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Indeterminate Control Diagrams as Health Control Tools

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Abstract. In recent decades, the development of techniques that allow continuous or periodic blood pressure measurement, both systolic and diastolic, in different individuals has shown that it experiences spontaneous variations in 24 hours. The variability of blood pressure has been calculated based on the standard deviation, and it has been possible to determine that this, with significant differences between individuals, behaves in such a way that the systolic pressure is higher than the diastolic. It has also been reported that the fluctuation is more significant in hypertensive patients than in normotensive patients, as the level of indeterminacy exists. Control charts, as in classical statistics, use the upper limit of control (ULC) and lower limit of control (LLC) to contain the existing uncertainties in the variable, although it would be advantageous to verify it using ambulatory blood pressure monitoring. The prognosis can be improved by ensuring an increase in blood pressure control in high-risk patients. This study focuses on the variations to which the variable is exposed by a level of indeterminacy existing with neutrosophic statistics. It is obtained that adult patients have the greatest affectations of this disease, which is why they require greater control and medical attention, and more precise equipment to obtain a successful result.

Keywords: Control charts, blood pressure, neutrosophic statistics.

1 Introduction

Health is a state of complete physical, mental, and social well-being, not only the absence of disease or illness, according to the World Health Organization (WHO) definition in its constitution approved in 1948 [1]. So a healthy person can live their dreams entirely. Today health is a process in which the individual moves on a health-disease axis, approaching one or the other extreme as the balance is reinforced or broken [2].

Among the diseases that affect balance is blood pressure, which is defined as the force of the blood pushing against the walls of the arteries. Every time the heart beats, it pumps blood into arteries [3].

Hypertension is the term used to describe high blood pressure. Blood pressure is highest when the heart beats, pumping blood. This is called systolic pressure. When the heart is at rest, between beats, blood pressure drops. This is defined as diastolic pressure [4, 5]. To control blood pressure, patients need to know the ideal values and the causes for concern. The blood pressure reading uses these two numbers; the systolic number is placed before or above the diastolic number. For example, 120/80 means a systolic pressure of 120 and a diastolic of 80 [6].

Blood pressure category	Systolic	Diastolic
Normal	-of 120	-of 80
Elevated	120 - 129	-of 80
Arterial Hypertension Level 1	130 - 139	80 - 89
Arterial Hypertension Level 2	140 and +	90 and +

Table 1: Blood pressure values according to the American Heart Association. Source [5]

In most people, systolic blood pressure rises steadily with age due to increased stiffness of the large arteries, long-term plaque build-up, and increased cardiovascular and heart disease [5]. As a result, patients are more likely to be told that blood pressure is too high as people become older [7]. Many factors can affect blood pressure: the amount of water and salt in the body, the state of kidneys, the nervous system or blood vessels, and hormone levels [8].

Today it is considered an incurable disease, but measurable, thanks to the correct use of the sphygmomanometer and controllable by maintaining a healthy life. Baumanometers or sphygmomanometers are instruments that measure BP, the best known being the mercury one; these need maintenance operations because they slowly lose their adjustment with continued use; in addition, aneroid sphygmomanometers decompensate with a simple blow, losing reliability [9].

The American Heart Association recommends using an automatic home blood pressure monitor that is worn on forearm. Wrist or finger blood pressure monitors are also available but may not be as accurate.

In recent decades, the development of techniques that allow continuous or periodic blood pressure measurement in different individuals has shown that it experiences spontaneous variations. These variations have been calculated based on the standard deviation in the 24-hour period, which has made it possible to determine that the variability of the mean arterial pressure is around 10% of the mean value with large differences between individuals and that the systolic variability pressure is higher than diastolic pressure [10], [11].

To define reading in the systolic and normal diastolic pressure, it is necessary to know the upper control limits (UCL) and lower control limits (LCL) (Table 1), represented in graphs. The Control charts help in the detection of unnatural models of variation in the data that result from repetitive processes and provide criteria to detect a lack of statistical control; these are applied in variables where the ranges at both frequency limits represent stability. A process is under statistical control when the variability is due only to "common causes" [12].

