MASS CASUALTIES TRIAGE ALGORITHM WITH THE USE OF StO$_2$ LEVELS, HR AND BODY TEMPERATURE MEASUREMENTS

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Objectives: The paper presents the advantages and disadvantages of the current mass events victim care system with use of the START (simple triage and rapid treatment) procedure and the usefulness of the StO$_2$, HR and body temperature measurements, which are communicated via the newly created communication system to the rescue personnel. The aims of this procedure were:

1. Providing answers to the following:
   - Is there a correlation between StO$_2$ values and the associated heart rate changes (Δ HR)?
   - Are the values of StO$_2$ and HR measured at ambient temperatures ranging from -15 to +40 degrees using the pulse oximeter reliable and reproducible?
   - What values of StO$_2$, HR and body temperature of the victim may be a basis for secondary evacuation (yellow band) of the victim, and at what point immediate evacuation (red band) is required?

2. Development of a medical segregation algorithm for use in mass operations, taking into account the values of StO$_2$, HR and body temperature of the injured.

Methods: The purpose of the study was to determine the needs for triage, is there a correlation between StO$_2$ values and associated HR values, determined in hypoxia. All of the subjects were evaluated for HR changes (ΔHR) associated with gradually decreasing StO$_2$ values, which were determined by near-infrared spectroscopy (NIRS).

Also, if StO_2 levels, HR and body temperature measurements are reliable in temperatures in the range of -15 to +40 degrees. Lastly, a modified medical segregation algorithm for the injured was developed, taking into account the results of the conducted research.

The test material was obtained from 100 pilots during training in the hypobaric chamber, under normobaric hypoxia conditions (when breathing in a low-oxygen gas mixture), and results from the thermal chamber examinations.

Results: The studies have shown that as the StO_2 decreases to about 85%, there is an increase in the heart rate. After that, in most of the subjects, it slows down without a transitional phase of oscillations or plateau rhythm. StO_2 levels ranging from 95% to 85% showed an average, significant relationship with HR -r = -0.361; p <0.001. In the StO_2 ranging from 84% to 70%, a significant but weak negative correlation with HR was found - r = -0.231; p <0.001.

Conclusions: Based on the results of the research and theoretical considerations, a validated triage algorithm was proposed.

Keywords: vital signals, simple triage, rapid treatment evacuation

INTRODUCTION

Triage is the medical segregation procedure to help the victims of mass accidents, developed to provide order in emergency assistance via codes. Procedure should be continued and validated until the end of the rescue operation. In the current system of segregation and treatment of victims in such events, the 'START' (simple triage and rapid treatment), the following facts/parameters are taken into account:

1. Whether the victim is able to walk.
2. The presence of spontaneous breathing and its frequency – with retained or restored airway patency.
3. The presence of pulse in the radial artery.
4. The capillary blood flow restitution time.
5. Consciousness, allowing reactions to simple commands.

Based on these, the "rescuer" (doctor, medical rescuer, fireman or other suitably trained person) performs medical segregation. Besides the undoubted benefits for the rescue of victims, this system has significant limitations. The most important of these is the fact that after first aid delivery and determining the order of evacuation (giving the appropriate colour of the straps), victims' health is no longer monitored by the rescuer. It should also be noted that measurements of shallow breathing frequency and capillary blood flow restoration time, as recommended for the initial segregation, may not always be possible to make. For example, at night or in inaccessible places, at low ambient temperatures and always in unfavourable circumstances such as stress and rush.

The possibility to determine saturation (StO_2/ StO_2), heart rate measurement (HR) and additionally the body temperature altogether provides a better, more accurate diagnose of the current state of affected individuals and gives opportunity to prioritize appropriate medical care. Our armband (EvaCopNet) with built-in sensors, records and measures the value of the abovementioned parameters and sends it via a wireless communication system to the rescue station. Apart from that it allows the rescuer to track the current location of the victim. Using this device has helped to create conditions for monitoring victims' health and whereabouts. Our research created the basis for the verification of the existing rescue algorithm. An answer to the question of whether the values of StO_2 and HR should be used as interrelated or completely independent of one another is needed for verification purposes.

