

Fuzzy Lymphedema Assessment based on Clinical and Functional Criteria

Patricia Vicentini

Health Informatics Department (DIS)
Universidade Federal de São Paulo (UNIFESP)
São Paulo, SP, Brazil, 04023-062
Email: patricia.vicentini@unifesp.br

M. del Carmen J. Perez

Vascular Surgery Division (DCV)
Universidade Federal de São Paulo (UNIFESP)
São Paulo, SP, Brazil, 04023-062
Email: patricia.vicentini@unifesp.br

Ernesto Araujo

Hospital Municipal Dr. José de Carvalho Florence (HMJCF)
São José dos Campos, SP, Brazil, 12243-000

Health Informatics Department (DIS)
Universidade Federal de São Paulo (UNIFESP)
São Paulo, SP, Brazil, 04023-062

Assoc. Paulista para o Desenvolvimento da Medicina (SPDM)
São Paulo, SP, Brazil, 04024-002
Email: ernesto.araujo@unifesp.br, ernesto.araujo.br@gmail.com

Abstract—A fuzzy lymphedema clinical and functional assessment for classifying the risk of developing and its severity is proposed in this paper. Different from the previous approach where reversibility, skin infection, and skin changes were the input variables, this new fuzzy lymphedema clinical assessment takes into account the elements that compose the Brazilian Society of Lymphology (SBL). Such a SBL-based metric not only takes into account pre-clinical cases with risk of worsening and infective-degenerative local complications but also points out functional data of limb edema with the involvement of articular joints. The proposed approach includes both clinical (Pitting, Skin Changes, Stemmer Signal and Reversibility) and functional criteria (Joint Involvement). The fuzzy lymphedema assessment based on clinical and functional criteria allows establishing therapeutic global rehabilitative programs, degree of assistance necessity of patients, and reduction of the daily living activities.

Index Terms—Lymphedema, Classification, Decision Support System, Fuzzy Logic, Artificial Intelligence, Computational Intelligence

I. INTRODUCTION

Lymphedema is a condition of localized fluid retention and tissue swelling caused by compromised lymphatic systems. Often found in the extremities of the body, lymphedema is a sort of protein-rich edema that does not cause pain to the patient. Nevertheless, it is a syndrome with high prevalence in the worldwide population. In later stages, lymphedema can be a social disease that disqualify patients in their daily functional and labor activities [1].

If, for one side, lymphedema definition and characteristics are well established, on the other side, its classification is a question that remains open. The importance of classifying lymphedema concerns recognizing such a syndrome when presenting higher chance of evolving to health complications. Further, an adequate classification allows assigning appropriate treatment and, thus, reducing the morbidity risk [2].

Most of the cases of lymphedema are diagnosed by clinical findings such as reversibility, pitting, stemmer signal, among others. Lymphedema can also be classified according to its

cause as primary (congenital, precocious or late presentation) or secondary (mainly associated to inflammatory processes, cancer, neoplasia, and trauma).

The etiological classification mechanisms of lymphedema present adhesion among experts in daily practice. Classifying them, however, according to their etiological aspects can be restrained. Existing etiological-based classifications not always takes into account the severity of their clinical or functional impairment [3], [4], [5].

The severity classification mechanisms of lymphedema, on the other hand, often take into account the clinical and functional characteristics. They are recommended because play a relevant role in the elaboration of criteria for measuring the risk and the development level of lymphedema. These classifications, however, present the inconvenient of not always being accessible to all experts. They or use expensive methods such as imaging tests either are too complex in its applicability due to subjective variables that depend on the observer's viewpoint. The later aspect concerns vague, imprecise, and uncertain qualification [6].

