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Medical Ethics-based ICU Admission Evaluation Using Fuzzy Logic for COVID-19-like Pandemic

COVID-19 Benzeri Pandemi için Bulanık Mantık Kullanarak Tıbbi Etik Temelli YBÜ Kabul Değerlendirmesi

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Abstract

Objective: In this study, a novel fuzzy logic model for intensive care unit (ICU) admission was developed by including not only the medical patient information but also medical ethics to aid in decision-making during pandemic respiratory infectious conditions such as Coronavirus disease-2019 to fill the gap in the literature.

Method: A two-stage fuzzy rule base incorporating experts' experiences was developed to reach a fair decision to prioritize patients for ICU admission. Age, oxygen saturation, and comorbidities were considered as medical risk factors, while the survival probability, discharge period expectancy, and life-cycle principle were considered as ethical parameters.

Results: The ranking score of fair admission is verified by the experts' decisions. As an important validation of the study, an excellent agreement was obtained between the experts' scores and the results of the fuzzy logic algorithm informed by medical information and medical ethics. The scores estimated from the fuzzy logic algorithm were highly positively correlated with those obtained from experts, having r=1 and p<0.01.

Conclusion: The final decision should be left to the responsible doctor in charge. The proposed algorithm is extensible to different numbers and types of medical inputs, ethical perspectives, and the severity of pandemic situations.

Keywords: Fair admission, fuzzy logic, intensive care unit, medical ethics, medical information

Öz

Amaç: Bu çalışmada, literatürdeki boşluğu doldurmak amacıyla, Koronavirüs hastalığı-2019 gibi pandemik solunum yolu enfeksiyonu durumlarında karara katkıda bulunmak amacıyla sadece tıbbi hasta bilgilerinin değil tıp etiğinin de dahil edilmesiyle yoğun bakım ünitesine (YBÜ) kabul için yeni bir bulanık mantık modeli geliştirilmiştir.

Yöntem: YBÜ'ye kabul için hastaları önceliklendirmek amacıyla adil bir karar vermeye ulaşmak amacıyla uzmanın deneyiminden yararlanılarak iki aşamalı bir bulanık kural tablosu geliştirildi. Tıbbi risk faktörleri olarak yaş, oksijen saturasyonu ve komorbiditeler dikkate alınırken, etik parametreler olarak hayatta kalma olasılığı, taburculuk süresi beklentisi ve yaşam döngüsü ilkesi dikkate alındı.

Bulgular: Adil kabul sıralama puanı uzmanların kararlarıyla doğrulanmaktadır. Çalışmanın önemli bir doğrulaması olarak, uzmanların puanları ile hasta hakkındaki tıbbi bilgi, klinik bulgular ve tıp etiğinin yönettiği bulanık mantık algoritmasının sonuçları arasında mükemmel bir uyum elde edildi. Bulanık mantık algoritmasından elde edilen puanlar, uzmandan elde edilen puanlarla yüksek düzeyde pozitif korelasyon göstermiştir (r=1 ve p<0,01).

Sonuç: Nihai karar sorumlu hekime bırakılmalıdır. Önerilen algoritma farklı sayıda ve türdeki tıbbi girdilere, etik bakış açılarına ve pandemik durumların şiddetine göre genişletilebilir.

Anahtar kelimeler: Adil kabul, bulanık mantık, medikal etik, tıbbi bilgi, yoğun bakım ünitesi

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Introduction

The intensive care unit (ICU) provides life support for critically ill patients. Therefore, admission decisions are the most vital phase of the triage. These units often face the risk of not being able to respond to the growing need for medical teams and allocating equipment. The Coronavirus disease-2019 (COVID-19) pandemic has made it clear that intensive care services need to be supported such that they can provide solutions to sudden peak demands using scientific innovation and proactive strategies. Admissions to the ICU at the beginning of the COVID-19 pandemic, due to decisions based on emotional and social status, revealed the need to use appropriate ethical criteria as well as medical ones. It is necessary to develop an objective, correct, logical, fast and ethically appropriate decision-making method for admission (1,2). For example, Cesari and Proietti (1) discuss the valuable experience they have had after the COVID-19 pandemic hit Italy. In their study, they cite the clinical ethics recommendations for allocating treatment in exceptional resource-limited situations by the Italian Society of Anesthesia, Analgesia and Intensive Care, including i) setting an age limit for allocation in ICU, and ii) considering the patient's comorbidities and functional status. They conclude that there is a need for the implementation of ethical principles into decisional algorithms and that these should be integrated into pandemic preparation globally.

