CP 599

LIFE SUPPORT FOR TRAUMA AND TRANSPORT (LSTAT™): A NATO LITTER-BASED CRITICAL CARE TRANSPORT PLATFORM

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Summary

A significant portion of the military field medical footprint is currently consumed by post surgical patients, which according to current doctrine, must be stable before evacuation.[1] This requirement results in a significant logistical burden for our ground forces. At present, we do not have adequate monitoring or therapeutic capabilities during ground or air transport to a definitive care treatment facility. In response to this need, we initiated a research and development activity to design and build a NATO-stretcher-based mini-intensive care unit that incorporates resuscitative and life-sustaining capabilities for field surgery and *en route* care. The LSTAT™ has 3 basic components: (i) the base unit, (ii) a NATO stretcher, and (iii) a canopy that covers the entire patient. The LSTAT™ base contains medical diagnostic and therapeutic components while medical parameters, system performance data and user interactions are continuously monitored and logged by an on-board CPU. Provision is made for storage of up to 36 hours of physiologic and system performance data which can be uploaded to a local or remote host computer. When necessary, this data can also be communicated to the receiving hospital during evacuation for review by physicians to aid in their medical preparations for treatment. This facility provides a new life support capability for transport of marginally stable or unstable patients which integrates with existing NATO evacuation platforms.

List of Symbols

ABP	Arterial Blood Pressure
CO_2	Carbon Dioxide
CVP	Central Venous Pressure
DARPA	Defense Advanced Research Project Agency
ECG	Electrocardiogram
Hb	Hemoglobin
HR	Heart Rate
ICP	Intracranial Pressure
ICU	Intensive Care Unit
IV	Intravenous
LAN	Local Area Network
LSTAT™	Life Support for Trauma and Transport
MTF	Medical Treatment Facility
NIBP	Non-Invasive Blood Pressure
O_2	Oxygen
RR	Respiratory Rate
TV	Tidal Volume
WRAIR	Walter Reed Army Institute of Research

Introduction

Clearing the battlefield quickly and efficiently while providing the patient the best possible care is a priority mission of the US tri-service, military medical community. At the same time, reduction in the size of the medical footprint and enhancement of the mobility of our MTFs is also a high priority. Expedient movement of the critical care patient population would contribute significantly to the attainment of these goals. Although a small fraction of the total casualty population, these patients require a disproportionately large number of man-hours and logistical support in the field.

Current US military evacuation procedures require that a patient be held in a field MTF until ready to return to duty or until stable enough to be evacuated[1]. For the critical patient, this can be several days or more before he can withstand the added stresses of ground or air evacuation with the attendant high ambient noise and vibration, and in the case of rotor-wing air evacuation, low atmospheric pressure conditions. Although there is little reason to believe that the high acoustical noise or vibration are, in themselves, medical hazards, they would, and do, significantly degrade the attendant care-giver's diagnostic and therapeutic capabilities *en route*. Heart and lung sounds are difficult if not impossible to detect above road or aircraft noise and even simple palpation of peripheral pulses can be very challenging in high vibration environments. These conditions create a significant hazard for the patient since a medical crisis

Paper presented at the AGARD AMP Symposium on "Aeromedical Support Issues in Contingency Operations", held in Rotterdam, The Netherlands, 29 September - 1 October 1997, and published in CP-599.

may escape detection *en route*. The LSTAT™ project was initiated to address this portable critical care transport requirement.

In April of 1993, a meeting of Army researchers and health care providers was convened at DARPA to discuss the concept of a critical care life support platform which was then called the "Trauma Pod". The principle operational objectives were to design and build an *en route* life support capability which was to be compact, man portable and useful throughout the entire evacuation chain. This required it to be compatible with both ground and air evacuation vehicles in all U.S.military services. Operationally it was also to serve as a pre-surgical, intra-operative and post-operative critical care life support capability for field surgical facilities. The design of this facility was to provide a developmental foundation for implementation of emerging new diagnostic and therapeutic technologies.

