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Design Considerations to Enhance the Safety of Patient Compartments in Ambulance Transporters

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The safety of the interior of ambulances is dubious and, in the event of sudden impact during emergency transport, potentially perilous to patients they carry. The workplace ergonomics of the interior of the passenger cabin is lacking. This article discusses an improved ergonomic interior design based on study findings, observations and subjective perception. It suggests design aspects and safety concepts aimed at increasing the safety of patients and paramedic staff inside the ambulance as a mobile workstation.

ambulance interior paramedics' safety back posture ergonomics

1. INTRODUCTION

Over the years, studies have indicated that the interior design of ambulances has various flaws. Some of them directly affect the quality of life saving treatment. Others have been found to endanger staff in the event of an accident or sudden impact. Shook and Spelt discussed problems such as easy access, the location of controls and noise attenuation [1]. Smith indicated that seat restraints required redesigning with modifications to allow better performance of clinical procedures and to prevent injuries caused by flying objects [2]. The suggestions included improving the location of controls for better overall comfort and usability.

Some flaws are directly related to bad ergonomic design that mean the staff perform tasks in a prolonged sedentary posture, exposed to the vibrations of the vehicle [3]. Doormaal, Driessen, Landeweerd, et al. found that the staff maintained extreme postures during 16–29% of the work time; they mainly lifted, moved and performed clinical procedures on patients [3]. The conclusion was that an improved ergonomically-based working environment was necessary. Landeweerd and Kant found performing clinical procedures strenuous [4]. According to Letendre and Robinson, Canadian paramedics reported cardiopulmonary resuscitation, intubation and accessing equipment and patients to be the most physically demanding activities [5]. Ferreira and Hignett reviewed the layout of the patient compartment of a British ambulance; they found that future patient compartment design should consider health, comfort and performance [6]. Gilad and Byran found a clear association between perception of subjective discomfort inside the ambulance and common variables [7]. Their findings showed that the interior design was based primarily on spatial use with little concern for ergonomics. More specifically, a kinesiological presentation of the main movements of the back, based on posture angle analysis of the motion patterns, indicated that most movements were performed in wide flexion. This suggests poor design as a cause that impairs both the functioning of personnel and the treatment given to patients. Their conclusion was that an ergonomic alternative work area layout design should be developed.

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As a result of those findings, we suggest in this paper comprehensive functional and behavioral analyses, which may lead to an alternative and safer layout design for ambulances. These suggestions may reduce paramedics' discomfort when treating patients and performing clinical procedures. It may also increase the use of seat belts and of safety restraints, which would generate additional safety benefits in the event of sudden impact or an accident.

2. METHOD

2.1. Preliminary Study

To understand clinical procedures, findings on work routines were gathered around the clock. Observations from two morning, two evening and two night shifts were studied. The teams were observed for the same time (8 h); all activities inside the ambulance, including work routines, sitting habits, clinical procedures and tools used, etc., were recorded. On the basis of the data observed and recorded, a questionnaire was administered, interviews were conducted and focused observations took place. Two types of advanced life support (ALS) teams were observed: one team consisted of two paramedics, namely a senior paramedic and a novice. The novice was the driver. Another team comprised a medical doctor and two paramedics (senior and novice). At night, only a two-person team was on call (it consisted of two paramedics like during daytime). The observations were selected randomly from the work roster, except that participants changed every shift. Since two types of ALS teams operated during the morning and evening shifts, they were both observed.

Call time, i.e., the time between the sounding of the alarm and the moment the ALS ambulance returned to the station, was divided into four periods: driving to scene, treating a patient on scene, treating a patient while transporting to hospital and returning to station. However, since we were primarily interested in the work inside the interior cell of the ambulance, the treat-a-patient-on-scene period was not studied. Also, drivers were observed only when they were not driving.

