Comparative Analysis of Anesthetic Methods and Their Influence on Postoperative Outcomes

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Abstract

Anesthesia is used as a neural blocker capable of preventing nociceptive impulses from entering the nervous system, before, during, and after surgery. Anesthetic agents should be able to enhance recovery processes, potencies, and relaxation of the muscles, including a wide range of safety, free from toxicity, reactivity problems, and possibilities of adverse effects. The objective of this study was to apply a multi-criteria decision-making method (MCDM) called fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) method to evaluate, compare, and rank 5 different types of anesthesia used for surgical operations including (general anesthesia, spinal anesthesia, epidural anesthesia, peripheral nerve blocks, and sedation) based on professionally selected parameters, to determine the preferred analgesic agent for specific patients. The results show that peripheral nerve blocks with a net flow of 0.0321 are among the most preferred anesthesia for patients with the considered contraindications and based on the selected criteria, assigned weights, and set preferences, followed by sedation with a net flow of 0.0083. Epidural anesthesia is ranked the lowest with a negative net flow of -0.0300. Expert opinion is always needed when assigning weights to criteria, and grading alternatives is the major challenge in multi-criteria decision-making studies. Fuzzy PROMETHEE is proposed to solve a multi-criteria decision-making problem in selecting anesthesia used for surgical operations.

Keywords: Anesthesia, Analgesic-agent, Pain-reduction, Surgical Operations, Fuzzy-PROMETHEE, Decision-making

1. Introduction

Anesthesia is a pain-reducing medication induced through incision needles or inhalation to cause

a loss of sensation, to significantly decrease the severity of incisional pain during surgery, movement-associated pains, and pains due to pressure amounted to the surgery site [1,2]. Anesthesia is used as a neural blocker capable of preventing nociceptive impulses from entering the nervous system, before, during, and after surgery[1]. Anesthetic agents should be able to enhance recovery processes, potencies, and relaxation of the muscles, including a wide range of safety, free from toxicity, reactivity problems, and possibilities of adverse effects [2,3]. Prior to reviewed studies, local anesthesia, sedation, peripheral nerve blocks, epidural, spinal, and general anesthesia have been proven to be very effective in decreasing the severity of pain [1–3]. Anesthesia was first introduced into medicine by William Morton in 1846 when he demonstrated that inhalation of ether can cause loss of sensation to pains associated with surgery [4]. This has led to the explosive exposure of surgical operations in different respects [4]. However, different factors are considered for selecting the preferred anesthesia depending on the type and duration of the operation [2]. The choice of anesthesia administered through inhalation and injection is dependent on factors such as the side effects, the cost, the patient's medical history, possibilities of reactivity, cardiac and pulmonary functions, and characteristics like age, weight, sex, etc. [2,5,6]. The age difference is an important factor to be considered when selecting the preferred anesthetic agent [2]. Due to differences in body mass index, body compositions, metabolic reaction rates, and cardiac outputs of patients, keen evaluation is needed for the proper administration of anesthetic agents to avoid toxicities and adverse effects possible through overestimation, as a result of pharmacodynamics and pharmacokinetics differences [2,7]. It is observed that elderly patients require surgery more than patients in other age groups [1,8], this makes it very important for individual evaluations to be carried out on patients before the selection of anesthetic agents is done. Some other related factors that are important when selecting the anesthetic agents of choice according to the American Society of Anesthesiologists (ASA), physical conditions classification system of vital signs, patient's medical conditions, patient's lifestyle such as (tobacco usage, obesity, diabetic, etc.) and patient's consent [2,7,8]. When considering these factors, it is possible to apply multi-criteria decision-making algorithms that are founded on human knowledge to the process of selecting different types of anesthetic agents used for surgical operations.

The fuzzy Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) decision-making method is a concept that is based on the evaluation and comparison of complex and multiple criteria [9,10]. In contrast to other multi-criteria decision-making systems, it has the advantage of being easy to implement [2,11]. To the best of my knowledge, the fuzzy PROMETHEE approach for the determination of anesthetic agents has only been applied in one study, which was carried out by [2]. The applications of this methodology have been offered in the existing literature. According to the study's findings, fuzzy PROMETHEE was used to compare, evaluate, and rank general anesthesia based on the physical criteria and the importance typically attributed to regularly used medications. However, the author has failed to compare general anesthesia with other available types of anesthesia. Thus, to cover the research gap, this study is aimed at proposing the use of Fuzzy PROMETHEE to compare, evaluate, and rank 5 different types of anesthesia used for surgical operations which include (general anesthesia, spinal anesthesia, epidural anesthesia, peripheral nerve blocks, and sedation) based on the physical parameters, contraindications of anesthetic agents and assigned importance weight of criteria based on expert's opinion which include; Patient refusal, medical conditions that are not optimized prior to surgery, Severe heart valve disease, significant pulmonary disease, congestive heart failure, age, mental illness, infection at

