Rescuing emergency cases of COVID-19 patients: An intelligent real-time MSC transfusion framework based on multicriteria decision-making methods

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Abstract

Mesenchymal stem cells (MSCs) have shown promising ability to treat critical cases of coronavirus disease 2019 (COVID-19) by regenerating lung cells and reducing immune system overreaction. However, two main challenges need to be addressed first before MSCs can be efficiently transfused to the most critical cases of COVID-19. First is the selection of suitable MSC sources that can meet the standards of stem cell criteria. Second is differentiating COVID-19 patients into different emergency levels automatically and prioritising them in each emergency level. This study presents an efficient real-time MSC transfusion framework based on multicriteria decision-making(MCDM) methods. In the methodology, the testing phase represents the ability to adhere to plastic surfaces, the upregulation and downregulation of specific surface protein markers and finally the ability to differentiate into different kinds of cells. In the development phase, firstly, two scenarios of an augmented dataset based on the medical perspective are generated to produce 80 patients with different emergency levels. Secondly, an automated triage algorithm based on a formal medical guideline is proposed for real-time monitoring of COVID-19 patients with different emergency levels (i.e. mild, moderate, severe and critical) considering the improvement and deterioration procedures from one level to another. Thirdly, a unique decision matrix for each triage level (except mild) is constructed on the basis of the intersection between the evaluation criteria of each emergency level and list of COVID-19 patients. Thereafter, MCDM methods (i.e. analytic hierarchy process [AHP] and *vlsekriterijumska optimizcija i kaompromisno resenje* [VIKOR]) are integrated to assign subjective weights for the evaluation criteria within each triage level and then prioritise the COVID-19 patients on the basis of individual and group decision-making(GDM) contexts. Results show that: (1) in both scenarios, the proposed algorithm effectively classified the patients into four emergency levels, including mild, moderate, severe and critical, taking into consideration the improvement and deterioration cases. (2) On the basis of experts' perspectives, clear differences in most individual prioritisations for patients with different emergency levels in both scenarios were found. (3) In both scenarios, COVID-19 patients were prioritised identically between the internal and external group VIKOR. During the evaluation, the statistical objective method indicated that the patient prioritisations underwent systematic ranking. Moreover, comparison analysis with previous work proved the efficiency of the proposed framework. Thus, the real-time MSC transfusion for COVID-19 patients can follow the order achieved in the group VIKOR results.

Keywords COVID-19 · Mesenchymal stem cell therapy · Multicriteria decision-making · AHP · VIKOR

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1 Challenges of biological requirements

Coronavirus disease 2019 (COVID-19) is a highly infectious disease that can cause mild to serious illness. Many patients with COVID-19 initially develop fever, cough and shortness of breath, which can lead to acute respiratory distress syndrome, resulting in breathing difficulties, low ratio of partial pressure arterial oxygen and fraction of inspired oxygen (PaO_2/FiO_2) and multi-organ failure [1–3]. In 1991, mesenchymal stem cells (MSCs) were discovered in the bone marrow; today, they can be isolated from different tissues such as the umbilical cord and adipose tissue [4]. MSCs have shown promising anti-inflammatory properties as they can modulate cellular immune responses. Considering their regenerative ability and immunoregulatory effect, MSCs can be used in the treatment of many diseases [5]. An experiment in mice revealed that MSCs can treat acute lung injury as a result of influenza A H5N1 infection [6]. Another research showed a significant effect of MSCs against H9N2 influenza virus [7]. MSC transfusion has been reported to reduce C-reactive protein levels in patients with chronic obstructive pulmonary disease [8]. Recently, the transplantation of MSCs to COVID-19 patients showed promising results by activating lymphocytes, increasing interleukin (IL)-10 levels and decreasing tumour necrosis factor-alpha(TNF-α) levels, indicating their potential ability to treat severe COVID-19 patients [9]. In another study, umbilical cord MSCs reduced C-reactive protein and bilirubin levels in COVID-19 patients [10]. MSCs can reduce TNF-α levels and increase IL-10 levels [11]. Recently, a modified stem cell treatment was adopted in the United Arab Emirates; in this treatment, stem cells were isolated from patients and then given as aerosol treatment to help regenerate lung cells and reduce immune system overreaction [12]. Human umbilical cord MSCs significantly improved the lymphocyte count and obviously reduced the levels of infection-related protein biomarkers such as C-reactive protein, TNF-α and IL6 in critical COVID-19 pneumonia patients [13]. However, the efficient implementation of MSC-based therapy to a large number of COVID-19 patients has many challenges, which can be divided into two stages. In the first stage, several methods are used in culturing MSCs, which might result in differences in the phenotype of the MSCs produced [14]. To avoid such variations/differences of stem cells from different sources, maintain their immunomodulatory property and prevent unwanted effects, MSCs should be cultured in well-defined conditions, such as low-serum or xeno-free media. In addition, control of virus-free culture will help to sustain homogenous MSC phenotypes. Previous studies that treated COVID-19 patients with MSCs did not report the sources of MSCs [15, 16]. The second stage is linked to the application of MSCs to different patients, which does not necessarily reflect their need or the level of infection severity. For instance, Leng and his group described the transfusion of MSCs to four patients with severe disease and two patients with moderate disease [17]. The study of [18] treated one critical patient with improvement after MSCs treatment. While only six severe patients were chosen to a study using stem cell (CAP-1002) for the treatment. Many of these studies showed improvement in patients' conditions. However, most studies conducted MSC therapy on a small number of patients because the patients must undergo selection criteria based on the level of severity of infection, including age, gender and history of chronic disease, and they should not be involved in another clinical trial [17].

Finding and testing eligible MSC protocols with efficient utilisation can be challenging as MSCs must meet the selection and general requirements in the first stage. Furthermore, dealing with very valuable MSCs and handling a large number of patients require an intelligent transfusion process for COVID-19 patients with different disease severity, and the prioritisation is challenging. Because the requirements in the second stage should follow the prioritisation of emergency COVID-19 patients in each severity level following the evaluation criteria, this process falls under a multicriteria decision-making(MCDM) problem. Consequently, selecting the best method of MSC preparation that complies with national health requirements and choosing the most suitable patients for the procedure are important to deliver effective cell-based therapy. Thus, intelligent computing issues should be investigated to propose a fully intelligent real-time MSC transfusion framework based on the emergency severity of COVID-19 patients to help medical teams solve the complex challenges mentioned above.

2 Intelligent computing challenges

In the medical domain, triage and prioritisation are performed to either classify patients into different emergency categories or prioritise them in due course. Triage is an emergency medical method that categorises the severity of the case of patients and determines the order of treatment [19]. Automating this task could significantly improve the quality of care and hospitalisation of patients to save as many lives as possible. Previous studies categorised patients with chronic heart disease into different emergency levels via an automated triage model [20, 21]. In patient prioritisation, saviours decide and provide appropriate medical services considering patients priority and their conditions [22]. The possibility of saving a patient's life increases if proper prioritisation is given for each patient according to his/her emergency case [23–29]. Numerous studies proposed solutions for prioritising patients with one or more chronic heart diseases on the basis of their health situation [19, 22, 23, 30–32]. Recently, the COVID-19 outbreak affected all sectors of society, especially healthcare, indicating the need for providing solutions to help and save

patients' life, given the limited number of resources [33]. Consequently, many researchers investigated the cases of COVID-19 patients and proposed methodological frameworks for prioritising them according to their emergency medical condition and laboratory test results [33, 34]. This process is quite complicated, especially when the rule of decision depends on different biological requirements that need to be followed [35]. In addition, the case of each infected patient must be analysed and identified considering all related criteria [33]. In this case, appropriate treatment should be given on the basis of the conditions of COVID-19 patients with prioritisation from critical to moderate [36].

This process helps infectious disease specialists to distinguish patient levels and identify the ideal asymptomatic carriers amongst other critical cases [37]. In this context, a previous study recommended to provide a combination solution of triage and prioritisation of patients with the same platform to evaluate the diagnostic value of triage level followed by the priorities of patients within each emergency level in order to save as many lives as possible [19].

We identified two research gaps in this field. Firstly, an automated real-time COVID-19 triage algorithm based on an official medical guideline for categorising patients into different classes is not yet available. Secondly, no study has succeeded or presented a distinct intelligent real-time MSC transfusion framework based on the severity of COVID-19 patients. To address these gaps, four specific computing issues are encountered as follows. Firstly, an automated system for differentiating the emergency level of COVID-19 patients should be developed, and their symptoms should be used as evaluation criteria [33]. Secondly, the prioritisation of COVID-19 patients within each emergency/triage level is relayed on the basis of different evaluation criteria related to each level [38]. Thirdly, different values of importance are often given for each criterion of each emergency case, which further increases the complexity of the task [22]. Finally, a prioritisation process of COVID-19 patients within each emergency/triage case requires synchronised consideration of the inverse relationship amongst the criteria; thus, a trade-off is created [39]. To solve the first issue, an accurate automated triage guideline needs to be created and used in the proposed MSC transfusion framework to fulfil the desired purpose. MCDM methods are essential to overcome the abovementioned challenges by prioritising COVID-19 patients within each triage level. MCDM is an extension of decision theory that covers any multi-objective decision. It can solve multi-criteria decision-making problems by formulating a decision matrix based on the crossover between the evaluation criteria of each triage level and list of COVID-19 patients. In general, the main goal of MCDM is to rank/prioritise a set of alternatives on the basis of different evaluation criteria. In conclusion, an intelligent real-time MSC transfusion framework must be proposed to help medical teams transfuse the

validated MSCs for COVID-19 patients on the basis of their severity and priority.

3 Methodology

The proposed framework is based on two distinct and consecutive phases (i.e. testing and development) as shown in Fig. 1. Several steps are presented in the testing phase as follows. Firstly, the framework should include the general requirements for human MSCs to be acceptable for cell therapy applications, such as adherence to plastic surfaces during standard culture. Secondly, the expression of surface antigen cluster of differentiation (CD)105, CD73 and CD90 (>95%), and non-expression of hematopoietic markers CD45, CD34, CD14 or CD11b, CD79 alpha or CD19 and human leukocyte antigen)HLA-DR, <0.2%) should be achieved [40]. Thirdly, MSCs must differentiate into lipocytes, osteoblasts and perichondral cells in vitro [41, 42]. In the development phase, firstly, an automated triage and patient classification system can be achieved according to the formal medical guideline of COVID-19 for the purpose of real-time monitoring. In such case, positive COVID-19 patients should be separated into four emergency levels/groups, namely, critical, severe, moderate and mild. Secondly, the prioritisation of positive COVID-19 patients within each emergency level can be provided using MCDM methods. In this stage, three decision matrices for three emergency/triage levels (i.e. moderate, severe and critical) can be constructed. These decision matrices are generated on the basis of the crossover between the number of positive COVID-19 patients and the number of specific criteria. In this stage, MCDM methods are used to weigh the criteria of each decision matrix and then prioritise COVID-19 patients. In such case, efficient MSC transfusion can be achieved and provided for most critical COVID-19 patients within each triage level.

