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Neutrosophic Evaluation of Dental Implant Success Rates

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Abstract: This article introduces the concept of neutrosophy, a philosophy that promotes neutrality and balance in decision making and evaluation of situations within the medical field. Neutrosophy, while not yet widespread, may prove useful in ethically complex medical scenarios by encouraging balanced decisions and multiple perspective consideration. In implant dentistry, the success rates are influenced by factors including implant location, patient's general health, implant type, and surgical technique. The article employs a neutrosophic approach to assess the success rates of dental implants in a more comprehensive and unbiased manner. The approach considers both quantitative and qualitative aspects, along with uncertainties, to achieve a balanced evaluation. The findings indicate that the top priority criterion is the absence of pain or discomfort, followed by functionality and long-term maintenance, while the survival rate of the implant is less preferred. In summary, neutrosophy presents a valuable approach to appraise the success rates of dental implants in a well-rounded and ethical manner, incorporating diverse viewpoints that can benefit both dental practitioners and patients in decision-making.

Keywords: Neutrosophy, dental implants, success rates, dentistry, patients.

1 Introduction

Neutrosophy is a philosophy that focuses on the concept of neutrality and the pursuit of equilibrium in decision-making and situation assessment. Although not extensively acknowledged in scientific or medical circles, the term has some applicability in these fields in particular circumstances.[1], [2]

In medical decision making, neutrosophy can help physicians make unbiased and objective medical decisions by considering all aspects of a clinical case, including risks and benefits, as well as the patient's preferences and values. When dealing with complex ethical situations in medical care, such as making end-of-life decisions or allocating limited resources, health care professionals may benefit from implementing neutrosophy. This approach can aid in approaching ethical dilemmas in a more balanced manner and considering multiple perspectives.[3]

Neutrosophy can encourage more open and balanced communication between doctors and patients, allowing patients to actively participate in making decisions about their health care. In medical research, neutrosophy could help scientists fairly evaluate the results of clinical studies and consider the validity of different therapeutic approaches [4]. In healthcare settings, where differences of opinion and conflicts may arise, neutrosophy could be used as an approach to mediate and resolve disputes impartially.[5], [6]

It is important to note that neutrosophy is neither a standard medical practice nor a recognized tool in the field of medicine. Medicine is based on solid scientific evidence, established clinical practices, and well-defined ethical principles. However, some principles of neutrosophy, such as seeking balance and considering multiple perspectives [7], may be useful in certain aspects of healthcare to promote more informed and ethical decisions. [8]

The evaluation of dental implant success rates is essential to determine the effectiveness and quality of dental implantology procedures [9]. This is important for both dental professionals and patients [10]. The following describes some key aspects of evaluating dental implant success rates:

1. Clinical parameters: Dental professionals evaluate the success rate of a dental implant by observing clinical parameters, such as implant stability, lack of mobility, health of surrounding tissues, and proper occlusion. These aspects are evaluated during long-term follow-up after implant placement.
2. X-rays: Panoramic x-rays or CT images, are used to evaluate the integration of the implant with the bone, proper position, and the absence of complications such as infections or bone reabsorption.

3. Evaluation of periodontal health: The health of the surrounding gums and the absence of periodontal disease are critical factors in evaluating the success of a dental implant. Inflammation or infection of the gums can jeopardize the stability of the implant.
4. Patient Evaluation: Patients also play a key role in evaluating the success rates of dental implants. They should follow oral care recommendations and maintain good oral hygiene to ensure the long-term success of their implants.
5. Risk factors: Assessment of patient risk factors such as general health, smoking, and pre-existing medical conditions is also important as they can influence the success rate of dental implants.

The evaluation of dental implant success rates is based on a series of clinical and radiological criteria, as well as the patient's active cooperation in the care and maintenance of oral health. Neutrosophy, if referring to any specific approach or technique, could potentially play a role in the evaluation. It is important that dental professionals use established and widely accepted methods to evaluate the effectiveness of dental implants.[11], [12-16]

The main objective of this research is to apply the neutrosophic approach to evaluate and analyze the success rates of dental implants from a more complete and balanced perspective. This will allow the development of a neutrosophic evaluation framework that allows considering not only quantitative aspects (for example, implant survival rates), but also qualitative aspects and uncertainties associated with success rates. In this way, providing recommendations and conclusions that may be useful to dental professionals and patients when making informed decisions about dental implants.

