

Fuzzy Chest Pain Assessment for Unstable Angina based on Braunwald Symptomatic and Obesity Clinical Conditions

Thiago Orsi, Ernesto Araujo, Ricardo Simões

Abstract—A fuzzy medical diagnostic decision system for helping support to evaluate patients with anginal chest pain and obesity clinical condition is proposed in this paper. Such an approach is based on the Braunwald symptomatic classification, the fuzzy set theory and fuzzy logic, and a risk obesity factor determined by a simplified Fuzzy Body Mass Index (FBMI). The fuzzy Braunwald symptomatic classification intertwined with the fuzzy obesity risk factor overwhelm the current rapid access chest pain clinic approaches that do not discriminate the obesity comorbidity or takes into account the subjectiveness, uncertainty, imprecision, and vagueness concerning such a clinical health condition. The resulting fuzzy obesity-based Braunwald symptomatic chest pain assessment is an alternative to support healthcare professionals in primary health care for patients with anginal chest pain worsened by the obesity clinical condition.

I. INTRODUCTION

CARDIOVASCULAR diseases compose a group of health conditions that affect the circulatory system, representing 33% of all the deaths in the world [1], [2]. Ischemic diseases, such as angina and acute myocardial infarction (AMI), assume an important role, being the latter the main cause of deaths. Unstable angina, in turn, is characterized by the worsening of the myocardial ischemic disease but without myocardial necrosis. It can also be described as a pre-anginal AMI. A process of ischemia leads to accumulation of metabolites in the myocardium, causing the sensation of discomfort or chest pain. The most characteristic symptom encompassing the ischemic diseases is, thus, the anginal chest pain.

Chest pain can also have a non-coronary symptom, for instance, diseases of the intestinal tract, pneumothorax, chest injury and pulmonary embolism, only to mention few. Associated to the intrinsic subjectiveness, uncertainty, and imprecision present in the cardiovascular analysis, it makes such a diagnosis a hard task chiefly for healthcare professionals in primary health care. Current research demonstrates that about 75% of the patients who have these pains are released from the hospital due to inconclusive diagnoses of coronary heart diseases. Despite the existence of sophisticated devices

and tests for accurate and efficient evaluations of patients with chest pain, about 3% of these released patients suffer of silent AMI [3].

A rapid triage of patients with symptoms of chest pain is, thus, necessary to obtain a lower mortality rate by achieving an early healthcare evaluation and a suitable interventional assistance and/or medication [4], [5]. Computational models are feasible sources to support decision making during diagnoses by identifying and treating actual health problems of patients. An alternative to improve computer models in health care is to employ the artificial intelligence technique. It allows reproducing the complexity of human thought, mainly in helping healthcare professionals in dealing with inherent imprecise and uncertain information in the diagnosis, in general, and of coronary diseases, in particular.

Medical diagnostic decision support systems (MDDS) came about the 50s and so far several other approaches have been widely available for the medical society. In 2006, a chest pain (CP) MDDS was designed by combining ontology and rules allowing health professionals to help deciding which action to follow [6]. Another CP-MDDS was proposed in 2011 by using the probabilistic reasoning for cardiac chest pain assessment [7]. A fuzzy system was conceived in 2010 for the definition of a rapid diagnosis of coronary heart disease risk by employing as input variables the clinical history, physical examination, and ECG report generating a suggestive diagnosis of the patient's condition [8], [9]. A fuzzy system came about in 2011 to deal with a rapid diagnosis of unstable angina, derived from the Braunwald classification [10].

Fuzzy systems advantage of enabling to mimic the human expertise, i.e., the human reasoning by employing IF-THEN rules, thus, allowing to infer the human decision making [11]. Such a characteristic is more evident in the field of medicine and health care [12], [13], [14]. The proposed approach is first based on the symptomatic Braunwald classification, which analyze the severity of the symptoms concerning the unstable angina. Such a risk classification does not discriminate comorbid factors that worsen the health clinical condition or takes into account the inherent subjectiveness, imprecision and uncertainty at the diagnosis. This paper extends previous work in which a fuzzy symptomatic chest pain assessment for unstable angina is based on Braunwald classification [10]. The proposed fuzzy system not only is able to represent the approximate reasoning and, thus, to handle imperfect information but embody obesity clinical conditions, as well, which plays an important role in determining the severity of unstable angina.