3.1 Phase 1: Testing

MSCs were originally identified in the bone marrow and classified as colony-forming unit-fibroblasts [43]. To achieve efficient treatment procedure, the source of MSCs should be determined (i.e. whether they are obtained from the same patient or a donor) as they have various sources besides the bone marrow, including umbilical cord, adipose tissue, muscle tissue, peripheral blood, dental pulp, synovial fluid and salivary gland [44]. Generally, the molecular features, expression of surface antigen and biological roles such as differentiation abilities and proliferation of MSCs can vary based on the source [45]. One of the first criterion for good MSC candidates for therapy is that the cells must competently adhere to the plastic surface under optimal culture conditions [46]. The second criterion for successful MSC isolation is the
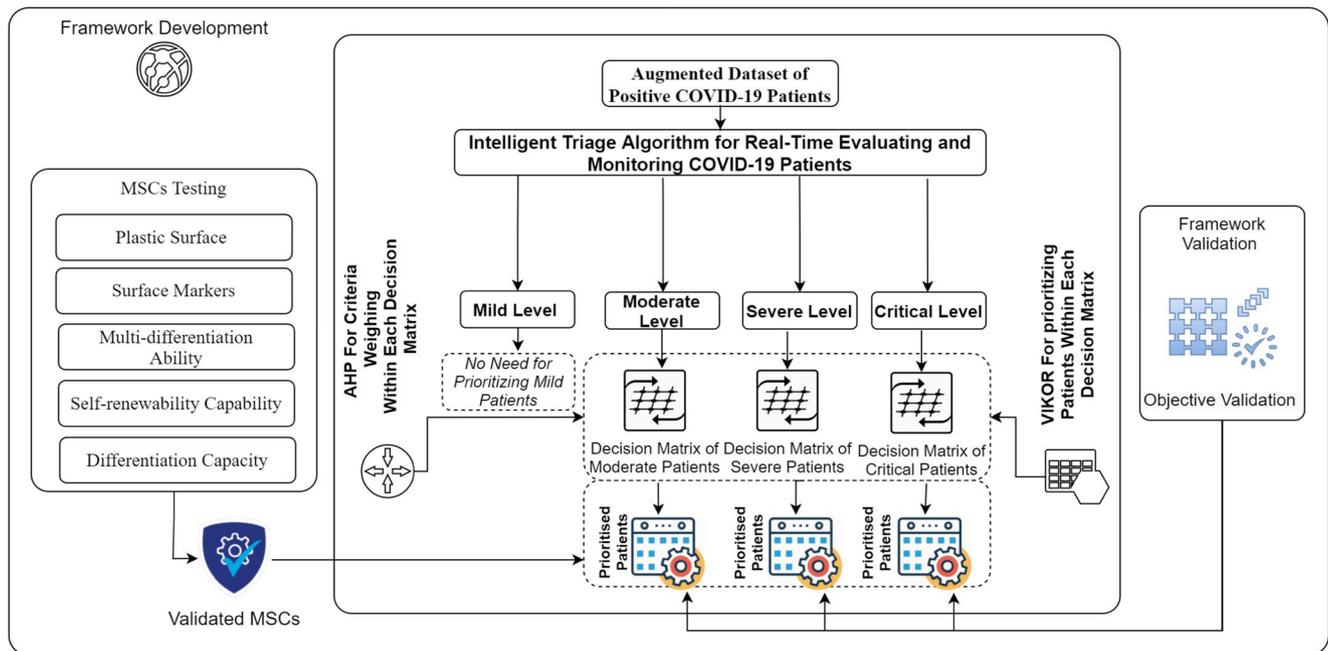
Fig. 1 Intelligent real-time MSC transfusion framework

expression of specific surface markers according to the origin of MSCs. Besides the markers mentioned above, additional markers can also be used for evaluating MSCs, including CD146, CD271/nerve growth factor receptor, MSCA-A, stage-specific embryonic antigen-4 and stromal cell marker-1 [47]. Aside from the expression of surface markers, MSCs should also have multi-differentiation ability; self-renewability; and capacity for differentiation into various lineages (see Fig. 2), including alveolar epithelial cells, perichondrial cells, osteocytes, adipocytes, heart cells, neurons and myocytes [48]. The dose and proposed protocols of MSCs differ depending on the purpose of their application, location of the study and nature of patients. So far, the concentration of MSC infusion ranges between 0.5×10^6 and 1×10^7 cells/kg. However, studies suggest using 2×10^8 and 4×10^7 cells, regardless of the patient's weight. MSCs are mostly infused through intravenous cell infusion, but some are administered through mist inhalation [15].

3.2 Phase 2: Framework development

This phase presents the development of the proposed MSC transfusion framework for positive COVID-19 patients. It includes three intelligent approaches. Section 3.2.1 discusses the generation of dataset augmentation for COVID-19 patients. Section 3.2.2 provides details of the automated evaluation and triage of COVID-19 patients according to their emergency conditions. Section 3.2.3 explains the prioritisation of positive COVID-19 patients within each emergency level using MCDM methods.

3.2.1 Dataset augmentation for positive COVID-19 patients

In this research, an augmented dataset of 80 positive COVID-19 patients was generated. The dataset of COVID-19 patients in the literature did not consider emergency levels that affect the real-time MSC treatment process [49]. To address this gap, the present study generated an augmented dataset of 80 patients that considers the triage standards and is based on the medical perspective to meet the criteria of COVID patients' emergency levels. In line with the literature, the generation process of patients' data included several runs intended to surpass limitations found in the study of [50]. Therefore, a pulmonologist with more than 10 years of experience gave a subjective judgment and validated the simulated patients' data based on the health conditions of real cases of positive COVID-19 patients reviewed in previous medical reports. The development of a consensus amongst experts to review the new dataset at the same time is challenging, and the process between data generation and data validation can take a long time. Therefore, this study generated the data of 80 patients according to medical experts and reliable reference ranges for each criterion of the four emergency levels in two scenarios. The first scenario presents the patients who need to be admitted to the hospital including four emergency levels (i.e. mild, moderate, severe and critical) and each of which contains 20 patients. For the purpose of evaluation and real-time monitoring, the second scenario can be presented after 72 h, taking into account the transformation process from one level to another and considering the improvement and deterioration procedure for those patients.

Fig. 2 Flowchart of MSC testing preparation and implementation in COVID-19 therapy
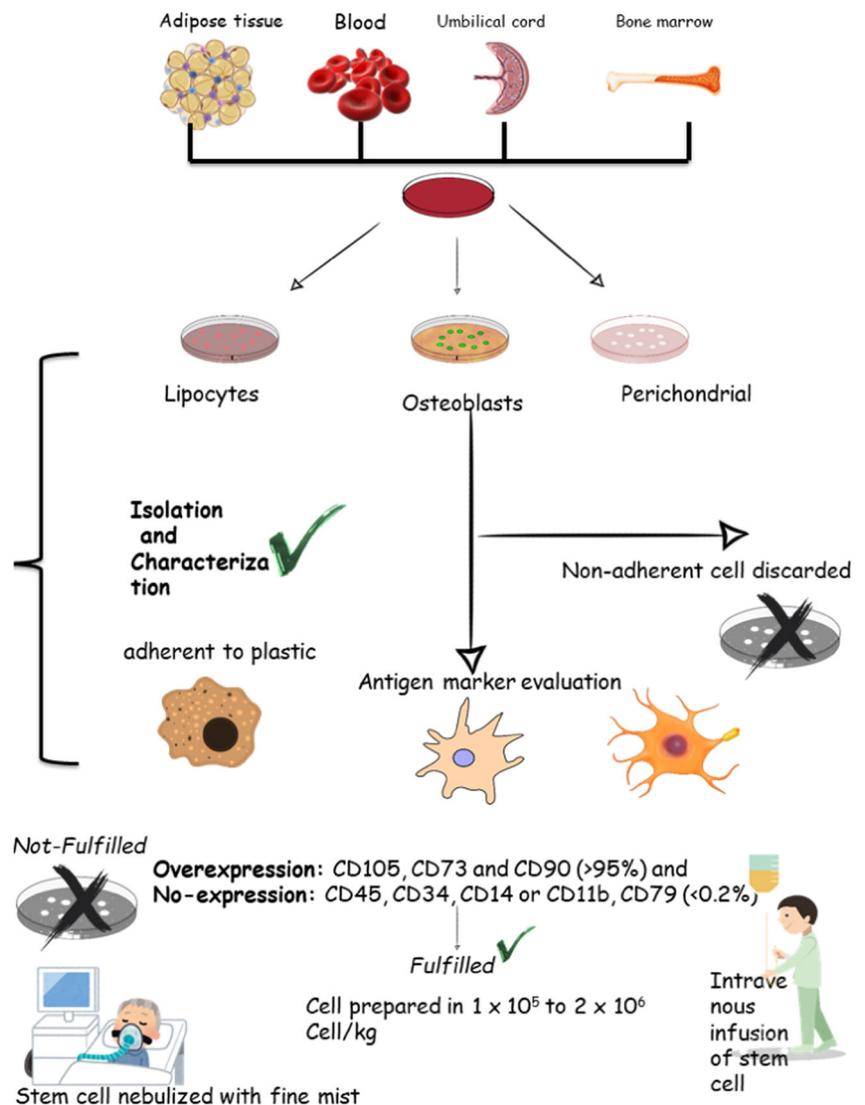
3.2.2 Evaluation and real-time monitoring

This section describes the evaluation and real-time monitoring of COVID-19 patients' conditions. The evaluation and monitoring of COVID-19 patients are essential and need to be achieved [51]. These processes can be performed by medical teams in the proposed framework every 24 h. Overall, the effective evaluation and real-time monitoring of any novel infectious disease, including COVID-19, has two main requirements: (1) identify a reliable triage guideline of the novel disease and (2) specify the criteria for each triage level. To this end, an automated triage and patient classification system needs to be provided according to the formal medical guideline of COVID-19. An accurate triage guideline was identified in a previous study [52]. As a proof of concept, this triage guideline can be used to evaluate COVID-19 patients and classify them according to their severity. In this research, the COVID-19 patients are triaged and monitored by medical teams based on the mentioned triage guideline. Figure 3 illustrates the triage guideline adopted in the present research.

Figure 3 shows that the adopted triage guideline classifies positive COVID-19 patients and separates them into four emergency levels/groups, namely, critical, severe, moderate and mild. COVID-19 conditions and symptoms can vary widely in different emergency levels, ranging from deadly pneumonia to loss of smell, or even no symptoms [40]. The medical teams perform the evaluation and triage processes intelligently. Figure 4 presents the automated triage algorithm used in the evaluation of positive COVID-19 patients.

Following the automated triage algorithm in Fig. 4, positive COVID-19 patients are evaluated and triaged into four emergencies according to their conditions. Each triage level has a corresponding emergency level (i.e. mild, moderate, severe and critical). When the evaluated COVID-19 patients do not have any symptoms (e.g. fever and fatigue) or pneumonia symptoms on X-ray or CT, their emergency level is