Operational Objectives:

- Improve field mobility
- Provide evacuation capability for transport of unstable patients for earlier evacuation
- Decrease patient holding requirements by allowing earlier evacuation
- Provide critical care capability throughout all levels of evacuation chain without moving patient
- Enable effective therapeutic intervention during transport
- Over-fly middle echelons of care
- Optimize use of care-giver 's time by automating patient record keeping and therapeutic device adjustments
- Stretch limited resources with "smart" resuscitation algorithms

Guidance from the Army's Directorate of Combat Doctrine and Developments at Ft. Sam Houston, defined the following requirements for a life support transport system.

LSTAT™ Requirements:

Minimal:

- Integral suction and ventilatory capabilities
- "Hands off" defibrillation system
- Integrated parenteral infusion system
- Compatibility with external O_2 delivery systems
- Physiological monitoring (non-invasive & invasive)
- BP, ECG,HR, Core temp, O_2 saturation
- Protection from Biological & Chemical agents
- Battery power support for at least 30 minutes

Optional:

- Self contained environmental control system
- Construct from materials allowing decontamination without removing or harming the patient
- Protection from chemical agent intrusion
- Allow patient treatment without compromising protection from chemical agent intrusion

LSTAT™ Design Principles

- Constrain external dimensions to NATO stretcher envelope
- Adhere to standard NATO attachment points
- Avoid diminishing vehicle patient transport capacity
- Avoid need for vehicle retro-fits
- Accomodate Army/Air Force ground and air evacuation vehicles
- Use servo-controlled automation to leverage care-giver's time (ventilation, O_2, and fluid delivery)
- Accomodate future telemedicine and sensor requirements

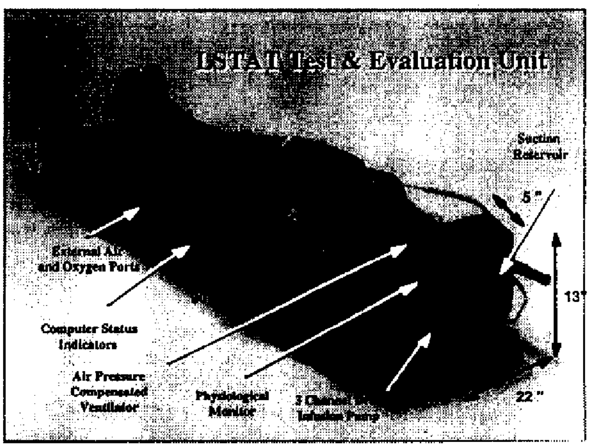

Fig. 1. LSTAT™ Design Test & Evaluation Unit shown here was built by Northrop Grumman Corporation, Pico Rivera, CA. Dimensions are given in inches.

LSTAT™ System Description

Physiologic Monitoring

Cardiovascular

- Non-invasive blood pressure
- 2-invasive pressures (e.g. CVP, ABP, ICP)
- Temperature (e.g. core, skin)
- ECG
- HbO_2 Saturation (pulse oximetry)
- Heart rate

Respiratory

- Airway Flow
- Airway Pressure
- Expired CO_2
- Respiratory rate
- Tidal volume
- Dynamic and static lung compliance

Blood chemistries

- Hand-held blood chemistry analyzer (e.g. blood gases, electrolytes)

Therapeutics

- Air Pressure compensated ventilator with buiilt in compressor
- Automated External Defibrillator
- 3-channel IV drug infusion pump (1L/hr/channel)
- Resuscitation infusion pump (6 L/hr)
- Oxygen cylinder (490L) with oxygen blending
- Continuous and Intermittent Suction