Scope of work
The aims of this procedure were:
1. Providing answers to the following:
   a. Is there a correlation between StO_2 values and the associated heart rate changes (Δ HR)?
   b. Are the values of StO_2 and HR measured at ambient temperatures ranging from -15 to +40 degrees using the pulse oximeter reliable and reproducible?

c. What values of StO_2, HR and body temperature of the victim may be a basis for secondarily evacuation (yellow band) of the victim, and at what point immediate evacuation (red band) is required?

2. Development of a medical segregation algorithm for use in mass operations, taking into account the values of StO_2, HR and body temperature of the injured.

METHODS

The testing material consisted of:

1. Levels of StO_2, HR and Δ HR obtained from 100 pilots during the assessment of the TUC "time of useful consciousness", while in the hypobaric chamber (KNC), under conditions corresponding to the height of 7,500 meters above the sea level.

2. Levels of StO_2 and HR obtained during the assessment of the TUC in pilots breathing the hypoxic nitrogen-oxygen gas mixture (7.1-7.3% oxygen) - corresponding to the altitude of 7,500 m under normobaric conditions [3].

3. Levels of StO_2 and HR measurements of four subjects in a thermobaric chamber under standard conditions, at temperatures of -15°C, 0°C, + 15°C, + 40°C.

While marking the TUC - time of useful consciousness (the time measured from the onset of acute hypoxia, to the end of one's consciousness and functional fitness) in the hypobaric chamber, pilots were exposed to acute hypoxia, corresponding to a height of 7,500 m. and reduced barometric pressure, which at this height is about 1/3 of the pressure at sea level. The study was conducted before the noon, subjects were seated and at least 2 hours after the meal. All pilots were equipped with personal high-altitude equipment - a helmet and a mask, connected to breathing regulators set at 100% oxygen in the chamber. The oxygen was inhaled for 45 minutes prior to altitude exposition as a decompression sickness precautionary measure. After this period the pressure in the chamber was lowered to that corresponding with 7500m (around 25 000 feet) and StO_2, HR and ECG were recorded and monitored. Each pilot was exposed to hypoxia by switching his breathing circuit to breathing chamber air. Additionally, as a psycho-physiological measure, pilots counted down from 1000 to 0 on a sheet of paper. Indications for termination of the test and re-administration of oxygen were manifestations of hypoxia such as: a substantial decrease in StO_2 (less than 70%), a sudden increase in heart rate by at least 20 per minute or rapid HR decrease, cardiac conduction disturbances and a large number of errors in counting numbers or unreadable hand writing.

A similar methodology was used to determine the TUC with breathing a low-oxygen gas mixture (7.1-7.3% oxygen), using a GSz-6 sealed helmet, under normobaric conditions. Criteria used for exposition termination were the same in both test procedures.

All of the subjects were evaluated for HR changes (ΔHR) associated with gradually decreasing StO_2 values, which were determined by near-infrared spectroscopy (NIRS). An integrated "Barbakan" monitoring system and a PXM - 200 pulseoximeter (put on the 2nd or 3rd finger of the hand) were used for recording.

The effects of temperature on the StO_2 sensor were measured using a thermobaric chamber at temperatures -15°C; 0°C; 15°C and 40°C, in normobaric conditions. The atmospheric pressure on the day of the test was 769mmHg/1025.25 hPa. StO_2 measurements at -15°C were recorded when the respondents reported feeling cold and chills. The MAX30100 (Pulse Oximeter and Heart-Rate Sensor ICs made by Maxim Integrated) sensor was used (fig. 1). The StO_2 measuring sensor and the skin surface temperature sensor are located on the inner side of the band. During the test, the device was placed on the inner side of the wrist (fig. 2). The test subjects did not wear gloves, the band was exposed directly to ambient temperature.

Fig. 1.   The wrist sensor band used in experiments.

Fig. 2.   Wrist sensor placed on the subject's limb.

