# Motion Sickness Prediction in Aeromedical Evacuation of Patients with Ebola

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**INTRODUCTION:** Aeromedical evacuation of patients affected by severe infectious diseases inside an aircraft transit isolator (ATI) system is at potential risk of motion sickness (MS). A test flight was then conducted to quantify this risk during the transfer of an Ebola patient from West Africa to Italy.

**CASE REPORT:** A mannequin was inserted inside an ATI and instrumented to provide acceleration parameters throughout the test flight. The analysis of the data predicted a MS incidence of about 2% for a 6-h flight, so the decision to use anti-MS drugs only in selected cases was taken (i.e., those with positive past history of MS, gastrointestinal disorders, or residual carsickness due to previous ambulance run). On this basis, an actual aeromedical evacuation of an Ebola patient was successfully performed without the use of any anti-MS drugs.

**DISCUSSION:** During aeromedical evacuation with ATI systems, the patient's risk of MS should be evaluated on an individual basis and calibrated according to the specific exposure to motion evoked by the flight platform used. Due to the possible onset of untoward effects, prevention with anti-MS drugs in these patients should be limited to selected cases.

**KEYWORDS:** airsickness, vibration, infectious diseases, aviation medicine.

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Motion sickness (MS) may play a significant role in the aeromedical evacuation of critical patients due to related distress and vomiting, with consequent dehydration and risk of airway occlusion in supine individuals.[5,18] It is usually evoked by passive and prolonged exposure to rotatory and/or linear accelerations whose intensity and duration parameters play a major role.[8,11,13] On this basis, a mathematical model has been developed to predict MS incidence in an unselected population passively exposed to moving environments.[8,11,13] In recent years, this method has been widely used to analyze the risk of MS in different transport vehicles.[3,13]

The aeromedical evacuation of patients is among those situations where the potential onset of MS must be taken into account.[5,18] Nevertheless, only a few reports document the incidence of MS in such situations, focusing the attention on both patients and staff members.[5,14,18] A very particular form of aeromedical evacuation is that of patients affected by highly contagious infectious diseases, where special needs for the prevention of spreading the infective agent recommend the use of specific aircraft transit isolators (ATI).[4] Inside an ATI, the patient is strapped in, lying supine and completely isolated from the surrounding environment by a thick plastic envelope. In such devices, the internal air pressure is continuously kept lower than the external ambient to avoid any possible air contamination in case of accidental leaks.

This condition generates a quite particular environment in which the patient is completely isolated and passively exposed to the aircraft's motion and vibrations, with a significant limitation of active movements. The plastic envelope also precludes the contrast of MS by visual fixation of external targets, while the strict confinement might further facilitate its onset in sensitive individuals due to the summating effect of psychological stress.[2,6] The duration of exposure to motion plays an important role in the genesis of MS so that its incidence may increase during long-haul flights. In such conditions, all the above contributing factors can simultaneously affect a patient inside an ATI

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(i.e., the passive prolonged exposure to motion, the subject's confinement, and the impaired external visual fixation).

In these cases, the use of anti-MS drugs could be an effective preventive method, although it may also induce several side effects such as sedation and/or antimuscarinic effects, which may negatively interfere with the aeromedical evacuation process.[15,16,20] Therefore, their administration should be limited to those patients considered at sufficiently high risk of MS. In this report, we describe the decision making strategy adopted by the Italian Air Force (ItAF) team for the aeromedical evacuation under biocontainment of a patient affected by Ebola.

## CASE REPORT

Due to the recent Ebola outbreak in West Africa, a preliminary investigation was conducted for a hypothetical patient evacuation from those countries to Italy. Among the different certification procedures adopted for such a task, a preliminary test flight was partly dedicated to the analysis of MS. At this scope, an ATI was tightly fixed on a pallet that was in turn inserted in midposition within a KC-767 fuselage, a military tanker version of the Boeing 767. This was the fully mission representative configuration in which the ATI was exposed to the full aircraft's motion and vibrations without using any specific cushion absorbing system.

The ItAF ATI system is the same as described in previous reports, where its characteristics are detailed.[4] Briefly, it is made of a wheeled stretcher completely wrapped around and isolated from the surrounding environment by a thick plastic envelope, which allows observation and monitoring of the patient from outside. Several accesses located in each side of the device allow access to the patient (**Fig. 1**).

The internal air ventilation is continuously ensured via an electric pump associated with a HEPA filter. Under operational conditions, the ambient pressure inside the ATI is kept slightly lower compared to the surrounding environment by the same pump to prevent the possible spreading of contaminated air in case of any accidental leak in the insulation barrier. Such a pressure difference slightly introflexes the plastic envelope, which is kept stable throughout the flight.

**Fig. 1.** The ATI system during the transfer of an Ebola patient into the KC-767 aircraft in Freetown airport (courtesy of the Italian Air Force).

