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Concept Development of a Modular Automated Care Stretcher

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ABSTRACT

A concept is proposed for a casualty evacuation stretcher with continuous monitoring and automated care functionality. The concept stretcher can assess a casualty's cardiovascular, respiratory and brain function and provide decision assistance and automatic life support. The system facilitates rapid care and evacuation in challenging casualty evacuation scenarios.

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Executive Summary

In this report we propose a concept for a casualty evacuation stretcher with continuous monitoring and automated care functionality. The investigative work underlying the concept was carried out by Timothy Mitchell on a 12 week placement as part of Defence Science and Technology Group's 2018/19 Summer Vacation Placement program.

Casualty evacuation is a time-critical mission. Maximum survivability requires rapid and effective care at the point of injury (POI) and safe transport to surgical facilities as soon as possible. Current casualty evacuation measures are impeded by large distances, dangerous environments, inefficient casualty information transfer and short supply of medical personnel and evacuation assets. Here we propose a concept for a stretcher with casualty monitoring and automated care capability. The readiness of underlying and related technologies is discussed, and the concept is evaluated for benefit and feasibility.

The proposed Modular Automated Care Stretcher (MACS) promises substantial benefit for Army medical capability. The system would project sophisticated care closer to the point of injury, allow greater freedom for optimisation of medical personnel distribution and would facilitate evacuation and provision of care in challenging environments. Furthermore, an optional isolation capsule module could prove useful in CBRN evacuations by reducing the number of personnel put at risk.

Core subsystems of MACS, including integrated conventional vitals monitoring and intravenous infusion and ventilation, could be implemented within five years. However further development of the concept will require collaboration with the end-users to ensure appropriate priorities and practical considerations are addressed.

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Contents

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Glossary

AAJT	Abdominal Aortic and Junctional Tourniquet
ABS	Acrylonitrile Butadiene Styrene
ACCS	Automated Critical Care System
ADF	Australian Defence Forces
BMI	Body Mass Index
BP	Blood Pressure
CASEVAC	Casualty Evacuation
CBRN	Chemical, Biological, Radiological or Nuclear
CMUT	Capacitive Micro-machined Ultrasound Transducers
COAST	Coagulopathy of Severe Trauma
CRoC	Combat Ready Clamp
DRABC	Danger, Response, Airway, Breathing, Circulation
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyography
EOG	Electrooculography
EtCO2	End-tidal CO2
FDA	Food and Drug Administration
GCS	Glasgow Coma Scale
GPS	Global Positioning System
HADR	Humanitarian Assistance and Disaster Relief
HR	Heart Rate
IPPV	Intermittent Positive Pressure Ventilation

IV	Intravenous
JETT	Junctional Emergency Treatment Tool
MACS	Modular Automated Care Stretcher
MEDEVAC	Medical Evacuation
NATO	North Atlantic Treaty Organisation
NG	Nastrogastric
POI	Point of Injury
PPG	Photoplethysmorgraphy
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
ROS	Reactive Oxygen Species
RR interval	Inter-beat (heart) interval
SAM-JT	SAM Junction Tourniquet
SAT	Sedation Assessment Tool
SJT	SAM Junction Tourniquet
SaO2	Arterial Oxygen Saturation
SpO2	Peripheral Capillary Oxygen Saturation
StO2	Tissue Oxygen Saturation
SvO2	Mixed Venous Oxygen Saturation
TPU	Thermoplastic Polyurethane
TRL	Technology Readiness Level
UAV	Uncrewed Air Vehicle
UGV	Uncrewed Ground Vehicle

1. Introduction

This report proposes a concept for a casualty evacuation stretcher with continuous monitoring and automated care functionality. The investigative work underlying the concept was carried out by Timothy Mitchell on a 12 week placement as part of Defence Science and Technology Group's 2018/19 Summer Vacation Placement program.

1.1. Background

Casualty survival and quality of recovery is heavily dependent on how quickly medical care is provided. 87% of modern combat fatalities occur before the casualty reaches a hospital and 24% of these deaths are deemed preventable. 50% of in-hospital combat casualty deaths are also deemed preventable [1]. The Australian Army follows the 10-1-2 metric as a planning guide for timely casualty treatment [2]. The 10-1-2 metric establishes the following goals:

- Evacuation, airway management and major bleeding control should be provided within 10 minutes from the time of injury.
- Advanced resuscitative care should be provided within 1 hour.
- Damage control surgery should be provided within 2 hours.

Ideally, medical assistance should be provided as soon as possible. The 10-1-2 metric is a guideline that balances the goal of immediate medical assistance against operational requirements and the challenges of casualty evacuation (CASEVAC) in realistic scenarios. Current barriers to immediate medical assistance include the tendency for battlefield casualties to occur at dispersed, remote or dangerous locations; occurrence of multiple simultaneous casualties; high proportions of combat injuries requiring trauma care; vulnerability of air evacuation to man-portable anti-air missiles; short supply of medical personnel, medical equipment and evacuation assets. In humanitarian assistance and disaster response (HADR) scenarios, large numbers of casualties can occur with a wide variety of conditions and injuries that place further strain on CASEVAC personnel and assets. Many medical assistance tasks such as cardiopulmonary resuscitation and casualty lifting also require multiple responders for optimum results.