An alternative to represent the inherent subjectivity concerning the human decision to quantify the severity of lymphedema is to use fuzzy set theory and fuzzy logic. They present great appeal in the real world, being of special interest to biosciences as confirmed by the considerable increase of medical studies related to the fuzzy logic in last decades. The literature has shown that the application of fuzzy sets has a great capacity for application to biomedical problems, due to the type of uncertainty involved in medical, biological, and epidemiological procedures. Fuzzy sets associate degrees of membership values in a subset instead a rigid yes or no decision. It also uses the partiality concept by a computationally effective way while fuzzy logic allows inference in approximate reasoning [7], [8].

The proposed approach uses the Mamdani method for representing the heuristic knowledge of experts to build the

TABLE I
LYMPHEDEMA CLINICAL AND FUNCTIONAL SEVERITY ASSESSMENT
ACCORDING TO THE BRAZILIAN SOCIETY OF LYMPHOLOGY (SBL).

Stage	Clinics
0	No edema in a risk patient
1	Edema which reduces spontaneously with anti-gravitation position, Pitting ++, Stemmer +, Involvement of at least two joints
2	Edema which do not reduce spontaneously but only with treatment, Pitting +, Stemmer +, Involvement of at least two joints
3	Edema which do not reduce spontaneously but partially only after treatment, Pitting +, Stemmer +, Involvement of at least three joints
4	Edema which do not reduce spontaneously but partially only after treatment, Pitting +, Stemmer +, Involvement of at least three joints, with skin changes

rule base of a Fuzzy Decision Support System (FDSS) to assess the clinical and functional severity of lymphedema. The proposed fuzzy system is based on the expertise obtained in the design of a previous lymphedema fuzzy system which is based on the classification adopted by World Health Organization (WHO) [9], [10]. This paper extends previous approach to the Lymphedema classification mechanism adopted by the Brazilian Society of Lymphology since it includes both clinical and functional criteria.

II. LYMPHEDEMA FUZZY DECISION SUPPORT SYSTEM

Current classification mechanisms for measuring the risk and the development level of lymphedema are accomplished by using classic (Aristotelian) set theory. According to it, the patient belongs to a set (class), or not, as exemplified in Table I. Therein are exposed the variables and criteria of classification for lymphedema clinical and functional severity assessment according to the Brazilian Society of Lymphology (SBL – Sociedade Brasileira de Linfedema). Nevertheless, it does not seem appropriate to attribute a Boolean classification for lymphedema severity since pitting, stemmer signal, reversibility (edema reduction) variables and terms as “partially” are inherently subjective, arbitrary, and dependent on the observer’s viewpoint and expertise. Further, a patient can simultaneously belong to grade 1 because it has a good reversibility, but presents 3 involvement joints that characterize grade 3 or 4.

Building a decision support system as a grading system for clinical and functional lymphedema assessment by using fuzzy logic can be an interactive and flexible alternative that represents the approximate reasoning or experts in supporting and improving the process of decision making.

Note that all the figures herein are normalized in the range from 0 to 1.

A. Input Linguistic Variable

The proposed FDSS for fuzzy lymphedema assessment based on clinical and functional criteria is based on the lymphedema evaluation method as recommended by the Brazilian Society of Lymphology as presented in Table I.

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Clinical signals evaluated by experts in the diagnosis of the severity of lymphedema forms the input variables of the proposed model. These are: Pitting (P), Skin Changes (C), Stemmer Signal (S), Reversibility (R), and Articular Joint, forming the Fuzzy (Skin)–Changes–Stemmer–Pitting–Reversibility–Articular–Joint Lymphedema Assessment.

