General Solution for the Clinical Application of Magnetocardiography

Jaakko Malmivuo, Juha Nousiainen
Ragnar Granit Institute
Tampere University of Technology
O. Sakari Oja, Arto Uusitalo
Tampere University Hospital
Tampere, Finland

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
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:

\[ \mathbf{J}_i = \mathbf{J}_i^F + \mathbf{J}_i^V \]

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

\[ \mathbf{J}_F = -\nabla \times \mathbf{E}_F \quad \mathbf{E}_F = \frac{1}{\mu_0} \int_0^\infty \mathbf{E}_T \cdot \nabla \, d\nu \\
\mathbf{J}_V = \nabla \times \mathbf{H}_V \quad \mathbf{H}_V = \frac{1}{\mu_0} \int_0^\infty \mathbf{H}_T \cdot \nabla \, d\nu \]

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.

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. 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.
PART III

CLINICAL STUDY

Patient material in the clinical study

Old inferior myocardial infarction (IMI) 90
73 male and 17 female, 59 +/- 19 years

Old anteroseptal myocardial infarction (AMI) 71
59 male and 12 female, 59 +/- 5 years

Normal healthy persons 152
85 male and 67 female, 54 +/- 11 years

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:
- **qmax t**

(Altogether over 130 parameters)

Results (A)

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

<table>
<thead>
<tr>
<th>ECG Param</th>
<th>Corr%</th>
<th>MCG Param</th>
<th>Corr%</th>
<th>EMCG Param</th>
<th>Corr%</th>
<th>p</th>
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<tbody>
<tr>
<td>Ez t80</td>
<td>80.2</td>
<td>Mz t80</td>
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<td>Ez t80</td>
<td>80.2</td>
<td>0.019</td>
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<td>Ez q15</td>
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<td>My q10</td>
<td>83.9</td>
<td>Ez q15</td>
<td>86.8</td>
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<tr>
<td>Ey q15</td>
<td>88.8</td>
<td>Mx q85</td>
<td>86.8</td>
<td>My q5</td>
<td>92.1</td>
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</tr>
<tr>
<td>Ey q50</td>
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<td>My q35</td>
<td>87.6</td>
<td>Mx q95</td>
<td>92.6</td>
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<tr>
<td>Ez qmin</td>
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<td>Ex q5</td>
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<tr>
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<td>Mz q5</td>
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<td>Mz t90</td>
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<tr>
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<td>Mz qmax t</td>
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<td>Ez q55</td>
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<tr>
<td>Ex q10</td>
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<td>My qmint</td>
<td>91.7</td>
<td>Ex q10</td>
<td>95.5</td>
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</table>
Correct classification N/IMI
152 normals / 90 IMI

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.
Comparison of leads' correct classification

<table>
<thead>
<tr>
<th></th>
<th>N/IMI</th>
<th></th>
<th>V/VECG</th>
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<th>N/AMI</th>
<th>V/EMCG</th>
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<td>98.0</td>
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<tr>
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<td>83.1</td>
<td>80.7</td>
<td>80.0</td>
<td>80.7</td>
</tr>
</tbody>
</table>

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.
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.