It is difficult to identify patients who are likely to benefit from admission to the ICU. Sabetian et al. (3) developed models based on machine learning to estimate the ICU requirement of patients with COVID-19. Certain risk factors can influence ICU triage. In literature, factors such as patients' age, comorbidities, chronic health status, ICU occupancy rate, oxygen saturation (SaO_2 level), respiratory rate, pulse rate, and presence of life-threatening conditions have been reported (2,4-6). Bates and Young (7) proposed a fuzzy logic algorithm to promote decision making in the ICU by considering only arterial blood pressure and urine output. Fernandes et al. (8) utilized a machine learning approach to identify emergency department patients with a high ICU admission rate. Polilli et al. (9) performed a retrospective study to build a risk score for the decision-making process at the emergency department using logistic regression and Cox modelling by using demographic and clinical data.

The ICU admission process should be ethically satisfactory in all aspects. The main motivation of this study is the search for a method to create a fair and non-discriminatory decision approach in the provision of life support in ICU services. Childress et al. (10) and Annas (11) draw attention to the fact that today's traditional medical ethics principles of patient autonomy, beneficence, not harming, and justice are insufficient when ICU scarcity arises in public health crises or disasters resulting in a tremendous increase in the patient population. White et al. (12) pointed out that admission decisions for ICUs in inadequate conditions should also be based on strong moral criteria such as distributive justice, focus on the common social benefit, certainty of criteria, transparency, sensitivity, and rationality. They confirm the use of maximizing life-years, life-cycle principle, and using multiple principles in an allocation strategy.

In literature, various hospitalization criteria for reaching ICU capacities and the high insufficiency caused by the pandemic conditions have been taken as the basis of the medical ethics debates so far (13). Childress and Beauchamp (14) mostly stated that the utilitarian approach, which emphasizes maximizing net social utility, and the equality approach, which emphasizes that people should have equal opportunities, are the most prominent in the distribution policies of scarce medical treatments, and they suggested combining these two. Persad et al. (15) consider maximizing benefits, which is an important utilitarian value, and explain it through strategies such as saving the most lives, saving the most life years, and using a prognosis-oriented strategy during medical resource scarcity. Rubio et al. (2) emphasized those patients' refusing the ICU treatment; expressed in advance directives should be taken into account. They suggested avoiding medical futility, saving the maximum number of lives and life-years, and maximizing the chance of living all stages of life, for the allocation strategy of scarce intensive care treatment in times of crisis. Norwegian nurses' and physicians' perceptions of the needs of significant others in ICUs validate that four factors: "attentiveness and assurance", "taking care of themselves", "involvement", and "information and predictability" effectively address these needs (16).

Halvorsen et al. (17), reported that significant others could induce unintentional discrimination of ICU patients. Family members who were demanding received more time and attention for both themselves and the patient. Patients' and families' status and position and/or an interesting medical diagnosis seemed to govern the clinicians' priorities of patients and families, consciously as well as unconsciously, and the principle of justice was violated. As reported by

Oerlemans et al. (18), sometimes the pressure of the need for ICU results in ethical problems such as refusing the admission or transferring the patient to another ICU far away after his medical stabilization, which sometimes worsens the patient's situation.

White et al. (12,19) criticized the existing ICU allocation strategies in possible pandemic crises and evaluated some ethical approaches such as broad social value, maximizing the life-years, the life cycle principle, and multiplier effect. They reached a conclusion that only focusing on saving the maximum number of lives is not satisfactory, whereas the life cycle principle is acceptable from the ethical point of view. There should be studies for ethically permissible allocation strategies, both to identify the most acceptable approach and to achieve the greatest possible extent of a fair process of decision making (12,19).

After a public health situation caused by the COVID-19 pandemic in Spain, Rubio et al. (2) also reported a consensus among 18 scientific societies and 5 institutes/chairs of bioethics and palliative care on a reference framework document with general ethical recommendations. These are i) maximizing survival after hospital discharge and the number of life-years saved, considering that chronological age should not be the only element to take into account, ii) triage should be based on principles of distributive justice, prioritizing the best "cost/opportunity" ratio and proportionality, not hospitalizing patients with minimum benefits foreseen, such as patients with advanced disease-related limited life expectancy.

Many medical applications, such as computer-aided clinical decision support systems (CDSS), have been studied so far. CDSS provide patient-specific information and advice to healthcare professionals and patients. The decision-making methods of these systems can be divided into four categories: algorithms (20,21), multi-criteria decision-making methods (22), statistical methods (23), and artificial intelligence methods (24).

