

Ontology for Heart Rate Turbulence Domain Applying the Conceptual Model of SNOMED-CT

Cristina Soguero-Ruiz¹, Luis Lechuga², Inmaculada Mora-Jiménez¹, Javier Ramos-López¹
Óscar Barquero-Pérez¹, Arcadi García-Alberola³, José L Rojo-Álvarez

¹Department of Signal Theory and Communications, University Rey Juan Carlos, Madrid, Spain

²Hospital Universitario de Fuenlabrada, Fuenlabrada, Spain

³Unit of Arrhythmias, Hospital Universitario Virgen de la Arrixaca, Murcia, Spain

Abstract

Although Cardiovascular Risk Stratification (CVRS) based on indices derived from electrocardiogram has been deeply studied, many current findings are not being widely used in the clinical practice. We proposed a framework for CVRS on the Heart Rate Turbulence (HRT) domain, because of its concise guidelines and index calculations. An ontology was built according to a set of rules defining clinical, anatomical, and electrophysiological features. Unlike other biomedical ontologies, ours was based on SNOMED-CT, what guaranteed the standardization and interoperability with emerging Electronic Health Records. The HRT ontology consisted of 310 concepts (289 taken from SNOMED-CT, and 19 as a local extension to model the main concepts of the HRT domain). As a case application, a database of 24-h Holter recordings from 27 patients with Congestive Heart Failure was analyzed, in which basic HRT indices from conventional and emergent signal processing procedures were compared, providing a consistence of 86% and 77% between averaged procedure for HRT index calculations and two processing procedures.

1. Introduction

Cardiovascular Risk Stratification (CVRS) based on indices derived from electrocardiogram (ECG) has received wide attention in the clinical, scientific and technical literature [1], however, many current findings in this area are not being currently used in the clinical practice. Maybe not only the required scientific evidence for some findings to be actually established into routine cardiac medicine is necessary, but also a clear and standardized connection among the current scientific knowledge, its availability for the cardiologist, and the actual patient data bases, are necessary for the clinical routine use and refinement of these indices.

Recent developments in Semantic Web applications have made the ontologies a key tool for logical and consis-

tent reasoning and for domain description support. Technical ontology has been defined [2] as a *formal, explicit specification of shared conceptualization*. An ontology typically consists of a finite set of terms (classes of objects of the domain), relationships among such terms, properties of relationships, value restrictions, disjointness between terms, and specification of logical relationships between objects [3]. Biomedical domain ontologies have been mostly applied to date for semantically driven information integration, by using different biomedical terminologies, modeling, and reasoning about complex entities [4]. An ECG ontology was first proposed in [5], and it was subsequently extended for inference capabilities given by OWL DL and SWRL [6]. An ECG-based decision making system was proposed in [7] using an ontological model for the ECG and for the heart rate variability measurements. In [8], a framework was proposed for predicting types of arrhythmia from ECG signal in a body sensor network node. Previous work on ECG ontologies has aimed to give a principled approach to this knowledge domain, but still their standardization with current and emerging Electronic Health Recordings (EHR) is not warranted. However, the Systematized Nomenclature of Medicine - Clinical Terms (SNOMED-CT) is becoming the standard for semantic interoperability both in EHR and in Hospital Information Systems (HIS), and it is the most comprehensive, multilingual clinical healthcare terminology worldwide [9].

Accordingly, we addressed a standardized framework for CVRS based on ECG-derived indices, by making an ontology completely based on SNOMED-CT conceptual model, hence yielding advanced interoperability capabilities. Our first focus was the cardiac indices obtained from HRT, for which concise guidelines and clear procedures for parameter calculations can be found [1].

2. Background

Figure 1 shows a basic block diagram for the interoperability among the EHR, the inference information sys-

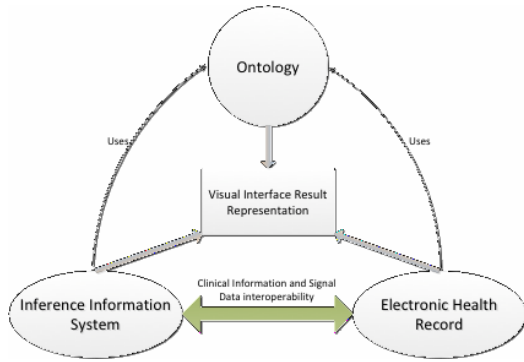


Figure 1. *Schema of the elements for interoperability.*

tem, the shared ontology, and the data presentation to the clinical user. The role of the underlying ontology consists of: (a) yielding a logical and actual structure to the relationships among the clinical concepts; (b) providing with a standardized information architecture; and (c) allowing the logical and conceptual inference to generate complete relationships among concepts from the current basic knowledge, and for detecting inconsistencies. A number of biomedical and cardiovascular ontologies have limited interoperability despite of their widespread use. In [10], a system was able to perform risk classification of patients using medical image analysis and semantically structured information of patient data, by means of MeSH thesaurus. Improved interoperability was achieved in [11] with an ontology for chronic patients built on the SNOMED-CT reference terminology.