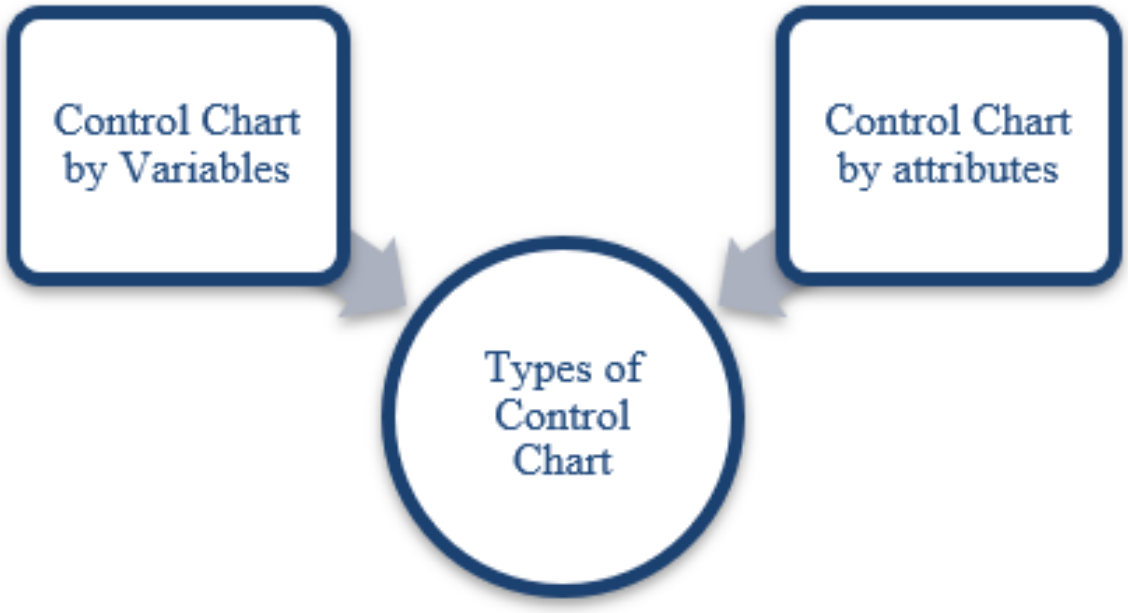

Figure 1: Types of Control Charts. Own elaboration

They are called variable control charts when the measurements can adopt a continuous range of values, for example length, weight, concentration, while attribute control charts are defined when the taken measures are not continuous [13, 14].

Control charts or control diagrams are used to control the development of production processes and identify possible instabilities and abnormal circumstances; what is intended with this type of analysis is to control the processes to ensure that they work correctly [15], [16]. A diagram serves to examine whether a process is in a stable condition or to ensure that it remains in that condition, while in health, these control charts allow verifying if a variable (BP) is within the parameters or limits required or a team is in optimal condition.

The control charts are implemented on the observed characteristics with the final objective of identifying the existence of assignable causes; these can not only identify the different types of assignable causes but also facilitate finding the capacity of the process that is based on the results of the estimation of the process parameters [17] [18].

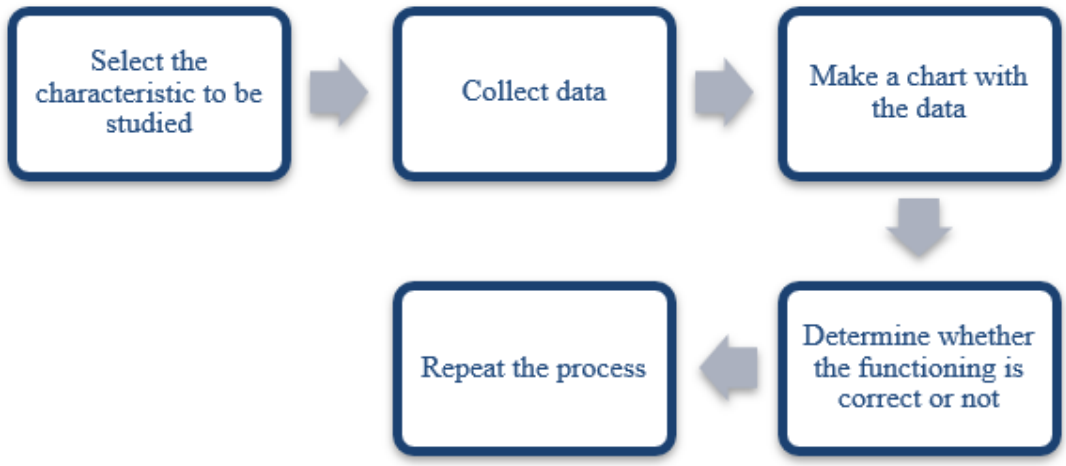

Figure 2: Steps to follow to create a control chart or diagram. Own elaboration

The main advantage of these fuzzy charts is their sensitivity over their conventional counterparts [19]. In addition, the designs of these graphs are enormously flexible and allow users to manage the vague data obtained during the measurement process [20-22].