Uncertainties can rarely be avoided in solving real-world problems. In such cases, fuzzy logic is a useful tool in solving problems. Fuzzy logic approaches have been successfully used in a variety of disciplines, including medicine. Data in linguistic format are frequently encountered in the field of medicine. The linguistic description of the same phenomenon may differ between people. In situations where there are uncertainties in human judgment, fuzzy logic concepts can be used to obtain approximate information. Thus, experts' knowledge and experience can be utilized in the decision-making process.

Ethical decision-making often involves a choice between distinct alternatives with the structure of a dilemma. There is always fuzziness and ambiguity in human thinking. Thus, fuzzy logic-based approaches are accepted as the most similar to human thought processes in terms of their ability to make appropriate decisions based on linguistic non-specific data (25).

In a previous study, it was aimed to propose a computer-aided method using a fuzzy-logic algorithm for patient admission to the ICU in order to achieve fair prioritization among different patients (26). The aim is to develop a fuzzy logic algorithm that can be used for obtaining accurate priority scores among disparate patients from objective parameters. Both medical information and ethical parameters were taken into account for the two-stage consecutive fuzzy logic algorithm. As a result, it became possible to make ethical and objective decisions regarding the admission of patients to the ICU independent of subjective decisions of medical staff.

Materials and Methods

Medical Information and Ethics Evaluation Software

In the creation of a fair ICU admission computer software model, appropriate methods and approaches from different disciplines were studied. The utilitarian approach and ethical principles are preferred in relation to patient information management in medical ethics, along with fuzzy logic as a decision tool, and they are used to incorporate both medical and ethical principles in justice.

Medical Patient Information Based Medical Ethics

As cited before, the strategies to maximize the number of lives saved and to maximize life-years are considered important in times of ICU scarcity. The utilitarian theory is broadly accepted for the allocation and distribution, of scarce treatments such as life-sustaining technology in public health crises. Non-discriminative fair decisions must be the main goal (27). Although the effect of the utilitarian approach has decreased in medical ethics of today, where respect for patient autonomy comes to the fore, it continues to be effective in some special areas such as public health. The theory focuses on the benefit of maximization of utility and results. In this respect, it pursues the ideal of increasing the general welfare and spreading happiness (28). The principled approach of medical ethics contributes to developing a balanced and reasonable strategy for the protection of both individuals and society in routine circumstances. It is based on generally accepted moral principles and medical tradition, emphasizing respect for autonomy, non-maleficence, beneficence, and justice. The principle of respect for patient autonomy is effectively embedded in medical practice, with the patient making their own medical decisions, after being informed by the physicians. The physician must obtain patients' decisions, desire, or preferences about life-sustaining treatment according to the legislation.

After satisfying the arguments above, the accepted ethical measures, such as survival probability, discharge period expectancy, and life-cycle principle (years to live by reaching an equality in individuals' whole life-cycle), have been used in the decision algorithm. The decision-making process of experts and the fuzzy logic algorithm representing their decisions have been forced to obey the principles reflecting the utilitarian method when encountering medical inputs of age, SaO_2 level, and comorbidities. Additionally, they consider the beneficence and non-maleficence principles of Childress and Beauchamp (14) for COVID-19 ICU insufficiency.

Fuzzy Logic

There are difficulties in transferring the personal experience and knowledge of the expert to conventional decision-making methods, which are necessary in cases without agreement among disciplines on criteria. In such cases, fuzzy logic rule tables are a highly effective means of incorporating the expert's contribution into the decision-making process. Fuzzy inference is the process of mapping a given input to output through a fuzzy logic based reasoning mechanism constituted of if-then rules, membership functions, and fuzzy logic operations such as if "input 1" and "input 2" and "input 3" then "output". A fuzzy inference system has four main steps. These are fuzzification, fuzzy rules, fuzzy inference, and defuzzification. In this study, Mamdani fuzzy inference was used. The fuzzy set defines and converts the result of the if-then rule into membership values during the fuzzification step of this inference.