SNOMED-CT Conceptual Model. But far from being just a terminology or thesaurus, the SNOMED-CT system is a multi-language linguistic tool. SNOMED-CT probably represents the most complete classification for clinical use, its main advantage being the reference to terminologies of most of different health professions, hence facilitating the communication within diversified health teams and in searching health information.

The concepts in SNOMED-CT are structured in 19 top-level hierarchies (axes). Although SNOMED-CT includes more than 311,000 concepts since 2011, this impressive number can be not enough for representing many clinical expert domains. Hence, local and national extensions can be created in SNOMED-CT, so that contents (such as subsets of concepts) may be delivered locally by a specific clinical expert group and can move to a national extension and to the international core. Most of current EHR and HIS are adopting SNOMED-CT as their standard for interoperability, and many authors agree that its conceptual model is in fact an ontology.

Basic Concepts on HRT. HRT is the phenomenon of short-term fluctuation in sinus cycle length over about 20 beats following a Ventricular Premature Complex

(VPC) [1]. HRT is usually assessed from 24-h ECG signals. From such recordings, a VPC tachogram is constructed by aligning and averaging the R-R interval sequences around isolated VPCs, according to the guidelines. HRT is quantified by two parameters: turbulence onset (TO) and turbulence slope (TS). TO reflects the amount of sinus acceleration following a VPC. TS reflects the rate of sinus decelerations that follows sinus acceleration. In this study, these parameters are calculated from the tachogram averaged from all VPC tachograms on a 24-h ECG record. TO is the shortening of the two sinus beat RR interval average after the compensatory pause, expressed as a percentage of the two sinus beat RR interval average preceding the VPC.

3. HRT ontology for CVRS

HRT Ontology. The HRT ontology defined in this study has been represented in the Ontology Web Language (OWL) [12]. According to the general methodology proposed in [3], the process of constructing the HRT ontology consisted of the following set of steps.

(1) *Determine the domain.* The domain was HRT.

(2) *Enumerate the relevant concepts* of the constructed ontology, to get a well-defined domain. First, a set of clinical, anatomical, electrophysiological, and pharmacological features, were identified in order to represent the HRT domain. This first set was mostly based on SNOMED-CT concepts (among more than 311,000 available concepts), however, a subset of concepts which were highly relevant for defining HRT could not be taken from SNOMED-CT. Accordingly, up to 19 over 300 concepts defined in our ontology had to be extended using the *Fuenlabrada Hospital* namespace. In Figure 2, an schema of the ontology is shown, where extended concepts are in a rectangle.

(3) *Define the concepts* and their hierarchy (down-top development process). After the concepts were enumerated, a hierarchy development was necessary. HRT concepts mapped directly in SNOMED-CT terminology were just included by following the SNOMED-CT hierarchy. For the remaining concepts, we first decided in which of 19 SNOMED-CT axes they were included, i.e., in a *body structure*, in a *clinical finding*, or in an *observable entity*. After, we assigned the concept to its parent class.

(4) *Define the properties of the concepts.* Data Properties define features associated with one concept, whereas Object Properties define a relationship between two concepts. SNOMED-CT defines some properties, but new properties can be generated for the most conceptual aspects of an specific domain, as shown in Table 1 for HRT.

(5) *Define the non-hierarchical relationships* (Table 1).

(6) *Use inference mechanism*, in our case, to get a risk stratification criterion in patients with cardiac disease, which is described next.