Candidates	Initials	Amount of people	Scale (years)	Variable	Sub-element
Group 1	P1	40	20 - 30	Blood pressure	• Diastolic (PD), • Systolic (PS)
Group 2	P2	40	31 - 50		
Group 3	Q3	40	51 - +70		

Table 2. Dimensions of the neutrosophic study. Own elaboration

For the analysis of the Control Diagrams, this study defines:

- Problem situation: Changes in the normal reading of blood pressure systolic and diastolic at different stages of life.
- Main objective: define the variations of the variable in the different stages of life
- Specific objectives:
  - Determine the variations that affect the analyzed variable
  - Carry out the measurement and modeling of the variable
  - Evaluation of the different equipment in the measurement of blood pressure

2 Materials and methods

Neutrosophic probabilities and statistics are a generalization of classical and imprecise probabilities and statistics. For example, the Neutrosophic Probability of an event E is the probability that event E will occur [23], the probability that event E does not occur, and the probability of indeterminacy (not knowing whether event E occurs or not). In classical probability nsup≤1, while in neutrosophic probability, nsup≤3 +.

The function that models the neutrosophic probability of a random variable x is called the neutrosophic distribution: $NP(x) = \big(T(x), I(x), F(x)\big)$, where T (x) represents the probability that the value x occurs, F (x) represents the probability that the value x does not occur, and I (x) represents the indeterminate or unknown probability of the value x.

Neutrosophic Statistics is the analysis of neutrosophic events and deals with neutrosophic numbers, the neutrosophic probability distribution [24], neutrosophic estimation, neutrosophic regression, etc. It refers to a set of data formed totally or partially by data with some degree of indeterminacy and the methods to analyze them. Neutrosophic statistical methods allow the interpretation and organization of neutrosophic data (data that can be ambiguous, vague, imprecise, incomplete, or even unknown) to reveal the underlying patterns [25]. In short, the Neutrosophic Logic[26, 27], Neutrosophic Sets, and Neutrosophic Probabilities and Statistics have a wide application in various research fields and constitute a new reference of study in full development. The Neutrosophic Descriptive Statistics includes all the techniques to summarize and describe the characteristics of the neutrosophic numerical data [28-33].

Neutrosophic Numbers are numbers of the form $N = a + bI$ where a and b are real or complex numbers [34], while "I" is the indeterminacy part of the neutrosophic number N.

The study of neutrosophic statistics refers to a neutrosophic random variable where X_l and $X_u I_N$ represents the corresponding lower and upper level that the studied variable can reach in an indeterminate interval $[I_l, I_u]$. Following the neutrosophic mean of the variable $(\bar{x}_N)$when formulating:

$$X_N = X_l + X_u I_N;\ I_N \in [I_l, I_u] \tag{1}$$

$$\text{Where } \bar{x}_a = \frac{1}{n_N} \sum_{i=1}^{n_N},\ X_{il}\ \bar{x}_b = \frac{1}{n_N} \sum_{i=1}^{n_N},\ X_{iu}\ n_N \in [n_l, n_u] \tag{2}$$

is a neutrosophic random sample. However, for the calculation of neutral squares (NNS) it can be calculated as follows:

$$\sum_{i=1}^{nN} (\bar{X} - \bar{X}_{iN})^2 = \sum_{i=1}^{nN} \begin{bmatrix} min \begin{pmatrix} (a_i + b_i I_L)(\bar{a} + \bar{b} I_L), (a_i + b_i I_L)(\bar{a} + \bar{b} I_U) \\ (a_i + b_i I_U)(\bar{a} + \bar{b} I_L), (a_i + b_i I_U)(\bar{a} + \bar{b} I_U) \end{pmatrix} \\ max \begin{pmatrix} (a_i + b_i I_L)(\bar{a} + \bar{b} I_L), (a_i + b_i I_L)(\bar{a} + \bar{b} I_U) \\ (a_i + b_i I_U)(\bar{a} + \bar{b} I_L), (a_i + b_i I_U)(\bar{a} + \bar{b} I_U) \end{pmatrix} \end{bmatrix}, I \in [I_L, I_U] \tag{3}$$