Fig. 3 Triage guideline used to classify positive COVID-19 patients
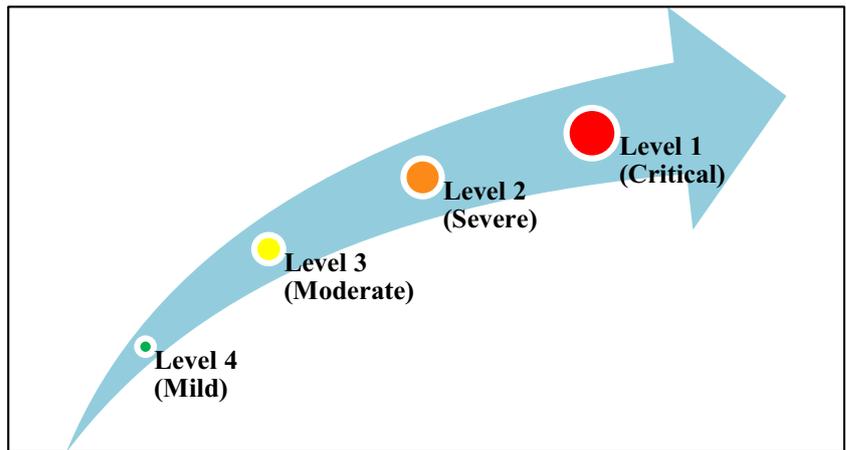
Fig. 4 Automated triage algorithm of positive COVID-19 patients
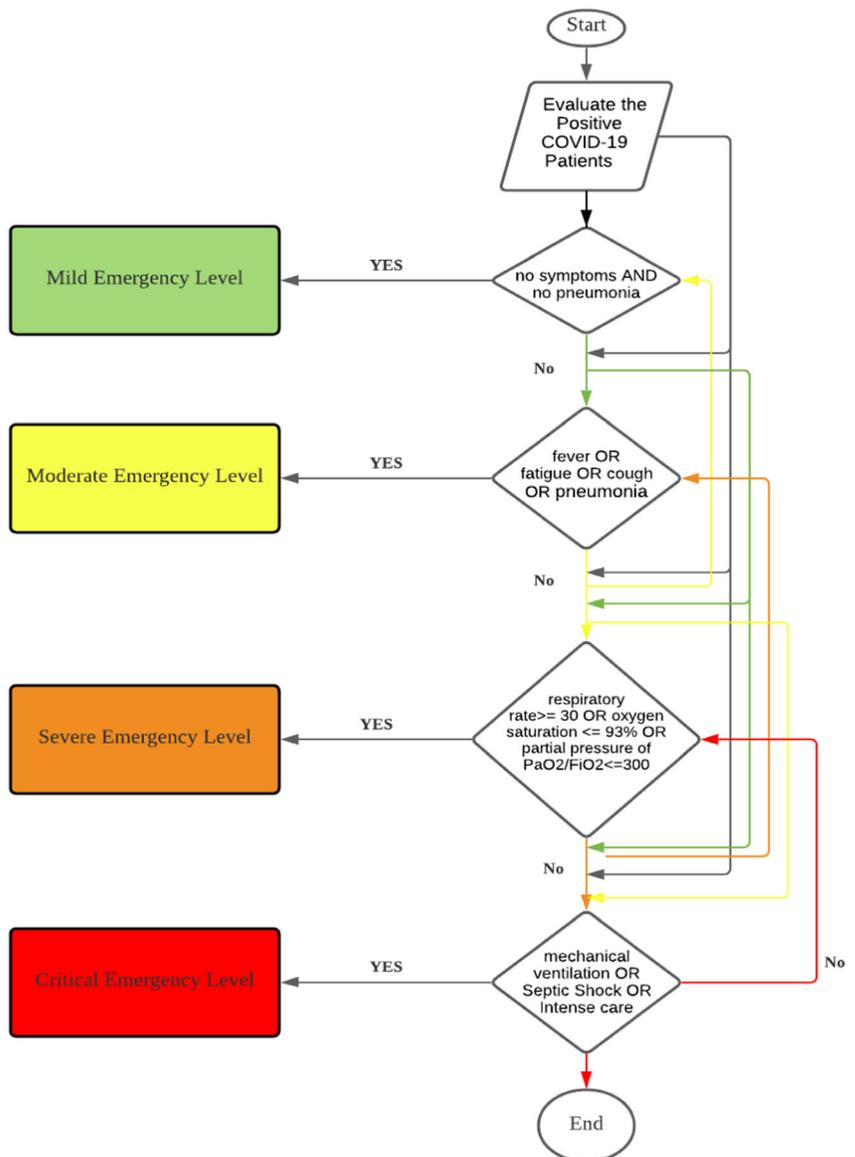
mild. This is because many COVID-19 patients initially report mild symptoms before developing fever, cough and other more severe symptoms [41]. A majority of patients with COVID-19 are expected to have relatively mild symptoms that can resolve at home [42]. When the evaluated COVID-19 patients have either one of the moderate symptoms (e.g. fever, fatigue, cough and pneumonia symptoms on X-ray or CT), their emergency level is moderate. Moreover, when the evaluated COVID-19 patients have one of the severe symptoms (e.g. respiratory rate $\geq$ 30 breaths/min, oxygen saturation $\leq$ 93% at rest and $PaO_2/FiO_2 \leq$ 300 mmHg), their emergency level is severe. In addition, if the evaluated COVID-19 patients require mechanical ventilation, exhibit septic shock and need intensive care admission and monitoring, their emergency level is critical. After evaluating the emergency levels of the admitted COVID-19 patients, the monitoring process will be achieved in real time because their emergency cases may change from better (i.e. improvement) to worse (deterioration) based on their immunity [39]. For patients whose emergency cases are going to be changed, the evaluation of their emergency cases can be achieved from the highest triage level until the lowest one according to the automated triage algorithm. For example, for the improved cases, when the critical COVID-19 patients do not meet the condition of the critical triage level anymore, the proposed automated triage algorithm will start to re-evaluate these patients to identify which triage level they belong in real time. This process will be achieved from the severe triage level until the mild level. If the patients meet the severe triage level condition, then their emergency level is severe. Otherwise, they will be evaluated based on the moderate and then mild triage levels if they meet the conditions. On the other hand, for the deteriorated cases, when mild COVID-19 patients do not meet the condition of this triage level anymore, the algorithm will start to re-evaluate these patients and identify their new triage level. This process will be achieved from the moderate level until the critical one.

3.2.3 Prioritisation of positive COVID-19 patients using MCDM methods

This section presents the prioritisation procedure of positive COVID-19 patients via MCDM methods. Section 3.2.3.1 proposes decision matrices of positive COVID-19 patients within each emergency level. Section 3.2.3.2 explains the development of an MCDM solution. Section 3.2.3.3 presents the MCDM contexts used in the prioritisation of COVID-19 patients.

Proposal of prioritisation decision matrices of positive COVID-19 patients In this stage, each emergency level contains several positive COVID-19 patients. For the purpose of MSC transfusion for positive COVID-19 patients, the following

question is raised: 'which patients should be provided first?' In an emergency situation, the highest priority should be given to positive COVID-19 patients with the most emergent case inside each triage level, whereas the lowest priority should be given to patients with the least emergent case inside the same emergency level. Wrong patient prioritisation can lead to incorrect MSC transfusion decision that can endanger the lives of patients. Different health conditions make it difficult to decide who should be provided with MSCs first amongst the positive COVID-19 patients within each emergency level. Prioritisation is important to transfuse MSCs quickly and reliably to positive COVID-19 patients, especially in emergency situations. Thus, the most critical patients who cannot safely wait within each emergency/triage level can be prioritised for MSC transfusion. In the decision-making approach, a decision matrix is composed of decision alternatives and identified evaluation criteria [33, 53]. In this research, a set of positive COVID-19 patients is the alternatives, and the symptoms of each emergency/triage are identified as the criteria. As mentioned earlier, the automated triage algorithm is based on four emergency levels, and each level has its own symptoms (i.e. criteria). Thus, to prioritise positive COVID-19 patients within each emergency/triage level, a unique decision matrix for each level should be constructed, except mild patients as they do not have any symptoms and their emergency case does not need MSCs compared with other COVID-19 patients (i.e. moderate, severe and critical) [17]. Consequently, three decision matrices (see Tables 1–3) are generated based on the crossover between the number of positive COVID-19 patients and the number of specific criteria of the related emergency level. The criteria of each triage level can be measured either subjectively or objectively. The subjective criteria refer to expert perspectives, judgments or opinions in the decision-making procedure [54]. In this regard, the medical teams' opinions can be involved in the prioritisation decision by evaluating the mentioned subjective criteria of COVID-19 patients. These criteria will be assessed by medical teams with 'Yes' or 'No' responses (with 'Yes' referring to patients having risky symptoms and 'No' referring to patients having no risky symptoms). On the contrary, objective criteria refer to the avoidance of expert subjective opinion and a process, and they are completely based on hard facts [55]. Moreover, from a medical perspective, the overall criteria can be distinguished under two groups, namely, benefit and cost criteria. The benefit criteria imply that a high measurement value is critical, whereas the cost criteria mean that a low measurement value is critical [33].

The moderate COVID-19 patient decision matrix is presented in Table 1. This decision matrix is constructed on the basis of the intersection between moderate COVID-19 patients with the four evaluation criteria, which are fever, fatigue, cough and pneumonia symptoms. The representative measurement of these criteria is objective measurement with

Table 1 Decision matrix of moderate COVID-19 patients

Criteria Moderate COVID-19 Patients	Fever	Fatigue	Cough	Pneumonia Symptoms
Patient 1	FE.M (P1)	FA.M (P1)	C.M (P1)	PS.M (P1)
Patient 2	FE.M (P2)	FA.M (P2)	C.M (P2)	PS.M (P2)
Patient n	FE.M (Pn)	FA.M (Pn)	C.M (Pn)	PS.M (Pn)

FE Fever, *FA* Fatigue, *C* Cough, *PS* Pneumonia Symptoms, *M* Measurement, *P* Patients, *n* Number.

fever criterion and subjective measurement with fatigue, cough and pneumonia symptoms criteria. Furthermore, these evaluation criteria are benefit criteria (i.e. the higher the measurement value, the more urgent the case).

The severe COVID-19 patient decision matrix is presented in Table 2. This decision matrix is constructed on the basis of the intersection between severe COVID-19 patients and three evaluation criteria, namely, respiratory stress, oxygen saturation and partial pressure of oxygen (PaO$_2$)/fraction of inspiration (FiO$_2$). The representative measurement of these criteria is a subjective measurement with respiratory stress criterion and subjective measurement with oxygen saturation and partial pressure of oxygen (PaO$_2$)/fraction of inspiration (FiO$_2$) criteria. Respiratory stress is a benefit criterion. Thus, the higher the measurement value, the more severe the case. By contrast, oxygen saturation and PaO$_2$/FiO$_2$ are cost criteria. Thus, the lower the measurement value, the more severe the case.

Table 3 presents the critical COVID-19 patient decision matrix. This decision matrix is constructed on the basis of the intersection between critical COVID-19 patients and three evaluation criteria, namely, mechanical ventilation, septic shock and intensive care admission and monitoring. All these

evaluation criteria are measured subjectively and considered as benefit criteria (i.e. the higher the measurement value, the more critical the case).

In summary, the data within the three decision matrices represent the measurement values of each positive COVID-19 patient based on the identified criteria of each emergency/triage level. However, these decision matrices are automatically updated using the automated triage algorithm in real time when the patient shows better or poorer measurements in the identified criteria of the related emergency level by shifting the patient to lower or higher emergency level, respectively. Moreover, according to the constructed decision matrices, three prioritisation issues will be generated and encountered (i.e. multi-criteria, important criteria and trade-off amongst the criteria), as discussed in Section 2. Thus, the prioritisation process of positive COVID-19 patients within each emergency/triage level for the purpose of identifying the most critical patients who need immediate MSCs is considered a complex MCDM problem. To address this problem, the development of a decision-making solution is essential.

Development of a prioritisation approach via MCDM methods

This section proposes an MCDM approach with two impor-

Table 2 Decision matrix of severe COVID-19 patients

Criteria Severe COVID-19 Patients	Respiratory Stress	Oxygen Saturation	PaO$_2$/FiO$_2$
Patient 1	RS.M (P1)	OS.M (P1)	PaO$_2$/FiO$_2$ (P1)
Patient 2	RS.M (P2)	OS.M (P2)	PaO$_2$/FiO$_2$ (P1)
Patient n	RS.M (Pn)	OS.M (Pn)	PaO$_2$/FiO$_2$ (Pn)

RS Respiratory Stress, *OS* Oxygen Saturation, *M* Measurement, *P* Patients, *n* Number.