2 Preliminaries

Definition 1. Let X be a space of points (objects) with generic elements in X denoted by x. A single-valued neutrosophic set (SVNS) A in X is characterized by truth-membership function T_A (x), indeterminacy-membership function I_A (x), and falsity membership function F_A (x). Then, an SVNS A can be denoted by A = {x, $T_A(x)$, $I_A(x)$, $F_A(x)$ x ∈ X}, where T_A (x), I_A (x), F_A (x) ∈ [0, 1] for each point x in X. Therefore, the sum of T_A (x), I_A (x) and F_A (x) satisfies the condition $0 \leq T_A (x) + I_A(x) + F_A(x) \leq 3$[13-17-20].

Decision-making normally involves human language or is commonly referred to as *linguistic variables*. A linguistic variable simply represents words or terms used in human language. Therefore, this linguistic variable approach is convenient for decision-makers to express their assessments. Ratings of criteria can be expressed by using linguistic variables. Linguistic variables can be transformed into SVNSs as shown in Table 1.

Table 1: Linguistic variable and Single Valued Neutrosophic Numbers (SVNNs). Source: [14]

Linguistic variable	SVNS
Extremely preferred (EXP)	(1,0,0)
Very very preferred (VVP)	(0.9, 0.1, 0.1)
Very preferred (VP)	(0.8,0,15,0.20)
Preferred (P)	(0.70,0.25,0.30)
Equally preferred (EP)	(0.50,0.50,0.50)
Not preferred (NP)	(0.35,0.75,0.80)
Very not preferred (VNP)	(0.20,0.85,0.80)
Very very not preferred (VVNP)	(0.10,0.90,0.90)
Extremely not preferred (ENP)	(0,1,1)

Definition2. Let Ek = (Tk, Ik, Fk) be a neutrosophic number defined for the rating of k-th decision-maker. Then, the weight of the kth decision-maker can be written as [15-18]:

$$\psi_k = \frac{1-\sqrt{[(1-T_k(x))^2+(I_k(x))^2+(\mathrm{F}(x))^2]/3}}{\sum_{k=1}^{p}\sqrt{[(1-T_k(x))^2+(I_k(x))^2+(\mathrm{F}(x))^2]/3}} \tag{1}$$

Further, in achieving a favorable solution, group decision-making is important in any decision-making process. All the individual decision-maker assessments need to be aggregated into a neutrosophic decision matrix in the group decision-making process. This can be done by using a single-valued neutrosophic weighted averaging (SVNWA) aggregation operator proposed by Ye [14-19].

Definition 3. Let D (k) = (dij (k)) mxn be the single-valued neutrosophic decision matrix of the k-th decision-maker and be the weight vector of decision-maker such that each where$\psi = (\psi_1\psi_2, \dots, \psi_p)^T\psi_k \in [0,1], D = (d_{ij})_{mxn}$

$$d_{ij} = \langle 1 - \prod_{k=1}^{p}\left(1 - T_{ij}^{(p)}\right)^{\psi_k}, \prod_{k=1}^{p}\left(I_{ij}^{(p)}\right)^{\psi_k}, \prod_{k=1}^{p}\left(F_{ij}^{(p)}\right)^{\psi_k}\rangle \quad (2)$$

Definition 4. Let A and B be two single-valued neutrosophic numbers (SVNNs), then the normalized Hamming distance between them is:

$$d(A, B)\frac{|TA - TB| + |IA - IB| + |FA - FB|}{3} \quad (3)$$

Definition 5. Let A= (T_A, I_A, F_A) be a SVNN, the complement of SVNN A is:

$$A.C. = (F_A, 1\text{-}I_A, T_A). \quad (4)$$

2.1 Method

Let $A = (A_1, \dots, A_m)$ be the alternatives, and G = (G1, G2, …, Gn) be the attributes. Let W = (w1, w2, …, wn) be the weights of the attributes, where 0≤wj≤1, $\sum_{j=1}^{n} w_j = 1$. Let aij, i = 1, 2… m, j = 1, 2, .., n, be the attribute value of the alternative A_i with attribute G_j, the $A = (a_{ij})\ m{\times}n = \langle(T_{ij}, I_{ij}, F_{ij})\rangle_{mxn}$is a SVNNs matrix, where T_{ij}, I_{ij}, and F_{ij} are membership degree, indeterminacy-membership degree, and non-membership degree, respectively. The steps to perform the analysis are described below:

- **Step 1:** Identify the decision alternatives to evaluate.
- **Step 2:** Determine the weights of decision-makers. Due to the method's logic, each decision-maker can have a unique and different evaluation from the rest of the decision-makers since each evaluation is awarded according to the level of knowledge of each expert regarding the decision topic discussed. The relative weight of each decision-maker is considered as linguistic variable and is converted into SVNN to later be identified by equation (1).
- **Step 3:** Convert linguistic assessments into SVNN given by experts. From the individual integer matrices obtained from the expert evaluations, the individual neutrosophic matrices of the decision-makers are constructed, as indicated in Table 1.
- **Step 4:** Obtain the initial relation matrix of alternatives A = (A1, …, Am) and attributes G = (G1, G2, …, Gn), where each aij, i = 1, 2, …, m, j = 1, 2, ..., n, is the value of the attribute of the alternative Ai with the attribute G. The A = (aij) m × n = $\langle(T_{ij}, I_{ij}, F_{ij})\rangle_{mxn}$ is an SVNNs matrix, where T_{ij}, I_{ij}, and F_{ij} are the degree of membership, degree of indeterminacy- membership, and degree of non-membership, using equation (2).
- **Step 5:** Standardize decision information. That is, normalize A = (aij) m × n into B = (bij) m × n. If the decision is a cost factor, the decision information should be changed to its complementary set using equation (3), while if it is an efficiency factor, it should not be changed.
- **Step 6:** Construct a preference function Pj (Bi, Br) of the alternative Bi relative to Br under the attribute Gj using (5).

$$P_j(B_i, B_r) = \begin{cases} 0, d \le p \\ \frac{d-p}{q-p}, p < d < q \\ 1, d \ge q \end{cases} \quad (5)$$

- **Step 7**: Calculate the relative weight of the attributes w_{jr}, which is the relative weight of Gj to Gr, where

$$w_{jr} = \frac{w_j}{w_r} = (j, r = 1,2, \dots, n) \quad (6)$$

- **Step 8:** Define the priority index π (Bi, Br) of the Bi scheme relative to Br by

$$\pi(B_i, B_r) = \frac{\sum_{j=1}^{n} w_{jr} P_j(B_i, B_r)}{\sum_{j=1}^{n} w_{jr}} \quad (7)$$

- **Step 9:** Calculate inflow Φ^+ (Bi), the outflowΦ^- (Bi) and the net flow Φ (Bi) as follows.

$$\Phi^+(\mathrm{B}_i) = \frac{\sum_{r=1}^{m} \pi(B_i, B_r) - \min_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_i, B_r)\}}{\max_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_i, B_r)\} - \min_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_i, B_r)\}} \quad (8)$$

$$\Phi^-(\mathrm{B}_i) = \frac{\sum_{r=1}^{m} \pi(B_r, B_i) - \min_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_r, B_i)\}}{\max_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_r, B_i)\} - \min_{1 \le i \le m}\{\sum_{r=1}^{m} \pi(B_r, B_i)\}} \quad (9)$$

$$\Phi(\mathrm{B}_i) = \Phi^+(\mathrm{B}_i) - \Phi^-(\mathrm{B}_i) \quad (10)$$

- **Step 10:** Classify all the alternatives according to the value of $\Phi(\mathrm{B}_i)$. The higher the value of $\Phi(\mathrm{B}_i)$the better the alternative.

2.2 Methodological process

To identify alternatives to evaluate, a comprehensive review of the scientific literature related to dental implant success rates was conducted. The review identified the key factors that have been investigated, as well as the traditional approaches used in their evaluation. The most frequent indicators used to determine the success of dental implants include:

- Implant survival rate: This is the main indicator and refers to whether the implant remains in place and functional. It is measured as the percentage of implants that have not failed or been lost over time.
- No pain or discomfort: The lack of persistent pain or discomfort around the implant is an important indicator of success.
- Functionality: The patient's ability to chew and speak without problems with the implant is considered an important indicator.
- Aesthetic appearance: In cases of implants in visible areas, the aesthetic appearance is evaluated, including the alignment and color of the artificial tooth.
- Long-term maintenance: The patient must maintain good oral hygiene and have regular check-ups with the dentist to ensure the long-term success of the implant.

It is important to note that standards of success may vary by study and dental health professional. In some cases, an implant can be considered successful even if it does not meet all these indicators, as long as it provides adequate function and does not cause significant problems. However, in general, a high success rate in all these aspects is sought to consider an implant successful in the long term.