Where $a_i = X_l b_i = X_u$. The variance of the neutrosophic sample can be calculated by

$$S_N^2 = \frac{\sum_{i=1}^{nN} (X_i - \bar{X}_{iN})^2}{n_N};\ S_N^2 \in [S_L^2, S_U^2] \tag{4}$$

The neutrosophic coefficient (NCV) measures the consistency of the variable. The lower the NCV value, the more consistent the factor's performance is. NCV can be calculated as follows [35].

$$\frac{\sqrt{S_N^2}}{\bar{X}_N} X100;\ CV_N \in [CV_L, CV_U] CV_N = \tag{5}$$

3 Results

Data collection

For the modeling and analysis of the results, 3 groups of 20 people were selected (Table 2). Blood pressure is taken from the patients included in the study for 10 days, and the variations are processed with the use of neutrosophic statistics to obtain the ranges of indeterminacy of the variable in the measurement of normal blood pressure. Two measurements were made for each day, and they were taken as ULC and LLC for DP and SP according to Table 1.

Variable analyzed: arterial hypertension For a sample of n = 10 days, for each group

Code	Initials	Candidates
a	P1	Group 1
b	P2	Group 2
c	Q3	Group 3

Table 4. Coding of candidates for modeling. Own elaboration

As a result of the existing indeterminacy, the use of neutrosophic statistics is necessary for its better understanding, since the use of classical statistics is not possible. For the development of the statistical study, the neutrosophic frequencies of the variable in each SP and DP sub-element and their variations are analyzed.

Days	Neutrosophic frequencies		
	P1	P2	Q3
1	[106; 107]	[118; 122]	[124; 125]
2	[104; 105]	[118; 123]	[123; 123]
3	[102; 107]	[116; 121]	[122; 131]
4	[105; 114]	[110; 118]	[128; 133]
5	[102; 104]	[120; 130]	[121; 128]

6	[103; 113]	[114; 118]	[122; 129]
7	[109; 119]	[118; 128]	[125; 132]
8	[105; 108]	[111; 114]	[129; 135]
9	[100; 109]	[110; 120]	[122; 124]
10	[100; 101]	[115; 118]	[128; 135]

Table 5. Neutrosophic frequencies of SP. Own elaboration

Days	Neutrosophic frequencies		
	P1	P2	Q3
1	[60; 63]	[78; 80]	[84; 84]
2	[60; 60]	[77; 78]	[88; 90]
3	[70; 70]	[76; 77]	[88; 92]
4	[68; 73]	[77; 78]	[81; 81]
5	[63; 64]	[72; 73]	[82; 84]
6	[62; 64]	[70; 74]	[87; 89]
7	[61; 64]	[78; 81]	[81; 82]
8	[60; 64]	[80; 84]	[88; 91]
9	[61; 65]	[72; 74]	[83; 83]
10	[70; 70]	[75; 77]	[86; 90]

Table 6. Neutrosophic frequencies of PD. Own elaboration

Tables 5 and 6 show the pressure variations in stable health conditions for people of different groups for the 10 days analyzed, with an occurrence level of 2 times per day for each group. It is visible that the measurements vary depending on the times the blood pressure is measured, although it is noteworthy that for each group there is a level of indeterminacy for aPS= 3, bPS=3, cPS= 3 and aPD= 10, bPD=3, cPD= 3, with a level of representativeness for the third group or older adult.

Neutrosophic statistical analysis

From the neutrosophic statistical analysis for the measurement of blood pressure (Table 7 and 8), it is observed that the representative mean, $\bar{x} = \in [\bar{x}_L; \bar{x}_U]$, the values of the neutrosophic means for SP and DP and their variations at the time of defining a normal arterial pressure are calculated. The contribution of the neutrosophic standard deviation $S_N \in [S_L; S_U]$ determines in which group a greater interest is required and where the measurement changes are more frequent as the person gets older $CV_N \in [CV_L\ ;\ CV_U]$.