The results obtained during the TUC measurement (in hypobaric conditions) were subjected to statistical analysis using the R package. For the values of StO_2 and HR obtained for each of the examined and for the whole group, the mean, standard deviation and minimum and maximum values were calculated. The HR values (ΔHR) for the StO_2 range from 95% to 85% were calculated respectively for the heart rate recorded with StO_2 of 95%. For the StO_2 range from 84% to 70% ΔHR was calculated with the HR value recorded at StO_2 of 84%. In order to evaluate the relationship between StO_2 and ΔHR, the Spearman correlation coefficient was determined. The statistical significance level was p <0.001.

RESULTS

The maximum, minimum and average values of StO_2 and HR for the whole group are presented in table 1.

Tab. 1.   The maximum, minimum and mean values of StO_2 and HR in the examined group.

N=100	Min	Max	Mean	SD
StO_2(%)	68	92	81,9	4,9
HR/min	72	147	110,7	15,4

HR- heart rate; StO_2 - tissue oxygen saturation

During the measurement, 87 patients had gradually increased HR with progressive decline in StO_2 values, followed by:

1. In 36 patients, there was an oscillation / plateau phase after which the HR dropped – HR response: increase-oscillation-decrease, as shown in figure 3.
2. In 51 subjects, the HR dropped without the transitional phase of oscillation/plateau – HR response: increase-decrease, as shown in figure 4.

In the remaining 13 subjects, the HR changes were not typical of any of the above described change models. The threshold value of StO_2 at which the above HR response types were observed was approximately 85% for most of the respondents.

For the majority of the respondents, the HR drop (regardless of type of response) occurred at StO2 <85% - as shown in figures 5 and 6.

On the common ordinate - HR signal and StO_2 signal. Blue line: StO_2 signal in the range of 95-85%, red line - StO_2 signal below 85%. Green line - filtered HR waveform.

Changes in heart rate (ΔHR) in the analyzed ranges of StO_2 values are shown in table 2.

Fig. 3.   HR response type: increase - oscillation / plateau – decrease.
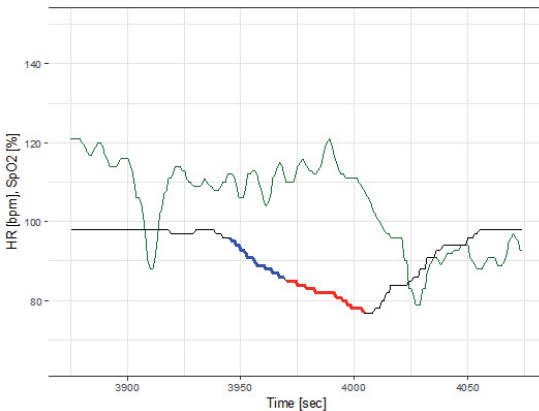
Fig. 4.   HR response: increase-decrease.

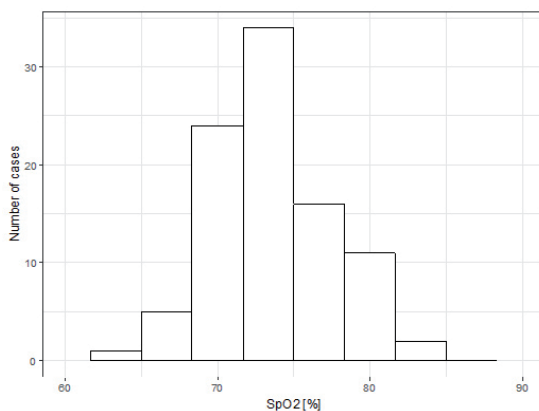Fig. 5.   Rapid HR drop at a StO$_2$ value of approximately 81%.

Fig. 6.   Histogram of StO$_2$ values at which rapid HR drop was observed.

	ΔHR (bpm)	
	StO2 95% - 85%	**StO2 84% - 70%**
Min	-27.59	-45.14
Max	32.25	30.22
Mean	2.85	3.19
±SD	6.56	7.84

Tab. 2.   Minimum, maximum and mean values of heart rate changes (ΔHR), depending on the StO$_2$ range.