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The obesity comorbidity has several anthropometric indices for measurement. They are subject to variations such as imperfect and subjective information and analysis according to the experience of healthcare professionals or the mechanism of evaluation. The proposed approach advantages of being simultaneously employed with the simplified Fuzzy Body Mass Index (FBMI) [15], [16] employed to compose a n -dimensional fuzzy input-output mapping for being used in the chest pain analysis, assessment, classification, and treatment for unstable angina.

II. FUZZY OBESITY CHEST-PAIN ASSESSMENT AND CLASSIFICATION FOR UNSTABLE ANGINA

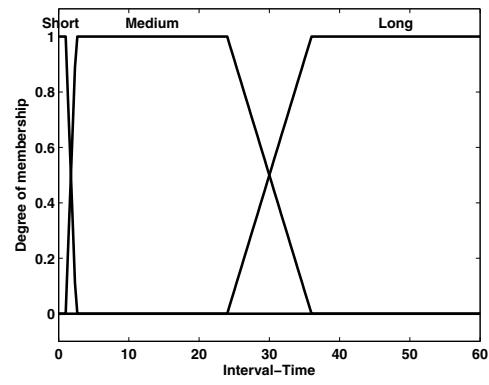
The fuzzy obesity chest-pain assessment and classification for unstable angina focus on the severity of symptoms, according to the Braunwald classification, intertwined and improved by fuzzy anthropometric parameters concerning weighting obesity of the patients.

A. Braunwald Symptomatic Chest Pain Classification

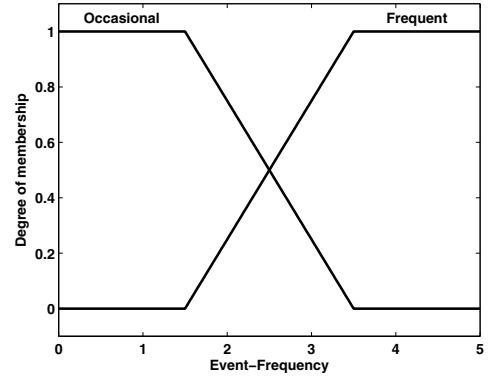
The Braunwald classification is one of the most employed approaches in clinical analysis of patients with chest pain for unstable angina. This criterion takes into account the severity of anginal symptoms, the clinical conditions of their occurrence, and intensity of the treatment. This classification is internationally recognized, reaching a high degree of acceptance. It advantages to stratify the risk of new and recent events, thus being chosen to serve as the basis for the designing the fuzzy obesity-based Braunwald symptomatic chest pain assessment.

Such a symptomatic criterion of risk analysis encompasses Class I, when angina manifests with less than two months, and occurs frequently or repeatedly 3 or more times a day, and accelerated with frequent changes initiated by effort, no pain at rest, *AR*; Class II, as subacute angina at rest, *SAR*, in which there are one or more events occurring at rest for 30 days and the last event occurrence higher than 48h; and Class III when there are acute angina at rest, *AAR*, by the presence of one or more events occurring at rest in the last 48h [17], [18], [19].

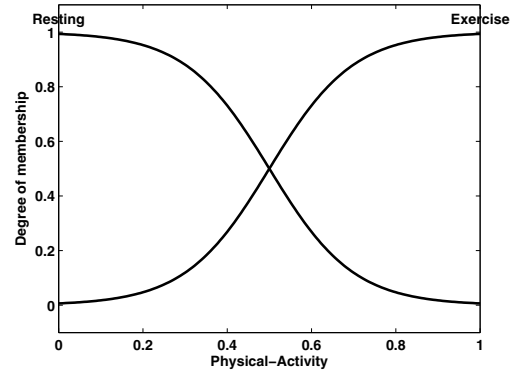
1) *Mathematically Modeling the Braunwald Classification*: The classical diagnosing anginal chest-pain input variables concerning the Braunwald symptomatic chest pain classification can be mathematically written as the *time interval*, $X_{time-interval}$, between the last two manifestations of chest pain, the *frequency of events*, $X_{frequency-events}$, and the level of chest pain *physical activity*, $X_{physical-activity}$, corresponding to the limiting factor for the anginal pain occurrence. In this sense, the categories of time interval correspond to *short*, $x_{time-interval} \leq 2$ days and *medium*, $2 < x_{time-interval} \leq 30$ days. Although not explicit in the Braunwald classification, the *long* period is greater than 30 days, $30 < x_{time-interval} < 60$ days. The frequency of events is assigned as *occasional* referring to less than 3 events a day, $1 \leq x_{frequency-event} < 3$, or *frequent* when there are three or more events, $3 \leq x_{frequency-event} \leq 5$. The lower limit is unitary since a patient that presents null events is



(a) Input Variable, $X_{Interval-time}$: Time interval.