Computer Software Design

The computer software algorithm of the proposed method with a two-stage Fuzzy Logic decision mechanism, is presented in Figure 1. It is important to emphasize that even the measure of ethical principles, based on medical patient information. Therefore, a brand new computer-aided decision-making software that is based on medical information and produces the effects of selected ethical measures, which are i) probability of survival, ii) ICU discharge period expectancy, iii) Life-cycle principle based years (left). After the ICU experts confirmed the first stage fuzzy logic decision unit algorithm and the outputs of these measures, these outputs will be used in the second stage of fuzzy logic decision unit to obtain a fair admission priority ranking. Figure 2 shows a two-stage fuzzy decision-making process sequentially. The first stage is a multi-input multi-output (MIMO) with three inputs (age, SaO_2 level, and comorbidities) and three outputs (survival rate expectancy, discharge period expectancy, and years to live after recovery based on life-cycle principles). The second stage is a multi-input single-output (MISO) system with three inputs from the first stage and one output of a priority score for ICU admission.

The membership functions of the inputs and output of MIMO and MISO are given in Figures 3, 4, respectively. Their ranges were determined using information from the most experienced ICU doctors.

The first input variable is age, and it is categorized as young, mature, and old. ICU candidates were further categorized in the second input as having severe hypoxemia, moderate hypoxemia, mild hypoxemia, and normal based on their SaO_2 levels. The survival probability is the first output, and it is classified as low, medium, or high depending on the patients' likelihood of survival with intensive care treatment based on the ICU experts' information. The discharge period, which is the second output of MIMO, shows the