1) Pitting (P):

Pitting refers to the consistency of the symptom of swelling in lymphedema. The consistency is evaluated by the palpation (touching) of the area presenting fluid retention and/or Godet signal, which consists of compression of the swollen area with the thumb. After removal of the thumb, it must be noticed the pitting. In hypertrophic, lipid, or spongy tissues, the depression caused by digital pressure disappears immediately (+++), which can characterize a soft or elastic type of swelling, for example, being defined as depressible edema. When the digital signal in the skin disappears in less than 1 minute, i.e., quickly (++); it is characterized a soft, malleable type of swelling being defined as partially depressing. Finally, but not less important, when the depression slowly disappears (+), or disappear in the range of 5 minutes or persists (0), the edema is defined as being non-depressing, also classified as hard or non-elastic type [11]. Additionally, it is important to emphasize that the soft swelling concerns better prognosis by characterizing the liquid present in this type of edema as being easier treated and by associating this sort of signal as presenting a tissue of less fibrosis [5]. The pitting variable and the partition of the universe of discourse in depicted in Fig. 1. The linguistic terms are Immediately, Quickly, and Slowly, characterizing the speed in which the swelling due to the pitting is reduced.

2) Skin Changes (C):

Skin changes are factors associated to progression or regression concerning developmental stages of lymphedema. Examples are surgical or burns scars, signs of venous stasis, fissures, bumps, dermatofibrosclerosis, dermatitis, and skin ulcers and warty lesions that can be considered as gateways

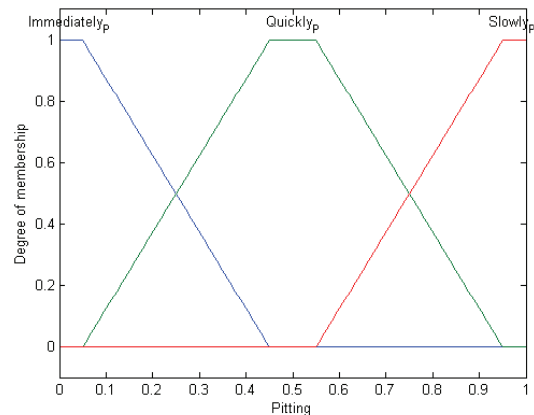


Fig. 1. Input Linguistic Variable: Pitting.

to infections. Some lesions are present and definitive while others (such as ulcers) may be transitory, making their classification still more difficult [2]. The classification of the Brazilian Society of Lymphology uses this variable to indicate greater severity, using only in the Grade 4. Clinically, it is a variable largely used for the assessment and grading the severity of lymphedema. Nevertheless, because it is a signal frequently discussed and presenting no consensus, it is difficult to determine a standard when taking into account all the current lymphedema classifications. Consequently, it brings forward a dangerous situation. The same classification term of skin changes employed by an expert can represent a complete different classification and meaning for another expert, resulting to erroneous problems in analysis, diagnosis, and treatment according to each reviewer. Further, this variable of classifications sometimes is used to quantify while others is employed to qualify the skin modifications. Due to that, this variable is also inherently subjective, arbitrary, and depends on the observer's viewpoint and expertise being able to be represented by employing fuzzy sets. The skin change variable and the partition of the universe of discourse in presented in Fig. 2 such that the linguistic terms comprise three classes of occurrence: Low, Moderate, and Intense.

3) Stemmer Signal (S):

This signal consists on skin thickening of the second toe and is obtained by the examiner when trying to do a grip of the skin from this region. In patients with lymphedema, it can be seen that there is an infiltration of the tissues, restricting an adequate grip of the skin [11]. Totally subjective and expert dependent, the universe of discourse and the fuzzy sets are shown in Fig. 3. Due to the nature of stemmer signal it is assigned only two linguistic fuzzy sets whose linguistic terms are None and Total.