(b) Input Variable, $X_{Event-frequency}$: Frequency of event.



(c) Input Variable, $X_{physical-activity}$: Physical activity.

Fig. 1. Input membership functions partition the respective universes of discourse, X_1 , X_2 , and X_3 .

healthy. The Braunwald risk classification does not determine the cutoff for partition the universe of discourse concerning the physical activity nor a range in which the level of activity (or resting) can be scaled up. It seems natural, however, to think about a balanced distribution between these classes. Due to that, the physical activity input variable is assigned to range from 0 to 1 while the cutoff is 0.5. The derived two levels of physical activity embrace the *resting* class, $0 < x_{physical-activity} \leq 0.5$ and the *active* class, $0.5 < x_{physical-activity} \leq 1$.

B. Fuzzy Braunwald Symptomatic Chest Pain Assessment for Unstable Angina

The Braunwald classification highlights the differences in prognosis subgroup as the patients lie in. Nevertheless, it lacks flexibility in cutoffs, struggling the inclusion of certain patients in some subgroups. Due to that, such an approach is not able to represent the inherent subjectiveness and approximate reasoning present in health care and medicine. The Braunwald Symptomatic Chest Pain Classification was, then, modified by employing fuzzy set theory and fuzzy logic in [10], [20] when yielding the *fuzzy Braunwald-based symptomatic chest pain assessment for unstable angina* and the *fuzzy five-class Braunwald-modified symptomatic chest pain assessment for unstable angina*. These fuzzy systems are obtained by, first, using the same three-dimensional Cartesian input space, $X_{interval-time} \times X_{event-frequency} \times X_{physical-activity}$, of the Braunwald criterion mapped into an output universe of discourse, $Y_{severity}$, carried out by a fuzzy IF-THEN inference mechanism and, second, the fuzzification of the Braunwald input crisp sets into fuzzy sets (membership functions) that partition their respective universes of discourse, as depicted in Fig. 1.

C. Body Mass Index (BMI)

The Braunwald classification, however, disadvantages in not containing comorbidity factors, which would improve the anginal chest pain diagnostic. Obesity is one of the most important risk factor for coronary heart diseases being of great importance in the diagnosis and prognosis. Due to that, it should be included in the design of a medical decision system to support the diagnosis of patients with coronary heart disease.

The Body Mass Index (BMI) is characterized by its capacity of weight excess, as given by $IMC = P/H^2$, where the body weight, P , of the individual is given in Kilograms [Kg] and the square of the height, H , express in square meters, [m^2] [21]. It is considered the main criterion employed in epidemiological studies and is the most known approach for obesity treatment and classification. Adopted by the World

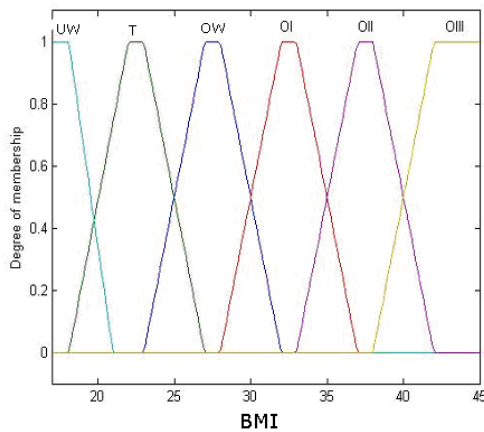


Fig. 2. Membership Functions for the Fuzzy Body Mass Index (BMI).