2.2. Participants

Thirty-one experienced emergency medical staff members (4 medical doctors and 27 paramedics) from five public ambulance stations in northern Israel, out of the 35 eligible participants (88%, four persons refused to participate), consented to be part of this study. They were assigned to eight ALS ambulances, were fully trained and paid on a monthly basis. The participants worked in three 8-h shifts: morning (7:00–15:00), evening (15:00–23:00) and night (23:00–7:00), which were scheduled according to a monthly work roster. Each staff member had at least four shifts per week plus a weekend shift every three weeks. The intensive care service serves a population of almost 450 000 and responds to an average of 350 emergency calls per month. Two hundred of those calls require the ambulance crew to take a patient to hospital; other calls are either cancelled (mild) or end in the patient being transferred to emergency medical technician (EMT) ambulances for treatment (semiserious). EMT staff are less qualified than paramedics so calls that are not a priority are passed to them.

2.3. Interviews and Observations

A questionnaire was distributed to all 31 participants. It had 32 questions and was divided into three sections: (a) general information: age, gender, weight, height, physical condition and athletic activities (6 questions); (b) professional data: seniority and the number and type of shifts (5 questions); and (c) work conditions: sitting habits, sitting comfort and safety when using equipment during patient treatment (21 questions).

There were 10 random free-flow one-on-one interviews. They were based on 20 questions and lasted 30 min each; they focused on work routines and activities, comfort, safety, and health complaints. To analyze qualitative data, speech was coded into meaningful categories, thus making organizing the text and discovering patterns possible.

2.4. Vehicles

The ambulances that were studied (Chevrolet Savana, General Motors, USA) are widely used in Israel. These vehicles are built and equipped according to the directives of medical life support organizations. Figure 1 shows the main components of the patient compartment: 1—utility cabinet (attached to the left wall of the vehicle, looking from the rear), which stores all the necessary medicines, drugs and equipment (including monitor, see next item); 2—monitor/defibrillator located on a shelf in the cabinet, near the paramedic's seat, to his/her right; 3—stretcher, located on the side and at the foot of the bench, fastened to the floor of the vehicle; 4—four-passenger bench (a wooden box also functioning as a storage space) attached to the right-hand wall opposite the utility cabinet. At the head of the bench is a side door, for easy entry by the paramedics on duty; and 5—paramedic's seat, located at the head of the stretcher and close to the monitor/defibrillator.

2.5. Internal Compartment Layout

The current layout was analyzed in terms of its functionality of as a mobile workplace; over 40 eight-hour shifts (day, evening and night), chosen at random over a 5-month period were observed. The main components (see section 2.4.) were analyzed in detail for ergonomic accessibility, safety against sudden impact, anthropometric dimensions and guidelines for suitability for performing clinical procedures [8]:

1. the distance and accessibility of the utility cabinet from the bench and the paramedic's seat (hand reach/grasp distance);
2. the distance and accessibility of the monitor/defibrillator from the bench and the paramedic's seat (reach/grasp and handling distance);
3. the stretcher positioned opposite the bench;
4. the bench, functioning as a seat in a moving vehicle; and
5. the paramedic's seat at the head of the stretcher.

When treating patients, the staff mostly sat on the bench, so the paramedic's seat was of limited interest only.

2.6. Computer Simulations and Moment Analysis

Computer simulations were used to evaluate the ergonomics of both the current and new designs. The simulations included a digital human model (DHM) positioned in two three-dimensional models drawn in ManneQuinPro version 10.2[1]. The tools for the evaluation provided data on