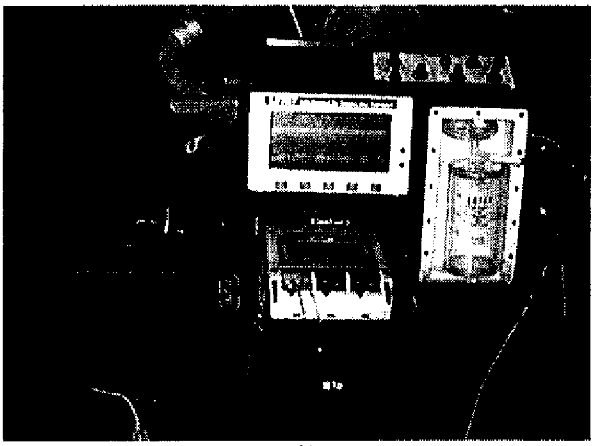

Fig. 2. Head-end view of LSTAT(tm) showing the secondary display, ventilator display and controls, physiological monitor, 3-channel drug infusion pump and the suction cannister. LSTAT(tm) is shown here supported on current field litter stands.

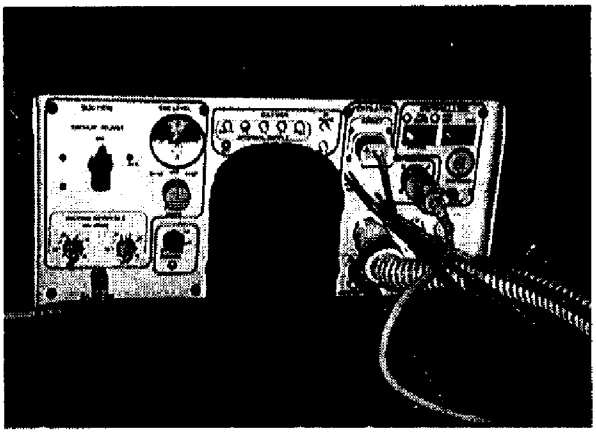

Fig. 3 View of the patient side of head fairing showing (left panel, top to bottom), vacuum gauge , vacuum level adjustment, continuous/intermittent suction mode selection switch, main power switch, intermittent suction duration and interval controls and Ethernet communication port; (center panel) oxygen tank status LEDs; (right panel) automatic external defibrillator power and controls, airway pressure and flow, mainstream carbon dioxide sensor connections, ventilator breathing circuit and expiratory valve connections, ECG, 2 invasive pressure transducers, temperature sensor, NIBP cuff and pulse oximeter connections.

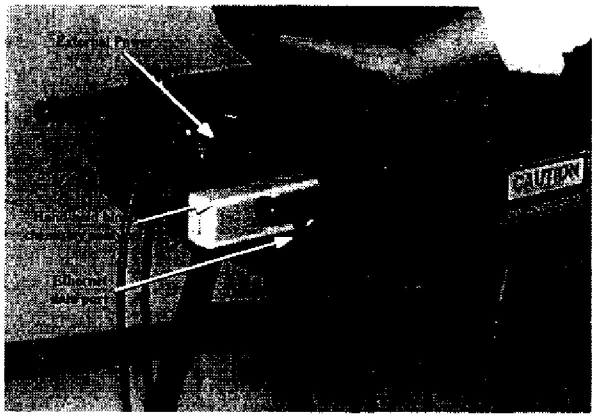

Fig. 4. Foot end of LSTAT(tm) showing the external power connection, a hand-held biochemistry analyzer and a second Ethernet data communications port. (Not seen is the internal oxygen tank shut off valve, trickle charge selector switch and subsystem fuse bank.)

System Monitoring

3-axis accelerometry
Tilt sensing
Compartment, battery and component temperatures
Barometric Pressure
Humidity
Power utilization power bus voltage
Battery charge level and recharge rate

System parameters are monitored to enable trouble-shooting of environmentally induced system failures and to provide the potential for elimination of data artifacts induced by high vibration or high impact events. Knowledge of the history of the environmental exposure of the units will also allow tailoring of maintenance schedules.