To analyze the risk of airsickness in such conditions, a torso and head first-aid training mannequin, weighing 11 kg, was positioned inside an ATI in supine position and properly strapped in to reflect real chest constraint conditions. Due to the nonlinear behavior of the loose stretcher tissue, we decided to directly instrument the dummy with three triaxial piezoelectric accelerometers (PCB Piezotronics Inc., Depew, NY), one centrally located on the fore and two other preaurally. The direct measurements from the two sides provided acceleration data near the labyrinth, completing the information on rotatory stimuli via the front sensor. The axis reference was set according to the physiological acceleration nomenclature, with the x-axis perpendicular to the patient's supine plane (positive outward from the chest), z-axis along the spinal direction (positive toward the head), and y-axis along the interaural line (left side positive).[10] The accelerometer set was connected to an acquisition front end and to a laptop via a local area network cable. Acceleration values were collected at 256 samples/second during the entire flight-test profile (taxi, ground roll, takeoff, climb, cruise, descent, approach, landing, and taxi), which lasted 1 h and 15 min. Data frames were converted in a suitable format for a spectral analysis, with the antialiasing filter limiting the maximum frequency to 128 Hz. The power spectral density was then estimated with the Welch method.[17] For spectral analysis, the frequency content was preferred to response peak identification. Acceleration root mean square (RMS) values were calculated with numerical integration within the power spectral density 0.1–0.5 Hz frequency band, considered to be critical for MS.[8] The Lawther-Griffin approach was considered to determine the risk of MS for an untrained subject with projection to a 6-h exposure time, since this was the estimated flight duration from West Africa to Rome using the KC-767.[8,13] For this purpose, the maximum acceleration RMS value was considered. The test flight was conducted under cloudy and windy conditions, with heavy rain at departure, so that some turbulence was met, especially during takeoff and climb. Throughout this flight, no relevant angular accelerations were observed for the yaw, pitch, or roll axes. Thus, their potential contribution to the genesis of MS was considered negligible. For linear accelerations, the mannequin's x-axis (i.e., the one corresponding to vertical aircraft movements) resulted in being the one reporting the highest levels by far. Therefore, we focused our attention on the acceleration magnitude and spectral content along this axis. Results of our analysis on this axis are summarized in **Table I**, where the Lawther-Griffin approach was considered and compared to the International Standard for a result coherence check.[11,13]

As evident from the table, our results indicated a low risk (about 2%) of MS, even if extended to a 6-h flight duration.[13] Of course, such a finding is for a standard situation of complete passive exposure to aircraft motion, as the one obtained using

**Table I.** Acceleration Data and MS Incidence Prediction.

| ANALYSIS APPROACH | DRIVING PARAMETER | MAX VALUE (x-AXIS) | MS INCIDENCE TEST FLIGHT CONDITION | MS INCIDENCE TIME PROJECTION* |
|---|---|---|---|---|
| Lawther-Griffin[13] | Motion Dose | 2.87 $m \cdot s^{-1.5}$ | 1.0% | 2.1% |
| ISO 2631-1[11] | MSDV | 0.04 $m \cdot s^{-2}$ | 1.3% | 3.3% |

Test results indicating the motion dose, the motion sickness dose value (MSDV), and the acceleration RMS as observed in the preliminary test flight (test conditions column).
* Prediction of MS incidence for a 6-h flight.

our mannequin. Thus, in an actual operational environment, it does not take into account possible additional patient's movements (e.g., head rotations).

A real patient transfer was then conducted on 25 November 2014, on a male Ebola patient of 50 yr of age from Freetown (Sierra Leone) to Rome (Italy), where he was hospitalized in a highly specialized facility (Biosafety Level 4). In this operation, the patient was firstly diagnosed as fit to fly by a preliminary aeromedical check performed at Freetown airport before being inserted inside the ATI. His history was negative for a high sensitivity to MS, and he had no MS signs and/or symptoms due to the previous ambulance transfer from the local hospital facility to the airport, nor was he affected by other clinical conditions potentially facilitating vomiting and/or MS onset, such as gastrointestinal disorders (common in Ebola, but absent in this patient at the time).[1,21] During the whole flight he was conscious and cooperating, and was repeatedly monitored by the medical team members via visual inspection, arterial pressure, $S_aO_2$, electrocardiogram, and temperature sampling. Due to the lack of preflight MS symptoms and/or signs, and other risk factors for vomiting onset (no gastrointestinal disorders and a body temperature of 36.8 C°), neither anti-MS nor sedative drugs were administered during the whole aeromedical evacuation procedure.