the injection site, type of surgery, complicated surgery, anesthesiologist experience, increased nausea and vomiting, history of malignant hyperthermia, systemic infection (sepsis), coagulopathy or bleeding disorders, major spinal deformities (like kyphoscoliosis, and arthritis), previous lumber, surgery, long surgical procedures, elevated intracranial pressure, patients with a risk of vomiting, neuromuscular diseases, and cost.

1.1.General Anesthesia

The use of anesthetic agents during surgery is currently of paramount importance as patients indicated for surgical treatments, experience high risk/rates of morbidity, mortality, and complications especially related to pulmonary and cardiovascular disabilities [2,15,16]. Therefore, it is of urgent medical importance to improve factors that would reduce the risks associated with surgical operations. General anesthesia has been a proposed anesthetic agent that has been hypothesized to facilitate rehabilitation and reduce the risks associated with postoperative complications during surgical operations [15,17,18]. General anesthesia offers improved hemodynamic stability, decreases blood loss to an extent, and gives an outcome of improved analgesia [18]. The effectiveness of general anesthetic agents has been compared with different anesthetic agents in different studies. A study by [15] examined about 18,158 patients indicated for hip fracture surgery in 126 hospitals in New York. 5,254 which is (29%) of the total number were administered epidural or spinal (regional) anesthesia. The efficacy of epidural anesthesia and spinal anesthesia was compared with general anesthesia using morbidity, mortality, and pulmonary complications as discharge criteria for comparison. It was concluded from the study that regional anesthesia has an improved survival rate and fewer pulmonary complications when compared with general anesthesia. Another study by [18] compared general anesthesia with spinal anesthesia in a randomized study of 120 patients indicated to undergo total knee arthroplasty. The criteria for comparison were; recovery time from total knee arthroplasty (46 vs 52h), nausea and vomiting, pain reduction rate, and less dizziness. It was concluded from the study that general anesthesia outperformed spinal anesthesia by meeting the discharge criteria in a shorter time compared to spinal anesthesia. This conclusion contradicts previous recommendations regarding regional anesthesia for surgical operations [15] [19].

1.2.Spinal Anesthesia

Spinal anesthesia has uniquely gained prominence with reference to landmark studies proving the superiority of spinal anesthesia over general anesthesia in terms of reducing complications associated with surgical operations [5] [20,21]. Efficacy in rehabilitation has been broadly observed with the use of spinal anesthesia, improvements in general anesthesia in terms of a decrease in blood loss, improved pain relief rate, improvements in blood flow, reduced pulmonary complications, shorter recovery time, and a drastic reduction in surgical stress response [22,23]. Spinal anesthesia has greatly challenged general anesthesia, although not totally without complications and various risks, that relatively occur in rare cases [5]. Some possible side effects of spinal anesthesia noticed are; spinal hematoma, infections, abscesses, longer stay in the post- anesthesia care unit, and risk of overdosing [24].

1.3.Epidural Anesthesia:

Epidural anesthesia is administered by injecting neuraxial blockade into the epidural space surrounding the spinal fluid sac [21,24]. It has been observed that epidural anesthesia is

associated with numerous benefits compared to general anesthesia[24]. Epidural anesthesia has been proven to reduce morbidity and mortality rates, increase postoperative analgesia, enhance cost- effectiveness, and reduction of surgical stress-related responses [25]. Epidural anesthesia has been observed to be associated with after-effects relating to nerve injury and other possible side effects such as renal failure, respiratory depression, pneumonia, infections, deep vein thrombosis, myocardial infarction, pulmonary embolism, and loss of blood that may result in transfusion requirements [21]. A study conducted by [21] containing 141 trials and 9559 patients, obtained a reliable estimate of the effects of epidural anesthesia. The result of the study showed that overall morbidity and mortality rate was reduced, the odds of deep vein thrombosis was reduced by 44%, pulmonary embolism was reduced by 55%, respiratory depression was reduced by 59%, pneumonia was reduced by 39%, transfusion requirements were reduced by 50%, renal failure, and myocardial infarction was also reduced when the neuraxial blockade was injected [21].