Recent advances in biosensors and diagnostic technologies hold potential for high quality continuous casualty monitoring in a lightweight, compact form factor with low power requirements. Continuous monitoring data could be used to inform systems that automate casualty care or provide semi-automated assistance. A system incorporating continuous monitoring and automated care into an agile platform that can access the point of injury (POI) may reduce the impact of obstructions to immediate medical care by projecting treatment assets which require less skill closer to the POI.

2. Scope

This report aims to develop a "smart stretcher" concept to facilitate evacuation and bring advanced care closer to the point of injury.

The main goals of the smart stretcher are to:

- provide continuous monitoring and recording of casualty status
- facilitate evacuation, airway management and major bleeding control
- reduce the skill required for advanced resuscitative care
- minimise time consuming or repetitive manual tasks in casualty care and evacuation.

Additional goals and requirements include:

- allowing modular functions that can be scaled according to available expertise and resources
- allowing hardware and software upgrades over time
- optimised size, weight and power for practical use at POI
- interoperability with vehicles
- allowing remote monitoring, communication and control of automated care devices
- preventing introduction of risks by achieving crashworthiness, robust and rugged design, and simple operation
- automated devices that are equally safe or more safe than manual devices
- allowing easy maintenance, repair and sterilisation.

This report will primarily focus on investigating subsystems that could be used in a smart stretcher and will consider their potential benefit in addition to the Technology Readiness Level (TRL) [3] of underlying technologies.[1] The report will also briefly consider the future viability of pairing a smart stretcher system with autonomous transport platforms or autonomous logistics platforms.

Questions used as part of the concept development are listed in Appendix A.

[1] See Appendix B for a summary of the Technology Readiness Levels Definitions.

3. Technology Review and Concept Development

3.1. Cannulation

Intravenous (IV) cannulation is the insertion of a tube to access a patient's venous system. Cannulation facilitates direct administration of medications, fluids and blood products, as well as allowing direct sampling or drainage of blood and fluid. The current tools and procedures for IV cannulation only achieve a 75% success rate in a controlled hospital environment and there is substantial variation depending on patient age, skin colour, pre-existing scar tissue, BMI and medical condition [4]. Failed cannulation attempts waste time and supplies, increase risk of infection, cause the casualty pain and increase the risk of vascular injury [4].

In a casualty evacuation (CASEVAC) scenario, the conditions and available resources can be even less amenable to safe and successful cannulation. For example, lighting may be poor, casualties can be incapacitated or uncooperative, and personnel with training and experience in cannulation may be physically unavailable. Currently, cannulation requires several manual steps (see Appendix D.3) that can be time consuming and prone to human error.

To project health capability closer to the point of injury (POI), a cannulation assistance subsystem attached to a "smart stretcher" could provide the following benefits:

- fluid therapy projected closer to point of injury
- increased speed of insertion
- reduced reliance on operator experience
- reduced reliance on favourable conditions such as bright lighting
- reduced reliance on attention and fine motor control
- increased insertion success rate
- reduced chance of accidental casualty harm.

Any cannulation module must consider both the casualty as a passive user and the operator as an active user, and should meet the following broad requirements:

- maintain or reduce risk of casualty infection and harm
- compatible with casualties of varied age, skin colour and BMI
- adaptable to unconscious, incapacitated or uncooperative casualties
- simple operation, quickly usable under stress and fatigue
- suitable for bright, dim, windy, noise, hot and cold environments
- minimal size, minimal weight, minimal power consumption
- minimal additional training required

- able to be sterilised and reused
- cost effective.

3.1.1. Cannulation Technology Review

Several devices have been developed that use ultrasound, visible light or infrared imaging to improve the contrast between vessels and surrounding tissue (

Table 3-1). Such devices are intended to improve the process of site selection; however they still rely on human decisions and motor skill for successful insertion. Other solutions have attempted automatic insertion using handheld or fixed systems (*Table 3-2*).

