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The Impact of a Patient Trolley's Intra-Hospital Speed and Position on the Quality of Ventilation Performed by a Self-Inflating Bag

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Abstract

Purpose: The aim of the study is to make a quantitative and qualitative assessment of selected parameters connected with a patient's ventilation using a self-inflating bag during simulated 'head-first' or 'legs-first' directions of patient transport.

Introduction: There is no assessment of the ergonomics of the work of medical personnel in the existing studies. The issue is relevant to everyday medical practice, as in many countries staff avoid transporting patients "feet-first" for cultural reasons. At the same time, little research has been devoted to the analysis of the impact of vibrations on the patient during medical transport. The presented work is an attempt to combine these topics in terms of ensuring the effectiveness of patient ventilation. Correct body position of the paramedic (no muscle fatigue) and low vibration values can improve the quality of ventilation.

Methods: Seventeen people participated in the conducted study. Their task included conducting alternative ventilation during the transport of the patient (Airway Management Simulator BT Inc.) by using the head or the legs technique: in the transport trolley's movement direction. At all times during the transport, video recording was carried out non–stop, and the spectrum of generated vibrations was recorded using the SVAN 958 vibration spectrum analyser, with a three-direction SVANTEK SV 39A disc for measuring whole body vibrations. Additionally, a survey was carried out. The task of the research participants was to indicate the degree of performer comfort related to the ventilation and the transport process on a Likert scale. All ventilation parameters were read directly from the Simulator. The assessment of the results was then subjected to statistical analysis.

Results: The duration of the patient transport by using the legs-first technique was shorter (57.5 s on average) in comparison with the head-

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first one (62.5 s on average). The subjective assessment of performer comfort on the transport and ventilation process with the legs-first technique was perceived as higher compared to the head-first one. During the patient transport, the highest aRMS acceleration values in the vertical direction were obtained for frequencies 8-25 [Hz], corresponding to the resonance frequencies of the head (17-25 Hz), trachea and bronchi (12-16 Hz), lungs (4-11 Hz) and the spine (8-12 Hz). According to other authors, vibrations with a frequency of 8-10 Hz lead to a decrease in blood pressure, bradycardia and bradypnoe; vibrations at a frequency of 11-12 Hz cause increased heart rate, peripheral vasoconstriction, fatigue, abnormal temperature, nausea, abdominal and chest pain, while vibrations above 12 Hz cause dangerous arrhythmia, muscle tremors, pain and bleeding.

Conclusion: The recommended position of intra-hospital patient transport is the legs-first technique. At the stage of preparation for transport, it is necessary to keep in mind the ergonomic aspects of carrying out possible rescue procedures, e.g. artificial ventilation, the effectiveness of which depends on the height of the patient's trolley, the elbow-shoulder angle of the paramedic, and their back inclination in the thoracolumbar section. The training of medical staff should include conducting high fidelity simulation of activities connected with e.g. transport, enabling future paramedics to acquaint themselves with the working conditions in terms of the effectiveness of actions and ensuring adequate work ergonomics.

Keywords: Intra-hospital transport, Patient transport, Ventilation during transport, Bag mask valve ventilation, Safety system of transport, Ergonomic aspect of medical transport, Vibration.

Introduction

Intra-hospital transport is one of the processes exposing patients to an increased risk of occurrence of life-threatening emergencies. The proper planning and the provision of equipment and qualified medical staff for the time of transport can minimize the risk of possible complications [1,2]. Broadly understood hypoxia, requiring immediate rescue intervention during intra-hospital transport is included as one of the most frequent unexpected events mentioned in literature. According to the guidelines, the transport team should be properly prepared for the risk of reversible causes of cardiac arrest, including equipment preparation [3]. There is no data in literature clearly showing the patient's position in relation to the transport direction (positioning with the head or the legs in the direction of transport). Interestingly, some medical staff choose the head-first technique based on the connotations with religious rituals as part of a funeral, in which the body of the deceased should be carried with the legs first [4].