1.4.Peripheral Nerve Blocks

Peripheral nerve block anesthesia is a superior type of anesthesia with efficient analgesic properties for the effective management of postoperative pain [26,27]. Peripheral nerve blocks increase patient satisfaction and decrease the stay in the post-anesthesia care unit and total stay in the hospital [27]. A study conducted by [26] comparing spinal anesthesia with peripheral nerve blocks against general anesthesia with peripheral nerve blocks concluded that peripheral nerve blocks shortened the length of stay in the post-anesthesia care unit and total stays in the hospital. The study strongly recommended the use of peripheral nerve blocks with general anesthesia for surgeries, especially for elective foot and ankle operations. Another study by [28] compared peripheral nerve blocks with general anesthesia for efficacy in pain management. A total of 14 randomized trials with 851 patients were included in the study. The meta-analysis demonstrated that peripheral nerve blocks are associated with a significant and massive reduction in pain compared to general anesthesia. A recent study compared peripheral nerve blocks with spinal anesthesia in terms of postoperative mortality and walking ability in aged patients indicated for hip fracture surgery. Patients above 65 years were included in the study and analysis was performed using the Kaplan-Meier method. Results from the study indicated that 360 patients were included; 200 received spinal anesthesia and 116 received peripheral nerve blocks. When evaluated and compared, peripheral nerve blocks outperformed spinal anesthesia and showed a lower risk of mortality but higher hospitalization costs [29].

1.5.Sedation

Sedation is simply a state of consciousness during a drug-induced depression [30]. Sedation can either be minimal (normal response to verbal stimulation), moderate (purposeful response to verbal stimulation), or deep sedation (purposeful response after repeated or painful stimulation) [30]. Sedation combined with interscalene block has been successfully used as an alternative analgesic agent [31]. When compared with general anesthesia in patients undergoing shoulder surgery and endovascular therapy of basilar artery occlusions in a study by [31,32], efficacy in analgesic properties was observed. The technique provided excellent intraoperative muscle relaxation, faster post-anesthesia care unit and hospital discharge times, and a decreased tendency for nausea and vomiting [31,32]. Sedation minimizes drops in blood pressure, especially during endovascular therapy and it enables assessment of neurological functions but with difficulty in immobility with risk in pulmonary aspirations [32]. When recommending sedation, patients' health status, age, concurrent medications,

anxiety levels, pain tolerance, and procedural variables are all checked to achieve the desired results [33]. Usually, for patients with long-term narcotic habits, sedation is generally accompanied by general anesthesia to manage difficulties [31]. Patients suffering from obesity or obstructive sleep apnea are at a high risk of hypoxemia when administered deep sedation [31,33].

2. Material And Methods

2.1.Fuzzy PROMETHEE and Applications

The term "fuzzy-PROMETHEE" refers to the combination of two separate concepts, namely fuzzy logic, and PROMETHEE. At one time, researchers merely scratched the surface of this conceptual combination in a very small fraction of its total iterations. The PROMETHEE has been demonstrated to be an efficient tool for comparing several alternative approaches using essential parameters (criteria) in order to evaluate their level of performance. The criteria, in order to be characterized as lingual data, are transformed into fuzzy scales using the weight of individual criteria. The end result will provide a ranking of the options, from the one with the most favorable outcomes to the least alternative. Many researchers for example, [34–37] have applied the fuzzy PROMETHEE methodology in their studies. An ultimate example of a multi-criteria decision- making (MCDM) approach is the fuzzy-PROMETHEE, which analyses multi-criteria scenarios, thereby creating a ranking organizational methodology aimed at comparing and evaluating alternatives [38]. Comparative decision-making is a complicated process, such as the one described above, that is typically difficult to achieve; however, due to the prevalence of such complications, fuzzy-PROMETHEE was designed to solve them. By translating language variables into mathematical quantitative variables, both numbers and non-numerical data [10,39].