Table 3-1. Summary of assisted cannulation technologies

Technology	Additional Information	TRL
AccuVein AV400 [5] A handheld device that scans veins using the infrared absorbance properties of haemoglobin, processes the reflected image and projects a real-time vein map using visible red light.	Weight: 275g Scanning depth: 10 mm (does not indicate vein depth). Scanning method: infrared. Battery: removable, rechargeable, 180 min on a single charge (approximately 90 insertion procedures), 180 min charging time. Compatible hands-free clamp available.	9 Available on the market since 2014
Veinlite [6] A handheld device that illuminates veins using LEDs.	Scanning method: transillumination.	9
Ultrasound Imaging Use of a standard ultrasound probe to image vasculature.	Generally large and expensive Only suitable for hospitals with pre-existing ultrasound imaging equipment. Usually only used in extremely difficult insertion cases.	9

Table 3-2. Summary of automated cannulation technologies

Technology	Additional Information	TRL
Pulse Handheld Veinfinder [7] Concept for a handheld veinfinding device with an integrated mechanism for guided insertion.	Scanning method: ultrasound.	2
SAGIV: Semi-automatic IV Catheter Insertion System (Hebrew University of Jerusalem) [8] Semi-automatic handheld device that uses infrared scanning to identify veins and robotics to insert and retract the needle.	Scanning method: infrared.	5 Prototype demonstrated in a paediatric ward in 2013[2]
Salisbury Robotics HaemoBot [9] [10] [11] Advanced robot for fully automated IV insertion. Uses a near-infrared stereo camera to generated 3D vein point clouds for algorithmic vein finding. Site preparation and needle insertion is performed by a robotic arm.	Scanning method: Stereo near-infrared. Fixed robot.	4 Successful tests performed on training models in 2015.
Vasculogic VenousPro [12] A portable robot using stereo near-infrared image guidance for autonomous IV insertion.	Procedure duration: 60s (in addition to manual preparation). Weight: 13 kg Scanning method: stereo near-infrared.	5 Successful validation performed on training models[3]
VeeBot [13] A portable robot for automatic blood drawing.	Scanning method: infrared and ultrasound.	6 Successful validation on human models

[2] Corresponding academic publications and further developments were not found during online searches.
[3] No further press releases or publications since 2016

3.2. Diagnostics

Meaningful information about the medical status of a casualty is critical to providing effective care. High quality continuously recorded information can be used to inform medics and doctors, to inform automated care systems and for analysis to improve future practices. Vital signs provide carers with key information about the state of the casualty and assist with triage and care planning. In a system that will implement any level of autonomous care, the quality of this care will be dependent on the casualty information given to the system.

The goals and requirements of a casualty monitoring subsystem are to:

- match current data quality (as a minimum)
- improve data interpretation
- increase speed of application and ease of use
- reduce required level of attention from responders
- reduce reliance on specialists for operation
- reduce chance of casualty harm
- allow remote monitoring and forward data transfer
- achieve compatibility with a wide range of patient conditions, injuries, ages and sizes
- maintain operation when subjected to environmental extremes and mechanical forces.

Common medical assessment procedures and parameters are summarised in Appendix 0.

3.2.1. Monitoring Technology Review

The current standard in vitals monitoring is effective. Most preventable damage occurs from a lack of inadequate treatment resources rather than inadequate diagnostics. For example, deaths caused by incompressible haemorrhage could not be prevented by more advanced monitoring. Potential improvements would relate mainly to adding convenience so that less time, energy, resources and effort are spent delivering, setting up and operating diagnostic equipment. This would in turn free up personnel and resources for treatment. Rapidly acquired and transmitted data could also be used to improve distribution of appropriate treatment assets.

With current systems, comprehensive monitoring can require many pieces of equipment. These increase weight, size, manual setup time and power consumption. Cables, wires and large equipment can also interfere with interventions and surgery, although this is alleviated by wireless technologies. Equipment interfaces are also separate and can be complicated to use. Data from multiple sensors are generally not well integrated into a single system that could direct automated care provision.

Non-invasive blood pressure monitoring is currently not continuous and is measured by intermittent cuff inflation. Repeated cuff inflation can be uncomfortable for casualties and carries a risk of blood clotting or vascular injury and can therefore only be carried out at 15 to 30 minute intervals [14].

Pulse oximetry using the patient's finger is well established but several issues have not yet been resolved. Peripheral perfusion can be poor during hypothermia, peripheral vascular disease, trauma or other states of physiological stress [15, 16]. The human body is tuned to prioritise blood flow to the brain and vital organs over peripheral tissues such as those in the finger. This can lead to blood oxygen readings that are not indicative of the central circulation to the brain and vital organs. In cases where blood oxygen levels are used to determine ventilation therapy and oxygen delivery, inaccurate readings can lead to induced hyperoxia which causes an overabundance of reactive oxygen species (ROS). The effects of induced hyperoxia on patient outcomes are not fully understood [17], however high levels of ROS are toxic and are linked to issues such as inflammation, respiratory damage, infection susceptibility, retinal damage and neuropathies [17]. Finger-located pulse oximetry is also vulnerable to motion artefacts.

Current techniques for assessing consciousness and depth of sedation could also be improved. Presently, behavioural cues and subjective observations are used when cumbersome polysomnography equipment is not practical [18].

There is also room for more specific rapid diagnostics such as infection and blood composition analysis using microfluidics and lab-on-chip technology. The usefulness of these sensors relies on having personnel or machines to interpret the data and access to equipment to enact a suitable response to the diagnostics.

