Neutrosophic Sets and Systems

Volume 44 *Impact of Neutrosophic Scientific Publication in Latin American context*

Article 6

8-6-2021

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Sara Guerrón Enríquez
Universidad Regional Autónoma de los Andes (UNIANDES, ut.saraxge69@uniandes.edu.ec

Zuly Ribel Nazate Chugá
Universidad Regional Autónoma de los Andes (UNIANDES, ut.zulynazate@uniandes.edu.ec

Ruth Isabel Tavera
Universidad Regional Autónoma de los Andes (UNIANDES, ut.ruthtavera@uniandes.edu.ec

María Clemencia Villareal Gel
Universidad Regional Autónoma de los Andes (UNIANDES, ut.mariavillareal@uniandes.edu.ec

Darvin Manuel Ramírez Guerra
Universidad de Holguín, dramirezg@uho.edu.cu

Neutrosophic Sets and Systems
{Special Issue:Impact of neutrosophic scientific publication in Latin American context}, Vol. 44, 2021
University of New Mexico

Neutrosophic Statistical Analysis of Arthrofibrosis of the Knee Rehabilitation

Sara Guerrón Enríquez [1], Zuly Ribel Nazate Chugá[2], Ruth Isabel Tavera[3] María Clemencia Villareal Gel[4] and Darvin Manuel Ramírez Guerra[5]

[1]Universidad Regional Autónoma de los Andes (UNIANDES), Troncal de la Sierra. Tulcán, Carchi, Ecuador.
E-mail: ut.saraxge69@uniandes.edu.ec
[2]Universidad Regional Autónoma de los Andes (UNIANDES), Troncal de la Sierra. Tulcán, Carchi, Ecuador.
E-mail: ut.zulynazate@uniandes.edu.ec
[3]Universidad Regional Autónoma de los Andes (UNIANDES), Troncal de la Sierra. Tulcán, Carchi, Ecuador.
E-mail: ut.ruthtavera@uniandes.edu.ec
[4]Universidad Regional Autónoma de los Andes (UNIANDES), Troncal de la Sierra. Tulcán, Carchi, Ecuador.
E-mail: ut.mariavillareal@uniandes.edu.ec
[5]Universidad de Holguín, Cuba, Email: dramirezg@uh**o**.edu.cu

Abstract. This research aims at deepening the validation of knee arthrofibrosis rehabilitation techniques. It begins with a bibliographic review and an initial diagnosis that justifies the need to investigate these issues, and aspects that give consistency to them. We designed both a pre-test and a post-test, where the patient is physically examined, as well as a questionnaire is applied about the degree of pain or degree of independence. In the study we proposed to the patients to answer questions about the pain degree in form of intervals rather than single values, this allows us to assess most accurately what patients feel, however, we gain in imprecision. To this end, we use the Neutrosophic Statistics theory, which extends the classical statistical methods to the interval-valued domains. Finally, after applying the t-Student's test we concluded the effectiveness of the treatment.

Keywords: Neutrosophic Statistics, rehabilitation, knee arthrofibrosis.

1 Introduction

Trauma to the knee causes a forced valgus or varus and results in a separation-type fracture. Axial trauma causes a collapse fracture. The combination of both causes a collapse-separation type fracture, aspects that affect the patient's locomotion, [1].

Knee deformities are one of the most relevant pathologies within the osteomyoarticular system since quadriceps muscle atrophy and joint instability can be more significant when the patient is standing and walking. This undoubtedly affects the daily activities and the work of the patient. These diseases are multiple, but Arthrofibrosis of the Knee (AFK) is one of those that cause the greatest disability and medical prescription.

Arthrofibrosis of the Knee is also known in the medical literature as the loss of joint movement after having suffered trauma or surgical intervention. Due to the disabling nature that it produces and the limitation in daily activities that it causes, it is one of the most difficult complications to manage in this joint, [1,2].

In accordance with the above-mentioned, the interest of the scientific community in conducting studies aimed at first avoiding it as much as possible has increased. This is known as *prevention* and then managing it in the most appropriate way, that is, its *treatment*.