Candidates	$\bar{x}_N$	YN	CVN
P1	[103.6; 108.7]	[3,674; 6,247]	[0.035; 0.057]
P2	[115; 121.2]	[5,196; 5,848]	[0.045; 0.048]
Q3	[124.4; 129.5]	[3,796; 4,644]	[0.031; 0.036]

Table 7. Neutrosophic statistical analysis of SP. Own elaboration

Candidates	$\bar{x}_N$	*YN*	*CVN*
P1	[64 + 66 I]	[6,567; 4,875]	[0.103; 0.074]
P2	[76 + 78 I]	[4,884; 4,385]	[0.064; 0.056]
Q3	[85 + 87 I]	[3,144; 4,556]	[0.037; 0.052]

Table 8. Neutrosophic statistical analysis of DP. Own elaboration

This means that for group 3 it is, on average, the one that affects the variations in blood pressure the most. On the other hand, the value of CV_N determines that it is more coherent when it comes to having more precise results due to the history that people have throughout of the life. Most medical studies establish a period of 7 to 10 days to determine through the results if the person has decompensating problems. It should be noted that the existence of LLC and ULC is indicated to give a definitive diagnosis (Figure 5). For this study, we will have for LLCDP ≤ 80 and ULCSP ≤ 120

From the results modeled in charts, we obtained:

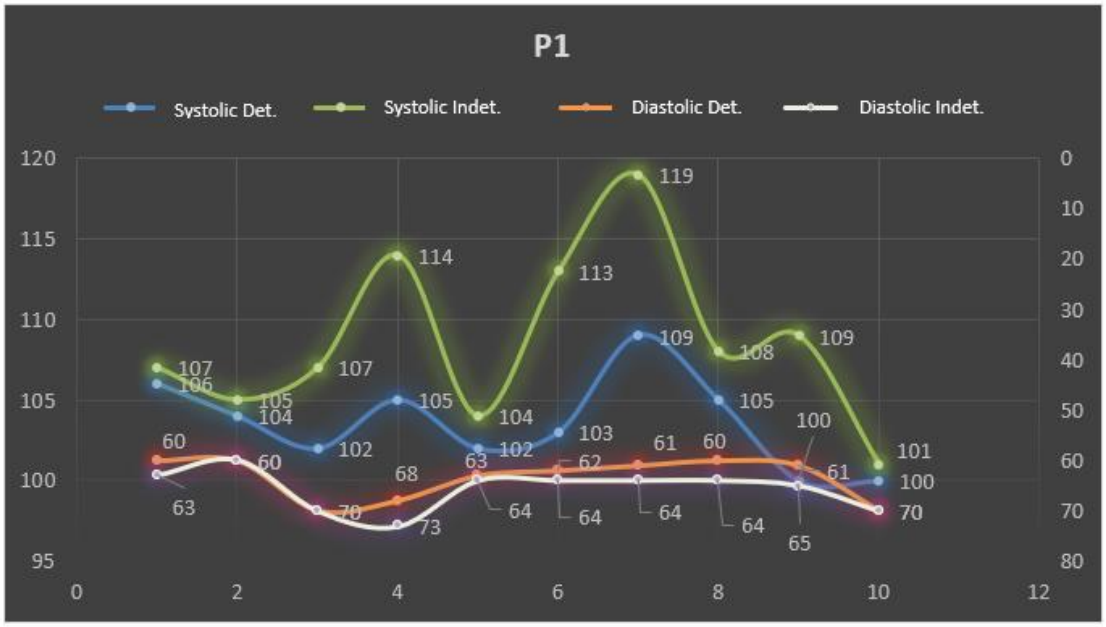

Figure 3. Neutrosophic scatter plot of the measurement variations for SP and DP in P1. Source: Own elaboration

In figure 3 for the P1 group, it is observed that the SP levels are between [100; 119], while in DP it ranges between [60; 73], with levels of indeterminacy existing for both sub-elements that are included in LLC and ULC.