Table 3-3. Casualty monitoring technologies

Technology	Additional Information	TRL
Athena Wireless Vital Signs Monitor (WVSM) [19] Automatic monitoring of Sp02, heart rate, non-invasive blood pressure and 3 lead ECG. Data can be remotely monitored up to a range of 180 m.	FDA cleared for use outside hospital. Up to 20 patients can be connected.	9
Automated Critical Care System (ACCS) [20] A modular smart stretcher with continuous vitals monitoring and automated care capability. See Appendix C.2 for more information.	Features an upgraded WVSM with additional functions including 12-lead ECG, EtCO2, respiration rate and temperature. Modular. ~12 kg. Detachable from stretcher. Telemetry enabled. Hot swap battery. Decision assist capability. See Appendix C.2 for more information.	7
MOVES® SLC™ [21] Mobile intensive care unit capable of monitoring FiO_2, $ETCO_2$, ABP, CVP, ICP, NIBP, SpO_2, 12-lead ECG, temperature	Support for defibrillator mounting. Support for infusion pump mounting. Ventilator, oxygen concentrator, suction and patient monitoring.	9
E-ambulance: Real-Time Integration Platform for Heterogenous Medical Telemetry System [22] A system model for monitoring patients, managing data, remote monitoring, automatic responses of suggestions and warnings for paramedics		3

Ear canal pulse oximetry [23] A potential method of measuring blood oxygen levels while avoiding inaccuracy caused by poor peripheral perfusion in hypotension, hypothermia, vasoconstriction, low cardiac output or peripheral vascular disease	The ear canal is supplied by arteries leading to the brain and is therefore indicative of blood oxygen in the brain. Quality raw PPG demonstrated with a high amplitude and high signal to noise ratio. Sensitive to respiratory modulation, however this could also be harnessed for breathing analysis. Minimal motion artefacts compared to other PPG sensor locations.	4
Ear canal polysomnography [18] A potential method of assessing sleep state and consciousness using electrodes placed inside the ear canal rather than around the head (potentially applicable to monitoring sedation).	Existing polysomnogram devices are large, stiff, unstable, not suited to use outdoors or with moving patients. Paper demonstrates proof of concept for an unobtrusive system that monitors facial muscles, electrical brain activity and eye movements. Ear is close to physiological EEG, EOG and EMG signals. Potential applications for soldier performance and health monitoring beyond the CASEVAC context.	4
Hearables: multimodal physiological in-ear sensing [24] An ear-canal located sensor with mechanical, chemical and electrical modalities for assessing brain, cardiac and respiratory functions.	A viscoelastic substrate to absorb motion artefacts. Electret condenser microphones for sensing mechanical disturbances (for artefact compensation, speech and breathing. Low impedance stretchable fabric to measure EEG signals.	5
An Ear-Worn Vital Signs Monitor [25] A wearable vital signs monitor located in the ear.	Electrocardiogram and ballistocardiogram capability for obtaining pre-ejection period, stroke volume cardiac output and pulse transit time.	4 Clinical human study performed on 13 subjects.
An exploration of behind-the-ear ECG signals from a single ear using inkjet printed conformal tattoo electrodes [26]	Signals are small and require substantial signal processing and automated extraction.	3

Technology	Additional Information	TRL
Investigates the use of tattoo electrodes placed behind the ear to measure heart rate through ECG.		
Self-powered ultra-flexible electronics via nano-grating-patterned organic photovoltaics [27] [28] Functional integration of conformable photovoltaics with a self-powered electrocardiographic sensor.	Overcomes issues with energy intensive fabrication damaging the active material of the functional device. High signal-to-noise ratio when applied to skin. Output power remains unstable under mechanical deformation.	3
Continuous blood pressure measurement using pulse wave velocity [29, 30] An accurate mathematical model used to measure blood pressure continuously and non-invasively	Uses BioStampRC® ECG and PPG data to calculate pulse wave velocity and in turn blood pressure.	3
Expanded polytetrafluoroethylene (PTFE) [31] A flexible, waterproof and breathable substrate for skin-wearable electronics	The material has been developed but applications require more research. Gore has established an innovation program to partner with wearables start-ups and develop applications for the material.	2
Butterfly iQ: Ultrasound on a chip [32] An affordable handheld ultrasound technology with AI image analysis capability.	Uses a "capacitive micromachined ultrasound transducer" rather than piezoelectric crystals to reduce price and increase portability. Priced at USD $2000 with plans to lower cost to $500 or below for consumer affordability.	9

3.2.2. Concept Ideation: Monitoring and Diagnostics

In the short term, a subsystem such as the Athena WVSM that integrates current technology is well suited to a smart stretcher system. The WVSM is modular and can therefore be scaled and upgraded to a reasonable extent. The WVSM also has telemetry capability and allows remote monitoring of multiple patients. The monitoring functions of

the WVSM II cover the current standard casualty status parameters for assessing cardiovascular and respiratory function.