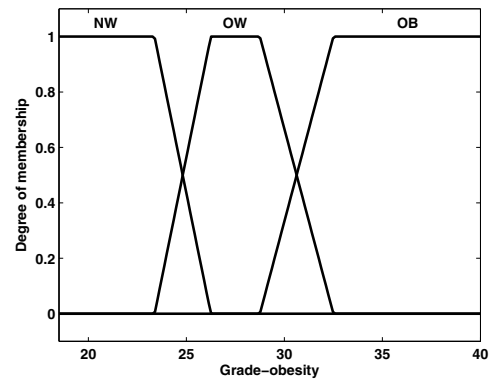


Fig. 3. Simplified Fuzzy Body Mass Index (FBMI).

Health Organization (WHO), the distinct classes of BMI for identification, evaluation and treatment of overweight and obesity in adults cover underweight (UW) when under than 18.4 kg/m^2 , thin (T) when ranges from 18.5 to 24.9 kg/m^2 , overweight (OW) from 25 to 29.9 kg/m^2 , obesity-grade I (OI) from 30.0 to 34.9 kg/m^2 , obesity-grade II (OII) from 35.0 to 39.9 kg/m^2 , and (morbid) obesity-grade III (OIII) when greater than 40 kg/m^2 .

D. Fuzzy Body Mass Index (FBMI)

The body mass index obesity classification is accomplished by using classic (Aristotelian) sets theory, in which the values belongs to a set, or not. The BMI was first modified and treated as fuzzy sets in [15] when composing the Miyahira-Araujo Fuzzy Obesity Index (MAFOI). One of the derivate results of achieving the MAFOI is the Fuzzy Body Mass Index (FBMI) that adapts the crisp classes adopted by the World Health Organization (WHO) to fuzzy sets [15]. In so doing, diverse values for FBMI classify individuals in different categories with more realistic degrees of compatibility when compared with those indexes for obesity evaluation with Boolean classification as usually utilized. According to the fuzzy body mass index, the fuzzification of the input crisp sets that partition the universe of discourse is given in Fig. 2.

As there is a relevance of obesity and modulation in categorizing the severity of chest pain, fuzzy subsets in grading obesity are grouped in this paper to obtain a simplified FBMI. Employed to achieve a fuzzy obesity chest-pain assessment for unstable angina, the subsets of obesity I, obesity II, and obesity III are grouped yielding a single *obesity* class. Further, the first two subsets of evaluation are aggregated in a *normal* class. In so doing, this paper employs the set of linguistic terms, $T_{weight} = \{\text{Normal (N), Overweight (OW), Obese (OB)}\}$, partitioning the (weight) fuzzy obesity input variable, as shown in Fig. 3.

E. Fuzzy Obesity Symptomatic Unstable-Angina Chest-Pain Model

According to the Braunwald classification for unstable angina and taking into account the levels of obesity, the

input linguistic variables are the physical activity, frequency of event, time interval, and a simplified fuzzy obesity measurement. The output linguistic variable covers very low, low, moderate, high, and very high symptomatic classes on the severity diagnosis. The proposed fuzzy obesity-based Braunwald-modified symptomatic chest pain assessment for unstable angina risk analysis and classification yields, thus, a four-dimensional Cartesian input space, $X_{interval-time} \times X_{event-frequency} \times X_{physical-activity} \times X_{weight}$, mapped into an output universe of discourse, $Y_{severity}$, by using a fuzzy IF-THEN inference mechanism. The input fuzzy sets given by $M_{interval-time}^{j_{interval-time}}$, $M_{event-frequency}^{j_{event-frequency}}$, $M_{physical-activity}^{j_{physical-activity}}$, and $M_{weight}^{j_{weight}}$ partition their respective universes of discourse X_i , for $i = 1, 2, 3, 4$, such that $j_{interval-time} = 1, 2, 3$, $j_{event-frequency} = 1, 2$, $j_{physical-activity} = 1, 2$, and $j_{weight} = 1, 2, 3$ yielding a set of 36 fuzzy regions. The output linguistic terms are given by $M_{severity}^{j_{severity}}$, such that $j_{severity} = 1, 2, 3$. The fuzzy sets employed in this proposed approach are the same as those previously designed in the fuzzy Braunwald-based symptomatic chest pain assessment for unstable angina and the fuzzy five-class Braunwald-modified symptomatic chest pain assessment for unstable angina [10], [20].