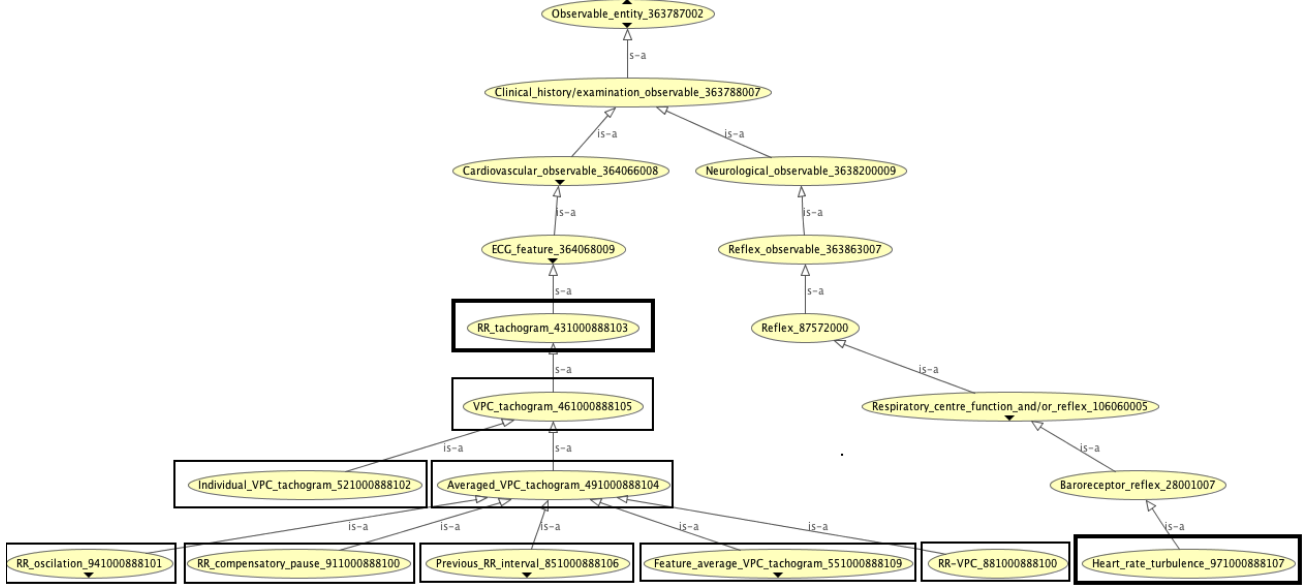


Figure 2. HRT ontology. Highlighted rectangles represent local extended concepts.

Table 1. Some SNOMED-CT properties in HRT ontology. Local extended concepts are in italic.

Individual	Property	Individual
Normal heart rate_78663003	Interprets_363714003	Cardiac conducting system structure_24964005
Disorder of cardiac function_105981003	Finding site_363698007	Heart structure_80891009
Disorder of cardiac ventricle_415991003	Finding site_363698007	Cardiac ventricular structure_21814001
24 hour ECG_252417001	Method_260686004	Monitoring-action_360152008
24 hour ECG_252417001	Using device_424226004	Electrocardiographic monitor and recorder_74108008
<i>HRT_971000888107</i>	<i>is a measurement of_161000888104</i>	Baroreceptor_reflex_28001007
<i>TO_641000888108</i>	<i>is influenced by_191000888105</i>	Left_ventricular_ejection_fraction_250908004
<i>TS_731000888107</i>	<i>is influenced by_191000888105</i>	Left_ventricular_ejection_fraction_250908004
<i>TS_731000888107</i>	<i>is calculated in_101000888100</i>	<i>Averaged tachogram_491000888104</i>

Table 2. Examples of Proposed SWRL Rules.

<i>Category 0:</i>
$TO(p?) \wedge swrlb : greaterThan(?p, -2.7)$
$TO(p?) \wedge swrlb : greaterThan(?p, -2.7)$
$\wedge TO(p?) \wedge swrlb : lessThan(?p, -2.3)$
$\wedge TS(p?) \wedge swrlb : greaterThan(?p, 11.0)$
$\wedge TS(p?) \wedge swrlb : lessThan(?p, 19.0) \Rightarrow$
$swrlb : equal(Category(?p, 0))$
<i>Category 1:</i>
$TO(p?) \wedge swrlb : greaterThan(?p, -2.7)$
$\wedge TO(p?) \wedge swrlb : lessThan(?p, -2.3)$
$\wedge TS(p?) \wedge swrlb : lessThan(?p, 11.0) \Rightarrow$
$swrlb : equal(Category(?p, 1))$
<i>Category 2:</i>
$TO(p?) \wedge swrlb : lessThan(?p, -2.7)$
$\wedge TS(p?) \wedge swrlb : lessThan(?p, 11) \Rightarrow$
$swrlb : equal(Category(?p, 2))$