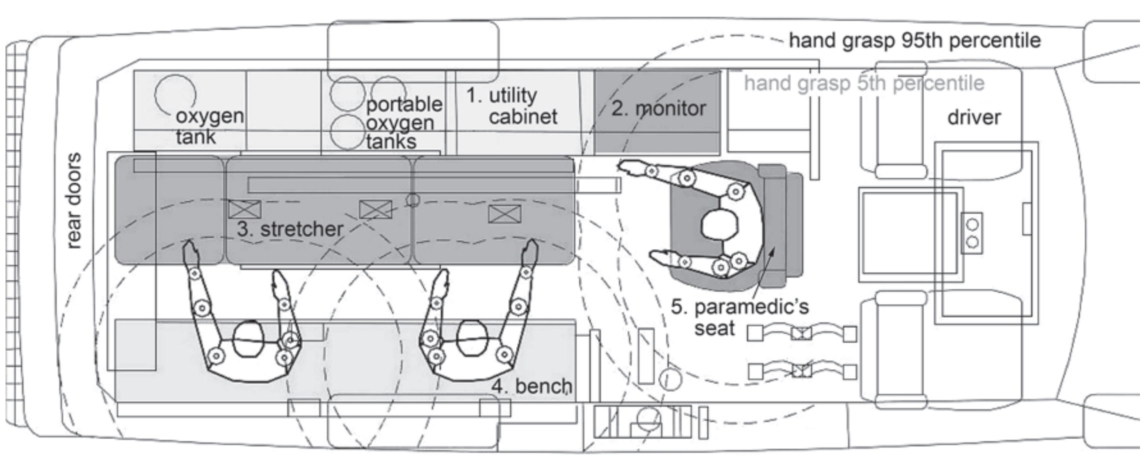

Figure 1. Plan view of the interior of the patient compartment.

[1] MannequinPRO is a registered trademark of NexGen Ergonomics; http://www.nexgenergo.com/ergonomics/humancad.html

TABLE 1. Detailed Subcriteria of Physical Components Analyzed

Item	Subcriteria Examined
Bench	adjustable height: 36.0–49.5 cm seat depth: 44.0–55.5 cm presence of leg rest supportive head and back rests adjustable seat and backrest angles [9] motor vehicle seat [10] swiveling ability (drive direction)
Stretcher	adjustable work-surface height: 43–54 cm elbows flexed at 90° when treating patient whole patient's body hand coverage (upper and lower patient's body) presence of leg room option of treating from both sides
Utility cabinet	reach and grasp envelope for 5th percentile of men (from bench): 56 cm convenient access to all compartments
Monitor/defibrillator	adjustable height: 119–136 cm center of screen at the height of line of sight optional horizontal movement of the screen optional pitching and turning aside view distance: 45–60 cm
Paramedic's seat	adjustable height: 36.0–49.5 cm seat depth: 44.0–55.5 cm presence of leg rest supportive head and back rests adjustable seat and backrest angles [9] motor vehicle seat [10] swiveling ability (drive direction)

Notes. All dimensions were compared to anthropometric estimates for U.S. adults.

potential injury risk and postural analysis, the reach and grasp envelopes, vision cones, and comfort and fit requirements.

The DHM was positioned in two common sitting postures while treating a patient: (a) sitting on the bench treating a patient (Figure 2) and (b) sitting on the bench reaching toward the utility cabinet with one hand. The DHM's lower back moments were analyzed for both sitting postures and in the two designs.

3. RESULTS

3.1. Questionnaire Findings

All 31 subjects filled out the work conditions questionnaire (21 questions). Table 2 is an example of the distribution of the answers to the questions on sitting habits, sitting comfort and body postures when using equipment during patient treatment.

3.2. Observations

The interview results strengthened some assumptions revealed by the survey. When performing clinical procedures that required paramedic–patient interaction, 10 participants preferred to sit on the bench at the side of the stretcher than on the paramedic's seat. The main reasons were no eye contact between the patient and the paramedic sitting on the paramedic's seat and the difficulty in accessing the patient's head and the upper limbs (e.g., to check the pulse) without deep back flexion.

Ninety percent of the participants complained of the difficulty and need to bend forward in deep back flexion when treating a patient lying on the stretcher. According to 60%, it was impossible, even though sometimes necessary, to reach the patient from both sides, resulting in the need to stand up and bend forward at times for better accessibility.