In this study, the fuzzy PROMETHEE method was deployed to compare and evaluate 5 types of anesthesia used respectively during surgical operations and to identify and determine the most preferred analgesic agent based on applied parameters. To achieve this aim, the aforementioned parameters in Table 1 were collected. These parameters were determined professionally by an anesthesiologist and from searched literature. Thereafter, the parameters were normalized to obtain a triangular linguistic fuzzy scale showing the importance weight of each criterion and the min/max preference as seen in Table 2. In addition, the Yagar index was applied to de-fuzzified the fuzzy values. Finally, the visual PROMETHEE program was deployed using the Gaussian preference functions.

Table 1. Linguistic Fuzzy Scale for the importance of criteria

Linguistic scale for ranking	Triangular Fuzzy Scale	Importance ratings of criteria
Very High (VH)	(0.75, 1, 1)	Patient refusal, medical conditions that are not optimized prior to surgery, Severe heart valve disease, significant pulmonary disease, congestive heart failure, Age, mental illness, infection at the injection site, Type of surgery, complicated surgery, Anesthesiologist experience, increased nausea, and vomiting

High (H)	(0.50, 0.75, 1)	history of malignant hyperthermia, systemic infection (sepsis), coagulopathy or bleeding disorders, major spinal deformities (Like Kyphoscoliosis, and arthritis), previous lumber, surgery, long surgical procedures, elevated intracranial pressure,
Medium (M)	(0.25, 0.50, 0.75)	patients with a risk of vomiting, Neuromuscular diseases,
Low (L)	(0, 0.25, 0.50)	cost
Very Low (VL)	(0, 0, 0.25)	

2.2.Case scenarios applied to the study

a) A 35 years old male patient without any underlying health challenges got involved in a fatal traffic accident [41] while returning from a night party. He had a fractured forearm in between the elbow and the wrist and had to be given immediate surgical care due to compromised perfusion of the arm [42]. The question is; which anesthetic technique is optimum for this patient? (Spinal or Epidural anesthesia would not be appropriate due to the affected site that needs a surgical operation. Spinal or epidural may be difficult as an application of pressure or elevation of the limb and exsanguination is usually accompanied by intense pain. And again, to avoid reactivities that may lead to drug toxicity, seizures, dizziness, coma, cardiac arrhythmias, and possible hypotension or loss of consciousness. These risks could be overcome with the administration of Peripheral nerve blocks [40]. General anesthesia would also be risky due to the patient's full stomach which could risk aspiration of the lungs during anesthesia induction. A peripheral nerve block would be the best for this patient).
b) A 75 years old female patient with hypertension, diabetes mellitus, and severe congestive heart failure has been indicated to undergo an amputation of the foot due to diabetic foot. Beta- blockers, oral antidiabetic drugs, and anticoagulant agents have repeatedly been used to manage the health condition of the patient. The question is which anesthetic technique is optimum for this patient undergoing amputation of the foot? (General anesthesia would be risky because of her severe congestive heart failure, however, if anticoagulant medications could be stopped and wait for an appropriate time for normalization of blood clot formation, spinal or epidural anesthesia can be tried, and also peripheral nerve blocks can be performed.)
c) A 2 years old healthy baby aspirated food to the lungs, as a result, the baby has been indicated to undergo bronchoscopy to perform lung cleansing immediately. The question is, which anesthetic technique is the most appropriate? (General anesthesia should be administered since caudal block or other techniques may not be appropriate).

2.3.Determination of Parameters Applied to Study

To determine the parameters applied to this study, this section explains the rationale behind assigning the weight of importance to each criterion based on the professional knowledge of experts and searched literature. Patients who are aware of the possible side effects of analgesic agents are always careful in agreeing to the usage of anesthetic agents during surgical operations. On this note, patients are educated on the benefits of administering