Methods

Design

Prospective experimental research was conducted. Part of the research was conducted in the realities of high fidelity medical simulation using the Airway Management Simulator BT Inc. courtesy of Simed Ltd which was previously calibrated. All ventilation parameters were read directly from the Simulator via connected tablet. As part of the experiment, seventeen medical students, who completed training in the field of ventilation technique with a self-inflating bag (led by a certified instructor of the Advanced Life Support European Resuscitation Council course) took part. The task of each of the participants was to ventilate the transported patient (using the head-first or the legs-first technique in the direction of the transport patient trolley). Participants rated comfort on the Likert scale by completing the questionnaire immediately after the simulation. The transport was supported by two additional people, whose task was to move the trolley while maintaining a constant speed (approx. 5-7 km/h). The research was carried out during the ride of the patient trolley on a smooth, horizontal PVC surface. The route was 33 m long and included straight sections, turns and passing through a door.

Each ride was recorded with a camera placed in the middle of the room (Figure 1).

During the research, vibration and video recordings were made to ensure the possibility of showing the differences in upper limb positioning and body leaning over the patient while performing of the ventilation process. In the measurements, the SVAN 958 vibration spectrum analyser, with the three-direction disc to measure whole body vibration SVAN SV 39A by Svantek was used. During the research, the disk was placed on the mattress of the transport trolley, under the head of the dummy (Airway Management Simulator – BT INC courtesy of SIMEDU Ltd.). Vibration measurements were made in three directions: X, Y, Z (Figure 2). Time was recorded with an accuracy of 1s during each of the rides. The recorded vibrations were caused mainly by the ventilation process and the patient transport itself. The signal from the three-direction vibration sensor (the

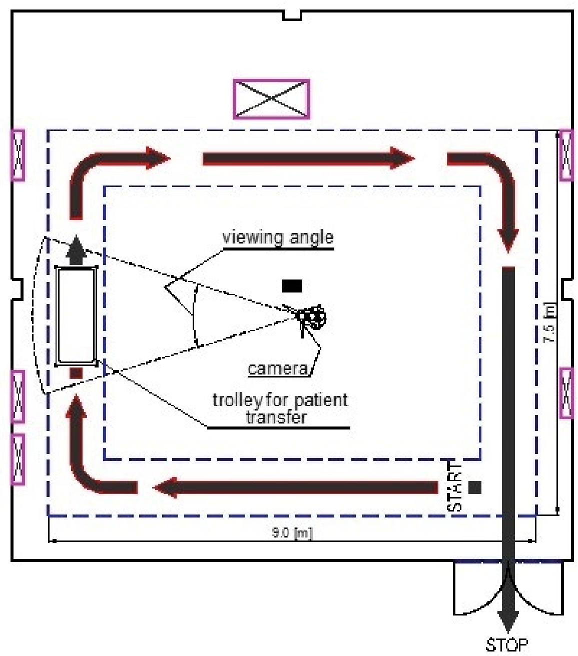

Figure 1: Diagram of the ride route.

value of vibration acceleration aRMS changes over time; signal processing in the program SvanPC++ by Svantek) was recorded in the spectrum analyser (sampling frequency 16 kHz).

Based on the recorded rides, parameters enabling us to make the assessment of each participant's body position during the ventilation process were indicated. They were: the bending angle in the elbow joint for the limb holding the self-inflating bag and the hand covering the face mask, the lumbar distance of the ventilating person from the transport trolley and the back deflection angle (Figure 3). The analysis was carried out in the Kinovea 0.8.15 program.

Based on the obtained results, the analysis of the correlation between the parameters describing the ergonomic (biomechanical) position and the ventilation parameters and the scale of comfort felt during the ride by each of the research participants was conducted.

During the study, ventilation parameters and mechanical vibrations transmitted to the body of the examined person were measured.

The recorded vibrations were referred to criterion curves defined by the ISO standard (the so-called the threshold of comfort, annoyance and harmfulness) [5]. The research was carried out in two stages: the first one, which was connected with the standardisation of the group in terms of ventilation by using a self-inflating bag, and the second one, during which the task was connected with the transport of the injured person along a section of approx. 33m, corresponding to the assumed/average length between the computed tomography laboratory and the "triage" room in the Emergency Room.

The assumed scenario of the research had the participants of the research forming a three–person team which conducted the intra-hospital transport. Then, the team receives information about an injured person, whose breathing has stopped with remaining circulatory parameters, and that the aim is to transport the injured person on a trolley with ventilation by using a self-inflating bag at the same time.