Table 3 Decision matrix of critical COVID-19 patients

Criteria Critical COVID-19 Patients	Mechanical Ventilation	Septic Shock	Intensive Care Admission and Monitoring
Patient 1	MV.M (P1)	SS.M (P1)	ICAM (P1)
Patient 2	MV.M (P2)	SS.M (P2)	ICAM (P1)
Patient n	MV.M (Pn)	SS.M (Pn)	ICAM (Pn)

MV Mechanical Ventilation, *SS* Septic Shock, *ICAM* Intensive Care Admission and Monitoring, *M* Measurement, *P* Patients, *n* Number.

tant purposes. Firstly, weights are assigned to the evaluation criteria of each triage level in the prioritisation process. This stage aims to solve the issue of importance by investigating the most effective criteria used in prioritisation. Secondly, positive COVID-19 patients within each triage level are prioritised on the basis of the weighted criteria from the first stage. This stage aims to eliminate two critical issues (i.e. multi-criteria and trade-off issues) through prioritising alternatives (positive COVID-19 patients). Furthermore, many MCDM methods are generally developed and used for weighting the evaluation criteria and alternative ranking [22, 56–59]. In the literature of MCDM, many ranking methods have been proposed, including TODIM (an acronym in Portuguese for interactive multi-criteria decision making) [60], qualitative flexible multiple criteria method (QUALIFLEX) [61], preference ranking organisation method for enrichment evaluation (PROMETHEE) [62], technique for order of preference by similarity to ideal solution (TOPSIS) [63] and *vlsekriterijumska optimizcija i kaompromisno resenje*(VIKOR) [64]. Each of these methods has its own strength and weaknesses; however, in developing the decision support system, the chosen method(s) has high contribution in the final decision-making outcome. Thus, to prioritise the COVID-19 patients' urgency in each emergency/ triage level, the most well-known ranking methods (i.e. TOPSIS and VIKOR) that show proven results are carefully studied, especially in the medical sector, and considered as the most superior methods for determining the best alternative [20, 33, 50, 65, 66]. TOPSIS and VIKOR are applicable for cases with numerous alternatives and criteria; these methods are also convenient to use when quantitative or objective data are given [67–70]. However, TOPSIS determines a solution with the shortest distance to the ideal solution and the greatest distance from the negative ideal solution, but it does not consider the relative importance of these distances [71]. Thus, VIKOR is one of the most practical ways for solving real-world problems because of the following advantages: (1) VIKOR is appropriate in terms of ranking for situations with many alternatives and attributes [20]; (2) VIKOR is superior in resolving decision-making problems when the criteria are incompatible or conflicting [72]; (3) VIKOR is considered a well-known method to balancing (i.e. trade-off) group utility and individual regret on the basis of expert's preference [73]; (4) VIKOR uses the acceptable advantage and stability test to provide the ideal solution and rank the alternatives [74]. The major drawbacks of VIKOR include the absence of weight generation provision [20, 21, 75]. This problem can be addressed by integrating VIKOR with weighting methods [76]. Generally, two weighting approaches are used in the decision-making process to identify the criteria weights, namely, objective and subjective methods [24]. Objective assessment methods take advantage of the information of each criterion to determine the weights of criteria. The most well-known

objective methods include CRiteria Importance Through Intercriteria Correlation (CRITIC) [77] and Entropy [78, 79]. These techniques do not depend on the subjective judgment of decision-makers in assigning the weights. The weights are directly assigned to attributes by a mathematical method [80]. These techniques were used in previous works, and they do not generate an inconsistency problem; however, subjective weights are the most important for assessing the results because they express the opinions of highly qualified experts with extensive experience [81]. On the other hand, the accuracy of the obtained weights' values for the evaluation criteria can be changed once the row data are changed. For instance, the continuous change in the value of positive COVID-19 patients leads to inaccurate computation in criteria weights. Thus, the procedure for determining weights in these techniques is not accurate for such case. Hence, in case of the need to assign weights for the criteria subjectively, these techniques cannot introduce the experience of decision-makers and subjective importance in the decision, which are considered drawbacks. Conversely, subjective assessment methods provide weight to the evaluation criteria according to the experience of decision-makers and subjective importance to each attribute. Subjective weights reflect the accumulated experience of decision-makers and subjective judgment to present decision-making background [80]. The two most superior subjective assessment methods are AHP [63, 82] and best worst method (BWM) [83]. In BWM, the weight of the criteria is calculated using the reference comparisons principle. Experts need to first identify one best criterion and one worst criterion and then determine the preference of the best criterion over all other criteria and the preference of all criteria over the worst criterion [84]. Although BWM reduces the number of comparisons compared with AHP (especially when the number of criteria is large), it shows limitation in some real-world application, where there is no single best and/or worst reference criterion over other criteria, which can badly affect the final results [83]. During emergency situations, equal attention should be paid to the evaluation criteria for each emergency level in the evaluation process. In such cases, AHP is the most suitable method for computing the importance of criteria for each emergency level, especially with the few criteria per emergency level. The preference comparison through AHP provides the required consistent and efficient results. Consequently, to prioritise COVID-19 patients within each emergency/ triage level, the present study uses an integration of AHP and VIKOR. AHP and VIKOR are commonly used MCDM approaches in various studies, especially in the medical domain [20]. AHP will be used for assigning weights for the criteria of each triage level subjectively by relying on expert judgment, and VIKOR will be used to provide a complete ranking of COVID-19 patients. The structure of the integrated AHP–VIKOR method for

prioritising COVID-19 patients within each emergency/triage level is presented in Fig. 5.

A. AHP Weighting Method for Weighting Criteria of Each Decision Matrix

This stage presents the process of providing subjective weights to the criteria of each triage level within each decision matrix based on the AHP method. The AHP approach involves several steps as follows.

Step 1. The problem is modelled as a hierarchy to start the AHP approach. The hierarchy contains the decision goal and the criteria that must be designed in each decision matrix [85]. Pairwise comparison amongst the criteria in each decision matrix of COVID-19 patient prioritisation is performed to extract the weights subjectively. Examples of pairwise comparison for criteria of the moderate decision matrix are illustrated in Fig. 6.

Step 2. The AHP constructs a pairwise matrix comparison using Eq. (1) to locate a weighting decision [86]:

$$A = \begin{pmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & \cdots & x_{nn} \end{pmatrix}, \tag{1}$$

where $x_{ii} = 1, x_{ji} = \frac{1}{x_{ij}}$.

Step 3. This step illustrates the design of a pairwise comparison questionnaire to the criteria in each decision matrix of COVID-19 patient prioritisation, which is given out to experts. However, the number of experts included in the questionnaire should be defined. The target experts are those who have relevant experience in the medical domain, besides COVID-19. Their preferences and judgments on the criteria of each decision matrix of COVID-19 patient prioritisation used in AHP are evaluated.

Step 4. In this stage, each element in matrix A is normalised to build the normalised matrix A_{norm}, A_{norm} (aij) as follows [87]:
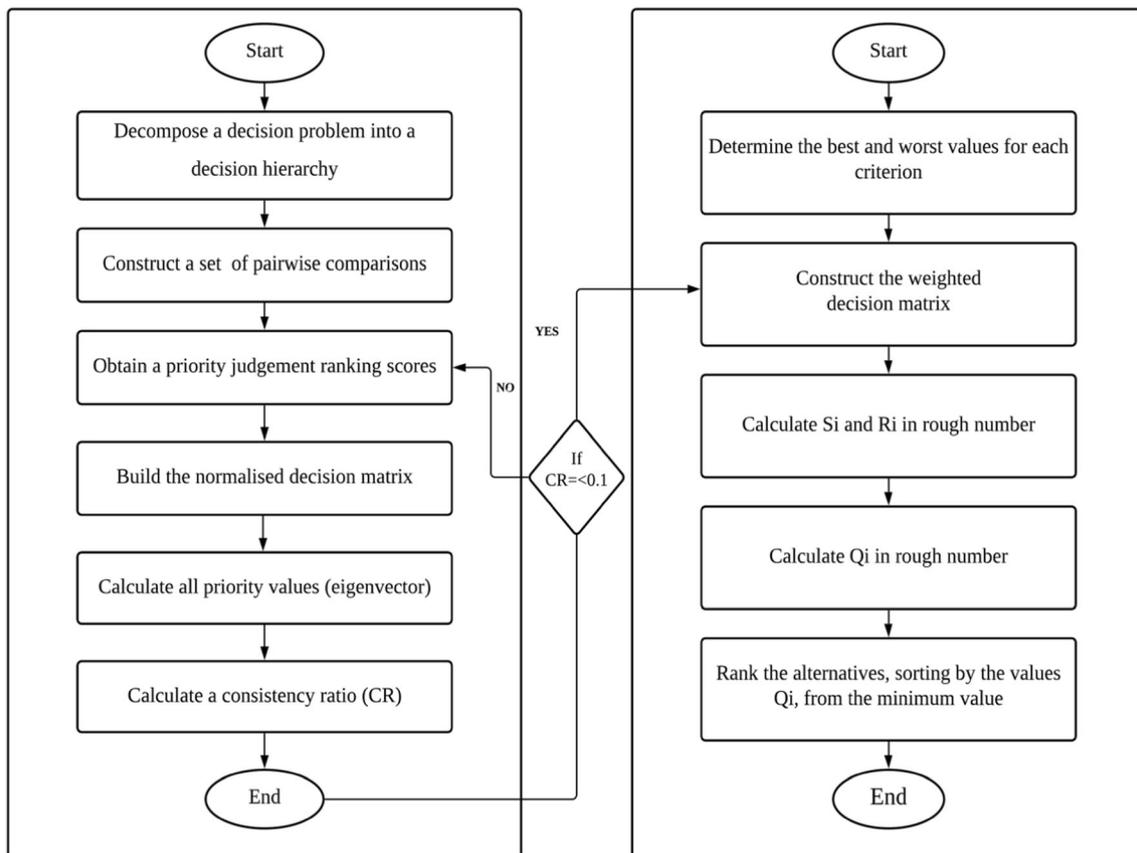
Fig. 5 Structure of the AHP–VIKOR method

Fig. 6 Pairwise comparison

<table>
<tr><td></td><td>Extremely</td><td>Very Strongly</td><td>Strongly</td><td>Slightly</td><td>Equal</td><td>Slightly</td><td>Strongly</td><td>Very Strongly</td><td>Extremely</td><td></td></tr>
</table>

Fever ——— Fatigue

9   7   5   3   1   1/3   1/5   1/7   1/9

Fever ——— Cough

9   7   5   3   1   1/3   1/5   1/7   1/9

Fever ——— Pneumonia

9   7   5   3   1   1/3   1/5   1/7   1/9
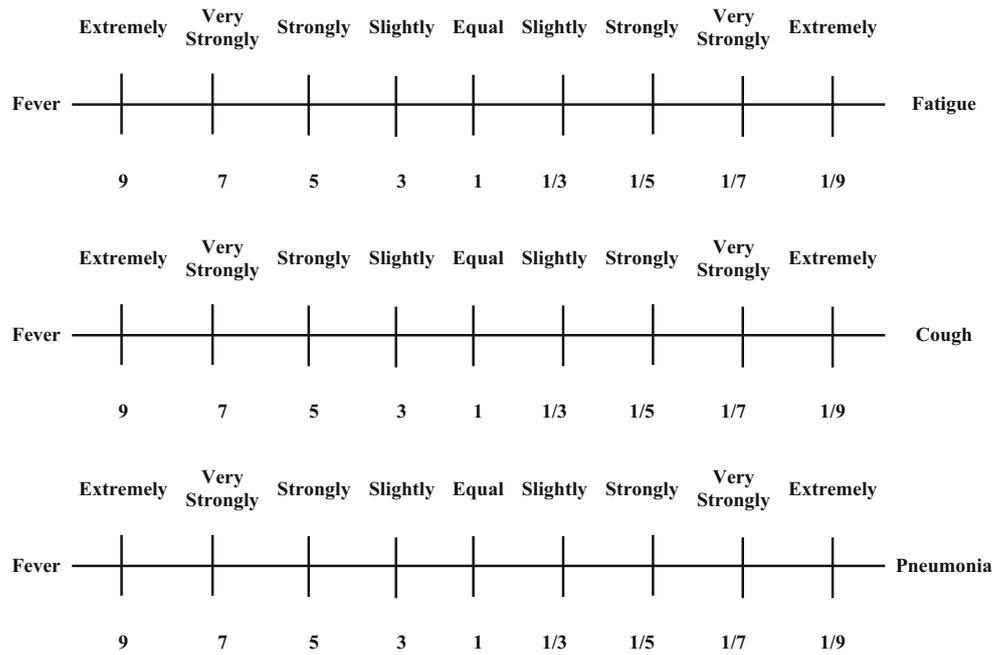
$$a_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} xij}, \tag{2}$$

$$A_{norm} = \begin{pmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{pmatrix}, \tag{3}$$

where $A(x_{ij})$ is given by Eq. (2).

