A Web-based Visualization Tool for Transforming the 12-lead ECG into a Body Surface Potential Map

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Abstract

The standard 12-lead ECG is often criticized for its lack of right sided and posterior leads. In contrast, the Body Surface Potential Map (BSPM) can employ over 200 leads to capture information from the entire surface of the torso. However, recording a large number of leads in routine clinical practice is impractical. This reality has led to the development of reduced lead sets, where a small number of leads are recorded and a mathematical transformation is used to derive the additional leads. In this study, we have developed a web based ECG viewer for transforming the 12-lead ECG into a BSPM. The resulting BSPM can then be explored using elaborate BSPM tools. This system was tested by transforming 20 12-lead aECG files into 192 lead BSPMs (Lux format). This was performed using transformation coefficients developed from an existing set of 192 lead BSPMs. The average transformation time on a PC (3GHz CPU, 3GB RAM) was 1.35 seconds. This tool presents more information than would be available with the 12-lead ECG. It has the potential to outperform current methods used to display ST elevation (24-lead view) and could therefore improve the recognition and diagnosis of myocardial ischemia.

1. Introduction

The 12-lead ECG is the most commonly used technique for assessing cardiac function. With just six precordial leads and six limb leads, it is often criticized for its lack of sampling from the right side of the chest and the posterior plane of the torso [1]. In contrast, the Body Surface Potential Map (BSPM) employs a large number of electrodes (32-213) placed around the entire surface of the torso and therefore captures a more complete picture of cardiac activity [2]. As a result, the BSPM has been shown to be more sensitive in detecting cardiac pathologies when compared to the standard 12-lead ECG [3]. Unfortunately, applying, and recording from, a large number of electrodes in a routine clinical scenario can be practically challenging [4]. This reality has lead to the research and development of reduced lead sets, where a small number of leads are recorded and a mathematical transformation is used to derive additional leads [5]. An example of this is the Lux-32 BSPM where 32 leads are recorded and a set of transformation coefficients is used to calculate the remaining 160 leads to yield a complete Lux-192 BSPM [6]. A shortcoming being that the 160 estimated leads are an approximation and in some cases differ from leads that would have been recorded. Nevertheless, the transformation provides the clinician with additional information that could be used to assist with a diagnosis. In this study, we have developed a web based ECG viewer that provides a platform to transform the 12-lead ECG into a BSPM [7]. In a previous study the 12-lead ECG was shown to estimate the Lux-192 BSPM with a correlation coefficient of 0.91 [8].

2. Methodology

This viewer was developed using a vector graphics technology (Adobe Flash) [9]. Unlike raster images, vector graphics can be scaled to different levels of detail without experiencing degradation and pixilation. In this regard, ECG scalar traces can be enlarged to a more detailed view allowing clinicians to accurately measure amplitudes and intervals. An enlarged view of the ECG also assists the clinician's in observing subtle features such as slurs and biphasic waves. The ECG viewer has also been designed to run inside the web browser. This allows the clinician to visualize the 12-lead ECG and the BSPM independent of geographical location and without the need to install and maintain software. A screenshot of this web based ECG viewer can be seen in Figure 1.
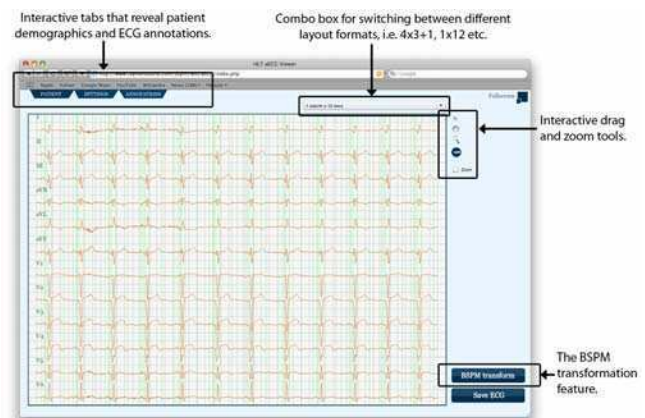

Figure 1: Web based 12-lead ECG viewer [7].

This ECG viewer can load and visualize a 12-lead ECG that has been formatted using the Annotated ECG (aECG) specification. The aECG format is an interoperable storage format based on the eXtensible Markup Language (XML) for storing the 12-lead ECG [10]. It was developed by Health Level Seven (HL7) to improve the administration tasks of the US Food and Drug Administration (FDA).