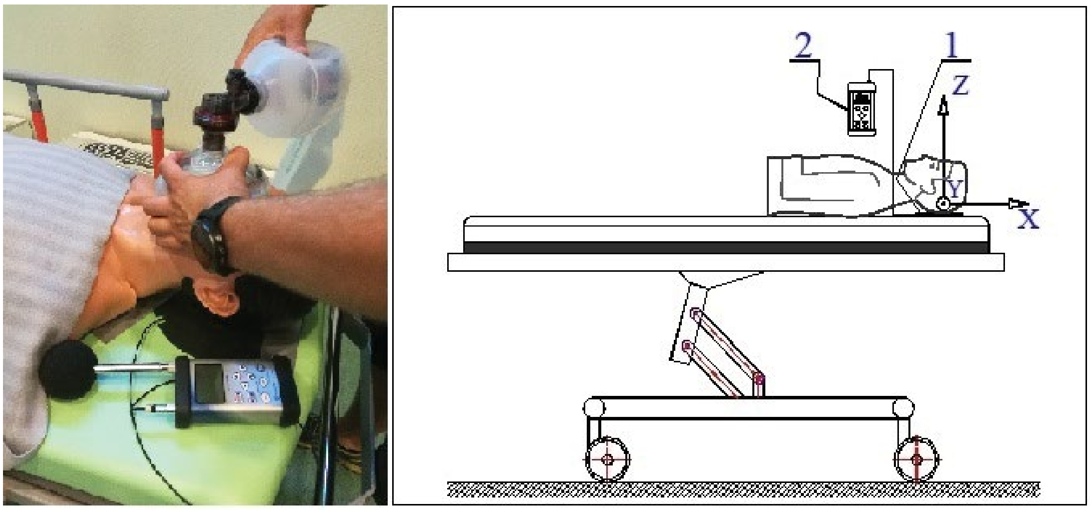

Figure 2: The measuring track for vibration measurement: (1 – SV 39A sensor, 2 – SVAN 958 analyser).

Figure 3: The method of describing the paramedic's body position parameters

Results

Ventilation results

Data was analyzed using the t-Student's test to determine if the distribution is normal or the Wilcoxon pair test, to show whether parameters do not have a normal distribution. The analysis of ride times with the patient in the head-first or legs-first technique during their simultaneous ventilation using a self-inflating bag indicates a statistically significant difference of the time of the ride in both groups. The transport of the patient with the legs -first technique is completed in a shorter time in comparison with the head-first transport. The medians of the transport times time are 57.5 s and 62.5 s respectively. ($p < 0.05$) (Figure 4).

Comparing the ventilation process itself during the transport of the patient with the head-first and the legs-first technique, the following parameters were taken into consideration: the effectiveness of breathing (percentage of breaths read by the simulator to the value given by the participant of the research), ventilation frequency (breaths/ min.), length of the breath (sec.), ventilation volume (ml.), score (parameter automatically generated in percentage, according to the producer's algorithm). The efficiency of ventilation and the frequency of ventilation turned out to be statistically significant in favour of the legs-first transport technique. Other analysed parameters did not show statistically significant differences, although it is worth paying special attention to the general poor results in both rides, particularly in relation to the score parameter.

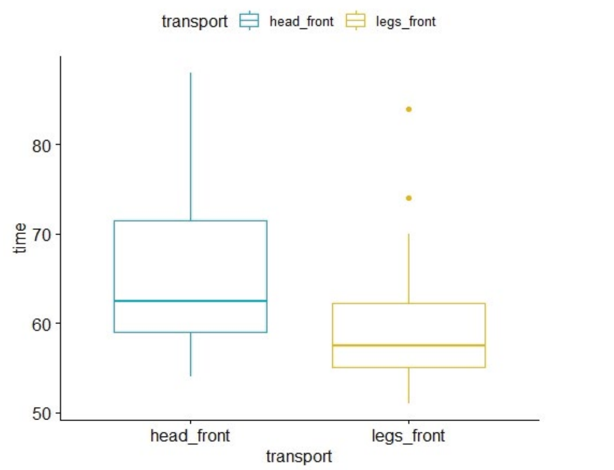

Figure 4: Patient transport times with the head-first (time_1) and the legs-first (time_2) technique with simultaneous ventilation with a face mask with a self-inflating bag (N = 17).

Detailed results are presented in table 1. The results obtained for n = 1 from the rides were excluded from the analysis due to a file failure.