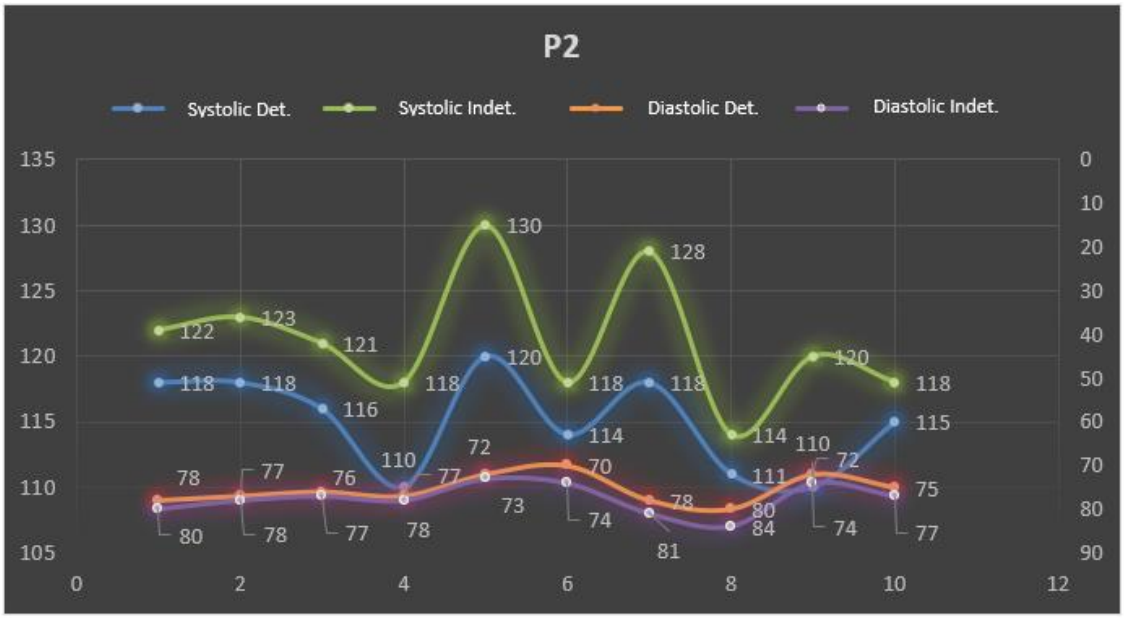

Figure 4. Neutrosophic scatter plot of the measurement variations for SP and DP in P2. Own elaboration

In the figure for group P2 it is observed that the levels of SP are between [110; 130], while in DP it ranges between [70; 84], with existing levels of indeterminacy for both sub-elements that are 90% included in LLC and only 50% is included in ULC for this range. It is evident that it is considered a not-so-normal pressure measurement for many health specialists when the patient was younger due to the physical and external changes that the person is exposed to.

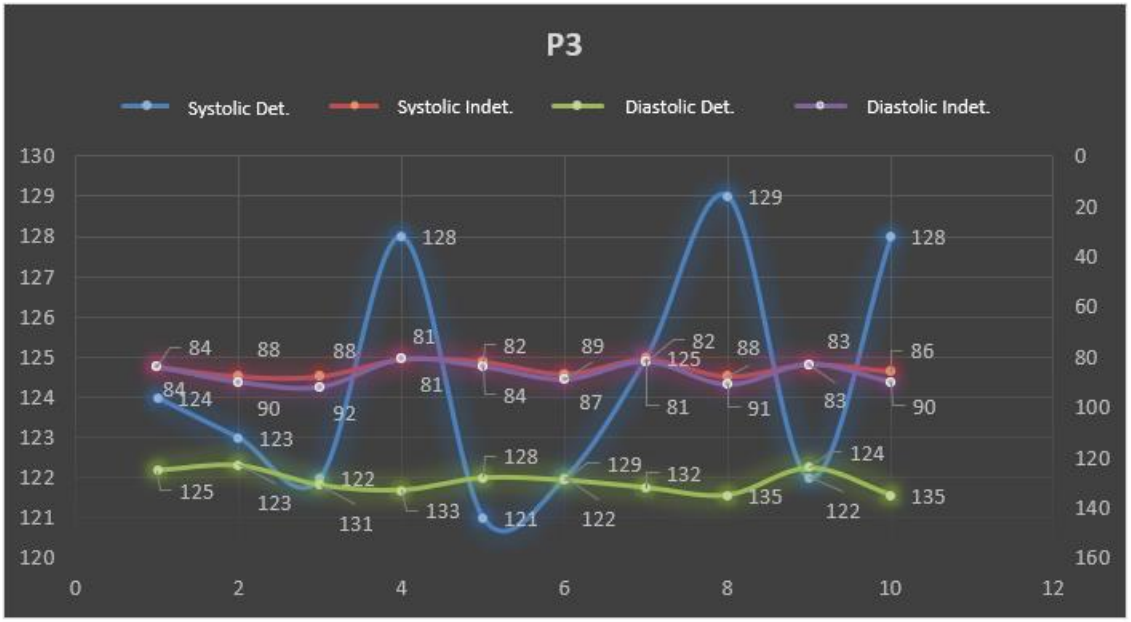

Figure 5: Neutrosophic scatter plot of the measurement variations for SP and DP in P3. Source: own elaboration

In the figure for the P3 group, it is observed that the levels of SP are between [129; 135], while in DP it goes between [81; 92], with an appreciable increase in the existing levels of indeterminacy for both sub-elements that are outside the ranges of LLC and ULC.