4) Reversibility (R):

Reversibility is the input variable that refers to the property of edema be reverted to its previous state. Such a capacity can occur spontaneously and natural, spontaneously when elevated, or after being subjected to treatment. Some clas-

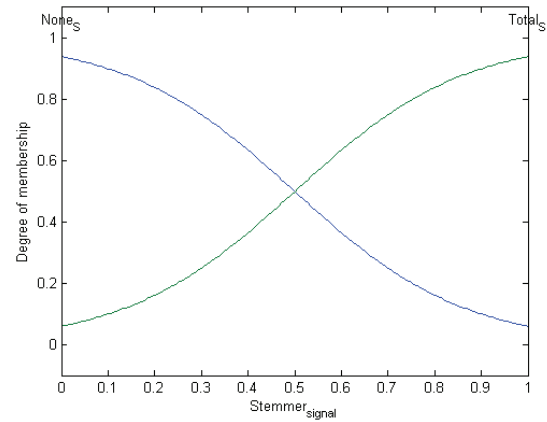


Fig. 3. Input Linguistic Variable: Stemmer Signal.

sifications only admit the possibility of edema, regardless being reversible, or not, while others stratify it based on the speed rating that lymphedema can reverse [3], [6], [10], [12], [13]. The classification recommended by the Brazilian Society of Lymphology uses the last two modes of reversibility. Moreover, the SBL classification is the only one that takes into account the treatment as a factor that boosts the reversibility speed [10] as presented in Table I. From the perspective of the variable reversibility, this classification comprises edemas that can reverse spontaneously but when in anti-gravitation position – i.e., the member put in elevate position –, featuring as Grade 1; edemas in which the swelling does not reduce spontaneously but reduces with treatment, being classified as Grade 2; and edemas in which the swelling does not reduce spontaneously but reduces partially with treatment, encompassing the Grades 3 and 4. It is worth pointing out that this classification does not contemplate the possibility of an edema does not revert. The reversibility variable and the partition of the universe of discourse in illustrated in Fig. 4 and the fuzzy sets are assigned in order to encompass the SBL requirements:

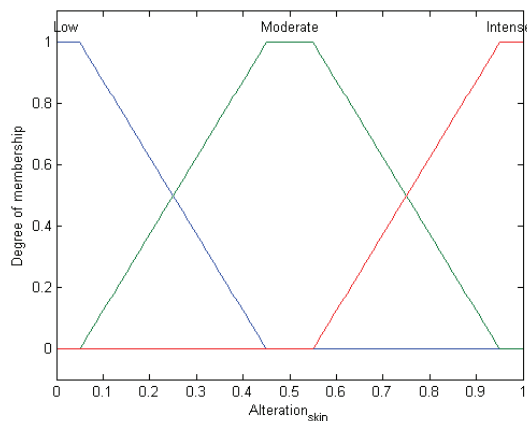


Fig. 2. Input Linguistic Variable: Skin Changes.

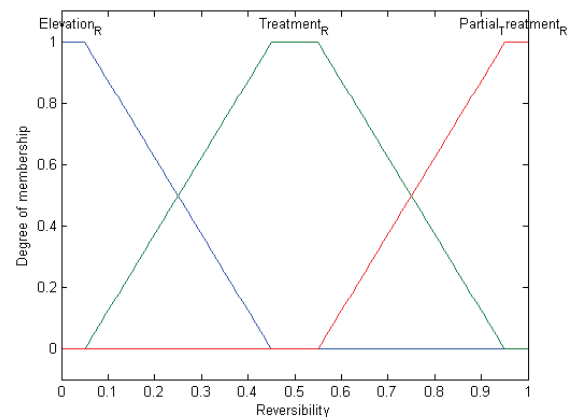


Fig. 4. Input Linguistic Variable: Reversibility.

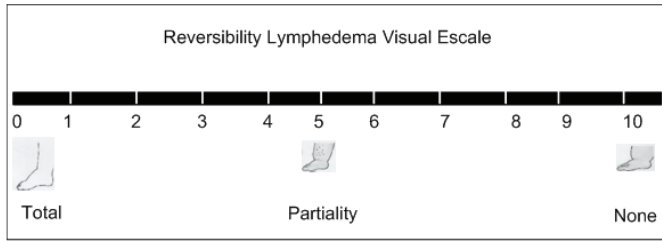


Fig. 5. Reversibility Lymphedema Visual Scale.