During the experiment, surveys, in which participants were to point the degree of comfort associated with the ventilation and transport process were also conducted. Comfort was assessed using a 5-point Likert scale that means: 1 – definitely low, 2 – low, 3 – medium, 4 – high, 5 – definitely high. Both the comfort of patient transport and ventilation were assessed by the participants as higher in the case of the transport with the legs-first position, compared with the head-first transport position, and the result was confirmed to be statistically significant ($p < 0.05$) – compare table 2.

Results of vibration measurements

Based on the recorded signal, spectral vibration charts were made for 1/3 octave bands (Figures 5 and 6) which were compared with the criterion curves according to ISO 2631.

Correlation between measured parameters

The correlation shows a relation between variables. To indicate the correlation strength, the correlation coefficient with values from -1 to 1 is used. If the correlation coefficient is positive, the values of both variables increase, when the coefficient is negative, both variables decrease. The scatter chart is a graphic interpretation of the correlation coefficient. To assess the correlation between the results of the research correlation the r-Pearson correlation was used. The strength of correlation between the measured parameters, describing the biomechanical and ergonomic attitude, and the ventilation parameters, the scale of comfort felt during the transport and ventilation, and the maximum recorded value of the amplitude of vibration acceleration are presented in figure 6.

An analysis of the correlation strength between the measured parameters was also carried out:

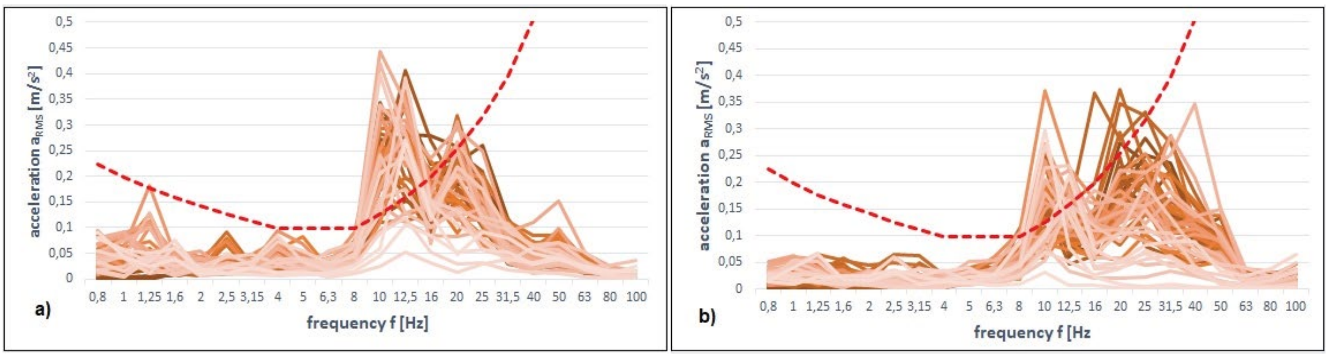

Figure 5: Amplitude-frequency characteristics (1/3 octave bands with the ISO criterion curve showing the threshold of comfort), towards the Z axis, for the selected ride: a) the head-first, b) the legs-first.

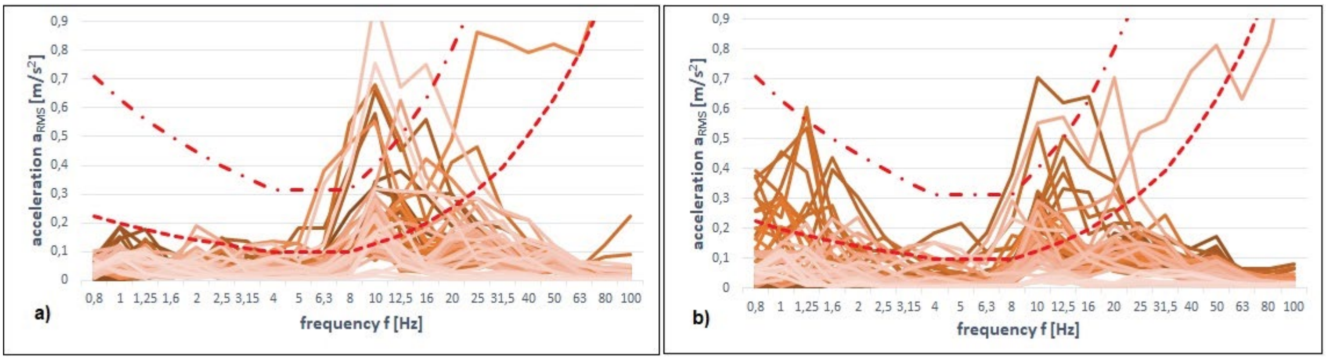

Figure 6: Amplitude-frequency characteristics (1/3 octave bands with the ISO criterion curve showing the thresholds of comfort and annoyance, towards the Z axis, for the ride with the highest recorded vibration amplitude; a) the head-first, b) the legs-first.