This disease can be presented in a localized or diffuse way in the compartments of the knee with intra-, extra-articular, or both, and its cause involves mechanical and biological factors, [3].

A prolonged period of immobilization, caused by this alteration of the osteomyoarticular system for more than two weeks, causes damage to the articular cartilage, bone structure, and soft tissues, which is why at the beginning of the process the significant rehabilitation is recommended by most researchers on this topic as soon as possible, [4]. The most important clinical picture is loss of joint movement, generally accompanied by quadriceps atrophy, increased volume, and pain. That is why this disease is a serious problem for human health [3,5].

Among the factors that most contribute to the development of this disease is the delay in the rehabilitation process when the first symptoms appear [6,7]. An important role is to explore the kneecap to verify that its mobilization is not blocked and does not cause pain.

When conducting a bibliographic search to enter the investigative process, we identified that the classification is dissimilar and has solid arguments that support it. However, in the present investigation, the one proposed by Del Pizzo is shared, since it is considered to allow a greater quantification to be based on the degree of limitation of joint movement since it helps to define prognosis [8].

So, this author suggests that this disease is grouped into three main groups: the group one in which there is an

extension of <5° and a flexion of > 110° is considered to have a *slight* severity, the second group is considered to have an extension of 5-10°, and a flexion of 90-110°. Here the patient has a *moderate* degree of severity, so the doctor must be attentive to avoid complications that may occur in the next group. The third group has an extension level of > 10° and a flexion level of < 90°. As we can appreciate, at this time the patients present a great affectation that leads to the disease that is considered as *severe*.

In the bibliography, it is recommended as a fundamental pillar of the treatment, prevention, and then rehabilitation as soon as possible [8]. Other authors prefer conservative treatments, manipulations under anesthesia, arthroscopy, quadriceplasties, among others, [3,5], including open surgical therapies [6,7]. These treatments are not available to everyone; some of them have major complications, and all eventually need rehabilitation.

According to Gerd-WihlhemBöger and collaborators in their book "Physiotherapy for orthopedics and rheumatology", cryotherapy, thermotherapy, electrotherapy, and a group of exercises aimed at strengthening the internal vastus musclesare posed as the main treatments for AFK in physiotherapy. The same treatment is valid for quadriceps femoris, as well as stretching the rectus anterior muscle and quadriceps femoris muscle, hamstring, and calf muscles, [6,7].

Several cases refer to prevention as an important component in most secular processes of joint trauma. Generally, patients need some type of temporary immobilization, which must be kept for the necessary time, since its prolongation can produce some type of joint stiffness, which we must prevent with rehabilitation exercises. It proposes a group of exercises to gain all possible joint amplitude, they are: passive and self-passive mobilizations using arthromotor pole therapy, special techniques such as manual therapy, rhythmic mobilizations, and rhythmic sequential mobilizations, and postural treatments of the joint, slightly forced [8].

Authors who have systematized this disease suggest that the most important prevention measures are to avoid prolonged bed rest and carry out early mobilization by performing active, active-assisted, or passive joint mobility exercises. A joint that performs a single daily movement throughout its entire travel will be free of contractures and stiffness. Special attention must be paid to the biarticular muscles [3].

The rehabilitation of this disease plays a leading role, that is why it is essential to assess its behavior in practice. An initial diagnosis is made in a sample of the Pastaza canton, where methods such as the survey of patients; observations to rehabilitation sessions and revision of the rehabilitation protocol, and the need to evaluate the follow-up of these patients, to continue the rehabilitation process and the use of statistical methods to quantitatively identify their level of recovery.

This study has the objective to carry out a neutrosophic statistical analysis on the rehabilitation of arthrofibrosis of the knee. Neutrosophic Statistics was introduced by F. Smarandache, which constitutes an interval-valued generalization of the classical Statistic. Thus, we designed a questionnaire where the interviewed patient could respond in an interval-value to express its degree of pain. We preferred to use this kind of scale to guarantee the accuracy of this study. This is because it is more comfortable to express a pair of limits values of subjective evaluation than using only one.