Step 5.   This step includes AHP pairwise comparison to use mathematical calculations, convert judgments and assign weights for the criteria of each prioritisation decision matrix. The weights of the decision criterion can be calculated using Eq. (4) [88]:

$$W_i = \frac{\sum_{j=1}^{n} a_{ij}}{n} \quad \text{and} \quad \sum_{j=1}^{n} W_i = 1, \tag{4}$$

where n is the number of compared criteria of each prioritisation decision matrix.

Step 6.   In this step, Eq. (5) is utilised to check the consistency ratio (CR) to the pairwise comparison matrix as follows [89]:

$$CR = \frac{Cl}{Rl} \tag{5}$$

The consistency index (CI) is calculated using Eq. (6) as follows [64]:

$$Cl = \frac{\lambda\max - n}{n - 1}, \tag{6}$$

where $\lambda\ max$ is the maximum eigenvalue of the judgement matrix. Random CI (RI) is calculated using Eq. (7) as follows [90]:

$$Rl = \frac{1.98(n - 1)}{n}.Cl.$$

A pairwise comparison matrix with a corresponding CR of no more than 10% or 0.1 is acceptable; otherwise, it will be ignored.

B.   VIKOR Method for Prioritising COVID-19 Patients

To start the prioritisation of COVID-19 patients within each emergency/triage level, the VIKOR method is utilised considering its suitability for such target. In addition, it can provide prompt results and determine which positive COVID-19 patients (i.e. moderate, severe and critical) need MSC transfusion urgently. COVID-19 patients can be prioritised and ranked according to the VIKOR method by utilising the calculated criteria weights of each decision matrix from the AHP method. The VIKOR method involves different steps [20, 53].

Step1.   Identify the best f^*i and worst f^-i values of all criteria within each decision matrix (i.e. moderate decision

matrix, severe decision matrix and critical decision matrix); i = 1, 2, ..., n. If the ith function represents:

A benefit criterion (i.e. fever, fatigue, cough, pneumonia, respiratory stress, mechanical ventilation, septic shock and intensive care admission and monitoring):

$$f_i^* = \max_j f_{ij} f_t^- = \min_j f_{ij}, \tag{8}$$

A cost criterion (i.e. oxygen saturation, PaO_2/FiO_2):

$$f_i^* = \min_j f_{ij} f_t^- = \max_j f_{ij}. \tag{9}$$

Step2. AHP is adopted to calculate each evaluation criterion of each prioritisation decision matrix. A set of weights w = $w_1, w_2, w_3, \cdots, w_j, \cdots, w_n$ from the experts is accommodated in the decision matrix; this set is equal to 1. The resulting matrix can also be determined using the following equation:

$$WM = w_i * \frac{f_i^* - f_{ij}}{f_i^* - f_i^-}, \tag{10}$$

A weighted matrix is computed as follows:

$$\begin{bmatrix} \frac{w_1(f_1^* - f_{11})}{f_1^* - f_1^-} & \cdots & \frac{w_1(f_1^* - f_{ij})}{f_1^* - f_1^-} \\ \frac{w_1(f_1^* - f_{21})}{f_1^* - f_1^-} & \cdots & \frac{w_1(f_1^* - f_{ij})}{f_1^* - f_1^-} \\ \vdots & \vdots & \vdots \\ \frac{w_1(f_1^* - f_{31})}{f_1^* - f_1^-} & \cdots & \frac{w_1(f_1^* - f_{ij})}{f_1^* - f_1^-} \end{bmatrix} \tag{11}$$

Step3. In this step, the Sj and Rj values, $j = 1, 2, 3, ..., J, i = 1, 2, 3, ..., n$ can be calculated using the following equations:

$$Sj = \sum_{i=1}^{n} w_i * \frac{f_1^* - f_{ij}}{f_1^* - f_1^-}, \tag{12}$$

$$Rj = \max_i w_i * \frac{f_1^* - f_{ij}}{f_1^* - f_1^-}, \tag{13}$$

where w_i is the weight of each criterion of each prioritisation decision matrix expressing their relative importance.

Step4. Determine the values of $Q_j, j = (1, 2, \cdots, J)$ using the following equation:

$$Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1 - v)(R_j - R^*)}{R^- - R^*}, \tag{14}$$

where

$$S^* = \min_j S_j, S^- = \max_j S_j,$$
$$R^* = \min_j R_j, R^- = \max_j R_j,$$

v is introduced as the weight of the strategy of 'the majority of criteria' (or 'the maximum group utility'); here, v = 0.5.

Step5. Now the alternative set (i.e. COVID-19 patients within each emergency/triage level) can be prioritised. This process is accomplished by sorting the Q values in ascending order. In each emergency/triage level, COVID-19 patients with the lowest Q value indicate that he/she is most risky.

Decision-making contexts The MCDM technique (i.e. VIKOR) can be adopted in two different contexts (i.e. individual and group) [65]. Therefore, selecting the proper context is recommended based on experiments with different aggregation operators to prioritise the COVID-19 patients within each emergency/triage case. Basically, two main contexts in decision-making are emphasised, namely, decision-making based on single individual decision-maker and GDM based on multiple decision-makers. In case of variation amongst the prioritisation results of COVID-19 patients of individual VIKOR for each expert, GDM can be applied to aggregate the result of multiple expert decisions into one unique rank. GDM is highly recommended when a decision requires a number of decision-makers for selecting the best alternative [39]. This method systematically collects and combines the knowledge and judgement of experts of respiratory diseases. In the group context, each expert gives his or her subjective judgment to the COVID-19 criteria of each decision matrix (i.e. moderate, severe and critical). The idea of GDM is to aggregate the results of multiple decisions from many experts into one unique decision. Previous studies on GDM suggested two common configurations, that is, internal aggregation or external aggregation [33], which were applied for several medical domains [20–22, 33, 53, 65]. Internal aggregation aims to aggregate the obtained weights from each expert and compute the average weights for each criterion. In the present study, internal aggregation can be used to combine the weights extracted from each expert by applying arithmetic mean, and the VIKOR method can be applied for prioritisation steps. Then, the final rank of the COVID-19 patients within each emergency/triage level can be obtained. The purpose of using internal aggregation is to eliminate the variation amongst the obtained weights from experts and unify a unique

weight for each criterion. External aggregation can also be applied in this study. In external aggregation, the process is separated into multiple ranks (prioritisation of patients based on each expert preference), and these ranks are aggregated into one final prioritisation.

4 Results and discussion

This section presents the results and discussion of the real-time MSC transfusion framework for different emergency cases of positive COVID-19 patients. Section 4.1 describes the results of augmented patients' datasets in addition to the real-time evaluation and monitoring processes. Section 4.2 presents the subjective weight measurements for the

evaluation criteria of each decision matrix using AHP. Section 4.3 presents the results of individual and group prioritisation of COVID-19 patients within each emergency level using VIKOR.

4.1 Results of patient dataset and real-time evaluation and monitoring processes

In this section, the augmented datasets of 80 positive COVID-19 patients were constructed on the basis of two scenarios as mentioned in Section 3.2.1. In the first scenario, patients that tested positive were distributed in real time into four emergency groups, namely, mild, moderate, severe and critical, using the proposed automated triage algorithm based on the related criteria of each triage level. Table 4 illustrates the

Table 4 Positive COVID-19 patients' dataset and their distribution

P_ID	Status	Criteria		P_ID	Status	Criteria			
		Symptoms	Pneumonia			Fever	Fatigue	Cough	Pneumonia
1	Mild	0	0	21	Moderate	1	0	1	0
2	Mild	0	0	22	Moderate	1	0	1	0
3	Mild	0	0	23	Moderate	1	0	1	1
4	Mild	0	0	24	Moderate	0	1	1	1
5	Mild	0	0	25	Moderate	0	1	1	1
6	Mild	0	0	26	Moderate	1	1	1	1
7	Mild	0	0	27	Moderate	0	1	1	1
8	Mild	0	0	28	Moderate	1	1	1	1
9	Mild	0	0	29	Moderate	0	1	0	0
10	Mild	0	0	30	Moderate	0	0	1	1
11	Mild	0	0	31	Moderate	1	0	0	0
12	Mild	0	0	32	Moderate	1	0	1	1
13	Mild	0	0	33	Moderate	1	0	0	0
14	Mild	0	0	34	Moderate	1	0	0	1
15	Mild	0	0	35	Moderate	1	1	1	1
16	Mild	0	0	36	Moderate	1	1	1	1
17	Mild	0	0	37	Moderate	1	0	0	1
18	Mild	0	0	38	Moderate	1	1	1	0
19	Mild	0	0	39	Moderate	0	0	0	1
20	Mild	0	0	40	Moderate	0	0	1	1
P_ID	Status	Criteria			P_ID	Status	Criteria		
		Respiratory rate	Oxygen saturation	PaO$_2$/FiO$_2$			Mechanical ventilation	Septic shock	Intensive care unit
41	Severe	1	1	1	61	Critical	1	1	0
42	Severe	1	0	1	62	Critical	1	0	0
43	Severe	0	1	1	63	Critical	0	1	0
44	Severe	1	1	1	64	Critical	0	1	1
45	Severe	0	0	1	65	Critical	1	1	0
46	Severe	0	0	1	66	Critical	1	1	0
47	Severe	1	0	0	67	Critical	1	1	0
48	Severe	1	1	0	68	Critical	1	1	0
49	Severe	0	1	0	69	Critical	0	0	1
50	Severe	1	1	0	70	Critical	0	1	0
51	Severe	0	0	1	71	Critical	0	1	1
52	Severe	0	1	0	72	Critical	1	1	0
53	Severe	0	1	1	73	Critical	1	1	0
54	Severe	0	0	1	74	Critical	0	0	1
55	Severe	1	0	0	75	Critical	0	1	0
56	Severe	1	1	1	76	Critical	1	1	0
57	Severe	0	1	1	77	Critical	0	1	1
58	Severe	0	0	1	78	Critical	0	1	0
59	Severe	0	1	0	79	Critical	1	0	0
60	Severe	0	0	1	80	Critical	1	1	0

categorisation and distribution of positive COVID-19 patients in the first scenario.

Upon admission, all patients were tested using either polymerise chain reaction or antibody test. According to the severity of infection, the proposed automated triage algorithm distributed the patients into four groups instantly (i.e. real time). The first group of patients was labelled as mild because these patients have no pneumonia and show no symptoms (asymptomatic) [91]. The second group was labelled as moderate because these patients exhibit one or more symptoms, including fever, fatigue and cough, or show pneumonia symptoms on X-ray [91, 92]. The third group was labelled as severe because the patients in this group have one or more severe symptoms, including respiratory rate > 30 breaths/min, oxygen saturation < 93% and PaO_2/FiO_2 < 300 mmHg [93]. Finally, the last group was considered critical as the patients in this group require a mechanical ventilator, exhibit septic shock and need to be admitted in the intensive care unit [94, 95]. In the second scenario, the evaluation and real-time monitoring of admitted COVID-19 patients are achieved based on two condition transformations (i.e. improvement and deterioration). Table 5 shows the categorisation and distribution of positive COVID-19 patients in the second scenario.

Table 5 shows the changes in the emergency level of admitted patients after 96 h using the proposed automated triage algorithm. The status of a group of patients (e.g. 29, 31, 37, 39) improved from moderate to mild [96]. Similarly, the status of some patients with severe and critical conditions (e.g. 49, 54, 60, 52, 57, 58, 75, 79, 80) improved with or without treatment [97–99]. This case is not only the scenario where rapid deterioration cannot be ignored as a possibility that could happen (e.g. patients) [100, 101]. The early detection of these rapid changes and monitoring of these transformations may reduce disease progression. Furthermore, early treatment with MSCs, when necessary, may help reduce mortality in critically ill patients. Despite the possibility of both scenarios, COVID-19 patients, unfortunately, are likely to progress to critical illness especially considering other factors such as age, gender and chronic disease history [102]. For this reason, sorting the prioritisation procedure based on MCDM methods for deteriorating patients and even for improving patients in real time is critical for MSC transfusion. Therefore, the severity of the newly diagnosed transformation condition should be evaluated to provide patients with real-time update and MSC treatment to improve treatment procedures.