All participants complained that the current seat belt layout did not promote their use because

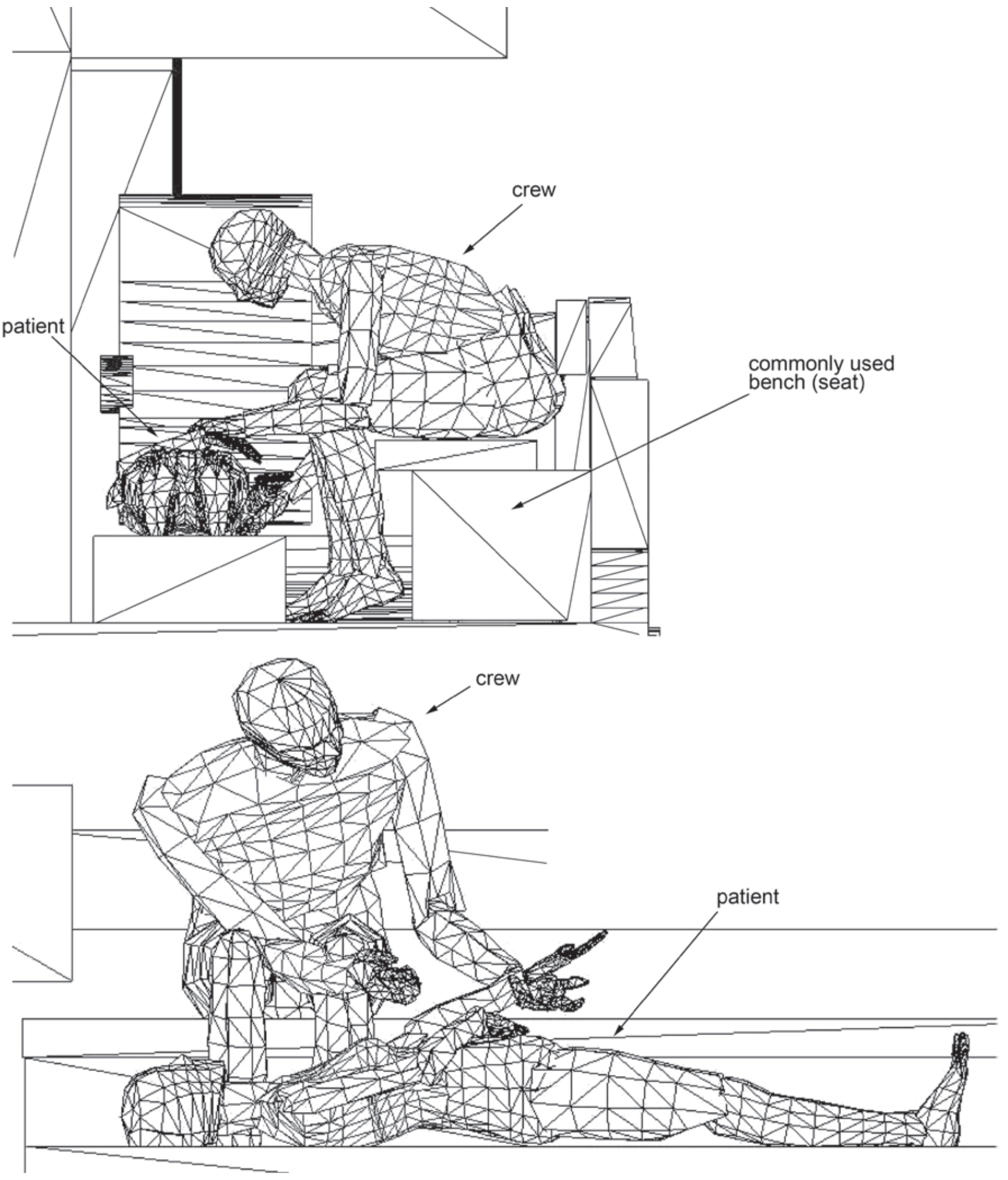

Figure 2. Moment analyses of current design when the digital human model is in the sitting-on-the-bench-treating-a-patient position (ManneQuinPRO version 10.2).

of the constant need to stand up and bend and the inconvenience of constantly buckling and unbuckling. So, the paramedics chose not to use them at all, despite the risk of self-injury and concern for patients' safety.