Comparative analysis

To determine the measure of indeterminacy regarding the measurements, it is associated for each and to the form of neutrosophic numbers. In the results obtained, it is observed that for the values they go from$\bar{x} = \in [\bar{x}_L; \bar{x}_U], S_N \in [S_L; S_U] CV_N \in [CV_L\ ;\ CV_U] CV_N$0.031 to 0.035 for systolic pressure and diastolic pressure from 0.037 to 0.103, with the levels of indeterminacy according to tables 9 and 10.

From the results obtained in the existing indeterminacy, it can be deduced that for patients between 51 and more than 70 years of age, there is a consistent and precise level of information when determining the variations in the measurement of blood pressure since as the patient debuts with this disease, more measurements are made throughout life and thus more information to analyze the existing uncertainties. Therefore, as a final result, a higher level of monitoring should be focused on patients in group 3.

Group	$\bar{x}_N$	YN	CVN
P1	104 + 109 I; I ∈ [0; 0.46]	3,674 + 6,247 I; I ∈ [0; 0.41]	0.035 + 0.057 I; I ∈ [0; 0.38]
P2	115 + 121 I; I ∈ [0; 0.50]	5,196 + 5,848 I; I ∈ [0; 0.11]	0.045 + 0.048 I; I ∈ [0; 0.63]
Q3	124 + 130 I; I ∈ [0; 0.46]	3,796 + 4,644 I; I ∈ [0; 0.18]	0.031 + 0.036 I; I ∈ [0; 0.13]

Table 9: Neutrosophic forms with a measure of indeterminacy for PS. Own elaboration

Group	$\bar{x}_N$	YN	CVN
P1	64 + 66 I;I ∈ [0; 0.30]	6,567 + 4,875 I;I ∈ [0; 0.34]	0.103 + 0.074 I;I ∈ [0; 0.39]
P2	76 + 78 I;I ∈ [0; 0.26]	4,884 + 4,385 I;I ∈ [0; 0.11]	0.064 + 0.056 I;I ∈ [0; 0.14]
Q3	85 + 87 I;I ∈ [0; 0.23]	3,144 + 4,556 I;I ∈ [0; 0.31]	0.037 + 0.052 I;I ∈ [0; 0.28]

Table 10: Neutrosophic forms with indeterminacy measure for PD. Own elaboration

Partial solutions

Aging is one of the main factors that cause blood pressure to increase more than it should, as the arteries harden with age, becoming less elastic, so a healthier diet and exercise practice would help control blood pressure variations in systolic and diastolic pressure.

- Patients with tension problems can control their levels thanks to modern devices adapted for use at home, for this reason, it is necessary for this group of people to have access to these, as well as to be handy and precise.

Conclusions

From the results, after having modeled the blood pressure variable, we concluded that:

- Control charts constitute a technology in the statistical field that allow health personnel to act quickly in case of inadequate performance of medical equipment that causes an increase in the variations in the modeled variables; however, it must be made explicit that the variables with more significant fluctuation it is necessary to apply the ULC and LLC depending on the conditions and the changing environment. An example of these is blood pressure, which, as these limits exist, can be violated by increasing indeterminacy and require new limits to control depending on age.
- The results of the neutrosophic statistics show that the use of the ULC and LLC in the control charts allows obtaining normal readings in fluctuations of variables with an existing level of indeterminacy and far from the precision of classical values.
- It is evidenced that adult patients present a trend and greater variation in normal blood pressure measurements. It is summarized that new ULC and LLC should be introduced depending on the groups of people and those secondary diseases that motivate the variations for the minimum and maximum.
- Although the main causes of the variation in blood pressure have not been determined, there is evidence that numerous nervous, reflex and behavioral factors are involved in the variations of the variable, so it is necessary to include the limits in the variation of the variation the indeterminacy. The neutrosophic statistical analysis shows a lower CVN value for people in the third group, where the measurements of this variable are more consistent when defining the indeterminacy.

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