When evaluating the variables that influence dental implant success rates, it is important to consider several key factors that can affect the outcome and durability of the implants. There are various criteria to evaluate regarding the success rates of dental implants, however, they are also considered depending on the particular interest on the objective to be achieved. This study was structured with four evaluation criteria presented and endorsed by the decision makers. For the analysis, each criterion was assigned equal weight (w = 0.25). The following criteria will be considered for analyzing these variables:

- (IL) Implant location: The location of the implant in the mouth can influence its success. Implants in the posterior area may be subjected to more chewing forces than those in the anterior area, which may affect the success rate.
- (PH) Patient's health status: Underlying medical conditions, such as diabetes, osteoporosis, smoking and other risk factors, can influence the success rate of dental implants.

- (TM) Type of implant and material: The type of implant and the material used are also influential factors. Titanium implants are common, but there are other options, such as zirconia implants. The choice of implant must be appropriate for the patient's needs.
- (SP) Surgical procedure: The surgical technique used to place the implant, including precision in drilling the site and initial stability, is essential for success.

3 Results and Discussion

Table 2 shows the evaluations given to decision-makers according to their relative importance in terms of the topic discussed.

Table 2: Evaluations granted to decision-makers according to their importance. Source: Own elaboration

Decision-makers	Linguistic assessment	SVNN	Numerical value
Decision-maker 1	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 2	Moderately important	(0.5; 0.5; 0.5)	0.17
Decision-maker 3	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 4	Very important	(0.9; 0.1; 0.1)	0.21
Decision-maker 5	Important	(0.75; 0.25; 0.20)	0.2

Once the decision-makers individually evaluate the indicated alternatives based on each of the chosen criteria or attributes for the evaluation, they are transformed through equation (2) to obtain the normal alternative decision matrix, which is shown in Table 3.

Table 3: Normal decision matrix of alternatives. Source: Own elaboration

	IL	PH	TM	SP
Implant survival rate	(0.61424; 0.38576; 0.35486)	(0.67429; 0.32571; 0.28374)	(0.7626; 0.2374; 0.2081)	(0.7257; 0.2743; 0.2519)
Absence of pain or discomfort	(0.55653; 0.44347; 0.42667)	(0.5; 0.5; 0.5)	(0.56731; 0.43269; 0.41301)	(0.5; 0.5; 0.5)
Functionality	(0.68696; 0.31304; 0.2988)	(0.54297; 0.47088; 0.45555)	(0.47187; 0.54413; 0.5515)	(0.6024; 0.4096; 0.3789)
Aesthetic appearance	(0.69071; 0.30929; 0.29523)	(0.61623; 0.38377; 0.35244)	(0.47187; 0.54413; 0.5515)	(0.5673; 0.4327; 0.413)
Long term mainte-nance	(0.5; 0.5; 0.5)	(0.55653; 0.44347; 0.42667)	(0.5; 0.5; 0.5)	(0.7445; 0.2555; 0.2555)

All selected criteria are considered benefit criteria; That is, they must be maximized, except for criterion 4, so that the normalized matrix obtained coincides with the normal matrix shown in Table 3. From it, the preference degree matrices Pj (Bi, Br) with respect to Gj are obtained. This calculation can be performed using the proposed linear function (4). For this case it is assumed that q = 1, p = 0 (see Figure 1).

Figure 1: Matrix of degrees of preference (Pn) for each criterion. Source: Own elaboration

$$P_1 = \begin{array}{c} \\ B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{array} \begin{vmatrix} B_1 & B_2 & B_3 & B_4 & B_5 \\ 0.0000 & 0.0000 & 0.0187 & 0.0199 & 0.0000 \\ 0.0239 & 0.0000 & 0.0426 & 0.0438 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0012 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0484 & 0.0245 & 0.0671 & 0.0683 & 0.0000 \end{vmatrix}$$

$$P_2 = \left|\begin{array}{cccccc} & B_1 & B_2 & B_3 & B_4 & B_5 \\ B_1 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ B_2 & 0.0721 & 0.0000 & 0.0102 & 0.0492 & 0.0244 \\ B_3 & 0.0619 & 0.0000 & 0.0000 & 0.0390 & 0.0142 \\ B_4 & 0.0229 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ B_5 & 0.0476 & 0.0000 & 0.0000 & 0.0247 & 0.0000 \end{array}\right|$$