3.3. Compartment Layout

Ergonomic and anthropometric evaluation of the physical elements in the ambulance compartment checked if the working environment was suitable for the medical procedures the staff provided (Table 3).

3.4. Suggested Compartment Layout

An improved alternative layout was suggested through computerized means with ergonomic, safety and anthropometric suitability for paramedics and patients in mind. Except for one, all

TABLE 2. Distribution of Selected Answers in the Work Conditions Questionnaire

Question	Options (%)*	Distribution (%)	Options (%)
Does location of paramedic's seat contribute to efficient and comfort performance of clinical procedures?	yes (26)	close to monitor and utility cabinet (88) patient face within hand reach (12)	
	no (74)	eye contact between paramedic and patient (90)	no eye contact (25) eye contact only when patient lies flat (61) eye contact only when patient lies in an inclined position (0) always good eye contact (14)
When sitting on the bench, does it feel comfortable?	yes (6)	patient upper limbs out of hand reach (100)	
	no (94)	inappropriate width and height dimensions (39) backrest dimensions and location (38) lack of armrests for each sitting place (21) lack of cushions to absorb shocks and bumps (2)	
Does bench–stretcher height difference contribute to efficient and comfort?	yes (23) no (77)		
Do you use seat restraints inside patient compartment?	yes (60)	always use restraints (3) always, but not when performing clinical procedures (17) on administrative rides only, without patient in vehicle (40)	
	no (40)		
Do you feel the need to steady yourself inside vehicle when it is moving?	yes (86) no (14)		
Have you been injured (or close to be) during emergency rides?	yes (79)	hitting against ambulance wall during sharp turns (40) injury caused by unwieldy objects (31) road accidents (8)	
	no (21)		
Have you injured (or close to) a patient during emergency ride?	yes (46)	injured once or more (13) almost injured (23)	
	no (54)		

Notes. *—participants could select more than one answer; therefore, percentages add up to over 100%.

modifications were practical and did not require remodeling the physical structure of the ambulance.

3.5. Analysis of Moments

The analysis of load experienced by the medical crew, simulated on a DHM sitting on the bench treating a patient, showed that the load on the lower back was 71 Nm. When the DHM was sitting on the bench reaching toward the utility cabinet with its hand, the load on the lower back was 31.2 Nm.

The new layout moment analysis showed improvement in decreasing the load on the lower back, compared to the current layout in both scenarios. For the DHM sitting on the bench treating a patient, the load on the lower back decreased by 74% to 18.4 Nm. When the DHM was sitting on the bench reaching toward the utility cabinet with its hand, the load decreased

TABLE 3. Variable Constraints in Ambulance Interior

Variable	Current Situation	Remarks
Bench	height above floor: 50 cm	suitable for 95th percentile of men only
	no leg rest	
	partial backrest and head rest support	no lumbar support
	seat depth: 35 cm	no good seat support
	failed seat standard [9][1]	seat and backrest without adjustable options
	failed motor vehicle seat standard [10]	no vibration absorbers or suitable restraints
	no swiveling ability	forced sitting position perpendicular to driving direction
Stretcher as work surface (sitting on bench)	height above floor[2]: 20 cm	forced deep back flexion at work surface paramedic's elbows stretched when treating patient partial treating coverage by hand[3]
	insufficient leg room	
	treating patients is possible only from side of bench	adjacent to utility cabinet
Paramedic's seat	fixed height: 45 cm	no footrest for shorter people
Utility cabinet	distance from bench: 78 cm	beyond 95th percentile of men's maximum horizontal and vertical grasp range (when sitting on bench) partial hand accessibility to compartments[4]
Monitor accessibility (sitting on bench)	no options for horizontal, vertical or pitch adjustments	height above floor (75 cm) falls beyond video display terminal guidelines for 95th percentile of men
	center of screen below line of sight	unnecessary forced neck flexion
Patient–paramedic eye contact (sitting on paramedic's seat)	partial eye contact[5]	patient lying flat on stretcher

Notes. 1—back rest: a 10-cm padded strip, the same length as the bench and located 10 cm above the top surface; 2—not adjustable (beyond ergonomic recommendations for work-surface height); 3—severe height difference shortens the hand reach envelope; 4—only when sitting on paramedic's seat; 5—eye-contact available only by using a mirror mounted on vehicle wall.

by 91% to 2.8 Nm. Figure 3 shows a simulation of the new layout.