Inference on CVRS with HRT. The HRT evaluation has been found useful for risk stratification after acute myocardial infarction and monitoring of disease progression in heart failure. HRT values are usually classified

into: *Category 0*, when both TO and TS are normal; *Category 1*, when either TO or TS is abnormal; and *Category 2*, when both TO and TS are abnormal. Up to four studies have reported that mean TO ranged from -2.7% to -2.3% and mean TS ranged from 11.0 to 19.2 ms/RR in healthy subjects [1]. By considering these limits, we created the instances of classes TO and TS. OWL can deal with classification problems using Description Logic, but many applications for risk stratification (as it was our case) need augmented OWL with Semantic Web Rule Language (SWRL) [13] (see Table 2 for several examples).

4. Results on a patient data base study

Some authors claimed that the averaging process in the VPC-tachogram calculation could be masking physiological effects, in addition to the expected denoising [14]. Accordingly, several advanced signal processing procedures have been proposed for denoising individual (rather than averaged) VPC-tachograms, including Support Vector Ma-

Table 3. Cardiovascular risk stratification results.

Patient Number	Avg. tachogram			Individual tachogram			Ind. tachogram SVM			Total no. Ind. tachograms
	C0	C1	C2	C0(%)	C1(%)	C2(%)	C0(%)	C1(%)	C2(%)	
1	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	37
2	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
3	-	-	x	0.0	40.0	60.0	0.0	10.0	90.0	40
4	-	-	x	0.0	17.4	82.6	0.0	16.3	83.7	86
5	-	-	x	0.0	0.0	100.0	0.0	100.0	0.0	1
6	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
7	-	x	-	0.0	11.0	88.9	0.0	22.2	77.8	9
8	-	x	-	0.0	100.0	0.0	0.0	100.0	0.0	1
9	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
10	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	2
11	-	-	x	0.0	13.0	87.0	0.0	13.0	87.0	23
12	-	-	x	0.0	0.0	100.0	0.0	100.0	0.0	1
13	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
14	-	-	x	0.0	50.0	50.0	0.0	0.0	100.0	2
15	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
16	-	-	x	1.8	35.7	62.5	3.6	28.6	67.9	56
17	-	x	-	0.0	100.0	0.0	0.0	0.0	100.0	1
18	-	x	-	0.0	100.0	0.0	0.0	0.0	100.0	1
19	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
20	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	2
21	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	4
22	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
23	-	-	x	33.3	33.3	33.3	0.0	66.7	33.3	3
24	-	x	-	0.0	100.0	0.0	0.0	0.0	100.0	1
25	-	-	x	0.0	0.0	100.0	0.0	0.0	100.0	1
26	-	-	x	0.0	50.0	50.0	0.0	0.0	100.0	2
27	-	-	x	1.4	11.6	87.0	0.0	2.9	97.1	69

chine (SVM) nonlinear regression. These methods have been proven to be effective for denoising from a technical and physiological point of view, however, their impact on the risk stratification capabilities has not been benchmarked with the averaged tachogram signal processing.

As a case study, we used our HRT ontology to compare the output of the HIS both for the conventional and emergent signal processing methods for calculating HRT indices. We used a database of 24h Holter recordings from Congestive Heart Failure (CHF) patients, collected in the Arrhythmia Unit of Hospital Universitario Virgen de la Arrixaca (Spain). RR-tachograms were analyzed to identify reliable isolate VPC tachograms, according to the criteria proposed in [1]. Up to 27 of 60 recordings were useful for this analysis (14 recordings with only one isolated VPC tachogram). Table 3 shows that conventional averaged calculated indices yielded 0, 5 and 22 patients on Category 0, 1, and 2, respectively, whereas the single-VPC procedure based on SVM yielded 0, 4, and 23 patients, hence showing that there will be differences in the inference depending on the underlying signal processing calculation algorithm. For comparison purposes, the patient classification according to individual VPC without averaging and without denoising, was 0, 4, and 20, where three patients could not be classified by majority.

5. Conclusion

An ontology for CVRS has been proposed on the HRT domain. Interoperability with EHR and HIS has been reinforced by using the SNOMED-CT conceptual model, and extension of the concepts and rules has been achieved. A simple application of risk categorization has been used for straightforward comparison of conventional and emergent criteria, and its impact in the classification of a patient data

base. Oncoming work is devoted to extend the methodology to other relevant ECG-derived indices for CVRS, and to include new properties (for instance, effect of drugs, effect of age, and others).

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