Data Collection, Display and Telemetry

2-Ethernet data communication ports
Secondary touch-screen computer display
Physiologic and Sytem Data logging

The two Ethernet data ports are available to support a secondary display in either a tethered or wireless mode to provide a display alternative in situations where the head end displays are not readily visible. These ports may alsobe used to interface with Ethernet-compatable ambulance radios to allow real time or patient trending data to be forwarded to a receiving hospital where a consulting care-giver can review it and anticipate incoming patient care requirements or can mentor the local care-giver on patient care issues *en route*. These data communication ports allow the LSTAT(tm) platforms to be networked together or may integrate with existing LANs. The data logging capability automates the patient record keeping task and will yield a comprehensive data collecting capability during *en route* care never before available.

Environmental Isolation

Fig. 5. LSTAT^{tm} shown standard field litter wheel system with canopy deployed for over-pressured environmental protection.

The LSTAT^{tm} has 3 basic components: (i) the base unit, (ii) a NATO stretcher, and (iii) a canopy that covers the entire patient. The LSTAT^{tm} base contains a ventilator, oxygen source, suction, capnograph, environmental control, onboard computer, batteries, and a physiologic monitoring system.

The physiologic monitoring system of the LSTAT^{tm} platform acquires and archives ECG, 2 invasive pressures, pulse oximetry, expired CO_2, airway pressure and flow waveforms. All discrete measured and derived variables such as heart rate, respiratory rate, temperature, NIBP etc. are also logged and available for trending.

The LSTAT^{tm} conforms with all NATO air and ground evacuation vehicles, is adaptable to aircraft, ground vehicle and domestic and foreign power requirements and can be battery powered to run autonomously for up to 1 hours without the environmental control unit and with all subsytems running at 100% duty cycle.

Advance Development Features

Algorithms are being developed to (i) servo control the ventilator based on the arterial oxygen saturation and end tidal CO_2 to properly ventilate a patient and (ii) drive a servo controlled intravenous fluid resuscitation pump based on blood pressure. Closed loop ventilator algorithms using feedback from capnography and pulse oximetry are being developed to provide appropriate ventilation under conditions where trained personnel are not available to properly manage a critically injured soldier. This control system automatically adjusts ventilatory parameters based on input from airwary pressure, airway flow, expired carbon dioxide and arterial oxygen saturation sensors. Oxygen delivery into the ventilatory circuit is controlled by the arterial oxygen saturation level which is determined by pulse oximetry methods. This system will conserve the limited oxygen supply while optimizing oxygen delivery to the patient. The utilization of capnography (expired carbon dioxide levels) will facilitate the appropriate setting of ventilatory parameters as well as serving as a validation tool for endotracheal tube placement. Closed loop fluid resuscitation algorithms which couple non-invasive continuous blood pressure measurements to the output of a high volume resuscitation pump have been developed to provide fluid resuscitation aimed at optimizing tissue perfusion while minimizing usage of resuscitation fluid resources. The algorithm has been designed to provide the appropriate volume of fluid in a timely fashion while avoiding over or under fluid resuscitation. The closed loop control of both the fluid and ventilation is an element which is directed at diminishing the adjustment requirements of the care-giver whose capabilities become overwhelmed in mass casualty care and transport situations. This servo-control feature can be over-ridden and controlled manually at any time at the care-giver's discretion.

Conclusion:

The LSTAT^{tm} is a stretcher-based mini-intensive care unit that incorporates resuscitative and life-sustaining capabilities into a universally adaptive platform for trauma management and unattended patient support. It allows the transport of medically unstable patients and fits into existing NATO evacuation platforms. The LSTAT^{tm} has been constructed to provide continuous care from the battlefield through transport to a surgical unit, and on to a fixed facility. With the canopy in place, the LSTAT^{tm} serves as a protected, temperature controlled pre-operative "waiting room" as well as a post-operative intensive care unit.

The LSTAT^{tm} platform not only has military application but also has excellent potential application for critical care in natural disaster settings where access to medical care may be difficult. In addition, the LSTAT^{tm} platform may serve as an ICU hospital bed which would greatly facilitate movement of ICU patients to other hospital areas such as X-ray, or MRI facilities.

References

1. Joint Pub 4-02.2, "Joint Tactics, Techniques and Procedures for Patient Movement in Joint Operations"