4. DISCUSSION

The main goals of the new design this article suggests are to increase the comfort and safety of work in the vehicle and to reduce injuries experienced by ambulance paramedics today. The new design considers the definition in Standard No. KKK-A-1822E [11] and is based on ergonomic requirements for comfort, secure sitting and safety against active and passive impact during rides.

The strenuous occupational postures derived from awkward working demands as experienced by paramedics have been found to constitute the primary source of musculoskeletal risk and symptoms that may lead to fatigue, lower cognitive performance and cumulative trauma disorders.

The current interior floor-to-ceiling clearance, measured inside the cabin is only 165 cm. This limits any upright posture or movement of the staff inside the patient compartment, thus compelling to move with bent back and bent neck postures, especially when entering through the rear doors (125 cm). We suggest increasing the roof height so staff can move in an upright position. We also recommend replacing the current bench with new seats with improved body restraints, a new adjustable work-surface design, a new suspended utility cabinet and a new location for the monitor (Figures 4–5). Table 4 shows the suggested layout with modifications in detail.

We believe these suggestions may reduce physical discomfort that can lead to human error and

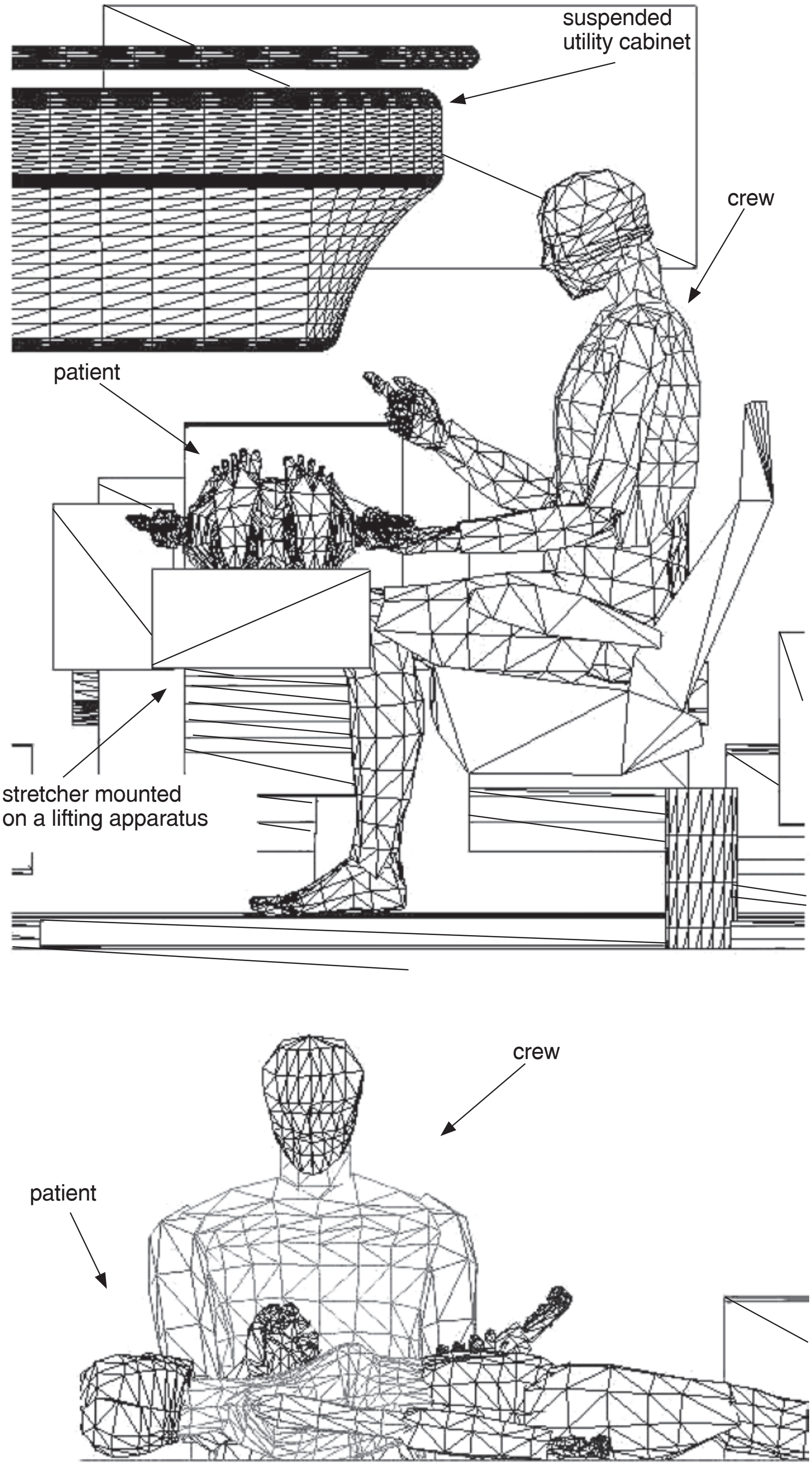

Figure 3. Moment analyses of suggested design when the digital human model is in the sitting-on-the-bench-treating-a-patient position (ManneQuinPRO version 10.2).

accidents, and decrease the risk of injury to staff and patients during clinical procedures. Moreover, they may also increase the use of seat belts by the former and safety restraints for the letter.

We focused on back flexion during medical procedures, since it reflects most of the problems found in the various studies. Additional observations of all joints, with data on duration, might give a more complete understanding about non-neutral postures during procedures. All modifications and layout design were tested only on a computerized model. To conclude, future patient compartments should be designed with consideration for health, comfort and performance. This proposed alternative layout should be considered to make work more efficient and

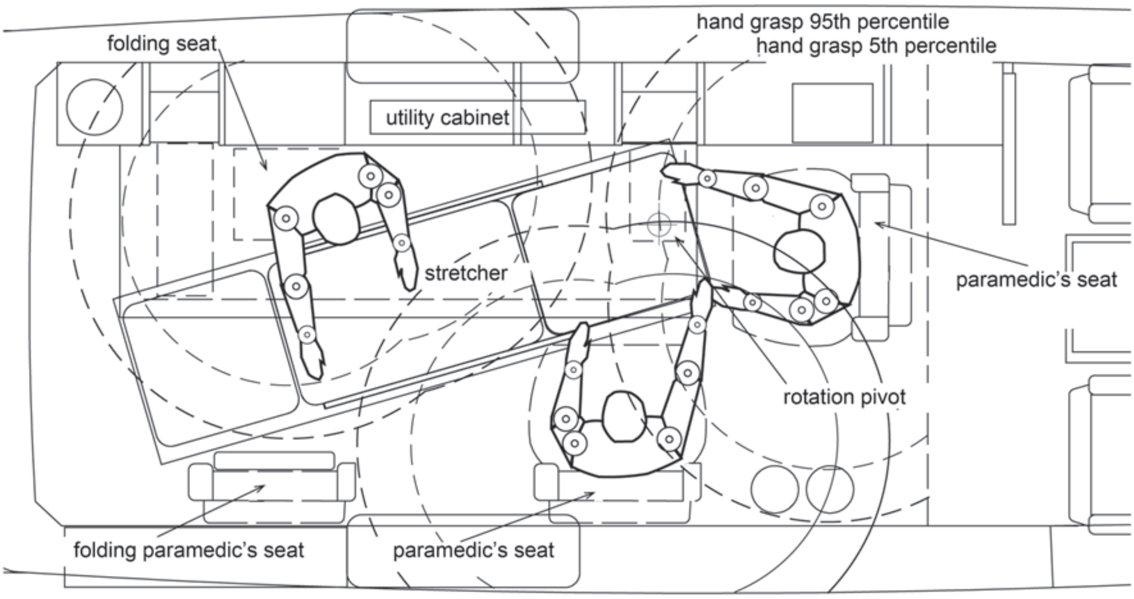

Figure 4. Plan view of the new layout of the patient compartment.