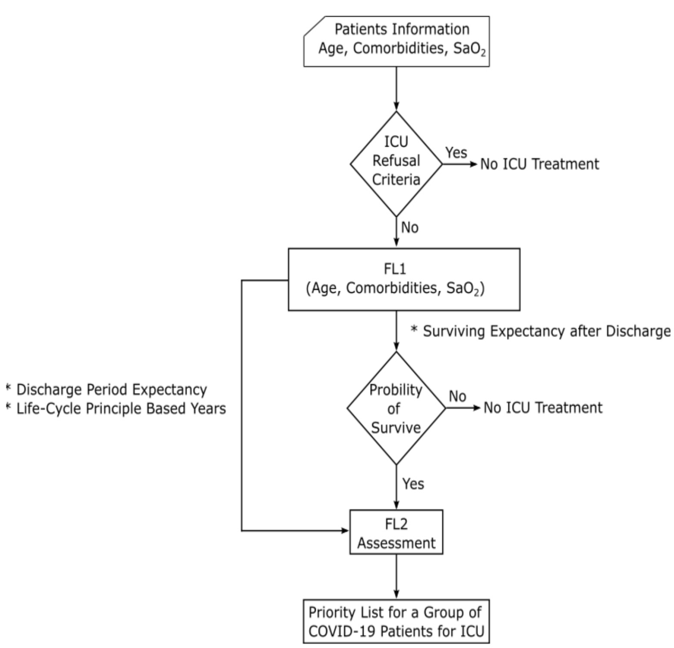

Figure 1. Computer software algorithm

ICU: Intensive care unit, COVID-19: Coronavirus disease-2019

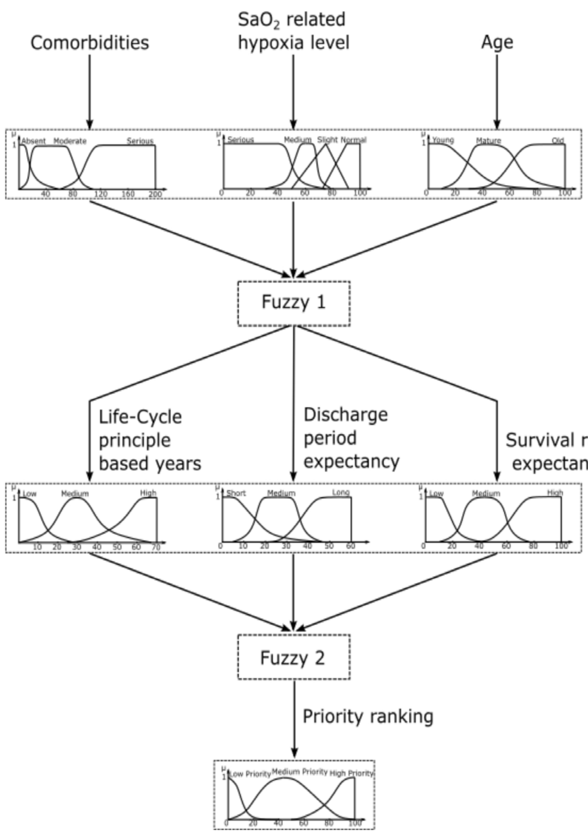

Figure 2. Fuzzy logic flowchart used in admission decision

patients' possible length of stay in the ICU and is classified into three categories: short, medium, and long. Life-cycle principle-based years left is the final output and it shows the life expectancy after discharge from the intensive care unit, which is categorized into three categories: Short, medium, and long as shown in Figure 3. The comorbidities of the patients were chosen as the last input and were divided into three categories (absent, moderate, and serious) depending on whether they were major or minor. Cardiac, pulmonary, renal, liver disease, and diabetes mellitus were considered as major criteria, while body mass index (≥30 kg/m^2), smoking, and others were considered as minor criteria (29). Table 1 shows how major and minor diseases were quantified based on membership limits. These scores are needed for related fuzzy logic input regarding comorbidities. Then, the total comorbidity score was computed by considering the severity of major and minor diseases that patients had.

The second stage input variables are first stage output variables, and their crisp values are used in the inference system of MISO with a new membership function of the related variables. The priority score, which is the final output of this study, is obtained as a crisp value from the second stage. This output is divided into three categories: low, medium, and high priority. The second-stage fuzzy logic membership functions are presented in Figure 4.