Examined parameter	Position during the transport	Median/Average	P
Efficiency of ventilation	the feet-first	100	0.019224
	the head-first	50	
Average frequency of ventilation	the feet-first	8.35	0.043020
	the head-first	5.8	
Average length of breath	the feet-first	0.52	0.052965
	the head-first	0.4	
Average volume of ventilation	the feet-first	0.4	0.162573
	the head-first	0.33	
Score	the feet-first	11.2	0.192986
	the head-first	9.7	

Table 1: Values of individual ventilation parameters during the legs-first and the head-first transport (N = 17).

Assessed parameter	Position during the transport	Median	P value
Comfort of a ride with the patient	The feet-first	4	0.04493966
	The head-first	2	
Comfort of patient's ventilation	The feet-first	3	0.04493966
	The head-first	2	

Table 2: Comfort assessment of the ventilation and transport of the patient with the legs-first and the head-first position. Scores in Likert's scale 1-5 (N = 18).

a. describing the biomechanical and ergonomic position of the person providing the ventilation: the height (H), the distance of the furthest point of the lumbar section from the trolley (FPLS), the elbow flexion angle (EA), the back leaning angle (BLA),

b. ventilation parameters: the number of breaths (NB), effectiveness of breaths (EB), the average frequency of ventilation (AFV), the average inspiration length (AIL), the average ventilation volume (AVV),

c. the comfort scale (CT) during the transport and ventilation (CV),

d. the maximum recorded value of the amplitude of vibration acceleration, for fre-quencies considered as the most bothersome for the transported patient: aRMS max for 8 Hz, 10 Hz, 12.5 Hz and 16 Hz (a_max 8, 10, 12.5, 16).

The strength of correlation for the analysed parameters in individual groups is shown in the graphs in figure 7.

Discussion

Preliminary research showed that the highest obtained values of vibration acceleration were mainly associated with the ventilation process, while the transport itself had a smaller impact (the smooth surface of the corridor and the mattress on the transport trolley contributed to this). The highest values of aRMS acceleration in the direction of the Z axis (exceeding the threshold of comfort according to ISO) were obtained for frequencies in the range from 8 [Hz] to 25 [Hz] depending on the person conducting the ventilation process. According to data in literature, these are frequencies that correspond to the resonance frequencies of the head (17-25 Hz), trachea and bronchi (12-16 Hz), lungs (4-11 Hz) and spine (8-12 Hz), and can also cause increased muscle tone (13-20 Hz) and head symptoms (13-20 Hz) [6-8].

According to Intas and Stergiannis, low-frequency vibrations of 8-10 Hz lead to a decrease in BP (blood pressure), bradycardia and bradypnoe [9]. Moderate vibrations with a frequency of 11-12 Hz cause increased heart rate, peripheral vasoconstriction, fatigue, abnormal temperature, nausea, abdominal and chest pain. High frequency vibrations above 12 Hz cause dangerous arrhythmias, muscle tremors, pain and bleeding. The highest acceleration values were recorded for the ride of the person No. 12 (pic. 6). In this case, not only has the ISO threshold of comfort been exceeded in the range of 2 Hz to 31.5 Hz for the head-first transport and from 0.8 Hz to 25 Hz for legs-first transport, but also the threshold of annoyance in the range of 5 Hz to 16 Hz (the head-first) and from 8 Hz to 16 Hz (the legs-first). According to Bellieni et al. the frequency range of 1-4 Hz is particularly

