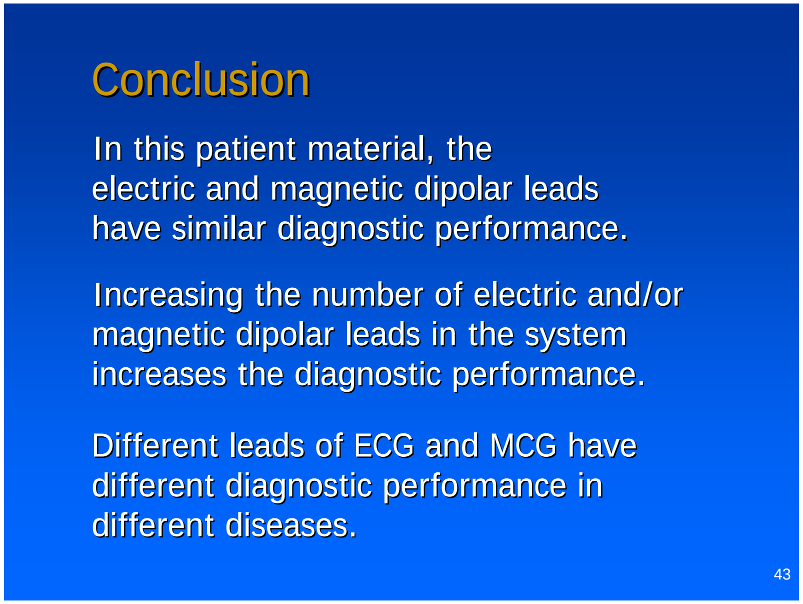
Comparison of leads' correct classification

VECG N/IMI

		Z	X	Y	X Z	Y Z	X Y	X Y Z
X Y Z	90.1	91.7	92.1	93.4	92.6			
Y Z	89.7	90.5	92.6	93.4	92.6			
X Z	87.6	88.4	90.5	93.0	90.9			
X Y	81.0	83.1	86.0	90.1	87.2			
Z	87.2	89.7	90.9	92.6	92.1			
Y	77.3	81.0	86.0	88.4	87.2			
X	72.3	79.3	82.6	84.3	88.4			
		80.2	82.2	84.7	88.0	88.8	89.3	91.7

VE VECG N/AMI VEMCG

		X	Y	Z	X Y	X Z	Y Z	X Y Z
X Y Z	88.4	89.9	88.9	87.9	91.3	89.9	91.3	91.3
X Y	88.4	89.9	90.3	87.9	91.3	89.9	90.3	91.3
X Z	84.6	89.9	88.9	88.9	90.3	88.9	90.5	81.3
Y Z	82.2	86.5	89.4	86.0	89.9	87.0	91.3	90.8
X	82.7	88.4	87.9	87.9	89.9	87.9	90.8	91.3
Y	81.3	84.5	86.5	85.5	88.9	86.5	90.8	90.8
Z	73.6	78.7	82.6	84.1	83.6	87.0	87.9	88.4
		76.8	79.2	83.1	80.7	86.0	86.0	87.4

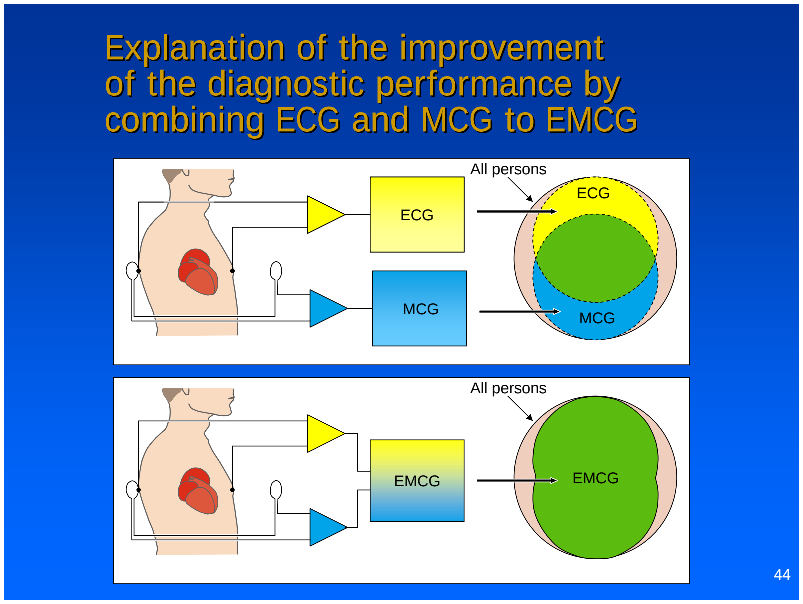


Conclusion

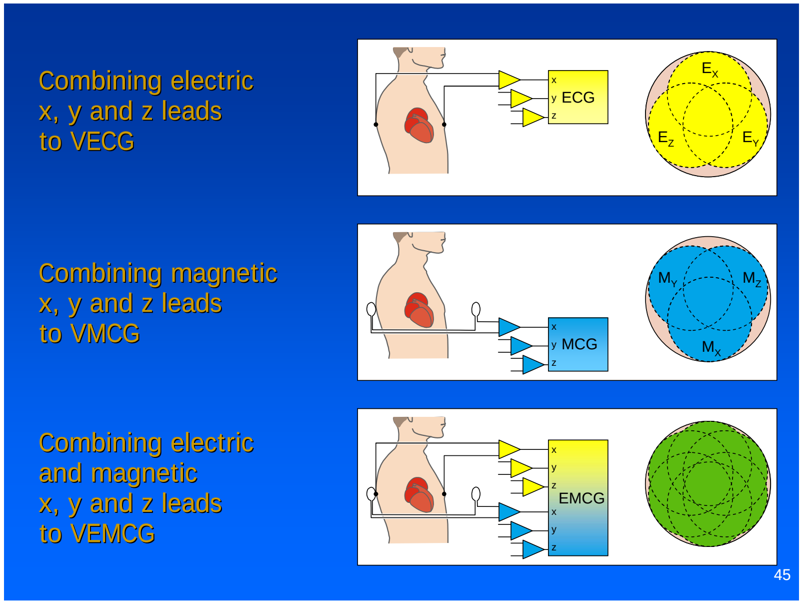
In this patient material, the electric and magnetic dipolar leads have similar diagnostic performance.

Increasing the number of electric and/or magnetic dipolar leads in the system increases the diagnostic performance.

Different leads of ECG and MCG have different diagnostic performance in different diseases.



Explanation of the improvement of the diagnostic performance by combining ECG and MCG to EMCG



Combining electric x, y and z leads to VECG

Combining magnetic x, y and z leads to VMCG

Combining electric and magnetic x, y and z leads to VEMCG

Conclusion

The issue: Which method has better diagnostic performance, ECG or MCG, is similar as: Which of the three component leads of ECG: X, Y or Z is best?

The 3+3 dipolar electric and magnetic leads all belong to the same 6-dimensional family of dipolar electromagnetic leads.

The Final Conclusion

Because MCG can be recorded in an unshielded environment, the instrumentation is cheap, combining ECG and MCG to EMCG significantly increases the diagnostic performance, MCG will have clinical value.