Elevation, Treatment, and Partial Treatment. Observe that it is considered that in all conditions the reversibility takes place. Additionally, the proposed fuzzy assessment innovates in presenting a qualitative reversibility assessment where the healthcare professional asks the patient to mark on a scale from 0 to 10 how the signal representing edema reverts (Fig. 5) according to previous approach suggested in [14]. Inspired on pain intensity scales, the proposed lymphedema reversibility scale (LRS) can deal with both singleton and fuzzy measurement following the same mechanism and understanding as presented for the fuzzy pain intensity scale in [15].

5) Articular Joint Involvement (AJI):

Articular joint involvement is a functional criterion used for evaluating the severity of Lymphedema. The articular joint involvement analysis points out functional data of limb edema when interested in dealing with big articular joint problems. According to this criterion it can evaluate only one big joint of the limb, two or the all three big articular joints. This aspect allows establishing the therapeutic global rehabilitative program, the degree of necessity of assistance of the patient, and the reduction of the daily living activities. Likewise stemmer signal, due to the nature of articular joint involvement analysis it is assigned only two linguistic fuzzy sets whose linguistic terms are Low and Total (Fig. 6).

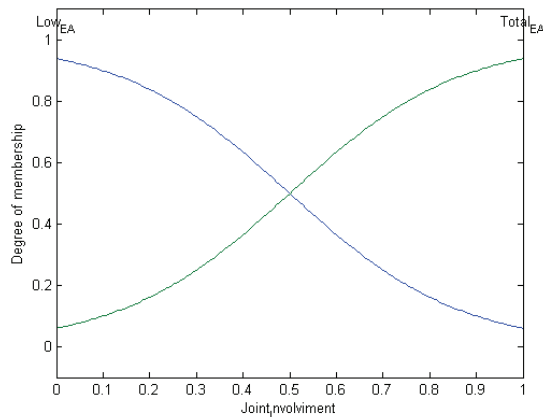


Fig. 6. Input Linguistic Variable: Articular Joint.

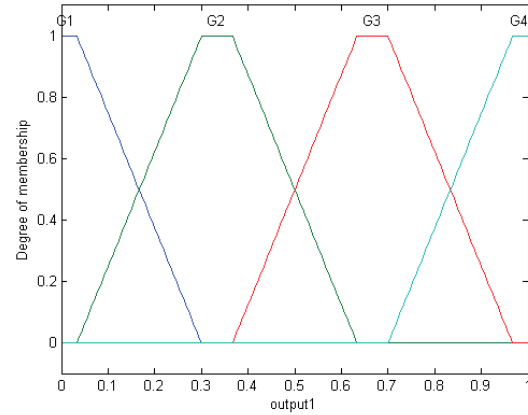


Fig. 7. Output Linguistic Variable: Lymphedema Severity.

B. Output Linguistic Variable

The outcome assessment of clinical and functional lymphedema is the severity linguistic variable. The linguistic terms that characterize the output variable are: $G1$, $G2$, $G3$ and $G4$, where $G(\cdot)$ means the grade of lymphedema severity in a discourse universe which ranges from 0 to 10 (Fig. 7). The classification of the Brazilian Society of Lymphology also uses the possibility of lymphedema presenting grade 0 that means the risk of developing lymphedema. When using the Fuzzy Lymphedema System the risk of developing lymphedema is imbedded since it can also compute the null value according to the inputs furnished to it. Further, the proposed system is able to grade the risk of developing lymphedema when the syndrome is in its initial stages.

C. Fuzzy Rules

The Mamdani fuzzy system presents its structure as a nonlinear mapping based on IF-THEN rules. Based on a review of the literature and internationally, worldwide valid classifications, the set of 3–3–3–2–2 linguistic terms that part the input universes of discourse, respectively, pitting, skin changes, stemmer signal, reversibility, and articular joint, yield a set of 89 valid fuzzy regions in a five-dimensional input space. Despite a complete 3–3–3–2–2 rule base contains 108 rules, there are rules not valid at all due to human health conditions as stated by the standard of clinical and functional criteria recommended by the Brazilian Society of Lymphology. Further, although rules could be merged in some circumstances, here they are formally separated to help enhancing transparency, mainly because there would be healthcare professionals not able to handle mathematical, logical languages.