anesthesia to facilitate surgical procedures. Medical conditions that are not optimized prior to surgery, affect the usage of anesthetic properties, especially for general anesthesia [2,15,16]. Peripheral nerve blocks can still be administered without prior knowledge of the patient's medical status in cases of emergency. Prior knowledge of a patient's medical status is an important criterion for administering anesthesia and therefore assigned 0.75 weight of importance. However, to assign our parameters, we consider minimization for the alternative that suits cases of emergency administration of anesthetic agents without optimizing the patient's medical history. Therefore, as seen in Table 3, peripheral nerve blocks and sedation have the lowest reactivity and the best chances of being used in this case, while general anesthesia has a high risk and should not be considered. Criteria like severe pulmonary disease, and mental illness, are also considered very important medical criteria and therefore assigned 0.75 weight of importance. To compare our alternatives with these criteria, minimization is required i.e. (the anesthetic agent that can be administered regardless of valve disease, pulmonary disease, congestive heart failure, neuromuscular disease, mental illness, risk of infections, nausea, and vomiting is considered more favorable to the decision-maker while the alternative with the highest risk of contraindication is not considered). For example, patients suffering from mental illness would not be administered epidural anesthesia or peripheral nerve block because of the high risk of neuropathy [21,24], hence, minimal risk is required, and general anesthesia alone or combined with sedation is considered more favorable in this case [30]. The effects of anesthetics on older people vary. Older patients who have anesthesia frequently develop post-operative delirium, schizophrenia, Alzheimer's disease, Parkinson's disease, and other neurological illnesses [2,7]. As a result, the age criterion is given a 0.75 weight of importance and is considered to be very important. The effects of anesthesia differ for healthy adult patients and should be carefully studied for both juvenile and adult patients. Although it is well known that the anesthetic dose decreases with age [2,7], general anesthesia shows fewer usage risks [21,24]. As a result, minimization is considered for this criterion, and the alternative with the lowest reactivity is thought to be more advantageous to the decision-maker [43]. The same explanation applies to other criteria in this study. All criteria are weighted based on the 3 case scenarios, giving similar criteria and weights accordingly.

Table 2: Data set showing Criteria for contraindication of alternatives with corresponding parameters

Alternatives/Criteria for contraindication	**Min/Max**	**Weigh t of import ance**	**Gene ral anest hesia** [2,15, 16]	**Spin al anest hesia** [5]	**Epidural anesthesi a** [21,24]	**Periphe ral nerve blocks** [26,27]	**Sed atio n** [30]
Patient refusal	Min	0.75	VH	VH	VH	VH	VH
medical conditions that are not optimized before surgery	Min	0.75	VH	M	M	L	L
Severe heart valve disease	Min	0.75	VH	H	H	L	M

significant pulmonary disease	Min	0.75	VH	L	L	L	M
congestive heart failure	Min	0.75	VH	L	M	L	H
history of malignant hyperthermia	Min	0.50	VH	L	L	L	L
patients with a risk of vomiting	Min	0.25	VH	M	M	L	H
Age	Min	0.75	L	H	VH	VH	M
mental illness	Min	0.75	L	H	VH	VH	M
infection at the injection site	Min	0.75	L	H	VH	VH	L
systemic infection (sepsis)	Min	0.50	H	M	M	L	M
coagulopathy or bleeding disorders	Min	0.50	L	H	VH	H	L
Neuromuscular diseases	Min	0.25	L	H	H	H	L
Type of surgery	Min	0.75	L	VH	H	VH	M
major spinal deformities (Like Kyphoscoliosis, and arthritis)	Min	0.50	M	VH	VH	L	M
previous lumber surgery	Min	0.50	L	H	H	L	H
complicated surgery	Min	0.75	L	M	H	H	VH
long surgical procedures	Min	0.50	L	L	L	VH	VH
elevated intracranial pressure	Min	0.50	L	VH	H	L	L
cost	Min	0.25	H	L	M	M	L
Anesthesiologist experience	Max	0.75	M	M	H	VH	M
increased nausea and vomiting	Min	0.75	H	L	L	L	H

Note: (very high (VH), high (H), moderate (M), low (L), very low (VL))

3. Results And Discussion

The PROMETHEE preference net flow results in Table 4 shows the complete ranking results for the preferred anesthesia. The resulting ranking using the F-PROMETHEE technique indicates that peripheral nerve block with a net flow of 0.0321 is among the most preferred anesthesia for patients with the considered contraindications, and based on the selected criteria, assigned weights, and set preferences. Followed by sedation with a net flow of 0.0083. while epidural anesthesia is ranked the lowest with a negative net flow result of -0.0300 (Table 4).