2 Materials and Methods

2.1 Population under study

In this study we use the following elements of classical statistics:

- p = approximate proportion of the phenomenon in the reference population,
- q = proportion of the reference population that does not present the phenomenon (1-p).
- The desired confidence level (Z). Indicates the degree of confidence that the true value of the parameter in the population will be found in the calculated sample.
- The absolute precision (d). It is the desired width of the confidence interval on both sides of the true value of the difference between the two proportions (in percentage points).
- N is population size.

Some results of the treatment were assessed on the degree of a scale between 0 and 10. Intervals are also allowed. So, we have a Neutrosophic Statistics problem, whose main concepts we explain in the next subsection.

Additionally, we use a confidence level of 95%, z = 1.96, d = 0.05 and N = 321. Then, the neutrosophic sample is n = 175.12≈176.

The traumatologist diagnosed 321 patients with arthrofibrosis of the knee belonging to the Pastaza canton of the Republic of Ecuador, 176 of them were selected using simple random sampling with the raffle procedure.

Within the sample, 105 are male and 71 are female. With a mean age of 44.7 ± 11.2. All patients signed the informed consent. Therefore, in this research, the protocols of the Declaration of Helsinki for research with human beings were followed. It is necessary to clarify that all the selected patients underwent a 12-week treatment. The first measurement was made at week 0 and the second at week 12.

Where muscle conditioning, flexion, and extension exercises were applied to aquatic activities (hydrokinecytherapy). In addition to receiving physical agents such as paraffin twice a week and in the final moments of the session they received occupational therapy.

Therefore, under these conditions, Neutrosophic Statistics were used.

2.2 Basic Notions of Neutrosophic Statistics

Definition 1:

([9]) Let X be a universe of discourse. Three membership functions characterize a Neutrosophic Set (NS), $u_A(x), r_A(x), v_A(x) : X \to \,]^-0, 1^+[$, which satisfy the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ is the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively, and their images are standard or non-standard subsets of $]^-0, 1^+[$.

Definition 2:

([9]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is a set of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\} \quad (1)$$

Where $u_A, r_A, v_A : X \to [0,1]$, satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indeterminate, and falseness of x in A, respectively. For convenience a *Single-Valued Neutrosophic Number* (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$.

Neutrosophic Statistics extends the classical statistics, such that we deal with set values rather than crisp values, [10].

Neutrosophic Descriptive Statistics is comprised of all techniques to summarize and describe the neutrosophic numerical data characteristics.

Neutrosophic Inferential Statistics consists of methods that permit the generalization from a neutrosophic sampling to a population from which the sample was selected.

Neutrosophic Data is the data that contains some indeterminacy. Similarly to classical statistics, it can be classified as:

- Discrete neutrosophic data, if the values are isolated points.
- Continuous neutrosophic data, if the values form one or more intervals.

Another classification is the following:

- Quantitative (numerical) neutrosophic data; for example a number in the interval (we do not know exactly), 47, 52, 67, or 69 (we do not know exactly);
- Qualitative (categorical) neutrosophic data; for example: blue or red (we don't know exactly), white, black or green, or yellow (not knowing exactly).

The univariate neutrosophic data is neutrosophic data that consists of observations on a neutrosophic single attribute.

Multivariable neutrosophic data is neutrosophic data that consists of observations on two or more attributes.

A Neutrosophic Statistical Number N has the form $N = d + I$, [11], where d is called determinate part and I is called indeterminate part.

A Neutrosophic Frequency Distribution is a table displaying the categories, frequencies, and relative frequencies with some indeterminacy. Most often, indeterminacies occur due to imprecise, incomplete, or unknown data related to frequency. As a consequence, relative frequency becomes imprecise, incomplete, or unknown too.

Neutrosophic Survey Results are survey results that contain some indeterminacy.

A Neutrosophic Population is a population not well determined at the level of membership (i.e. not sure if some individuals belong or do not belong to the population).

A simple random neutrosophic sample of size n from a classical or neutrosophic population is a sample of n individuals such that at least one of them has some indeterminacy.