In the medium to long term, further improvements could be made. Systems similar to the WVSM and WVSM II could be upgraded with brain function assessment tools including and EEG, EOG. The quality of sensor data could also be updated to next-generation hardware. Implanted biosensors have the potential to get close to the physiological signal and produce accurate and reliable data, however implantation carries risks and has ethical implications. Implanted biosensors could also only be used for monitoring combat casualties (if they were implanted prior to combat) and would not be suitable for HADR. A potential compromise is to place a multi-functional biosensor in the ear canal, where it can be easily removed without surgery, but still is very close to blood vessels and electrophysiological signals. Ear-located devices already exist in both military and civilian sectors with hearing aids, cochlear implants, music earphones, communication devices and hearing protection in regular use. Developments in producing robust, rugged and comfortable ear-worn devices are likely to be leveraged in the near future to develop capable "hearables" for continuous monitoring of medical status. Using the technologies in Table 3-3, it is plausible that a monitoring device with continuous EEG, SpO2, heart rate, body temperature and blood pressure could be developed.

3.3. Bleeding Management

Haemorrhage is currently the leading cause of preventable combat deaths. The Eastridge Study published in 2012 found that 91% of potentially survivable combat deaths were caused by haemorrhage [1]. Out of lethal haemorrhage cases, 67% were truncal, 19% junctional and 13.5% peripheral extremity. Smart stretcher functionality that facilitates control of bleeding is desirable to reduce these statistics. The lethality of bleeding is time dependent and rapid treatment is essential to avoiding multiple-organ failure, reducing the risk of sepsis, and the risks associated with massive transfusion [33].

The goals and requirements of a bleeding management subsystem are:

- provide earlier bleeding control
- provide more effective bleeding control
- allow a single responder (or a small number of responders) to effectively manage bleeding in multiple casualties
- easy to use
- limited training required
- easily transported.

3.3.1. Bleeding Management Technology Review

Currently, extremity tourniquets are effective and can be self-applied. Axilla, groin and neck injuries are compressible but require manual application of pressure which can be impractical in a battlefield CASEVAC environment. Several clamping tools have been

developed that are effective if applied quickly, but require time and resources to store, transport and apply (*Table 3-4*). Chest and abdominal wounds are the most challenging to manage in a pre-hospital setting and several devices for injecting expandable sponges and foams are in development to fill this gap (*Table 3-4*).

Table 3-4. Bleeding management technologies

Technology	Additional Information	TRL
RevMedx XSTAT-30 and XSTAT-12 [34] Device for haemostatic control of bleeding from junctional wounds in the groin or axilla. Operates by syringe-like injection of expanding sponges into a wound cavity.	FDA approved Sponges expand 20 seconds after injection and contact with fluid. Injected sponges need to be surgically removed afterwards. Suitable for 4 hours of use, after which surgical intervention is necessary.	9
Combat Ready Clamp (CRoC) [35] Collapsible aluminium clamp for junctional bleeding.	650g weight. FDA approved. Collapsible but requires assembly at point of use.	9
Junctional Emergency Treatment Tool (JETT) [36] A belt-type clamp with pads for compression of thigh, groin and lower limb wounds.	FDA approved. Capable of bilateral occlusion of both lower limbs. Pre-assembled. Adjustable pad position.	9
SAM Junctional Tourniquet (SAM-JT) [37] A belt-type clamp that secures an inflatable compression device to compress junctional wounds.	FDA approved for bleeding control and pelvic fracture immobilisation.	9
Abdominal Aortic & Junctional Tourniquet [38] A belt-type clamp that secures an inflatable compression device to compress junctional wounds.	FDA approved.	9

Technology	Additional Information	TRL
iTClamp [39] Non-tourniquet haemostatic device that clamps wound with a "hair-clip" mechanism.	FDA approved.	9
Laser activated nanomaterials for rapid wound repair [40] Demonstrates proof of concept for wound repair using laser-responsive nanomaterials instead of sutures and staples.	Demonstrated in pig intestines and mice skin. Creates a seal 7 times stronger than traditional sutures. Focuses light-generated heat on gold nanorods embedded in a silk protein matrix. Fibroin protein in the silk binds to collagen. The activating laser is near-infrared and therefore has potential to penetrate tissue for repairing non-superficial wounds.	3
Arsenal Medical ResQFoam [41] Injectable foam for controlling "non-compressible" abdominal wounds.	Consists of two polymers that are injected into the abdominal cavity as liquid, but form rapidly expanding foam when combined. Foam must be removed surgically.	6 Approved for clinical trial in July 2018 [42]
Self-propelled coagulant delivery [43, 44] Demonstration of proof of concept for delivering coagulants against the flow of blood.	Uses gas-generating micro particles to deliver a coagulant (thrombin) against blood flow towards the wound vasculature. Demonstrated in animal models where the technique halted traumatic haemorrhage.	4
Zimmer Automatic Tourniquet System [45, 46]	Intended for complete blood occlusion in operative limbs during	9 Note that the