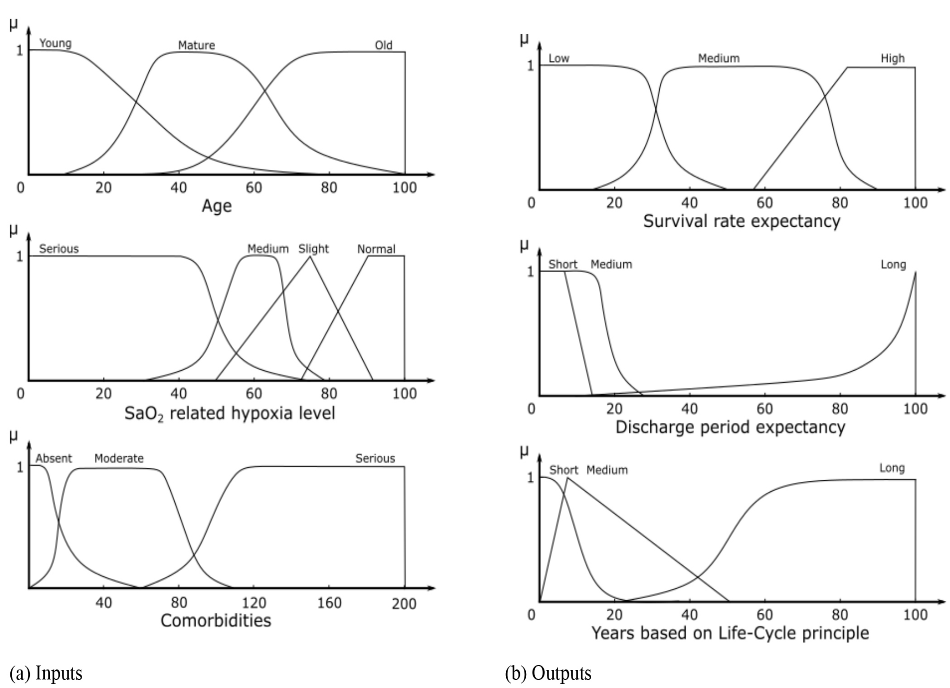

Figure 3. Membership functions for the first Fuzzy logic assessment

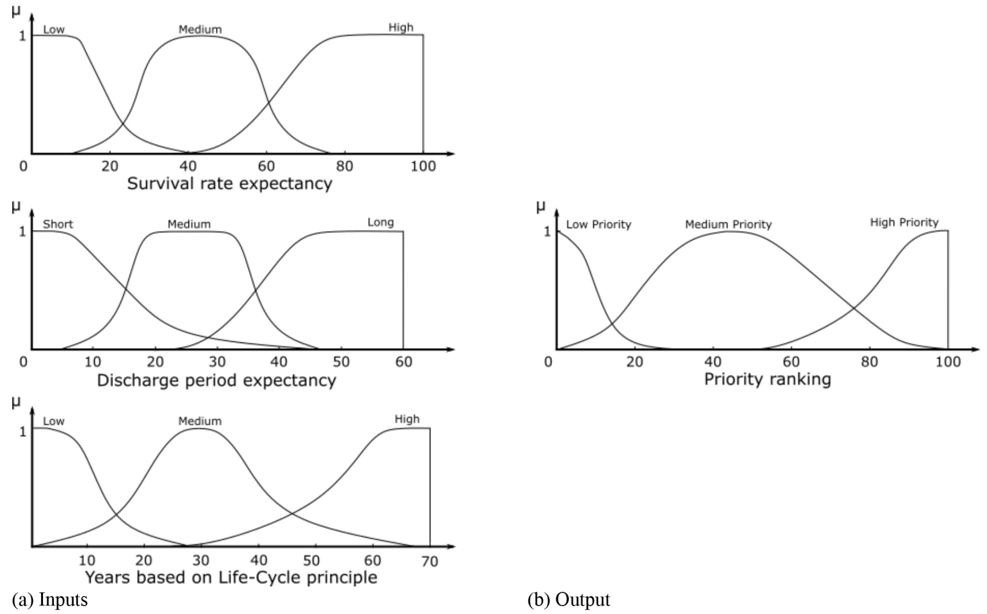

Figure 4. Membership functions for the second and final Fuzzy logic assessment

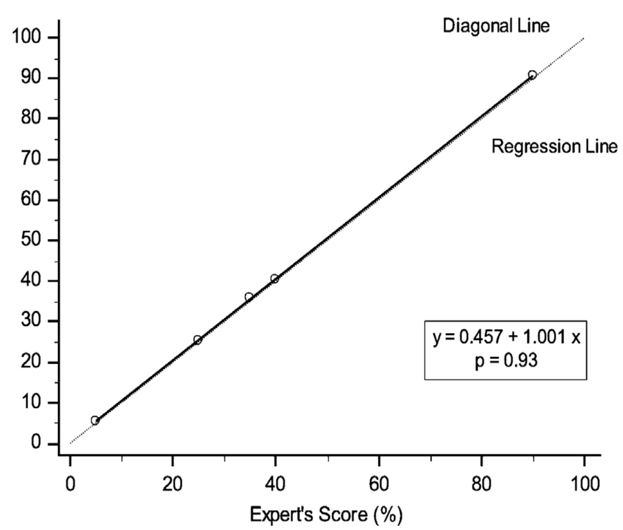

Figure 5. Comparison of expert's score and Fuzzy logic score with Passing-Bablok analysis

To design the rule base for the admission of ICU candidates, the influence of each parameter on the admission of patients to the ICU was determined by referring to the experiences of eminent ICU experts. The underlying logic of these rules was that the patient's possibility of ICU admission increased with the severity of his/her status, which was represented as inputs. The proposed fuzzy system had 36 rules at the first stage (Table 2) and 27 rules at the second stage (Table 3).

Statistical Analysis

Passing and Bablok (30) regression analysis was employed to evaluate the agreement between the scores obtained from the proposed fuzzy logic algorithm and those from the expert assessment. This method is particularly robust for assessing the linearity and agreement between two measurement methods without assuming normality or equal variance.

Ethics

The patient data used in our study were not taken from real patients; instead, a data set was created by consulting expert physicians for possible scenarios. Therefore, since the study does not include real patient data, there is no need to obtain ethics committee approval.

Results

Tables 4, 5 demonstrate the patient scores, calculated by the first phase of the proposed fuzzy logic decision-making method, and the ICU experts' scores. Comorbidity scores were calculated using Table 1, based on the patients' major and minor diseases. Patient data are hypothetical, and offered by a very experienced expert who is the head of a 36-bed ICU. The proposed fuzzy decision-making process was challenged and tested using these potentially critical patient data representing real pandemic conditions.

Table 1. Additive score of the major and minor diseases to be used in third input of the first stage

Number of major comorbidities	Score	Number of minor comorbidities	Score
1	50	1	5
2	80	2	10
3	120	3	15
4 and more	170	4 and more	20 and 30

The survival rate expectancy, ICU discharge period expectancy, and years to live after discharge based on the life-cycle principle estimated by the fuzzy logic algorithm are presented in Table 4. It is seen that the experts' average evaluation scores are in good harmony with those obtained from fuzzy logic software.