The Fuzzy Lymphedema assessment based on clinical and functional criteria recommended by the Brazilian Society of Lymphology is, thus, represented as IF-THEN *fuzzy rules* in

the form:

- R_1 : IF $\langle \text{Pitting reduces Immediately} \rangle$ AND ...
 $\langle \text{Stemmer is None} \rangle$ AND ...
 $\langle \text{Skin Changes is Low} \rangle$ AND ...
 $\langle \text{Reversibility is Elevation} \rangle$ AND
 $\langle \text{Articular Joint is Low} \rangle$...
 THEN $\langle \text{Lymphedema Severity is G1} \rangle$,
 R_2 : IF $\langle \text{Pitting reduces Quickly} \rangle$ AND ...
 $\langle \text{Stemmer is None} \rangle$ AND ...
 $\langle \text{Skin Changes is Low} \rangle$ AND ...
 $\langle \text{Reversibility is Elevation} \rangle$ AND
 $\langle \text{Articular Joint is Low} \rangle$...
 THEN $\langle \text{Lymphedema Severity is G1} \rangle$,
 ...
 R_{88} : IF $\langle \text{Pitting reduces Quickly} \rangle$ AND ...
 $\langle \text{Stemmer is None} \rangle$ AND ...
 $\langle \text{Skin Changes is Intense} \rangle$ AND ...
 $\langle \text{Reversibility is Partial} \rangle$ AND
 $\langle \text{Articular Joint is Total} \rangle$...
 THEN $\langle \text{Lymphedema Severity is G4} \rangle$,
 R_{89} : IF $\langle \text{Pitting reduces Slowly} \rangle$ AND ...
 $\langle \text{Stemmer is None} \rangle$ AND ...
 $\langle \text{Skin Changes is Intense} \rangle$ AND ...
 $\langle \text{Reversibility is Partial} \rangle$ AND
 $\langle \text{Articular Joint is Total} \rangle$...
 THEN $\langle \text{Lymphedema Severity is G4} \rangle$,

(1)

such that linguistic terms part the respective universes of discourse, X_k and Y and the input vector of the premise is given by $x = [x_1, x_2, x_3]^T$, while the output is associated to y .

III. RESULTS AND DISCUSSION

At the XX International Congress of Lymphology, in a special session concerning consensus on lymphedema staging, the Brazilian Society of Lymphology proposed a classification mechanism for lymphedema [10]. This classification is, here, chosen to design a Fuzzy Decision Support System to classify the lymphedema clinical and functional severity as a comparative metric. This choice is carried out because such a SBS-based lymphedema assessment is the classification that best represents the intermediate states of the clinical and functional signals assessed by healthcare professionals.

The proposed fuzzy classification, however, advantages upon the inspired classification method by the fact that depressibility (pitting) can be graded as immediately, quickly and slowly reduced, instead of, depressing or not. Contrary to the inspired model that does not achieve the real demand in diagnosing patients porting the two concomitant intermediate possibilities, the fuzzy lymphedema assessment satisfy this demand when employing fuzzy set theory. This aspect makes fuzzy set theory effectively applied; it allows the quantitative mapping of membership degree of evaluated clinical signs and the overlapping of classes. The SBL classification allows yet that the functionality assessment be evaluated when associated to the linguistic variable articular joint involvement.

In order to demonstrate the effectiveness of the proposed fuzzy decision support system for classifying the lymphedema severity, data from literature and experts are employed. Results obtained by the comparison between the proposed method of lymphedema classification and the SBL approach is shown in Table II. Seven patients presenting diverse severity levels of lymphedema are distributed therein.