The set of linguistic terms, $T_{time-interval} = \{short, moderate, long\}$, partitioning the time-interval input variable corresponds to trapezoidal membership functions, distributed in $X_{interval-time} = [0, 60]$ (Fig. 1(a)). The frequency-event input variable is partitioned by the linguistic terms $T_{event-frequency} = \{occasional, frequent\}$ in two trapezoidal membership functions, distributed in $X_{event-frequency} = [0, 5]$, as depicted in Fig. 1(b). Two Gaussian classes partitioning the physical-activity input variable correspond to the linguistic terms $T_{physical-activity} = \{resting, exercise\}$ and their membership functions, distributed in $x_{physical-activity} = [0, 1]$, as illustrated in Fig. 1(c). Likewise, the severity of angina pain is the diagnostic output variable, $Y_{severity}$. Distinct from the original Braunwald classification which employs three stages for the anginal severity output linguistic variable, without loss of generality, here it is partitioned by five fuzzy homogenously distributed classes in $Y = [0, 1]$, as designed in the fuzzy five-class Braunwald-

modified symptomatic chest pain assessment for unstable angina [10]. The set of linguistic terms $T_{severity} = \{very-low, low, moderate, high, very-high\}$ and their associated trapezoidal membership functions are illustrated in Fig. 4.

The set of 3-2-2-3 linguistic terms within the four-dimensional input premise space given by $x = [x_1, x_2, x_3, x_4]^T$ yields a set of 36 valid Mamdani fuzzy obesity unstable-angina chest-pain system:

- R_1 : IF $\langle Time-Interval \text{ is Short} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Occasional} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Rest} \rangle$
 $\langle Obesity \text{ is Normal} \rangle$
 THEN $\langle Severity \text{ is High} \rangle$
- R_2 : IF $\langle Time-Interval \text{ is Short} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Occasional} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Exercise} \rangle$
 $\langle Obesity \text{ is Overweight} \rangle$
 THEN $\langle Severity \text{ is High} \rangle$
- R_3 : IF $\langle Time-Interval \text{ is Short} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Occasional} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Exercise} \rangle$
 $\langle Obesity \text{ is Obese} \rangle$
 THEN $\langle Severity \text{ is Very High} \rangle$
- ...
- R_{34} : IF $\langle Time-Interval \text{ is Long} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Frequent} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Exercise} \rangle$
 $\langle Obesity \text{ is Normal} \rangle$
 THEN $\langle Severity \text{ is Low} \rangle$
- R_{35} : IF $\langle Time-Interval \text{ is Long} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Frequent} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Exercise} \rangle$
 $\langle Obesity \text{ is Overweight} \rangle$
 THEN $\langle Severity \text{ is Moderate} \rangle$
- R_{36} : IF $\langle Time-Interval \text{ is Long} \rangle$ AND ...
 $\langle Frequency-Event \text{ is Frequent} \rangle$ AND ...
 $\langle Physical-Activity \text{ is Exercise} \rangle$
 $\langle Obesity \text{ is Obese} \rangle$
 THEN $\langle Severity \text{ is High} \rangle$.

(1)

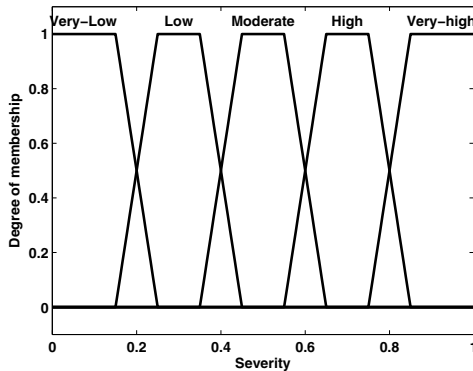


Fig. 4. Output Variable, $Y_{severity}$: Severity.

III. DISCUSSION AND ILLUSTRATIVE EXAMPLE

The resulting severity surfaces for the fuzzy obesity symptomatic chest pain assessment for unstable angina based on the Braunwald five-class modified classification and a simplified fuzzy body mass index are shown in Fig. 5. The smooth medical diagnostic decision surfaces represent the human thought obtained through the input-output variables as a result of the model of evaluation of patients with unstable angina chest pain worsened by the obesity comorbidity. These surfaces are obtained through the use of fuzzy theory to represent the subjectivity of the diagnostic classification of unstable angina and the fuzzy logic that mimics human reasoning.