StO$_2$ - tissue oxygen saturation; ΔHR – decrese/increase of heart rate

In the StO$_2$ range of 95%-85% there is a significant, average negative correlation between the HR value and StO$_2$ - Spearman correlation coefficient $r = -0.361$; $p < 0.001$. In the StO$_2$ range of 84%-70% there is a significant, poor, negative correlation between the HR and StO$_2$ values of the Spearman correlation coefficient $r = -0.231$; $p < 0.001$.

Similar correlation was observed between StO$_2$ and HR values during TUC measurement using a nitrogen-oxygen (7.1-7.3% oxygen) mix under normobaric conditions.

Studies in the thermobaric chamber show that measurements of StO$_2$ and HR values at temperatures of -15°C to +40°C were unaffected/within the range of 95-98%. The discrepancies between the values of consecutive StO$_2$ determinations at 4-minute intervals (for 16 minutes) ranged between 1 and 2%, occasionally up to 3%, which is

consistent with commonly accepted error criteria for this measurement method.

The temperature of 4 patients was measured in the thermobaric chamber. The correlation coefficients between the measured body temperature, measured at room temperature of 22°C, and measured by the sensor (located in the band) at selected ambient temperatures are shown in table 3. The average body temperature of the subjects prior to entry into the chamber was $36.7 \pm 0.14°C$.

	Tambient	Correction factor
1	-15°C	+14.6±0.29°C
2	0°C	+12.6±0.23°C
3	+15°C	+10.6±0.12°C
4	+40°C	+1.6±0.26°C

Tab. 3. Correction factors between the temperature of the body examined before entering the thermal chamber and measured by the sensor in the band at various temperatures inside the chamber.

DISCUSSION

StO_2 determinations are made mainly for clinical purposes, the diagnosis and monitoring of respiratory illness. It should be emphasized that in a healthy individual, the oxygen saturation level should be within the range of 94%-99%. In patients with mild respiratory diseases, StO_2 is 90% or above. Usually, oxygen therapy is administered if the StO_2 value is less than 90%. Numerous studies have been conducted on tissue saturation in the affected population.

Saturation was measured during hospital admission, as a predictor for hospitalization [2], the severity of shock and prognosis of healing [1,6]. It can help predict the need for blood transfusions during the next 24 hours in patients with a high shock risk [5]. So far, data on the study of the usefulness of StO_2, HR and body temperature measurements for medical segregation in mass accidents is nonexistent. The authors underline that the lower the value of StO_2, the worse the prognosis is [1], which - although obvious - at the same time does little to contribute to the rescue algorithm in mass events. Some studies show that the possibility of hospitalization was higher in patients with a StO_2 value below 75-76% [2]. But it is surprising that their general condition was not correlated with the outcome of StO_2 measurement. Some patients with 67% StO_2 values were not eligible for hospital treatment. It is proposed that for the needs of triage, the statistical cut-off value of StO_2 should be 76-78%. In addition, there is no information on the further fate of patients not qualified for hospital treatment despite such low saturation values, and equally important for the START algorithm is how long they had a reduced StO_2 value before they reached the hospital emergency department. And how did it affect the prognosis?

The system (during the EvaCopNet project) of monitoring and transmitting the current values of these parameters to the rescuers has created a basis for verifying the current algorithm of the START system. In our own studies, an insufficiently big negative correlation was found between StO_2 and HR values to allow for the use of such interrelation (in a significantly related way) for triage. However, it was found that in most pilots the heart rate increased with the drop of StO_2 up to the value of 85% and then gradually decreased.

But it should be emphasized that:
– the study involved clinically healthy pilots,
– StO_2 and HR markers were performed in persons at rest and relaxed, under specific oxygen deficiency conditions. Therefore, the results may, for the purposes of triage, only be useful for examining the correlation between StO2 and HR values,
– hypoxia is individually varied and even unequal in the same pilots during subsequent periodic examinations,
– lesser tolerance to hypoxia is observed in: older people, less fit (with lower VO2max), physically overworked or sleep deprived. Subjects with increased metabolism (e.g. with elevated body temperature, hyperthyroidism, hyperactivity), anaemia, vascular-motor dysfunction (e.g. under the influence of alcohol) cope even worse.