Technology	Additional Information	TRL
A microprocessor controlled system for supplying and measuring pressure of an inflated cuff tourniquet.	surgery in a hospital setting. Uses a finger and toe placed sensor to estimate limb occlusion pressure prior to application.[4]	system is only at TRL 9 for hospital applications

3.3.2. Concept Ideation: Bleeding Management

Most of the currently available technologies listed in *Table 3-4* would be able to function independently of the smart stretcher system. Solutions involving a clamp could benefit from being stabilised by or attached to the stretcher frame, however it is more likely that the time lost by setting up the stretcher before controlling bleeding would be more significant. The US Department of Defence has sponsored studies comparing junctional clamps and tourniquets (JETT, SJT, AAJT, CRoC) for efficacy and usability in a combat environment. These studies found that the SJT outperformed other solutions in cost, weight, effectiveness and time to effectiveness [47] and was preferred by combat lifesavers [48]. Nevertheless, SJT success rates were low in realistic situations and it was determined that additional training was needed for correct application [48].

Currently it is recommended to inspect compressed wounds regularly to ensure the tourniquet or clamp has not shifted. Functionality built into the smart stretcher to detect bleeding could free up the attention of responders allowing them to complete other tasks. Bleeding detection could also be paired with future automated tourniquets or be used to optimise application of current and future haemorrhage control solutions. Hospital-based devices such as the Zimmer Automatic Tourniquet systems (*Table 3-4*) can be used during surgery to optimise application of occlusive tourniquets, but these devices are large and designed for limb blood flow occlusion for surgery rather than haemorrhage control. A practical way of automating bleeding detection in the pre-hospital setting does not currently exist. Possible approaches include thermal imaging, Doppler ultrasound to detect distal blood flow [49] or a "wetness" sensor using capillary flow. These techniques would require substantial research and development to create an implementation that is reliable while avoiding high costs, size, weight and power consumption.

A basic example of how a Doppler ultrasound could be integrated into a junctional tourniquet is illustrated in *Figure 3-1*. Butterfly Network has developed Capacitive Micromachined Ultrasound Transducers (CMUT) for their Butterfly iQ handheld ultrasound device [50]. CMUT technology opens the possibility of low cost, miniature ultrasound devices. A scaled down ultrasound array could be embedded within a tourniquet or a patch that can be attached next to the tourniquet. Sensor data could be wirelessly transmitted and then analysed to assess bleeding. Inflation of bleeding management devices similar to the SAM-JT could then be controlled using information from the sensors and medics could be alerted when problems arise.

[4] The specific technique used to calculate limb occlusion pressure was not identified within publically available information

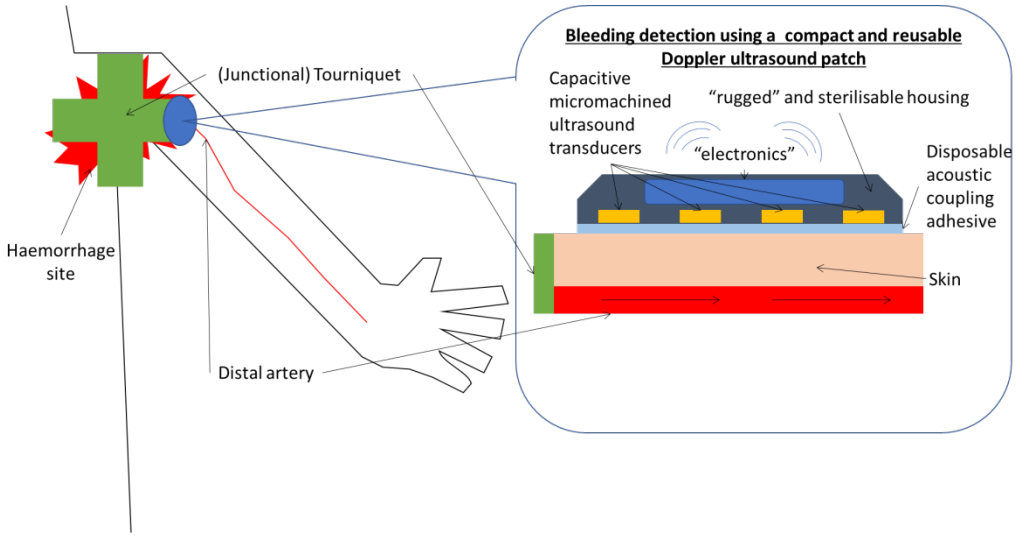

Figure 3-1. Theoretical concept for monitoring bleeding using a compact and reusable Doppler ultrasound system attached to a tourniquet

3.4. Stretcher Frame

3.4.1. Concept Ideation: Stretcher Layout and Structure

In broad terms, there are two potential approaches to a smart stretcher system. The first approach is to create a system that attaches to a standard stretcher frame. The second approach is to integrate the core equipment into the stretcher itself.