The priority scores for ICU admission of the candidates estimated by the second phase of the fuzzy logic algorithm

Table 2. Fuzzy decision rules of the first stage

Age	SaO_2 related hypoxemia	Comorbidities	Survival rate expectancy	Discharge period expectancy	Years to live after recovery
Young	Serious	Absent	Medium	Short	Long
Young	Serious	Moderate	Medium	Medium	Long
Young	Serious	Serious	Low	Long	Medium
Young	Medium	Absent	High	Short	Long
Young	Medium	Moderate	Medium	Medium	Long
Young	Medium	Serious	Medium	Long	Long
Young	Slight	Absent	High	Short	Long
Young	Slight	Moderate	High	Medium	Long
Young	Slight	Serious	Medium	Medium	Long
Young	Normal	Absent	High	Short	Long
Young	Normal	Moderate	High	Medium	Long
Young	Normal	Serious	Medium	Medium	Long
Mature	Serious	Absent	Medium	Medium	Medium
Mature	Serious	Moderate	Medium	Medium	Medium
Mature	Serious	Serious	Low	Long	Short
Mature	Medium	Absent	Medium	Medium	Medium
Mature	Medium	Moderate	Medium	Medium	Medium
Mature	Medium	Serious	Low	Long	Medium
Mature	Slight	Absent	Medium	Short	Medium
Mature	Slight	Moderate	Medium	Medium	Medium
Mature	Slight	Serious	Low	Long	Medium
Mature	Normal	Absent	High	Short	Medium
Mature	Normal	Moderate	Medium	Medium	Medium
Mature	Normal	Serious	Low	Long	Medium
Old	Serious	Absent	Medium	Long	Short
Old	Serious	Moderate	Low	Long	Short
Old	Serious	Serious	Low	Long	Short
Old	Medium	Absent	Medium	Long	Short
Old	Medium	Moderate	Low	Long	Short
Old	Medium	Serious	Low	Long	Short
Old	Slight	Absent	Medium	Medium	Medium
Old	Slight	Moderate	Low	Long	Short
Old	Slight	Serious	Low	Long	Short
Old	Normal	Absent	High	Medium	Medium
Old	Normal	Moderate	Low	Long	Short
Old	Normal	Serious	Low	Long	Short

are also provided in Table 5. Priority score indicates the candidate priority ranking for ICU admission in justice, depending on both medical records and medical ethics evaluation, which is based on survival rate expectancy, discharge period expectancy, and life cycle principle, considering these factors were also derived from patients' medical records. The priority order is presented from highest to lowest score. There has been a perfect match, as an important verification of the study, between the experts' scores and the medical ethics dominated fuzzy logic algorithm.

Table 3. Fuzzy decision rules of the second stage

Survival rate expectancy	Years to live after recovery	Discharge period expectancy	Priority ranking
Low	Short	Short	Low priority
Low	Short	Medium	Low priority
Low	Short	Long	Low priority
Low	Medium	Short	Low priority
Low	Medium	Medium	Low priority
Low	Medium	Long	Low priority
Low	Long	Short	Medium priority
Low	Long	Medium	Medium priority
Low	Long	Long	Low priority
Medium	Short	Short	Low priority
Medium	Short	Medium	Low priority
Medium	Short	Long	Low priority
Medium	Medium	Short	Medium priority
Medium	Medium	Medium	Low priority
Medium	Medium	Long	Low priority
Medium	Long	Short	High priority
Medium	Long	Medium	High priority
Medium	Long	Long	Medium priority
High	Short	Short	Low priority
High	Short	Medium	Low priority
High	Short	Long	Low priority
High	Medium	Short	High priority
High	Medium	Medium	Medium priority
High	Medium	Long	Low priority
High	Long	Short	High priority
High	Long	Medium	High priority
High	Long	Long	Medium priority

Agreement between experts' scores and fuzzy logic scores was evaluated by Passing and Bablok (30) regression analysis. The scores estimated from the proposed fuzzy logic algorithm were highly positively correlated with those obtained from an expert, having r=1 and p<0.01. r and p are the correlation coefficient and the cumulative sum control chart test p-value, respectively, as presented in Figure 5.

Discussion

The admission of candidates to the ICU is a critical decision and depends on patients' medical records. It is experienced that evaluation has been depended on medical experts' experiences, certain ethical parameters and sometimes possibly affected by subjective considerations such as cultural, social, psychological priorities of the locals during pandemic. The decision must not be affected by non-medical and non-ethical factors. Therefore, it was aimed to develop a computer-aided algorithm to determine a fair priority ranking of the candidates to the ICU by using objective parameters, in terms of medical and ethics ones, for Coronavirus-like pandemic conditions such as COVID-19. Medical information dominated ethical principles have been effective in experts' decisions such as saving more lives, maximizing the life-years after discharge and life-cycle principle. Survival rate expectancy, ICU discharge period expectancy and years to live after discharge (a measure for life-cycle principle) were obtained from medical patient

Table 4. Fuzzy logic ICU admission scores and experts' scores for the first stage