It is also worth noting that:
– factors other than saturation may influence the HR level of victims: pain, anxiety, stress, environmental or weather conditions and most importantly, the health condition before the event,
– injured persons with a decreased haemoglobin level can have normal haemoglobin saturation and at the same time be in severe hypoxia,
– StO_2 measurement has some limitations - the causes of incorrect measurement may be: movements, muscular tremor, lack of adequate pulse wave amplitude (e.g. hypothermia, reduced peripheral perfusion due to hypotension, tachycardia or significant bradycardia – resulting in prolonged response time of the pulse oximeter), lowered Hb value - by 7-6 g% , administration of pressure amines, car-

bon monoxide poisoning (in such event SpO_2 values oscillate within 100%),

– smoking can result in the overestimation of the SpO_2 score, and nail polish (green, blue, black) may lead to underestimation (depending on the light absorption).

For above-mentioned reasons, regardless of the results of the studies, the relationship between StO_2 and HR values cannot be used in a coherent manner. For triage, it is important to establish the StO_2, HR and body temperature values for victims at which a patient still has a chance of survival, including the potential for oxygen therapy and the time needed for hospital transport or specialist medical attention.
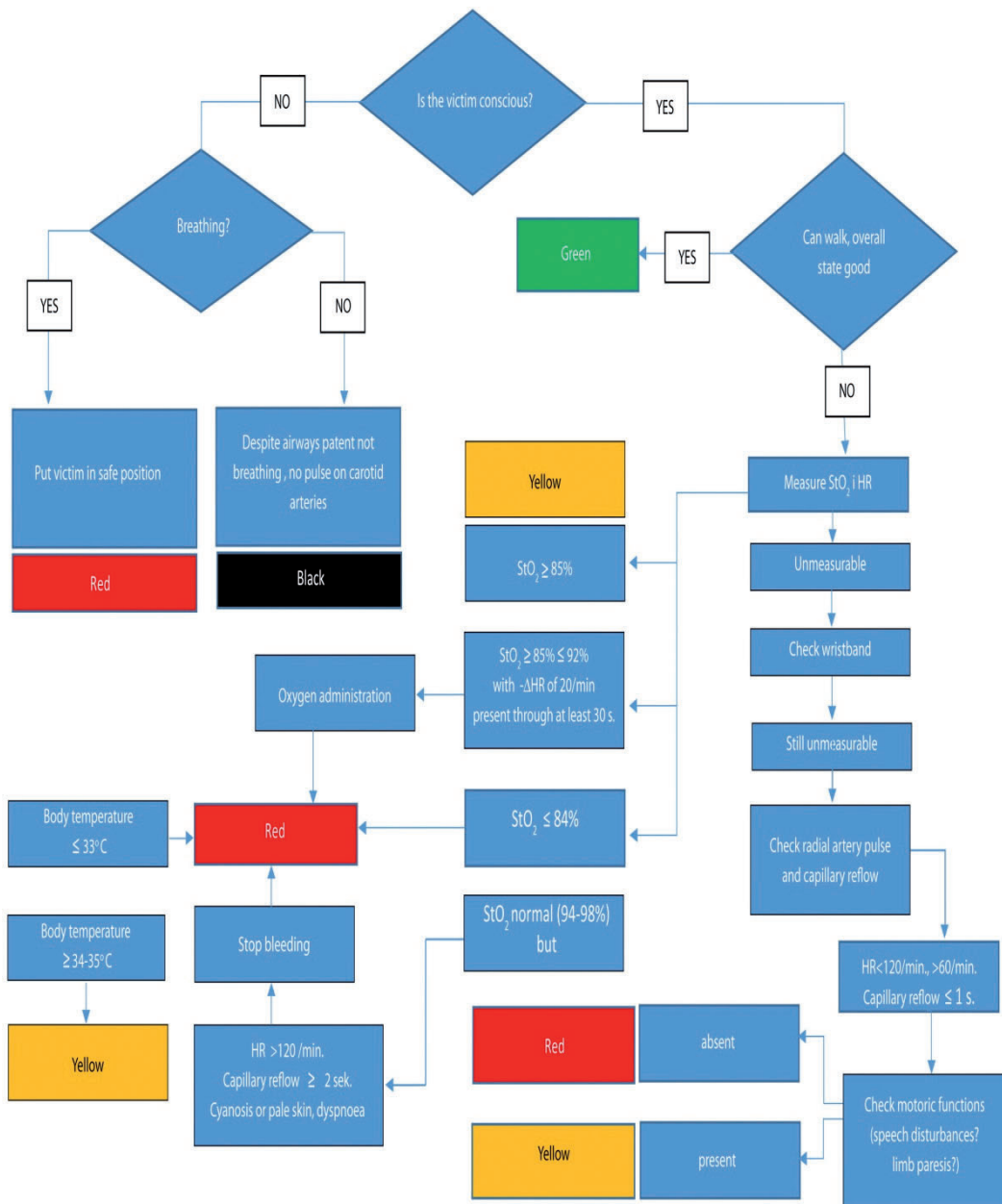
-ΔHR - heart rate decrease
HR - heart rate
StO_2 - tissue hemoglobin oxygen saturation