4.2 Weight determination Utilising AHP

This section presents the result of measurement weights to evaluate the criteria for each decision matrix (e.g. moderate, severe and critical) used in the prioritisation of positive COVID-19 patients in real time by using the AHP method.

As mentioned in Section 3.2.3.2-A, six steps were used, and three experts were asked to conduct their assessment and preferences for measuring the levels of multi-criteria via comparison questions. The questions were re-allocated twice amongst the experts because for the first time there was a CR issue with the experts' answers. Table 6 displays the weight results for the first, second and third experts of the multi-criteria of each decision matrix.

Table 6 shows the criteria weight results used in the prioritisation of positive COVID-19 patients based on three experts. These experts differed in assigning weights to each evaluation criterion of each emergency level. The first level is moderate, where the first, second and third experts gave the most weight to pneumonia and the least weight to fatigue. In the second level (severe), the first, second and third experts gave the highest weight to the respiratory rate and the least weight to PaO_2/FiO_2. Finally, the third level is critical. Due to the sensitivity of this level, experts differed in their evaluation. The first expert gave the most weight to intensive care and the least weight to mechanical ventilation. On the other hand, the second and third experts gave the highest weight to septic shock and the least weight to mechanical ventilation. Moreover, the CR results indicate that the results of criteria weighting, which were extracted from all experts, have acceptable values because they are less than 0.1.

4.3 Prioritisation of COVID-19 patients using VIKOR

To identify COVID-19 patients who must receive MSCs immediately (i.e. real time), the COVID-19 patients within each emergency level need to be prioritised to distinguish patients with the highest risk. As mentioned in Section 3.2.3.2-B, the VIKOR method was used for prioritising different emergency levels of COVID-19 patients. The classified COVID-19 patients within both scenarios that resulted from the automated triage algorithm in Section 4.1 are prioritised thoroughly. To discuss the patient's prioritisation according to different levels, the results and discussion were divided into two different decision-making contexts, namely, individual and group prioritisation, as mentioned in Section 3.2.3.3.

4.3.1 Individual VIKOR prioritisation for COVID-19 patients

In this section, the results of the individual decision-making context for patients within the three COVID-19 emergency levels (i.e. moderate, severe and critical) are presented based on VIKOR using the given weight of the evaluation criteria extracted from expert opinions in Section 4.2. The prioritisation results for COVID-19 patients of the first scenario are presented in Table 7.

Table 7 shows that the COVID-19 patients within each triage level were prioritised according to the Q value in ascending order. At the moderate level, patients 26, 35, 36 and

Table 5 Patients' transformations from initial admission to improvement and deterioration conditions

Improvements

P_ID	Status	Criteria — Symptoms	Criteria — Pneumonia	Previous status	New status
29	Mild	0	0	Moderate	Mild
31	Mild	0	0	Moderate	Mild
37	Mild	0	0	Moderate	Mild
39	Mild	0	1	Moderate	Mild
45	Mild	0	0	Severe	Mild
47	Mild	0	0	Severe	Mild
49	Mild	0	0	Severe	mild
51	mild	0	0	Severe	Mild
54	Mild	0	0	Severe	Mild
55	Mild	0	0	Severe	Mild
60	Mild	0	0	Severe	Mild

P_ID	Status	Fever	Fatigue	Cough	Pneumonia	Previous status	New status
42	Moderate	0	0	1	1	Severe	Moderate
43	Moderate	0	1	1	1	Severe	Moderate
46	Moderate	0	0	1	1	Severe	Moderate
50	Moderate	1	0	1	1	Severe	Moderate
52	Moderate	1	1	0	1	Severe	Moderate
53	Moderate	1	1	0	1	Severe	Moderate
57	Moderate	1	1	0	0	Severe	Moderate
58	Moderate	1	0	0	0	Severe	Moderate
59	Moderate	1	0	0	1	Severe	Moderate
62	Moderate	1	0	0	1	Critical	Moderate
63	Moderate	1	0	0	1	Critical	Moderate
69	Moderate	1	0	0	1	Critical	Moderate
70	Moderate	1	0	0	1	Critical	Moderate
74	Moderate	0	0	0	1	Critical	Moderate
75	Moderate	0	1	0	1	Critical	Moderate
78	Moderate	1	0	1	1	Critical	Moderate
79	Moderate	0	0	0	1	Critical	Moderate
80	Moderate	1	0	1	1	Critical	Moderate

P_ID	Status	Respiratory stress	Oxygen saturation	PaO$_2$/FiO$_2$	Previous status	New status
61	Severe	1	1	1	Critical	Severe
64	Severe	0	0	1	Critical	Severe
65	Severe	0	0	1	Critical	Severe
66	Severe	1	1	1	Critical	Severe
67	Severe	0	0	1	Critical	Severe
68	Severe	1	1	1	Critical	Severe
71	Severe	0	0	1	Critical	Severe
72	Severe	1	1	1	Critical	Severe
73	Severe	1	0	1	Critical	Severe
76	Severe	1	0	1	Critical	Severe
77	Severe	1	0	1	Critical	Severe

Deterioration

P_ID	Status	Fever	Fatigue	Cough	Pneumonia	Previous status	New status
3	Moderate	0	0	1	1	Mild	Moderate
8	Moderate	0	0	0	1	Mild	Moderate
10	Moderate	1	0	0	0	Mild	Moderate
11	Moderate	0	0	1	1	Mild	Moderate
12	Moderate	0	1	1	0	Mild	Moderate
13	Moderate	0	1	1	0	Mild	Moderate
14	Moderate	0	0	1	0	Mild	Moderate
17	Moderate	1	0	0	0	Mild	Moderate

P_ID	Status	Respiratory stress	Oxygen saturation	PaO$_2$/FiO$_2$	Previous status	New status
2	Severe	1	0	0	Mild	Severe
5	Severe	0	0	1	Mild	Severe
6	Severe	1	0	0	Mild	Severe
7	Severe	1	1	0	Mild	Severe
9	Severe	1	0	1	Mild	Severe
15	Severe	1	0	1	Mild	Severe
16	Severe	1	0	1	Mild	Severe
20	Severe	1	1	1	Mild	Severe
21	Severe	1	0	1	Moderate	Severe
22	Severe	1	1	1	Moderate	Severe
33	Severe	1	1	0	Moderate	Severe
34	Severe	0	0	1	Moderate	Severe
35	Severe	0	0	1	Moderate	Severe

P_ID	Status	Mechanical ventilation	Septic shock	Intensive care unit	Previous status	New status
1	Critical	1	0	0	Mild	Critical
4	Critical	1	0	1	Mild	Critical
18	Critical	1	0	1	Mild	Critical
19	Critical	0	0	1	Mild	Critical
23	Critical	1	0	1	Moderate	Critical
24	Critical	1	1	1	Moderate	Critical
25	Critical	1	0	1	Moderate	Critical
26	Critical	0	1	0	Moderate	Critical
27	Critical	1	1	0	Moderate	Critical
28	Critical	0	1	0	Moderate	Critical
30	Critical	0	1	0	Moderate	Critical
32	Critical	0	1	1	Moderate	Critical
36	Critical	0	0	1	Moderate	Critical
38	Critical	0	1	1	Moderate	Critical
40	Critical	1	1	1	Moderate	Critical
41	Critical	1	0	1	Severe	Critical
44	Critical	1	1	0	Severe	Critical
48	Critical	1	0	0	Severe	Critical
56	Critical	1	1	0	Severe	Critical

28 obtained a Q value of zero due to equal values in the criteria; however, the experts provided different orders, indicating that the patients were prioritised in a first come first serve basis or based on their ID. For instance, patient 26 was admitted to the hospital before patient 28; thus, he was prioritised first. At the severe level, patients 43 had an order of 7 for the first expert and 9 for the second and third experts. Patient 49 obtained an order of 11 for the first expert and 12 for the second and third experts. Similar to the case in the moderate level, patients 41, 44 and 56 got a Q value of zero, and patients 45, 46, 51, 54, 58 and 60 obtained a Q value of one. However, they were prioritised in a first come first serve basis or according to their ID. For instance, patient 41 was admitted to the hospital before patient 44; thus, he was prioritised first. In the critical level, the prioritisation of the first expert differed from that of the second and third experts. Conversely, the prioritisation of the second and third experts was consistent. Patients 64, 71 and 77 obtained a Q value of zero, whereas patients 62, 63, 70, 75, 78 and 79 got a Q value

of one. However, they were prioritised in a first come first serve basis as discussed in the moderate and severe emergency levels. For the second scenario, the evaluation and real-time monitoring of the prioritised COVID-19 patients in the first scenario (Table 4) are achieved based on two condition transformations, namely, improvement and deterioration. The prioritisation results for COVID-19 patients in the second scenario are presented in Table 8.

As shown in Table 5, the status of COVID-19 patients either improved or deteriorated after 72 h. Table 8 displays the Q value and order of patients based on weights obtained from three experts using the AHP method from Table 6. In the improvements, COVID-19 patients with two emergency levels are included, which are moderate and severe. The prioritisation is achieved for both levels. At the moderate emergency level, patient 42 was in the severe emergency level at order 6; however, this case improved to moderate level, and the order reached 12. On the other hand, patient 58 had an order of 19 in the severe level; however, the case improved to

Table 6 Criteria weight results of the three experts and their CR

Moderate								
Expert 1			Expert 2			Expert 3		
Criteria	Weights	CR	Criteria	Weights	CR	Criteria	Weights	CR
Fever	0.282		Fever	0.229		Fever	0.280	
Fatigue	0.086	0.065	Fatigue	0.070	0.055	Fatigue	0.120	0.081
Cough	0.093		Cough	0.193		Cough	0.120	
Pneumonia	0.539		Pneumonia	0.508		Pneumonia	0.470	
Severe								
Expert 1			Expert 2			Expert 3		
Criteria	Weights	CR	Criteria	Weights	CR	Criteria	Weights	CR
Respiratory rate	0.429		Respiratory rate	0.480		Respiratory rate	0.633	
Oxygen saturation	0.429	0.000	Oxygen saturation	0.405	0.031	Oxygen saturation	0.260	0.053
PaO_2/FiO_2	0.143		PaO_2/FiO_2	0.115		PaO_2/FiO_2	0.106	
Critical								
Expert 1			Expert 2			Expert 3		
Criteria	Weights	CR	Criteria	Weights	CR	Criteria	Weights	CR
Mechanical ventilation	0.200		Mechanical ventilation	0.106		Mechanical ventilation	0.074	
Septic shock	0.200	0.000	Septic shock	0.765	0.069	Septic shock	0.643	0.092
Intensive care unit	0.600		Intensive care unit	0.129		Intensive care unit	0.283	

moderate level, and the order was changed to 18. At the severe emergency level, patient 64 had an order of 1 at the critical level; however, the case improved to severe emergency level, and the order was changed to 8. Patient 71 had an order of 2; however, the case improved to severe level, and the order was changed to 11. In the deterioration, COVID-19 patients with three emergency levels are included, which are moderate, severe and critical. The prioritisation is achieved for all three levels. At the moderate level, the data of patients were equal. Patients 3 and 11 got a Q value of zero, but they were prioritised in a first come first serve basis or according to their ID. At the severe emergency level, patient 35 had an order of 3 at the moderate level; however, when the status changed to deterioration under severe level, the order changed to 13 in real time. At the critical emergency level, patients 26 and 28 had an order of 3 at the moderate level; however, when their conditions changed to deterioration under critical level, their orders changed 16 and 18, respectively. Overall, the extracted weights from the three experts affected the prioritisation. For instance, the first and second experts gave higher weights to cough than fatigue. By contrast, the third expert gave an equal weight for cough and fatigue criteria. Thus, in the second scenario, for improved patients in the moderate level, the prioritisation results of all experts showed that patients 50, 78 and 80 got a Q value of zero. Thus, they obtained a high

priority level. Conversely, patients 52 and 53 got a high priority level based on the results of the third expert, in addition to patients 50, 78 and 80. Patients 50, 78 and 80 had a value of one for all criteria of this emergency level except fatigue (as mentioned, this criterion got a weight less than cough), which had a value of zero, whereas patients 52 and 53 had a value of one for all criteria except cough, which had a value of zero. Thus, the equality in weighting of both cough and fatigue criteria by the third expert affected the prioritisation result of these patients (i.e. 52 and 53). This is why these patients obtained a high priority based on the opinion of this expert.