During the flight, which lasted 6 h and 15 min and was performed in good weather conditions (i.e., without significant turbulence during all flight phases), a complete absence of airsickness was observed, along with no derangements of all those parameters being monitored. In the postflight follow-up, no staff members were infected, which confirmed the effectiveness of this isolation method, in agreement with our past experience.[12] The clinical outcome of this Ebola case was positive, with no residual deficits, and the patient was eventually discharged from hospital on the 2nd of January 2015.

## DISCUSSION

The aim of this study was to analyze and quantify the MS risk during the aeromedical evacuation of an Ebola patient inside an ATI system in a long-haul flight. In this case, the usefulness of a preliminary evaluation of the MS risk during aeromedical evacuations was confirmed, as previously documented by other authors.[5,18] When an ATI system is used, the onset of airsickness may significantly impair the clinical outcome, especially if vomiting occurs, due to fluid loss and the risk of ab ingestis disorders facilitated by the patient's supine position. On the other hand, the systematic use of anti-MS drugs may reduce the patient's ability to cooperate with the ATI operators due to the probable onset of drowsiness.[15,16,20] This may reduce the effectiveness of the in-flight clinical checks. Moreover, patient's cooperation during the postflight transfer from the ATI into a smaller ambulance stretcher isolator must be considered.[4,12] Besides a reduced level of arousal, anti-MS drugs can also induce various antimuscarinic effects that may influence the overall clinical state and bias the parameters being monitored. Therefore, when possible, the use of such medications should be limited to selected cases, where an actual risk of MS occurs.

The passive exposure to acceleration plays a fundamental role in the genesis of MS, so that its analysis could contribute to calculating the risk of MS. In our preliminary test flight, the highest input on our accelerometers was observed for vertical linear accelerations, corresponding to the x-axis of a supine patient. This body position should not significantly influence the incidence of MS, since this can occur without significant changes in all stimulus directions (i.e., fore-aft, lateral, and vertical).[7,9] In our case, the ATI characteristics reduce the patient's capability of visual fixation on external targets, inhibiting such a protective factor against MS.[2,6] This situation is similar to that reported by Bos et al. in their "inside viewing" condition, where sickness was the highest with respect to the "outside viewing" and the "blindfolded" conditions.[2]

However, based on the sole acceleration parameters, our data indicate a MS risk of about 2% during a 6-h aeromedical evacuation on the KC-767 (Table I). Such a finding is probably conservative due to the low mannequin weight with respect to a human body, with consequent over-estimation of acceleration values. Moreover, in our study, the MS risk was extrapolated from the preliminary flight test data, where an exposure of 1 h and 15 min was recorded and subsequently calculated for a 6-h flight. This induced an over-weighting of the takeoff and landing phases, when the highest levels of acceleration were recorded. Furthermore, this method does not take into account the beneficial effect of flat cruise periods, where very low acceleration parameters are observed, and the patient can recover from hypothetical MS symptoms occurred during takeoff and climb. In fact, the high cruise levels [>30,000 ft (9144 m)] flown by large aircraft such as the KC-767 reduce the exposure to air turbulence, lowering MS incidence. In addition, the possibility of placing the ATI close to the aircraft's center of gravity (i.e., in midposition within the fuselage) should further reduce the acceleration stimulus. This approach might be particularly useful in Ebola patients, where vomiting due to infection is reported in many cases.[1,21]

The clinical situation of candidates for aeromedical evacuation should also be evaluated for preflight induced carsickness, since they usually reach the airport inside an ambulance.[19] Therefore, our present experience, although limited to one

single case, showed that the preflight check plays a fundamental role in the decision process for anti-MS drug administration. Those subjects with a past history of high sensitivity to MS, with gastric disorders, or who are affected by residual signs and/or symptoms of carsickness due to the previous ambulance run should be preventively treated with anti-MS drugs to avoid an in-flight worsening of their symptoms. Conversely, in other patients (i.e., those with negative results for all those risk factors), these drugs should be avoided due to their negative side effects.[15,16,20] In fact, at least according to our experience, a cooperative patient is extremely useful during all aeromedical evacuation steps when using the ATI.

In agreement with our flight test findings, no anti-MS drugs were administered during the real patient transport and he was able to cooperate with the medical team during the whole flight, as during the postflight transfer into a Biosafety Level 4 ambulance, according to ItAF standard operational procedure.[4,12] Most of our findings can be probably applied to many other flight platforms, where similar ATI systems and evacuation procedures are adopted. Therefore, although based on a single case experience, a few practical considerations can be hypothesized: 1) the patient's risk of MS should be evaluated for all those flight platforms used for aeromedical evacuation with ATI systems, especially when long-haul flights are planned; and 2) when a low MS risk is observed, the use of anti-MS drugs might be limited to those patients already affected by preflight MS due to previous exposure to motion or at actual risk of vomiting due to their past history and/or to concurrent infection-induced gastric disorders.

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