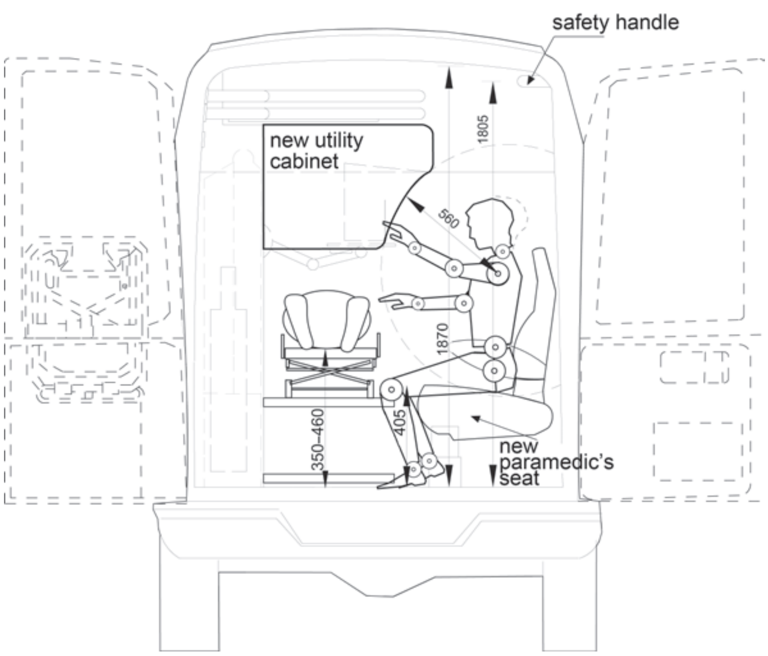

Figure 5. Cross-section of the patient compartment with the suggested suspended cabinet and the lifting apparatus (all measurements in centimeters).

TABLE 4. Detailed Suggested Modifications to Enhance Current Layout

Current Item	Suggested	Improvement
Roof-to-ceiling distance in patient compartment	another type of vehicle with a minimum of 256.4 cm is preferable	fitting height of roof and rear door to allow 95th percentile of men (187 cm) to enter and stand in upright position inside compartment new height to be lower than maximum permitted height (279 cm) suggested by Standard No. KKK-A-1822E [11]
Bench	two new seats for paramedics (instead of bench) with leg rests	one at patient's head, the other (with folding option) at patient's legs ability to swivel and face driving direction
Seat belts and restrains	additional 2 types of seat belts (waist and diagonal)	better body movement waist seat belt will include rigid protective material to protect inner organs (liver, stomach, kidneys) against sudden impact while chair faces stretcher (perpendicular to direction of driving)
Stretcher	mounting on a lifting platform apparatus	possibility to adjust stretcher height to operator's elbow level (reduce the need for back flexion) platform with stretcher should revolve around pivot at patient's head
	new folding seats for paramedics	at patient's legs opposite existing seat possibility to sit next to patient when platform is swiveled aside (treatment from either side of stretcher)
Utility cabinet	re-arrangement with new suspended part above stretcher	drawers in hand-grasp range (5th percentile of men) of medical attendant seated in any seat decreased need for arm hyperextension; 30% improvement in access to cabinet drawers (Figure 5)
Portable monitor	new adjustable arm with platform mounted on vehicle wall	monitor located on new arm along old paramedic's seat for staff member seated behind patient's head
	new liquid crystal display screen on new suspended utility cabinet	better access to monitor's buttons better viewing distance

safer. Uncomfortable and extreme postures can thus be reduced.

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