The viewer exhibits various tools and features that where developed in this study. Standard features include drag and zoom functionality and interactive calipers for measuring intervals and amplitudes. The user can also interactively add and refine beat markers by dragging and dropping vertical lines using the computer mouse. Visualization features include the ability to switch between various layout formats, i.e. 4 columns by 3 rows and 1 rhythm strip (4x3+1), 1 column by 12 rows (1x12) and a superimposition of all the leads. What may be viewed as the most novel feature of the system is the ability to transform the 12-lead ECG into a BSPM. This process can be described in seven steps as illustrated in Figure 2.
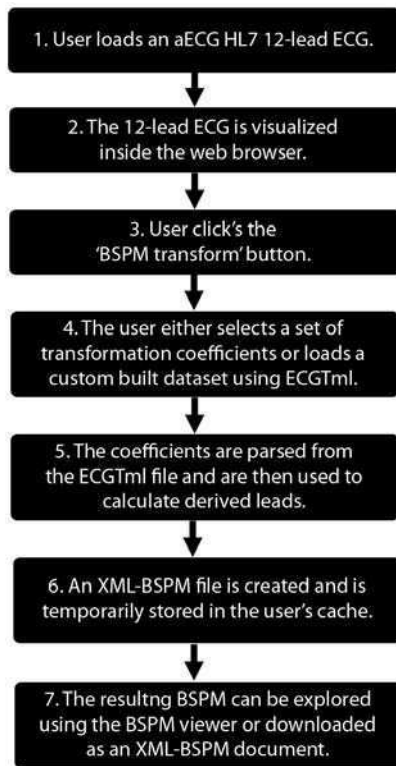

Figure 2: The seven steps to transforming a 12-lead ECG into a BSPM.

The transformation process is based around a structured mediator that stores and defines the transformation coefficients. Once the 'BSPM transform' button has been clicked, the user has the option to load a custom set of coefficients or to select one of the pre-stored datasets. The user can load a custom set of coefficients using a structured format that has been developed in this study. This format was developed using XML and has been named the Electrocardiogram Transform Markup Language (ECGTml). The use of the ECGTml format can be viewed in steps four and five of Figure 2. ECGTml has a number of benefits. For example, it allows researchers and systems to share transformation coefficients in a standard and open fashion. The schema for this format can be viewed in Figure 3.
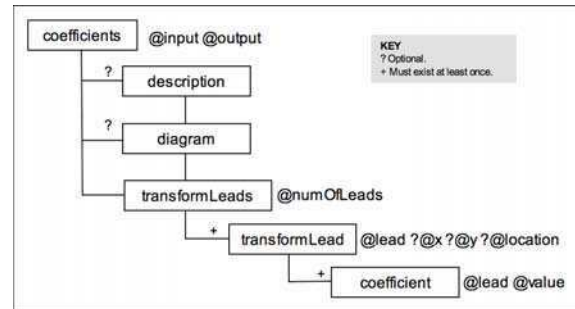

Figure 3: XML schema for ECGTml.

The root element **coefficients** has two required attributes called **input** and **output**. The **input** attribute specifies which dataset the stored coefficients are to be used with, i.e. '12-lead ECG'. In a similar way, the **output** attribute specifies the name of the resulting dataset after the coefficients have been applied to the input dataset, i.e. 'Lux-192 BSPM'. These attributes allow for the storage of any lead set transformation other than the 12-lead ECG to the Lux-192 BSPM as described in this paper. The **root** element has one required sub element (**transformLeads**) and two optional elements (**description, diagram**). The **description** element should be used to encapsulate a comprehensive textual description of the purpose and use of the transformation coefficients. The **diagram** element stores a 2D representation of a torso using Scalable Vector Graphics (SVG). The **transformLeads** element has one required attribute called **numOfLeads**. This attribute stores an integer and is used to represent the number of derived leads, also known as target leads. The **transformLeads** element has one required sub element called **transformLead**, which can appear multiple times. Moreover, the **transformLead** element has one required attribute (**lead**) and three optional attributes (**x**, **y**, **location**). The **lead** attribute is used to store the name of the derived lead. The **x** and **y** attributes are coordinates which are used with reference to the SVG torso schematic stored inside the **diagram** element. This allows for a 2D coordinate system to be used to locate the

derived leads. The *location* attribute is used to store the generic anatomical location of the derived lead, i.e. 'RL' (Right Lateral). The *transformLead* element has one required sub element called *coefficient*, which can appear multiple times. The *coefficient* element has two required attributes called *lead* and *value*. The *value* attribute stores the actual coefficient and the *lead* attribute specifies which lead to multiply the coefficient with. An excerpt of an ECGTml document can be viewed in Figure 4.

```
<transformLeads numOfLeads="192">

  <transformLead lead="1" x="28" y="112" location="RL">
  <coefficient lead="I" value="-0.333333"/>
  <coefficient lead="II" value="-0.333333"/>
  <coefficient lead="v1" value="1.19E-07"/>
  <coefficient lead="v2" value="-5.96E-07"/>
  <coefficient lead="v3" value="3.58E-07"/>
  <coefficient lead="v4" value="-4.29E-06"/>
  <coefficient lead="v5" value="0"/>
  <coefficient lead="v6" value="9.54E-07"/>
  </transformLead>
  <transformLead lead="2" x="28" y="136" location="RL">
  <coefficient lead="I" value="-0.311298"/>
  <coefficient lead="II" value="-0.310385"/>
  <coefficient lead="v1" value="0.06785884"/>
  <coefficient lead="v2" value="-0.01597738"/>
  <coefficient lead="v3" value="-0.006460547"/>
  <coefficient lead="v4" value="0.007402897"/>
  <coefficient lead="v5" value="-0.007392406"/>
  <coefficient lead="v6" value="0.000300407"/>
  </transformLead>
  <transformLead lead="3" x="28" y="160" location="RL">
  <coefficient lead="I" value="-0.351312"/>
  <coefficient lead="II" value="-0.271002"/>
  <coefficient lead="v1" value="0.120117"/>
  <coefficient lead="v2" value="-0.05000913"/>
  <coefficient lead="v3" value="0.02852833"/>
  <coefficient lead="v4" value="0.002281666"/>
  <coefficient lead="v5" value="-0.006233692"/>
  <coefficient lead="v6" value="0.01531267"/>
  </transformLead>
```