$$\mathrm{P}_3 = \left|\begin{array}{cccccc} & \mathrm{B}_1 & \mathrm{B}_2 & \mathrm{B}_3 & \mathrm{B}_4 & \mathrm{B}_5 \\ \mathrm{B}_1 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ \mathrm{B}_2 & 0.0683 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ \mathrm{B}_3 & 0.1198 & 0.0515 & 0.0000 & 0.0000 & 0.0225 \\ \mathrm{B}_4 & 0.1198 & 0.0515 & 0.0000 & 0.0000 & 0.0225 \\ \mathrm{B}_5 & 0.0973 & 0.0290 & 0.0000 & 0.0000 & 0.0000 \end{array}\right|$$

$$P_4 = \left|\begin{array}{cccccc} & B_1 & B_2 & B_3 & B_4 & B_5 \\ B_1 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ B_2 & 0.0827 & 0.0000 & 0.0364 & 0.0290 & 0.0815 \\ B_3 & 0.0463 & 0.0000 & 0.0000 & 0.0000 & 0.0451 \\ B_4 & 0.0537 & 0.0000 & 0.0074 & 0.0000 & 0.0525 \\ B_5 & 0.0012 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{array}\right|$$

Using equation (6), the integral priority index is obtained, as shown in figure 2, from which the inflow, outflow and net flows of each alternative are obtained, as shown in table 4.

Figure 2: Integral priority index of the Bi scheme relative to Br. Source: Own elaboration

$$\Pi = \left|\begin{array}{cccccc} & B_1 & B_2 & B_3 & B_4 & B_5 \\ B_1 & 0.000 & 0.000 & 0.005 & 0.005 & 0.000 \\ B_2 & 0.062 & 0.000 & 0.022 & 0.030 & 0.026 \\ B_3 & 0.057 & 0.013 & 0.000 & 0.010 & 0.020 \\ B_4 & 0.049 & 0.013 & 0.002 & 0.000 & 0.019 \\ B_5 & 0.049 & 0.013 & 0.017 & 0.023 & 0.000 \end{array}\right|$$

Table 4. Input, output, and net flows of the alternatives. Source: Own elaboration

	Φ+	**Φ−**	**Φ**
Implant survival rate	0	1,000	-1,000
Absence of pain or discomfort	1	0.000	1,000
Functionality	0.691	0.036	0.654
Aesthetic appearance	0.555	0.167	0.388
Long term maintenance	0.703	0.150	0.553

The positive and negative values in this analysis denote the degrees of preference and non-preference with respect to other alternatives. It can be observed from the obtained results that the absence of pain or discomfort is the most preferred variable compared to the others. Its superiority over the other variables is undisputable. Functionality and long-term maintenance are prioritized, with the implant survival rate being the least preferred. However, the analysis of negative feedback shows that the implant survival rate is the most non-preferred among the other systems.

The net flows confirm the data provided by the negative and positive flows and show that the aspect of preference by analysts regarding the success rates of dental implants during decision making was the absence of pain or discomfort, placing functionality and long-term maintenance in second and third place, respectively.

Conclusion

Neutrosophy is a philosophy that promotes the search for balance and neutrality in decision-making and evaluation of situations, and although it is not widely recognized in the medical field, it can be useful in certain contexts of medical care, especially in ethically complex situations.

In the field of dental implantology, evaluation of success rates is essential to determine the effectiveness of procedures. This evaluation is based on clinical parameters, radiographs, periodontal health, patient evaluation, and patient risk factors. The location of the implant, the patient's overall health, the type of implant and material used, and the surgical technique are key factors that influence the success rates of dental implants.

In this study, a neutrosophic approach was applied to evaluate and analyze the success rates of dental implants from a more complete and balanced perspective. This allowed to consider both quantitative and qualitative aspects, as well as the associated uncertainties. The results of the neutrosophic analysis indicated that the absence of pain or discomfort was the most preferred criterion among the analysts, followed by functionality and long-term maintenance. The implant survival rate had the lowest level of preference.

The net preference flows confirmed that the absence of pain or discomfort is the most important aspect in dental implant decision making, highlighting its relevance in patient satisfaction and the long-term success of the procedure. The neutrosophic approach provides a useful tool to evaluate dental implant success rates in a more balanced manner and considering multiple perspectives, which can help dental professionals and patients make more informed and ethical decisions in this field. However, the importance of using established and widely accepted methods in evaluating the effectiveness of dental implants in clinical practice is highlighted.

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