3.4.1.1. Attached Approach

The attached approach offers versatility because the system can be used independently of the stretcher and can separated into smaller lightweight packages for more flexible transport and storage. An attached system also has the advantage of being usable with existing stretcher assets.

NATO has agreed on a standard for stretchers [51] to facilitate interoperability and cooperation. This standard is commonly followed by military stretcher manufacturers and has been adopted as a de facto standard by NATO allies such as the ADF. A smart stretcher that adheres to the specifications of the NATO standard is desirable for physical interoperability with existing platforms. The NATO standard focuses on constraining the overall size and specifying the size and position of handles and supports to ensure compatibility with vehicles. The standard is not targeted towards compatibility with attachments and presents a problem for an attached smart stretcher system because the features used as attachment points may not be consistent between different NATO stretchers. For example, the Talon II Model 90C Collapsible Handle Litter [52] has a round profile frame while the ProMIL 217 NATO Field Stretcher [53] has a rectangular profile. Many NATO stretchers, such as the Ferno Special Operation Forces Litter, also have folding mechanisms with variable positions that could interfere with attachments.

Once a system is attached to a stretcher, the resulting platform may no longer conform to the NATO standard. Any attachments that significantly increase width may prevent the stretcher from fitting into narrow spaces such as ambulances. Attachments underneath the stretcher may also cause problems with ground clearance when placed on uneven terrain, and could potentially interfere with vehicle loading mechanisms, such as the ProMIL 150 NATO Stretcher Platform [54], that are designed for NATO stretchers.

The weight distribution of an attached system should also be taken into consideration. A system attached above or beside the stretcher will shift the centre of gravity of the overall system and may cause stability issues when transported across unstable terrain. Attachments above the patient may also restrict access for bleeding management and other interventions. On the other hand, a system attached below the stretcher is more likely to maintain stability and would not restrict access to the casualty.

3.4.1.2. Integrated Approach

A system where the essential modules are integrated into the stretcher has the potential to reduce the number of pieces and simplify initial setup. The overall weight of the system may also be slightly reduced by sharing casing and protection elements between the core components and the stretcher frame.

Although the overall weight may be decreased, it would also be concentrated in the stretcher. This has implications for casualty lifting, which is typically performed by lifting the casualty vertically and manoeuvring the stretcher underneath (see 0 Casualty Lifting Techniques). In the case of an attached system, the stretcher can be kept with minimal weight and bulk by withholding attachments until the casualty has been successfully lifted. For an integrated system however, it may be difficult to manoeuvre a relatively heavier and bulkier system around the other lifting personnel. Introducing lifting difficulties would increase the total time to evacuation and would increase the risk of creating further injury during casualty lifting.

If the stretcher system is designed to fit into the NATO standard, there are additional space constraints to consider that may restrict hardware. The stretcher frame would also be subjected to substantial loading during vehicle transport and soldier handling and integrated components may require additional reinforcement. A purpose-built stretcher could also allow for universal attachment points suitable for any additional modules including isolation or environmental control pods.

3.5. Capsule

Combat casualties may be contaminated by chemical, biological, radiological or nuclear (CBRN) threats and HADR casualties may have infectious diseases. In these situations it is desirable to have capability to isolate casualties while still providing care at the POI and allowing a contained evacuation pathway to more advanced facilities.

With the continual rise of autonomous vehicles, it may also become feasible for casualties to be evacuated by uncrewed platforms. UAVs and UGVs may already be deployed in the

area of operations and therefore could be better placed for time critical evacuation. Uncrewed vehicles could also be used to transport casualties through weather, CBRN and combat hazards without placing additional lives at risk. To be successful, evacuation by uncrewed vehicles needs to be safer than waiting for conventional evacuation platforms. A smart stretcher could potentially fulfil a similar role to en-route paramedic teams by keeping the casualty stable and managing emergency interventions, however the effects of vehicle transport also need to be considered. Dedicated evacuation platforms are typically designed for carrying patients and have features such as protection, shock absorption, temperature control and pressure control. On the other hand, autonomous logistics vehicles may be better placed but do not have such features. A capsule module with shock absorption and environment control features could be added to the smart stretcher to be used with generic uncrewed vehicles. Previous NATO consideration of casualty evacuation using uncrewed vehicles is described at Appendix D.