A stratified random neutrosophic sampling is the pollster groups of the (classical or neutrosophic) population by a stratum according to a classification; afterward, the pollster takes a random sample (of appropriate size according to a criterion) from each group. If there is some indeterminacy, we deal with neutrosophic sampling.

Additionally, we describe some concepts of interval calculus, which shall be useful in this paper.

Given $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ two neutrosophic numbers, some operations between them are defined as follows, [12]:

$N_1 + N_2 = a_1 + a_2 + (b_1 + b_2)I$ (Addition),

$N_1 - N_2 = a_1 - a_2 + (b_1 - b_2)I$ (Difference),

$N_1 \times N_2 = a_1a_2 + (a_1b_2 + b_1a_2 + b_1b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1+b_1I}{a_2+b_2I} = \frac{a_1}{a_2} + \frac{a_2b_1-a_1b_2}{a_2(a_2+b_2)}I$ (Division).

Additionally, given $I_1 = [a_1, b_1]$ and $I_2 = [a_2, b_2]$ we have the following operations between them ([12]):

1. $I_1 \leq I_2$ if and only if $a_1 \leq a_2$ and $b_1 \leq b_2$.
2. $I_1 + I_2 = [a_1 + a_2, b_1 + b_2]$ (Addition);
3. $I_1 - I_2 = [a_1 - b_2, b_1 - a_2]$ (Subtraction),
4. $I_1 \cdot I_2 = [\min\{a_1 \cdot b_1, a_1 \cdot b_2, a_2 \cdot b_1, a_2 \cdot b_2\}, \max\{a_1 \cdot b_1, a_1 \cdot b_2, a_2 \cdot b_1, a_2 \cdot b_2\}]$ (Product),

$\frac{I_1}{I_2} = \left[\frac{a_1}{b_1}, \frac{a_2}{b_2}\right]$, always that $0 \notin I_2$ (Division).

5. $\sqrt{I} = \left[\sqrt{a}, \sqrt{b}\right]$, always that $a \geq 0$ (Square root).
6. $I^n = \underbrace{I \cdot I \cdot \cdots \cdot I \cdot I}_{\text{n times}}$

2.3 Instruments

To carry out the research, it was necessary to select and apply a set of theoretical, empirical, and statistical methods that are discussed below.

Analytic-synthetic: allowed to carry out a study on the theoretical and methodological foundations that support the neutrosophic statistical analysis on the rehabilitation of knee arthrofibrosis. It was used for the systematization, generalization, and specification of the processed information. It was useful in interpreting the empirical information obtained, as well as in preparing the proposal.

Inductive-deductive: used to make inferences and generalizations of the neutrosophic statistical analysis on the rehabilitation of knee arthrofibrosis, as well as the interpretation of the data obtained, from which new logical conclusions are deduced.

Participant scientific observation: it was used to directly observe the rehabilitation process of patients with arthrofibrosis of the knee, through an immediate perception of it, which made it possible to know quickly the reality and was used during the research process.

Measurement: it was used to identify the transformations that occurred in the selected sample through the use of the tests and instruments for evaluating the pathology and emphasis was placed on its critical assessment

Survey: it was carried out on 100% of the members of the sample, as this was the instrument used to assess patients regarding their behavior in carrying out daily activities. The questionnaire is the following:

Questions

1-How do you rate your performance in daily activities? (Check the option that best describes the situation)

-----Independent

----- With some limitations

----- With external help

----- I cannot perform daily activities

2-How do you assess your performance as a result of the discomfort caused by this pathology in your work activity? (Check the option that best describes the situation)

----- Well

----- Regular

----- Bad

The analysis is guided by a workflow of three activities. Statistical analysis is based on a neutrosophic environment to model uncertainty.

The analysis is supported by a neutrosophic statistical scheme that can address criteria of different nature in a neutrosophic environment [13-15]. The logic followed in the activities carried out in the investigation is shown below:

Moment 1. Application of the visual analog scale of pain,

Moment 2. Analysis of the goniometric measurements,

Moment 3 Application of a survey to patients.