Figure 4: An excerpt of an ECGTml document.

Once a set of transformation coefficients has been selected, the ECGTml file is parsed and the coefficients are used to calculate the derived (target) leads in the BSPM. Each sample value of the derived lead is calculated using equation 1.

$$\text{DerivedLead}_{(t)} = \sum_{i=1}^{n} \text{Lead}_{(i,t)} \cdot \text{Coefficient}_{(i)}$$

(1)

where $\text{DerivedLead}_{(t)}$ represents one sample value of the derived lead at time t and n represents the number of basis leads and coefficients. In this scenario n being the upper limit would be equal to the number eight as there are eight basis leads (I, II, V1, V2, V3, V4, V5, V6). $\text{Lead}_{(i,t)}$ represents a sample value of the ith lead at time t and $\text{Coefficient}_{(i)}$ represents the ith coefficient. For example, the highlighted BSPM lead 2 in Figure 4 would be derived using equation 2.

$$\begin{aligned}
\text{DerivedLead2} &= (\text{LeadI} * -0.311298) + (\text{LeadII} * -0.310385) + \\
&(\text{Leadv1} * 0.06785884) + (\text{Leadv2} * -0.01597738) + (\text{Leadv3} * -0.006460547) + \\
&(\text{Leadv4} * 0.007402897) + (\text{Leadv5} * -0.007392406) + (\text{Leadv6} * 0.000300407)
\end{aligned}$$

(2)

Once all of the leads have been derived, the BSPM is automatically converted into the XML-BSPM format and stored in the user's cache. At this stage, the user can either save the BSPM as an XML-BSPM document or visualize and explore the data using elaborate BSPM tools.

The BSPM visualization feature is available online as a separate tool [7] and can load and visualize both single beats and continuous BSPMs. A BSPM can only be loaded if it has been formatted using the open source XML-BSPM format [11]. The viewer loads the torso that is stored in the header of the XML-BSPM file and displays it in the browser. The first beat of each BSPM lead is drawn over its associated electrode location on the torso. The user can intuitively select one of these beats using the computer mouse. The magnifying glass acts as a visual cue to indicate the currently selected lead. The entire selected lead is then visualized inside the graph view area. In this area, the user can drag a camera like object whilst rendering the corresponding area of interest on the torso for all the leads in real time. Finally, the user can visualize and explore the BSPM using advanced tools such as the interactive isopotential and the isointegral tools. A screenshot of the interactive isopotential tool can be viewed in Figure 5. The user drags the red needle in the graph view area and the voltage values of that instant in time are displayed on the torso using a red to blue color scheme. The viewer also consists of a comments feature where multiple experts can communicate and contribute to a collaborative diagnosis. Finally, the user can convert the BSPM to an SVG image where they can print and share static BSPM images.

Figure 5: A screenshot of the interactive isopotential tool.

3.   Results

The transformation feature was tested by transforming 20 12-lead aECG files into 192 lead BSPMs (Lux format). This was performed using transformation coefficients developed using statistical analysis from an existing set of 192 lead BSPMs. The transformation coefficients where optimized for the ST segment. The average time for transforming the 12-lead ECG into the Lux-192 BSPM on a PC (3GHz CPU, 3GB RAM) and in a web browser was 1.35 seconds. This included the time to parse the coefficients from the ECGTml file, perform the actual transformation and to generate the XML-BSPM file. One disadvantage to this technique is that ten seconds of data of 192 leads stored using the XML-BSPM format can exceed three megabytes. A Lux-192 BSPM derived from one of the aECG 12-lead ECGs can be viewed in Figure 6.

Figure 6: A Lux-192 BSPM derived from a 12-lead ECG.

4.   Conclusion

We have developed an accessible coherent framework where researchers and clinicians alike can transform the 12-lead ECG into a BSPM. The resulting BSPM presents more information than would be available with just the 12-lead ECG. As a result, this feature has the potential to outperform current methods used to better represent ST elevation such as the 24-lead view [12] and could therefore improve the recognition and diagnosis of myocardial ischemia. In a future study, we will investigate the clinical advantage of assessing STEMI in a transformed BSPM and compare it with the STEMI assessment of just the 12-lead ECG.

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