Patient no.	SaO_2 related hypoxemia	Age (years)	Comorbidities		Survival rate expectancy (%)		ICU discharge period expectancy (days)		Years to live after ICU discharge	
			Number of minor diseases	Number of major diseases	Expert's scores	Fuzzy scores	Expert's scores	Fuzzy scores	Expert's scores	Fuzzy scores
1	55	18	0	0	80	79.95	7	7.03	60	64
2	70	40	0	2	50	54.14	14	16.24	24	27
3	65	54	1	2	40	40.79	21	22.35	17	12.2
4	60	68	2	1	35	34.35	24	23.43	10	6.68
5	55	82	3	0	30	24.01	30	27.34	3	3.67

ICU: Intensive care unit

Table 5. Fuzzy logic ICU admission scores and experts' scores for the second stage

Patient No.	Survival rate expectancy (%)	ICU discharge period expectancy (days)	Years to live after ICU discharge (years)	Priority ranking	
				Expert's* scores	Fuzzy logic score
1	80	7	60	90	90.6
2	50	14	24	40	40.5
3	40	21	17	35	35.8
4	35	24	10	25	25.2
5	30	30	3	5	5.5

*: Expert estimates the survival rate expectancy, ICU discharge period expectancy, years to live after ICU discharge and achieves his scores. The fuzzy logic mimics the decision process. ICU: Intensive care unit

information, namely age, SaO_2 and comorbidities. Ethical basis on which consensus has been formed in literature for ICU scarcity conditions were imposed in the decision of the proposed fuzzy logic algorithm software and verified that these admission decisions are also compatible with the experts' decision.

It was taken into account that survival rate expectancy, discharge period expectancy, and life-cycle principle-based years to live after ICU discharge were dependent on the patients' age, SaO_2 level, and comorbidities.

Several research studies considered only patients' medical information for the decision-making process using different algorithms and machine learning methods. Patients' age, comorbidities, chronic health status, ICU occupancy rate, SaO_2 level, respiratory rate, pulse rate, and presence of life-threatening conditions are important parameters affecting the admission of patients to the ICU (2,4-6). Patients' age, SaO_2 and comorbidities have been used among the medical parameters. In addition to existing literature, ethical parameters in terms of survival rate expectancy, ICU discharge period expectancy, and years to live after ICU discharge have also been considered. Since the ICU admission process should be ethically satisfactory in all aspects, it was crucial to consider both medical and ethical parameters. The pros and cons of this study are presented. Designing a two-step fuzzy logic algorithm and increasing the number of inputs placed a significant burden on determining the rule table and model. However, the results were in perfect agreement with the expert's opinion and clearly demonstrated the effectiveness of the developed algorithm.

Study Limitations

The medical data and ethical criteria are international medical factors globally accepted in respiratory infectious conditions, such as pandemics like COVID-19. On the other hand, similar pandemic diseases might need the evaluation of medical measures with different weights within a fuzzy logic algorithm. For example, younger ages might be a more significant factor. But the body and the construction of the fuzzy logic software presented in this study can be adopted to new pandemics easily because it is an open-source computer program. Of course, during this adaptation period the programmer needs the guidance and approval of the eminent experts. The other limitation is the undeniable legal responsibility of the ICU personnel in command. One must not forget that the outputs of the software must not have a dominant effect in decision making, and everybody needs to follow the instructions of the responsible personnel.

Conclusion

This brand-new fair fuzzy logic algorithm will contribute to the decision processes of intensive care specialists. It can easily be revised with subsequent studies according to the scarcity of ICU resources and different ethical approaches. Taking into account risk factors and medical ethics principles, it is a strong candidate to help ensure fair ICU admission byimitating the decision-making process of very experienced ICU doctors during the COVID-19 pandemic as well as other respiratory infectious pandemics, without causing any ethical debates and accusations.

Ethics

Ethics Committee Approval: The patient data used in our study were not taken from real patients; instead, a data set was created by consulting expert physicians for possible scenarios. Therefore, since the study does not include real patient data, there is no need to obtain ethics committee approval.

Informed Consent: The patient data used in our study were not taken from real patients.

Footnotes

Authorship Contributions

Concept: S.Y., N.Y., Design: S.Y., D.K., B.S., N.Y., Data Collection or Processing: Z.S., D.K., B.S., Analysis or Interpretation: S.Y., D.K., B.S., Z.S., Literature Search: S.Y., D.K., B.S., Writing: S.Y., D.K., B.S.

Conflict of Interest: No conflict of interest was declared by the authors.

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