The patients can respond to the questionnaire on an interval-valued scale if necessary. The scale is a subinterval of [0, 10]. Thus, the answer can be 5 (a medium value) or [3, 4]. Then, the patient can express his feeling more precisely than if using a one-valued scale. On the other hand, the results in Question 2 are processed in the way that "Well" is converted into [7, 10], "Regular" into [4, 6], and "Bad" into [0, 3]. Next, these data are scaled to [0, 1] dividing by 10.

The statistical analysis of the method is designed to verify the experimental significance of the implementation of the proposal. The different activities of the analysis are described below.

The experimental design proposal is guided by a sequence of steps proposed by Grau [16-18]. The proposed steps to experiment are described below:

Step 1: Decide how many and which independent and dependent variables are included in the experiment.

Step 2: Choose the manipulation levels (measurement level) of the independent variables and translate them into experimental treatments.

Step 3: Choose or develop an instrument or tools to measure the dependent variables.

Step 4: Select the experimental design to carry out. For true experiments, decide whether participants are randomized or matched on some variable (s).

Step 5: Select a sample of people to carry out the pre-experiment.

Step 6: Analysis of the results

The level of neutrosophic significance α could be a set, not necessarily a neat number as in classical statistics [19]. A neutrosophic p-value is defined in the same way as in classical statistics: the smallest significance level at which a null hypothesis H_0 can be rejected.

The distinction between the classical p-value and the neutrosophic p-value is that the neutrosophic p-value is not a neat number as in classical statistics, but a set (in many applications it is an interval).

To know the validity of the results, the following was taken into account: Neutrosophic p-value = p ($z < z_{critical\_value}$, when H_0 is true). Where p(*) means classical probability calculated assuming that H_0 is true, the probability of observing a test statistical value is more extreme than what was obtained.

Statistical analyzes were performed with SPSS v. 20 (SPSS Inc, Chicago, IL, United States). The data relating to the descriptive statistics will be presented through the distribution of frequencies, while the t-Student test was used since the data are normally distributed. For which a confidence level of 95% and a maximum error of 5% were taken into account, considering a value of $p \leq 0.05$ as statistically significant.

3 Results

This section describes the results of the neutrosophic method applied.

1. We defined two variables:

- Independent variable: treatment developed,
- Dependent variable: improvement in the execution of daily activities.

The answers may contain interval-valued data representing that the patient is not sure what to answer. This possibility to answer in form of an interval allows more accuracy even though there is more imprecision.

International validated instruments are used for this pathology, such as:

- The visual analog scale of pain, goniometric measurements, and surveys of activities of daily living.
- A measurement is performed in the pre-test and post-test, all were tabulated with the SPSS computer software for Windows version 20.

2. Select the experimental design to carry out. In this case, a pre-experiment with a pre and post-test is carried out on the same group. Where the aforementioned parameters are evaluated in the second and sixth after the treatment is finished.
3. G O1 represents the results after the second week after treatment, whereas XO2 represents the sixth week after treatment.

Where:

- G represents the group that was selected
- O1 O2 Represent the pre and post-test applied to the group
- X Experimental condition (independent variable of the hypothesis)

4. Select a sample of people to carry out the pre-experiment (this coincides with section 2.1 of this document).
5. Analyze the results.

When observing the results of Table 1, it can be argued that there was an increase from pre to post-test. Then, at the first time of measurement, only 18 patients (approximately 10% of the sample) reported an absence of pain. This tendency was increased to 88 (50%), making it evident that the rehabilitation program improves pain over

time. Mild and moderate pain also had improvements in the second measurement.

Assessment	Pre-test		Post-test	
Pain intensity	Quantity	Percentage	Quantity	Percentage
Absence	18	10	88	50
Mild	[123, 126]	[69.89,71.59]	[65, 70]	[36.93, 39.77]
Moderate	[32, 35]	[18.18, 19.89]	[18, 23]	[1.023, 13.07]
Severe	0	0	0	0

Table 1: Results of the application of the visual analog scale of pain.