Table 4: PROMETHEE Preference Net flow

Rank	Alternatives	Outranking Net Flow	Positive Net Flow	Negative Net Flow
1	Peripheral nerve blocks	0,0321	0,0943	0,0623
2	Sedation	0,0083	0,0712	0,0628
3	General anesthesia	-0,0017	0,0997	0,1013
4	Spinal anesthesia	-0,0088	0,0512	0,0600
5	Epidural anesthesia	-0,0300	0,0437	0,0736

It is worthy of note that although peripheral nerve block tops the list of preferred anesthesia based on the contraindications, conditions, criteria, and alternatives presented in this study, preferred anesthetic agents for surgical operations may differ from one decision-maker to another. In addition, more than one anesthesia may be combined for better analgesic effects. The result obtained from this study does not give a standard but it only shows the applicability of the fuzzy PROMETHEE technique. In light of the fact that different decision-makers may come up with different analgesic solutions based on the criteria and alternatives they choose, the outcome reached by a decision-maker is not always a standard. To properly analyze and pick the best anesthesia for any surgical procedure as well as the most appropriate dosage, and for selecting the criteria and assigning the weight of importance to each criterion, it is imperative to consult an expert anesthesiologist.

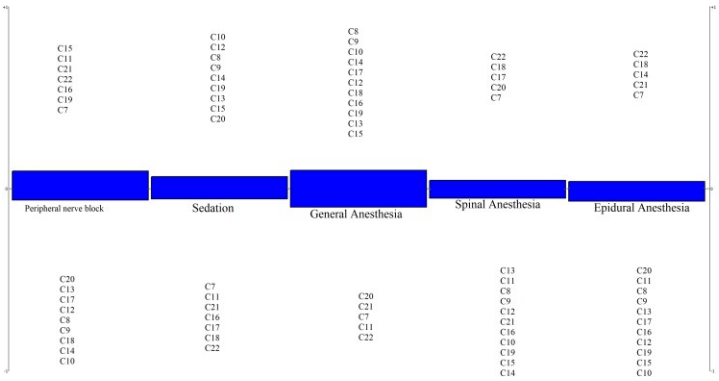

Figure 1. Showing the positive and negative ranking results.

Figure 1 shows the positive and negative parts of the 5 types of anesthesia considered in this study based on the assigned weights. It can be observed in Figure 1. C1, C2, C3, C4, C5, C6, C7, C8 to C22 represent the criteria considered in Table 3. For proper representation, C1 = Patient refusal and the same goes for other criteria. Figure 1 shows that peripheral nerve blocks have a wide positive standing for efficacy on the following criteria; C15 = major spinal deformities (Like Kyphoscoliosis, and arthritis), C11 = systemic infection (sepsis), C21 = Anesthesiologist experience, C22 = increased nausea and vomiting, C16 = previous lumber surgery, C19 = elevated intracranial pressure, and C7 = patients with a risk of vomiting. And a narrow negative standing for C20 = cost, C13 = Neuromuscular diseases, C17 = complicated surgery, C12 = coagulopathy or bleeding disorders, C8 = Age, C9 = mental illness, C18 = long

surgical procedures, C14 = type of surgery, C10 = infection at the injection site. The more positively the criteria are positioned on the graph, the more positively the technique is impacted. In a similar vein, the less the criteria add to the technique's negative side, the lower it appears on the graph's negative side. This explanation applies to the remaining treatment alternatives as seen in the figure below.

4. Conclusion

This study has shown that fuzzy PROMETHEE can be deployed to compare and evaluate different types of anesthesia and to determine the most preferred analgesic agents for patients undergoing surgical operations. Criteria and weights that influence the evaluation and comparison of anesthetic types were decided upon by the expert anesthesiologist in charge and reviewed literature. Fuzzy PROMETHEE can be deployed to determine and identify the optimal anesthesia among other types. With this method, all available anesthetic agents can be evaluated and compared intelligently and systematically by deploying as many criteria as needed based on the decision-maker's choice. The fuzzy PROMETHEE application is ranked with significant efficacy compared to other methods. Fuzzy values that are not crisp are included in the decision-making process in this study, these fuzzy data processes have too many parameters to be set properly with other methods; however, fuzzy PROMETHEE can handle this kind of vague data very well. By deploying fuzzy PROMETHEE for comparing and evaluating different types of anesthetic agents, this study has circumvented the hurdles surrounding the intelligent, systematic, and professional selection process of preferable anesthetic agents that have been in existence. There is only one existing technique in which anesthesiologists perform a preoperative assessment by reviewing the patient's health history and overall medical status before selecting the most appropriate analgesic agent based on experience, but with the help of this study, anesthetists, patients, and patient's relatives can partake in the decision-making process and professionally make decisions in this regard of uncertainty.

Limitations of Study

Expert opinion is at all times needed for appropriate assigning of importance weights to criteria and grading alternatives. This process is the major challenge in multi-criteria decision-making studies

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