In daily practice, experts hardly face patient with lymphedema presenting the same clinical conditions. Subtle or large differences are present and the severity assessment mechanism must be able to capture these variations. For instance, when using the traditional method for classifying lymphedema, the patient can present reversibility only after treatment, thus characterizing it as grade 3 or 4, but not more than two articular joints are involved, which characterizes a grade 1. Pitting, skin changes, stemmer sign are healthcare

TABLE II
RESULTS COMPARISON BETWEEN THE BRAZILIAN SOCIETY OF LYMPHOLOGY CLASSIFICATION AND THE PROPOSED MODEL.

Pitting		Skin Changes		Stemmer Signal		Reversibility		Joint Involvement		SBL Classification	PASRIJ Classification	Severity Value
0.1	Immediately	0.1	Low	0.1	None	0.1	Limb Elevat	0.1	Low	Grade 1	Grade 1	0.15
0.1	Immediately	0.2	Low	0.3	None	0.1	Limb Elevat	0.3	Low	Grade 1	Grade 1 & 2	0.39
0.1	Immediately	0.2	Low	0.3	None	0.5	Treatment	0.3	Low	Grade 2	Grade 2	0.43
0.5	Quickly	0.9	Intense	0.6	Total	0.5	Treatment	0.5	Total	Grade 3	Grade 2 & 3	0.51
0.7	Slowly	0.6	Low	0.7	Total	0.6	Treatment	0.4	Low	Grade 3	Grade 3	0.63
0.8	Slowly	0.7	Intense	0.7	Total	0.6	Treatment	0.7	Total	Grade 3	Grade 3 & 4	0.74
0.8	Slowly	0.6	Intense	0.8	Total	0.8	Partial Treatm	0.8	Total	Grade 4	Grade 4	0.87

professional dependent. Such an inherent subjectivity in the process of staging the severity of lymphedema demonstrates vagueness and uncertainty which hampers the standardization of a classification that can be easy, simple, and widely applied. The seven patients presented in Table II feature subtle differences among the input parameters of evaluation. Observe that when the objective is to analyze classes, the results obtained with the fuzzy lymphedema system are quite similar to the method of classification used by the SBL. They barely differ except when the patient presents clinical characteristics simultaneously belonging to two classes when using the proposed fuzzy assessment. The fuzzy system allows this possibility because the classes accept the relevance of severity in different degrees being an advantage, more than a problem, mainly because the final result of evaluation can cope not only with qualitative but quantitative results.

Due to that, the proposed fuzzy lymphedema clinical and functional severity assessment not only is compatible to SBL-inspired model but carries two other important features. First, not only a class of severity is presented but there is a value, score associate to the classification allowing the value be used for objective comparative analysis and for being employed as the factor for determining the medication. Second, both qualitative and quantitative values are able to be determined by using computers or any of now-a-day available electronic devices.

It is noteworthy that this paper is a result of activities in research and development at the Hospital Municipal Dr. José de Carvalho Florense (HMJCF) and Universidade Federal de São Paulo (UNIFESP), and approved by two Committees for Research Ethics.

IV. CONCLUSION

The use of Fuzzy Logic becomes an alternative to stage the clinical and functional severity of lymphedema. Diagnosing and grading the diverse levels of severity of lymphedema requires dealing with diverse subjective parameters and variables that depends on the observer's viewpoint and expertise. The proposed approach turns out to be an effective tool of classification method that may cooperate with the standardization of therapeutic management of lymphedema and its classification, which is essential for the systematization of health care and decreasing morbidity in patients with high developed lymphedema.

The clinical parameters comprise pitting, skin changes, stemmer signal and reversibility whereas the functional criterion is the articular joint Involvement. The fuzzy lymphedema assessment based on clinical and functional criteria allows establishing therapeutic global rehabilitative programs, degree of assistance necessity of patients, and reduction of the daily living activities.

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