Results of goniometric measurements

Table 2 refers to the results obtained in the goniometry. Where the existence of improvements was found in the second measurement. Thus, in the extension movement in the pre-test, it could only be carried out completely 53 (approximately 30% of the sample). While the rest (123 or 70%) did not complete it. However, in the second moment of measurement, there was a transformation in this aspect; since 158 patients (approximately 90%) performed it completely and only 18 (10%) did not complete it. Therefore, it becomes evident that in the second moment of evaluation the results are better.

On the other hand, the bending movement also obtained satisfactory results in the second moment of evaluation. In the first measurement, only 36 patients performed this movement completely and the rest (140 or 80%) did not complete it. In the second measurement, an increase was evidenced, since 140 patients were able to perform the movement completely and only 20% were not completed.

	Pre-test		Post-test	
Movement	Complete	Not complete	Complete	Not complete
Extension	53	123	158	18
Flexion	36	140	140	36

Table 2: Results of goniometric measurements

Results of the patient survey

The survey evaluated the performance of patients in daily activities (DA). Where table 3 and 4 show the results of both questions that this non-blood contains. Therefore, an analysis of them is carried out below.
Results of question 1 (Table 3).

In the first assessment, only 52 patients (30%) reported that they carried out these activities independently. However, after reapplying the instrument in the second measurement, it was increased to 123 patients. Aspects that denote the transformation that occurred in the sample in the second measurement.

The category with some limitations, at the initial moment of the investigation 88 patients (50% of the sample) considered that they had difficulties. While in the second measurement, it was reduced to 35, which makes evident the improvement of patients in ADL. For its part, the category with external help also had a decrease, since from 36 patients at the initial moment, only 18 obtained this evaluation.

Assessment	Pre-test		Post-test	
AVD	Quantity	Percentage	Quantity	Percentage
Independent	52	30	123	70
With some limitations	88	50	35	20
With outside help	36	20	18	10
I can not do them	0	-	0	-

Table 2: Results of question 1 of the survey

The results of question 2 (Table 4) obtained in the first one, only 35 patients (approximately 20%) say that this

pathology does not affect work activities, while 53 (30%) consider that their performance is regular. While the majority, 88 (50%), refer to it as bad, as this disease causes ailment and affects physically, functionally, and psychologically.

While once the treatment was applied, 123 patients (70%) consider that at the moment their performance is good, as this is logical by reducing pain and improving the movements of this joint, its results in this aspect are obvious. Only 53 (30%) considered that their performance is regular and none stated that it was bad after receiving treatment.

Assessment	Pre-test		Post-test	
AVD	Quantity	Percentage	Quantity	Percentage
Well	35	20	123	70
Regular	53	30	53	30
Bad	88	50	0	0

Table 3: Results of question 2 of the survey

Study validation

Before delving into the results of inferential statistics, the following statistical hypothesis is proposed:

H_0: treatment developed does not significantly improve the daily activities in patients with arthrofibrosis of the knee (MD≤ MA).

H_a: treatment developed if it significantly improves the daily activities in patients with arthrofibrosis of the knee (MD≤ MA).

For the interval-valued data, we processed the mean of the interval. When processing the data with the SPSS for Windows version 20 computer software, it is obtained through the t-Student's test that there are significant differences in the second measurement with a confidence level of p = .000 in all the variables in the studies. So, H_a is accepted and thus the results of this investigation are validated.

Conclusion

The results obtained lead us to the following conclusions:

1. The analysis of the theoretical and methodological references on the rehabilitation of arthrofibrosis of the knee shows the existence of different bibliographic sources on the subject, however, tools are required to promote a correct evaluation.
2. The followed methodological logic was based on the general methods of science for the application of clinical scales such as visual analog pain, functional tests such as goniometry, and a survey to know the performance of patients.
3. The interpretation of the results offers validity to the research since by using a statistical analysis of the t-Student test, the effectiveness of the received treatment was confirmed. Let us note that we used imprecise data, for achieving more accuracy, patients can express with more fidelity what they feel.

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Received: February 10, 2021. Accepted: April 19, 2021