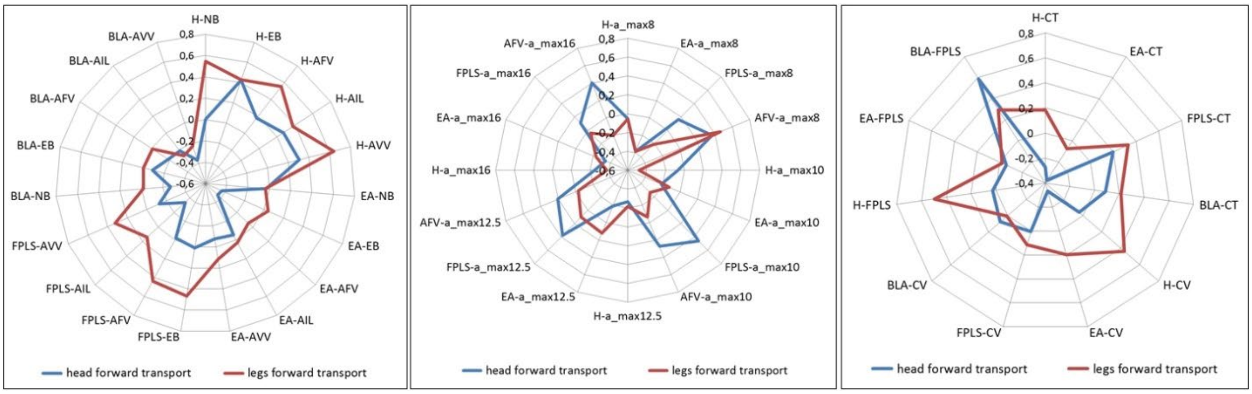

Figure 7: Strength of correlation between parameters describing the biomechanical position and ergonomic and ventilation parameters.

dangerous for the respiratory system and can contribute to hyperventilation, that in turn can lead to hypocapnia [10].

A strong correlation between the measured parameters was obtained in four cases: in three cases for the legs-forward transport – between the height of the ventilating person and the number of breaths, the increase and average ventilation frequency, and the increase and average ventilation volume. For the head-forward transport, correlation was obtained in only one case – between the angle of the back inclination and the distance of the furthest point of the lumbar section. A moderate correlation was obtained in 30% of the head-first transport cases and 24% of the legs-first transport cases.

The guidelines of the European Resuscitation Council (2015) give the highest priority to basic emergency skills in life-threatening situations. These skills were included in the acronym ABC (A-airway, B-breathing, C-circulation). Therefore, the ability of effective ventilation with use of the self-inflating bag is the absolute foundation of effective rescue operations [11].

For effective ventilation, especially performed by less experienced staff, it is recommended to use Laryngeal Tube (LT) with Bag Mask Valve (BMV) in comparison with ventilation using BMV with lower ventilation efficiency ($p < 0.0001$) [12]. In order to reduce the rate of incidents of sudden health risk, a checklist was designed for intra-hospital transports including the necessary equipment connected with, among others, with ventilation and protection of respiratory tract patency.

During receiving instructions associated with correct patient transport during ventilation, the transport trolley operating manual is an often omitted aspect, and hence, adjusting the height of the trolley by the staff responsible for the transport is often not taken into consideration. It should also be pointed out whether the transportation of a patient in a life-threatening condition with the risk/need for ventilation should not be conducted by using a transport trolley, properly designed for this purpose, additionally equipped with a transport respirator [13].

Conclusion

The legs-first transport technique has an influence on increasing of the correctness of ventilation using the self-inflating bag, additionally shortening the time of transport and improving rescue operations, as well as the subjective feeling of comfort. There is a strong correlation between the height of the ventilating person and the effectiveness of ventilation. Owing to such research results, the need for the development of ergonomic standards in hospitals and medical staff education is indicated. In the research, the highest obtained values of vibration acceleration were mainly associated with the conducted ventilation process. The ventilation process conducted in an improper way results negatively on the effectiveness of ventilation. It has also been observed, that there is a possibility of drawing up guidelines connected with the ventilating person's body position, which can influence on the effectiveness of the conducted ventilation process. It is also possible that the ventilation process carried out in the proper way, can reduce the impact of vibration on the patient. One must remember about taking the right attitude towards the ergonomics of potential rescue operations. As a group of the research authors, we recommend including an additional important point to each checklist: "ensure ergonomic comfort during procedures of rescue operations at every stage of patient transport".

A further conclusion drawn from the research is a change of the teaching strategy of rescue operations from a static level to a dynamic level. It means learning how to carry out transport with the simultaneous conduction of some emergency procedures, e.g. replacement ventilation, conducting cardiopulmonary resuscitation, and monitoring of basic physiological parameters.

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