In summary, there was agreement between the experts involved in the prioritisation of patients because their weights for the criteria of these levels were similar. Moreover, in the first scenario, the order in the moderate level matched 100% amongst experts. In the severe level, the order matched 65% amongst experts; however, there was a difference of 35% between them regarding the order for seven patients (i.e. patients 43, 47, 49, 52, 53, 55, 57). Moreover, in the critical level, the order matched 20% amongst experts, but there was a difference of 80% between them regarding the order of 16 patients (e.g. patients 6, 61, 63, 65 and 66). In the second scenario, for the improved patients, the order in the moderate emergency level matched 78% amongst experts, but there was a difference of 22% between them regarding the order of

Table 7 Prioritisation results of the first scenario

Moderate									Severe									Critical								
Expert 1			Expert 2			Expert 3			Expert 1			Expert 2			Expert 3			Expert 1			Expert 2			Expert 3		
Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order
21	0.842	16	21	0.811	16	21	0.839	16	41	0	1	41	0	1	41	0	1	61	0.833	6	61	0.031	4	61	0.306	4
22	0.842	17	22	0.811	17	22	0.839	17	42	0.75	6	42	0.652	6	42	0.351	6	62	1	15	62	1	19	62	1	19
23	0.126	5	23	0.106	5	23	0.198	5	43	0.75	7	43	0.771	9	43	0.854	9	63	1	16	63	0.099	13	63	0.349	13
24	0.416	9	24	0.348	9	24	0.46	9	44	0	2	44	0	2	44	0	2	64	0	1	64	0	1	64	0	1
25	0.416	10	25	0.348	10	25	0.46	10	45	1	15	45	1	15	45	1	15	65	0.833	7	65	0.031	5	65	0.306	5
26	0	1	26	0	1	26	0	1	46	1	16	46	1	16	46	1	16	66	0.833	8	66	0.031	6	66	0.306	6
27	0.416	11	27	0.348	11	27	0.46	11	47	0.833	10	47	0.717	7	47	0.411	7	67	0.833	9	67	0.031	7	67	0.306	7
28	0	2	28	0	2	28	0	2	48	0.25	4	48	0.185	4	48	0.143	4	68	0.833	10	68	0.031	8	68	0.306	8
29	1	20	29	1	20	29	1	20	49	0.833	11	49	0.836	12	49	0.914	12	69	0.167	4	69	0.986	17	69	0.877	17
30	0.463	12	30	0.386	12	30	0.529	12	50	0.25	5	50	0.185	5	50	0.143	5	70	1	17	70	0.099	14	70	0.349	14
31	0.892	18	31	0.915	18	31	0.908	18	51	1	17	51	1	17	51	1	17	71	0	2	71	0	2	71	0	2
32	0.126	6	32	0.106	6	32	0.198	6	52	0.833	12	52	0.836	13	52	0.914	13	72	0.833	11	72	0.031	9	72	0.306	9
33	0.892	19	33	0.915	19	33	0.908	19	53	0.75	8	53	0.771	10	53	0.854	10	73	0.833	12	73	0.031	10	73	0.306	10
34	0.184	7	34	0.332	7	34	0.268	7	54	1	18	54	1	18	54	1	18	74	0.167	5	74	0.986	18	74	0.877	18
35	0	3	35	0	3	35	0	3	55	0.833	13	55	0.717	8	55	0.411	8	75	1	18	75	0.099	15	75	0.349	15
36	0	4	36	0	4	36	0	4	56	0	3	56	0	3	56	0	3	76	0.833	13	76	0.031	11	76	0.306	11
37	0.184	8	37	0.332	8	37	0.268	8	57	0.75	9	57	0.771	11	57	0.854	11	77	0	3	77	0	3	77	0	3
38	0.795	15	38	0.773	15	38	0.769	15	58	1	19	58	1	19	58	1	19	78	1	19	78	0.099	16	78	0.349	16
39	0.514	14	39	0.49	14	39	0.599	14	59	0.833	14	59	0.836	14	59	0.914	14	79	1	20	79	1	20	79	1	20
40	0.463	13	40	0.386	13	40	0.529	13	60	1	20	60	1	20	60	1	20	80	0.833	14	80	0.031	12	80	0.306	12

Table 8 Prioritisation results of the second scenario

Improvements

Moderate

Patient	Q (Expert 1)	Order	Patient	Q (Expert 2)	Order	Patient	Q (Expert 3)	Order
42	0.44	12	42	0.345	12	42	0.466	12
43	0.373	11	43	0.295	11	43	0.364	11
46	0.44	13	46	0.345	13	46	0.466	13
50	0	1	50	0	1	50	0	1
52	0.014	4	52	0.229	4	52	0	2
53	0.014	5	53	0.229	5	53	0	3
57	0.932	17	57	0.95	17	57	0.898	17
58	1	18	58	1	18	58	1	18
59	0.082	6	59	0.278	6	59	0.103	6
62	0.082	7	62	0.278	7	62	0.103	7
63	0.082	8	63	0.278	8	63	0.103	8
69	0.082	9	69	0.278	9	69	0.103	9
70	0.082	10	70	0.278	10	70	0.103	10
74	0.514	15	74	0.482	15	74	0.569	15
75	0.446	14	75	0.433	14	75	0.466	14
78	0	2	78	0	2	78	0	4
79	0.514	16	79	0.482	16	79	0.569	16
80	0	3	80	0	3	80	0	5

Improvements

Severe

Patient	Q (Expert 1)	Order	Patient	Q (Expert 2)	Order	Patient	Q (Expert 3)	Order
61	0	1	61	0	1	61	0	1
64	1	8	64	1	8	64	1	8
65	1	9	65	1	9	65	1	9
66	0	2	66	0	2	66	0	2
67	1	10	67	1	10	67	1	10
68	0	3	68	0	3	68	0	3
71	1	11	71	1	11	71	1	11
72	0.25	4	72	0.185	4	72	0.143	4
73	0.75	5	73	0.652	5	73	0.351	5
76	0.75	6	76	0.652	6	76	0.351	6
77	0.75	7	77	0.652	7	77	0.351	7

Deterioration

Moderate

Patient	Q (Expert 1)	Order	Patient	Q (Expert 2)	Order	Patient	Q (Expert 3)	Order
3	0	1	3	0	1	3	0	1
8	0.086	3	8	0.19	3	8	0.129	3
10	0.824	4	10	0.965	6	10	0.83	4
11	0	2	11	0	2	11	0	2
12	0.92	6	12	0.931	4	12	0.871	6
13	0.92	7	13	0.931	5	13	0.871	7
14	1	8	14	1	8	14	1	8
17	0.824	5	17	0.965	7	17	0.83	5

Deterioration

Severe

Patient	Q (Expert 1)	Order	Patient	Q (Expert 2)	Order	Patient	Q (Expert 3)	Order
2	0.833	9	2	0.717	9	2	0.411	9
5	1	11	5	1	11	5	1	11
6	0.833	10	6	0.717	10	6	0.411	10
7	0.25	3	7	0.185	3	7	0.143	3
9	0.75	5	9	0.652	5	9	0.351	5
15	0.75	6	15	0.652	6	15	0.351	6
16	0.75	7	16	0.652	7	16	0.351	7
20	0	1	20	0	1	20	0	1
21	0.75	8	21	0.652	8	21	0.351	8
22	0	2	22	0	2	22	0	2
33	0.25	4	33	0.185	4	33	0.143	4
34	1	12	34	1	12	34	1	12
35	1	13	35	1	13	35	1	13

Deterioration

Critical

Patient	Q (Expert 1)	Order	Patient	Q (Expert 2)	Order	Patient	Q (Expert 3)	Order
1	1	15	1	1	18	1	1	18
4	0.292	2	4	0.928	11	4	0.847	11
18	0.292	3	18	0.928	12	18	0.847	12
19	0.417	9	19	0.987	16	19	0.887	16
23	0.292	4	23	0.928	13	23	0.847	13
24	0.875	11	24	0.156	4	24	0.372	4
25	0.292	5	25	0.928	14	25	0.847	14
26	1	16	26	0.216	8	26	0.412	8
27	0.875	12	27	0.156	5	27	0.372	5
28	1	17	28	0.216	9	28	0.412	9
30	1	18	30	0.216	10	30	0.412	10
32	0.292	6	32	0.129	2	32	0.097	2
36	0.417	10	36	0.987	17	36	0.887	17
38	0.292	7	38	0.129	3	38	0.097	3
40	0	1	40	0	1	40	0	1
41	0.292	8	41	0.928	15	41	0.847	15
44	0.875	13	44	0.156	6	44	0.372	6
48	1	19	48	1	19	48	1	19
56	0.875	14	56	0.156	7	56	0.372	7

patients 52, 53, 78 and 80. At the severe emergency level, the order at this level matched 100% amongst experts. However, for the deteriorated patients, the order at the moderate level matched 50% amongst experts, but there was a difference of 50% between them regarding the order of patients 10, 12, 13 and 17. At the severe emergency level, the order at this level matched 100% amongst experts. At the critical emergency level, the order at this level matched 11% amongst experts, but there was a difference of 89% between them (e.g. patients 1, 4, 18, 19 and 23). Thus, there is a difference between an order for each expert in some levels and for some patients (except the prioritised moderate patients in the first scenario,

the prioritised severe patients in the improved patients of the second scenario and the prioritised severe patients in the deteriorated patients of the second scenario). Due to the sensitivity of the MSC transfusion procedure for the prioritised patients within each emergency level and its association with a potentially fatal disease, the order for all patients should be unified to reach more conclusive results in real time.

4.3.2 Group VIKOR prioritisation for COVID-19 patients

According to the previous discussion, there is a variation between the results of individual VIKOR prioritisations based

on the preferences of the involved experts. Thus, GDM context is an effective solution to eliminate such variation and produce a unified order for different emergency levels of COVID-19 patients within each mentioned scenario. The results of both scenarios of patients within the three COVID-19 emergency levels (i.e. moderate, severe and critical) are presented based on two group VIKOR configurations, namely, internal and external. For the internal group VIKOR results, due to the differences of the extracted weights amongst the preferences of the three experts for the criteria of each emergency level, there is an essential need to aggregate the weights of the experts using an arithmetic mean to eliminate such differences and produce grouped weights as mentioned in Section 3.2.3.3. Table 9 shows the arithmetic mean results for the criteria of each COVID-19 emergency level.

The arithmetic mean results show that the most important criterion of the moderate emergency level is pneumonia, and the least important criterion is fatigue. For the severe level, the respiratory rate is the most important criterion, whereas partial pressure is the least important criterion. In the critical emergency level, septic shock is the most important criterion, whereas mechanical ventilation is the least important criterion. However, the arithmetic mean results of each criterion can be used in the internal configuration of group VIKOR. In addition, the external group VIKOR can be produced by aggregating the resulting score (i.e. Q) of the prioritised patients within each emergency level of each scenario as mentioned in Section 3.2.3.3. Tables 10 and 11 show the internal and external group VIKOR results of the first and second scenarios.