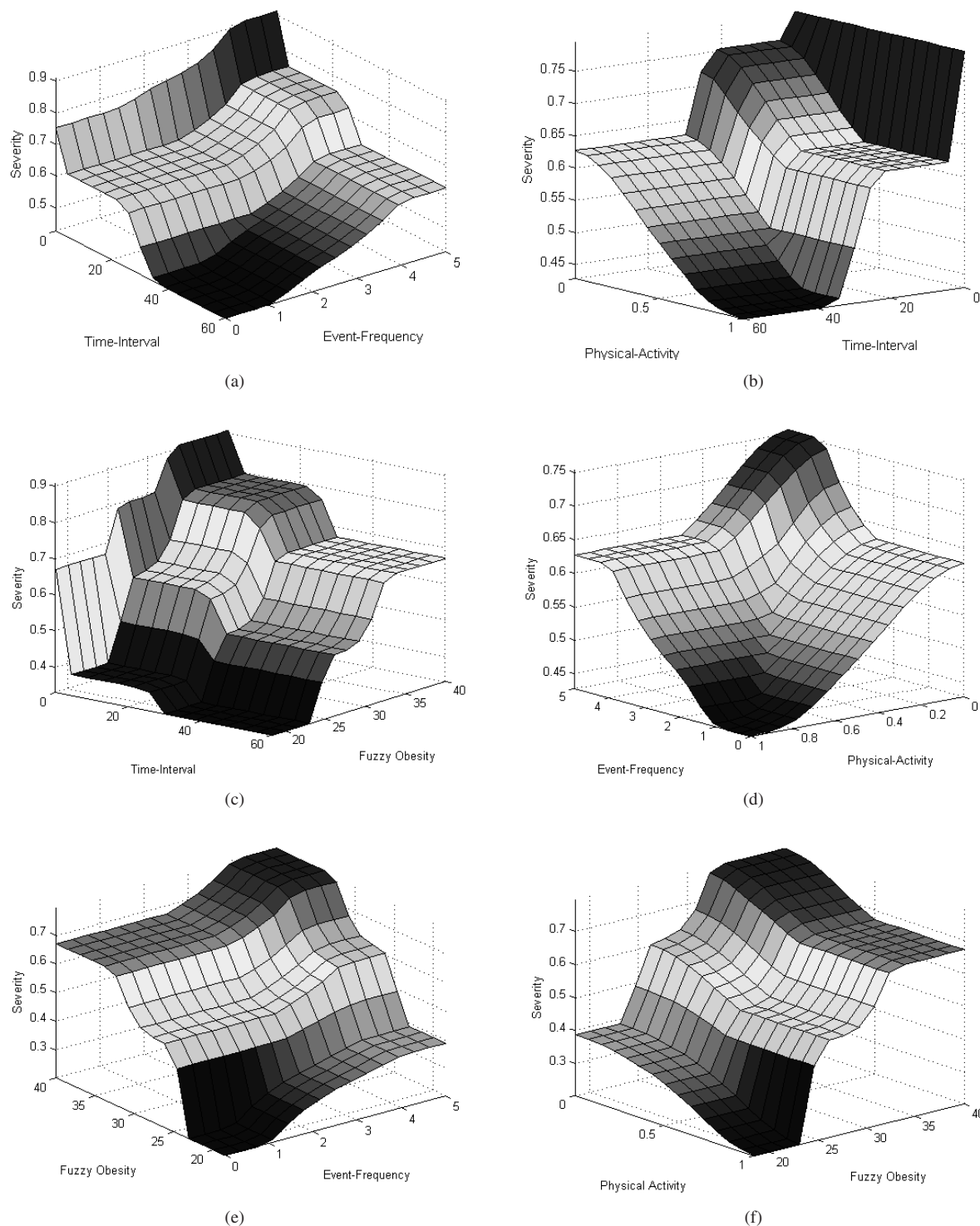


Fig. 5. Fuzzy obesity symptomatic chest-pain assessment for five classes covering very low, low, moderate, high, very high anginal severities: time interval $\times$ frequency of occurrence (5(a)), time interval $\times$ physical activity (5(b)), time interval $\times$ fuzzy obesity (5(c)), frequency of occurrence $\times$ physical activity (5(d)), frequency of occurrence $\times$ fuzzy obesity (5(e)), and physical activity $\times$ obesity (5(f)) for chest pain severity.