Fig. 7.   Verified algorithm for dealing with victims.

In this study it was shown that in most pilots the heart rate increased with the drop of StO_2, up to its value of 85%, and then gradually decreased, which was in line with the beginning of the hypoxia decomposition. The results of the study were included in the developed algorithm as well as the values of StO_2, Δ HR and body temperature. It is worth noting that for the needs of the START system, the very fact of the presence of a measurable heart rate, which allows for the measurement of StO_2 level, is valuable.

The time of useful consciousness for pilots breathing with a low oxygen gas mixture (7.1-7.3% oxygen) - under normobaric conditions, is about 2 minutes longer than that measured in low pressure chamber at a simulated altitude of 7,500 m above sea level (under hypobaric conditions) and is within the range from 4 min 40 s to over 10 min 30 s (average 7 min 20 s to 8 min 10 s). It shows that even in such extremely unfavourable conditions of oxygen shortage, the rescuer providing medical care at the scene of the event would have enough time to administer the necessary oxygen therapy. These facts are included in the proposed triage algorithm.

Studies conducted in a thermal chamber show that the temperature in the range of -15 to +40 degrees Celsius, does not affect the functionality or reliability of the sensors used to determine SpO_2 levels as the subjects were kept at -15°C until the first sensations of cold or light chills (about 16 min), our results could not be used to assess temperature effect on the SpO_2 value of the human body. With longer-lasting cooling of the body, it would

be expected that circulatory/congestive hypertension would lead to an additional decrease in SpO_2. Hypothermia is a condition in which the body temperature drops below 36.6 degrees Celsius. Its value below 29 degrees Celsius is life-threatening. For triage purposes, it is worth noting that during therapeutic hypothermia (for the purpose of protecting the CNS), the controlled cooling of the body is kept to a temp of between 32 and 33 degrees for 12 to 36 hours. Taking into account all of the above, it seems that, for the purposes of the START algorithm, if the victim's body temperature is less than or equal to 33 degrees Celsius, he/she requires immediate first aid (covering with a thick blanket, warm jacket, warm tea, etc.) and the band turns red. If the victims' temperature is 34-35 degrees, the band turns yellow. The wristband used in the project has the option to change colour automatically.

In conclusion, further validation of the algorithm, which would allow even more accurate use of the StO_2 and HR values for the triage, would require testing with enforced (breathing a low-oxygen gas mixture) and reduced levels of StO_2 values. The question of how long can an injured person with certain StO_2 values safely wait to receive specialist medical help should be answered. Based on the results of the research and theoretical considerations, we propose a verified algorithm for dealing with victims in mass events, presented in figure 7.

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