As shown in Table 10 and the previous discussion related to the first scenario, there is no justification for the unification of their orders based on group context because the order of moderate patients matched 100% amongst the experts. Patients in the severe and critical levels possessed variations in their orders. Thus, group context is needed. At the severe level, the three patients with the highest risk based on internal and external group VIKOR for the first scenario are patients 41, 44 and 56. However, patients 58, 54 and 51 had the lowest risk. At the critical level, patients 64, 71 and 77 had the highest risk, whereas patients 74, 69 and 78 had the lowest risk.

As shown in Table 11 and the previous discussion related to the second scenario, because the order of severe patients

under the improved patients matched 100% amongst the experts, there is no justification for the unification of their orders based on group context. However, group context is needed to eliminate the variation in orders of moderate patients amongst the involved experts. At the moderate level of the improved patients, patients 50, 78 and 80 had the highest risk based on internal and external group VIKOR for the second scenario, whereas patients 58, 57 and 79 had the lowest risk. For the deteriorated patients, two emergency levels for COVID-19 (i.e. moderate and critical) are included in the group result because their orders are varied. Considering that the individual ranks of the three experts are similar in the severe level, there is no justification for the unification of their orders based on group context. At the moderate level of the deteriorated patients, patients 3, 11 and 8 had the highest risk, whereas patients 14, 13 and 12 had the lowest risk. At the critical level, patients 40, 32 and 38 had the highest risk, whereas patients 48, 1 and 36 had the lowest risk. In summary, COVID-19 patients in both scenarios were prioritised similarly between the internal and external group VIKOR. Thus, the process of MSC transfusion in real time for the prioritised COVID-19 patients within each emergency level can be achieved according to the order of each patient after evaluating the group results. The next section presents the evaluation results of group VIKOR to investigate the reliability of the framework results.

5 Evaluation

In this section, the efficiency of the proposed real-time MSC transfusion decision-making framework is evaluated and tested through two assessment processes. Firstly, the systematic ranking of the COVID-19 patients' ranking results is evaluated. Secondly, a comparison analysis is conducted to compared the proposed framework with a recent related work.

5.1 Systematic ranking evaluation

This section presents the process of objective validation for group results of the first and second scenarios of the prioritisation of COVID-19 patients within each emergency

Table 9 Arithmetic mean results

Moderate		Severe		Critical	
Criteria	Weights	Criteria	Weights	Criteria	Weights
Fever	0.265	Respiratory rate	0.514	Mechanical ventilation	0.127
Fatigue	0.093	Oxygen saturation	0.365	Septic shock	0.536
Cough	0.136	PaO$_2$/FiO$_2$	0.121	Intensive care unit	0.337
Pneumonia	0.507				

Table 10 Patient prioritisation results based on internal and external group VIKOR for the first scenario

Severe						Critical					
Internal			External			Internal			External		
Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order
41	0.000	1	41	0.000	1	61	0.398	4	4	0.390	4
42	0.563	6	42	0.584	6	62	1.000	19	19	1.000	19
43	0.792	9	43	0.792	9	63	0.483	13	13	0.483	13
44	0.000	2	44	0.000	2	64	0.000	1	1	0.000	1
45	1.000	15	45	1.000	15	65	0.398	5	5	0.390	5
46	1.000	16	46	1.000	16	66	0.398	6	6	0.390	6
47	0.632	7	47	0.654	7	67	0.398	7	7	0.390	7
48	0.187	4	48	0.193	4	68	0.398	8	8	0.390	8
49	0.861	12	49	0.861	12	69	0.859	17	17	0.677	17
50	0.187	5	50	0.193	5	70	0.483	14	14	0.483	14
51	1.000	17	51	1.000	17	71	0.000	2	2	0.000	2
52	0.861	13	52	0.861	13	72	0.398	9	9	0.390	9
53	0.792	10	53	0.792	10	73	0.398	10	10	0.390	10
54	1.000	18	54	1.000	18	74	0.859	18	18	0.677	18
55	0.632	8	55	0.654	8	75	0.483	15	15	0.483	15
56	0.000	3	56	0.000	3	76	0.398	11	11	0.390	11
57	0.792	11	57	0.792	11	77	0.000	3	3	0.000	3
58	1.000	19	58	1.000	19	78	0.483	16	16	0.483	16
59	0.861	14	59	0.861	14	79	1.000	2	20	1.000	20
60	1.000	2	60	1.000	2	80	0.398	12	12	0.390	12

case. The results of the proposed framework were validated by utilising an objective approach similar to [20, 22, 53, 65]. To validate the group prioritisation results of both scenarios, the prioritised COVID-19 patients within each emergency case were divided into four groups. Every group within each emergency level consists of a number of prioritised COVID-19 patients. The number of COVID-19 patients within each group varies depending on various scenarios. The validation results will not be influenced by the number of groups or COVID-19 patients within each group. However, the last group must have the largest or equal number of patients compared with others. The statistical approach (i.e. mean) was calculated for the normalised row data of the prioritised patients within each group to ensure that the set of the prioritised COVID-19 patients within each emergency level in both scenarios is subjected to systematic ordering (Eq. 15).

$$mean = \frac{1}{n} \sum_{i=1}^{n} x_i. \tag{15}$$

The first group must reach the best value, which has to be proven when the mean is measured. We assumed that the first group acquired the best in mean compared with the other three groups. However, for the second group, the mean results have to be poorer than those in the first group and better than those in the third and fourth groups or equal to those in the third group. Accordingly, for the systematic ranking results, the first group must prove that it is the best compared with the other groups. Table 12 shows the validation results for both scenarios.

In the validation results, the groups were compared for each emergency level on the basis of each scenario. In both scenarios, the validation results indicate that the first group in each emergency COVID-10 level is the best one amongst others followed by the second, third and fourth groups. This is because their mean value is the lowest one as the normalisation technique used in a VIKOR method scaled the data of each patient in ascending order. In sum, the statistical results indicated that the patient prioritisation in each emergency COVID-19 level of both scenarios is undergoing systematic

Table 11 Patient prioritisation results based on internal and external group VIKOR for the second scenario

Improvements						Deterioration											
Moderate						Moderate						Critical					
Internal			External			Internal			External			Internal			External		
Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order	Patient	Q	Order
42	0.414	12	42	0.417	12	3	0	1	3	0	1	1	1	18	1	1	18
43	0.342	11	43	0.344	11							4	0.807	11	4	0.689	11
46	0.414	13	46	0.417	13	8	0.134	3	8	0.135	3	18	0.807	12	18	0.689	12
50	0	1	50	0	1							19	0.879	16	19	0.764	16
52	0.086	4	52	0.081	4	10	0.873	4	10	0.873	4	23	0.807	13	23	0.689	13
53	0.086	5	53	0.081	5							24	0.508	4	24	0.468	4
57	0.928	17	57	0.927	17	11	0	2	11	0	2	25	0.807	14	25	0.689	14
58	1	18	58	1	18							26	0.580	8	26	0.543	8
59	0.158	6	59	0.154	6	12	0.909	6	12	0.908	6	27	0.508	5	27	0.468	5
62	0.158	7	62	0.154	7							28	0.580	9	28	0.543	9
63	0.158	8	63	0.154	8	13	0.909	7	13	0.908	7	30	0.580	10	30	0.543	10
69	0.158	9	69	0.154	9							32	0.191	2	32	0.173	2
70	0.158	10	70	0.154	10							36	0.879	17	36	0.764	17
74	0.520	15	74	0.522	15	14	1	8	14	1	8	38	0.191	3	38	0.173	3
75	0.448	14	75	0.448	14							40	0	1	40	0	1
78	0	2	78	0	2							41	0.807	15	41	0.689	15
79	0.520	16	79	0.522	16							44	0.508	6	44	0.468	6
80	0	3	80	0	3	17	0.873	5	17	0.873	5	48	1	19	48	1	19
												56	0.508	7	56	0.468	7

ranking. Thus, MSC transfusion for COVID-19 patients with different emergency levels must follow the order achieved in the group VIKOR results.

5.2 Comparison analysis

In this section, comparison analysis was used to compare this study with a recent related work [63] in terms of the following perspectives:

Medically Compared with [63], which used convalescent plasma (CP) from COVID-19 survivors to be transfused to infected patients, the present study used MSCs, which can treat severe cases by replacing damaged tissues [103]. Besides the ability to stop cytokine storm, MSCs have the ability to decrease the rate of cell death and produce antioxidant substances for boosting general immunity [104]. With the emergence of more aggressive and contagious variants of COVID-19 worldwide [105], MSCs provide a possible procedure to treat extremely virulent variants of COVID-19 by decreasing lung inflammation and promoting cell regeneration [106]. MSCs can also work simultaneously with CP in restoring pulmonary function and tissue regeneration in COVID-19 patients [107].

Practically Compared with the framework of [63], which integrated AHP and TOPSIS methods to prioritise the most eligible donors of CP amongst the list of alternatives for the most critical patients based on five biomarker criteria (i.e. PAO_2/FIO_2, CRP [mg/L], IL-6 [pg/mL; cytokines], albumin [g/L] and IgM [ELISA titre]) that were formulated in two decision matrices (i.e. patient/donor matrices), the present study proposed an automated triage algorithm for prioritising positive COVID-19 patients based on the emergency case and medical guideline to categorise them according to their emergency/triage level and follow the evaluation criteria of each level. Compared with five criteria in [63], 10 different criteria were used in the present work. However, PAO_2/FIO_2 were used in both studies. Moreover, 10 criteria were classified based on the related emergency level. Consequently, three different decision matrices were constructed based on the intersection between the positive COVID-19 patients and the evaluation criteria of this emergency level separately. In addition, the automated triage algorithm introduced an intelligent real-

Table 12   Validation results

	Validation of first scenario									
Group	Moderate	Severe	Critical	Improvements	Moderate	Severe	Deterioration	Moderate	Severe	Critical
Group 1	0.0050	0.0190	0.0700		0.0259	0.0000		0.0893	0.0135	0.0492
Group 2	0.0540	0.1620	0.1120		0.0514	0.0202		0.1536	0.0946	0.1230
Group 3	0.0990	0.2000	0.1380		0.0718	0.1216		0.1883	0.1351	0.1691
Group 4	0.1790	0.2860	0.2360		0.1383	0.2929		0.2044	0.2602	0.2303

time patient movement and priority reordering amongst these three decision matrices according to the improvement or deterioration of cases. Furthermore, the proposed integrated framework of AHP and VIKOR overcame the limitation of TOPSIS adopted in [63], which might affect the accuracy of the final decision.

6 Conclusion

The challenges of the efficient transfusion of MSCs to emergency cases of COVID-19 patients can be addressed by proposing an efficient real-time MSC transfusion framework based on the integration of MCDM methods. The proposed framework is achieved by presenting two distinct phases as presented in Fig. 1. Systematic ranking assessment based on statistical method (i.e. mean) and comparison analysis are achieved to evaluate the patient prioritisation of each triage level. The outcome of such an intelligent framework is to transfuse validated MSCs to the prioritised COVID-19 patients within each emergency/triage level. The proposed framework offers significance in promoting the health of COVID-19 patients. The present study provides the following recommendations for future work. Firstly, several machine learning methods should be adopted for detecting and classifying real medical images of COVID-19 patients within mild and moderate emergency levels and compare their performance. Secondly, the proposed framework can be utilised with any future generation of coronaviruses or other new viruses to help infected patients based on the identified criteria. Thirdly, big data life cycle stages of the prioritisation process for patients within each triage level should be discussed in detail. Fourthly, for rescuing and prioritising a huge number of patients, the proposed framework can be used in indoor/outdoor hospitals over a telemedicine environment. Fifthly, the privacy and security of patient information should be provided in addition to the network security of telemedicine architectures. Lastly, additional MCDM methods such as TODIM, QUALEFLEX and PROMETHEE should be used and compared in the process of COVID-19 patient prioritisation within each triage level to test their suitability and efficiency in handling such cases.

Declarations

Competing interests   No conflict of interest.

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