The proposed fuzzy score achieves mostly the same general characteristics than the previous *fuzzy Braunwald-based symptomatic chest pain assessment for unstable angina* and *fuzzy five-class Braunwald-modified symptomatic chest pain*

assessment for unstable angina works. It reaches toward smoothly grading the severity classification and assessment, covers the whole Cartesian space – but, in this case, encompassing a four-dimensional input space –, simultaneously

that enables quantitative and qualitative assessment – i.e., values and categories – for the risk of unstable angina. This system, however, goes further by comprising a fuzzy obesity comorbidity risk factor not present in those previous systems or in other medical diagnostic decision support systems.

The relationship between the input variables emphasizes the importance of the input parameters of clinical evaluation. The anginal chest-pain severity worsens as the health conditions of analysis are decreased in their natural properties. Among the input variables, the time interval assumes relevance in classifying the severity. The shorter the period of angina attacks the more severe is its classification (Fig. 5(a), 5(b), and 5(c)). The plateaus on these graphics are in agreement with the subclasses that partition its universe of discourse, respectively associated to the frequency of occurrence, physical activity, and fuzzy obesity. There is also a rapid increase in severity when shortening the time interval due to the importance that it assumes in the physiological dynamic that worsens the risk of an AMI. The level of obesity variable can achieve higher plateaus as the FBMI increases, resulting in faster worsening of the severity of unstable angina and being a major factor in their assessment, as expected (Fig. 5(c), 5(e), and 5(f)). In turn, the frequency of events and the physical activity input variable affects quite linear and smoothly the severity, respectively, when increasing the chest pain attacks from 1 to 5 and lessening the level of exercises from working out to rest. In spite of having no sharp influence on the medical diagnostic decision surfaces, these linguistic variables are fundamental when taking into account the severity of chest pain.

Consider, as illustrative examples, two patients with the set of data given onwards. The first patient reports having angina events about 30 days in complete rest and an average of two frequencies of occurrence. Such a patient presents a FBMI of 29 kg/m^2 , being classified simultaneously as moderate and high severities. As before mentioned, the proposed fuzzy obesity symptomatic chest pain assessment for unstable angina is also able to score the degree of severity that, for this case, assigned the value of 0.62 in a scale ranging from 0 to 1. Taking into account a second patient, there is a report of presenting a frequency of chest pain of four when in physical activity firing both the moderate and high membership functions with a degree of 0.75. Further, this patient is measured with a FBMI of 36 kg/m^2 and describes an interval of pain occurrence about 45 days. According to the proposed fuzzy score, the clinical condition of such a patient is determined as high and very high, resulting in a score of 0.749. These examples demonstrate that some patients may simultaneously be classified into different classes, unlike the classical Braunwald classification. Such a characteristic of classification enables to better understand and rating the stage the patient really is. Another advantage of the proposed system is the assignment of scores to patients, quantifying the severity of unstable angina.

Such a fuzzy obesity unstable-angina chest-pain system presents to be a feasible alternative to such a presented

problem and its performance potential demonstrated by experimental data, since there is no similar approach in the literature. Such a system can contribute in raising the agility, quality, and homogeneity of healthcare professionals in the diagnosis and prognosis of patients, mainly in primary health care.

IV. CONCLUSION

This paper presents a fuzzy rapid obesity chest-pain assessment and classification for unstable angina that maps the physical activity, frequency of event, time interval, and a simplified fuzzy body mass index input variables into three classes by covering low, moderate, and high symptomatic classes on the severity output variable. The use of fuzzy set theory and fuzzy logic in the design of a medical decision system to support the diagnosis of patients with coronary heart disease who have a risk obesity factor allows representing the subjectiveness and the approximate reasoning simultaneously that enables to handle imperfect information present in the healthcare assistance. The proposed approach not only overwhelms the drawbacks of the Braunwald unstable angina classification by covering the entire Cartesian space, smoothing the severity classification, and enabling quantitative and qualitative assessment for the risk of unstable angina but encompasses the obesity comorbidity risk factor, as well, usually neglected in the current rapid access chest pain clinic approaches. The resulting system becomes a feasible alternative to be employed in healthcare assistance, mainly when taking into account the primary health care.

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