3.5.1. Capsule Technology Review

Table 3-5. Isolation Capsule Examples

Technology	Additional Information	TRL
Sonics Milpod [55] Specialist man portable stretcher for extracting and treating contaminated casualties.	Claims a 10 second deployment time. Consists of an inflatable base and frame covered by a PVC casualty envelope. Glove positions along the length. Built in stretcher and spine board. Integrated bodily waste drainage. Optional heating and environmental control. Negative (10 hr run time) and positive (8.5 hr run time) pressure systems. 9.2 kg	8
Medica Pacifica Isolation Stretcher [56] Collapsible isolation chamber for casualty extraction.	Negative pressure system. ABS pole frame covered by a TPU film. Glove portals on three sides. 8 hour battery life.	9

4. Concept Overview

The ideas articulated above for each subsystem are combined in the Modular Automated Care Stretcher (MACS) concept. The subsystems are modular, allowing the stretcher to be scaled from a POI system, which can be carried by service personnel, to a hospital bed. An artistic illustration of this concept is shown in Figure 4-1.

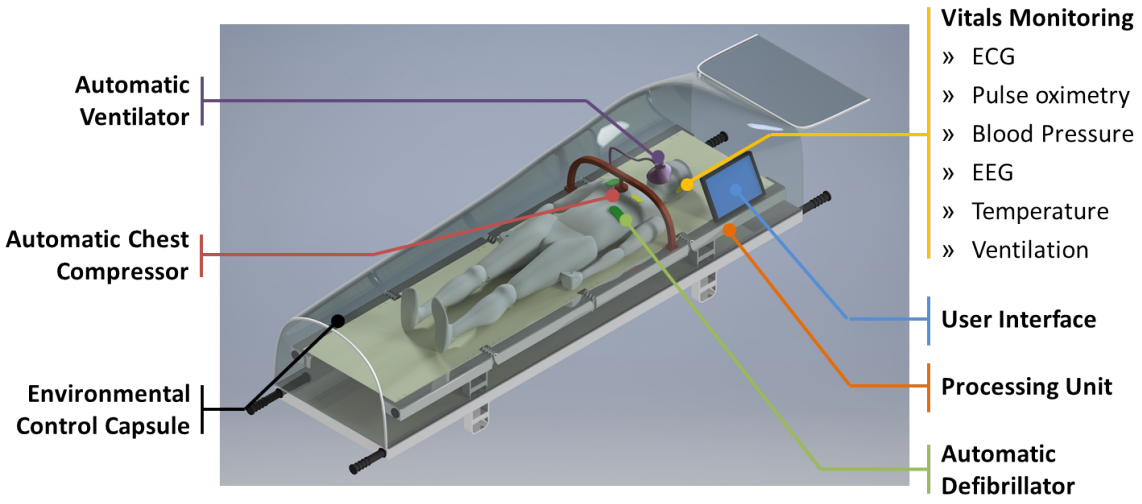

Figure 4-1. An artistic impression of the Modular Automated Care Stretcher (MACS) Concept

The key functional subsystem of MACS is continuous vitals monitoring. In this concept, pulse oximetry, EEG and temperature are measured by an ear-worn device. Continuous blood pressure and ECG are measured using wireless patches on the casualty's skin. Ventilation is monitored by sensors placed in a ventilation and suction mask. The mask is able to supply oxygen from an oxygen generator that can be stowed within the frame of the stretcher. An automatic chest compressor, automatic defibrillator and wireless user interface are attachable along the length of the frame using standardised, powered attachment points. A processing unit is located inside the stretcher frame along with hot-swappable batteries. The stretcher frame folds to a backpack size, is built to the NATO standard's minimum dimensions and fits inside a capsule built to the NATO standard's maximum dimensions. Both the capsule and the stretcher have collapsible handles to minimise the transport and storage footprint. The capsule provides CBRN isolation, positive or negative pressure ventilation, gloves for casualty access and temperature control.

5. Evaluation and Recommendations

A smart stretcher system such as MACS holds substantial benefit for Army medical capability. The system would project sophisticated care closer to the point of injury, allow greater freedom for optimisation of medical personnel distribution and would facilitate evacuation and provision of care in challenging environments.

If implemented, the cannulation and infusion technologies discussed would improve cannulation capability and potentially allow personnel with minimal training to administer fluid therapy. Handheld cannulation aids such as Veinlite and AccuVein are already at TRL 9 and could be adopted relatively quickly. Currently these devices are not used in the operational context and the next step would be to conduct usability studies and workshops to further assess practicality and benefit for CASEVAC applications. Since these handheld devices still require training, it may be that the benefit provided is not sufficient to justify the financial cost and the burden of carrying an extra piece of equipment. Automated cannulation technologies exist at TRL 4-6, however these are large and heavy and unlikely to be suitable for CASEVAC applications. Smaller, portable automated solutions similar to the PULSE Veinfinder are at TRL 2 and are only realistic in the long term.

Integration of vitals monitoring into a streamlined system would provide valuable casualty data that can be recorded for efficient information transfer throughout the evacuation continuum. Systems combining conventional monitoring such as the WVSM and MOVES SLC exist at TRL 7-9 while the system articulated in MACS uses technologies that are currently at TRL 3-5. The main advantages of the MACS monitoring subsystem concept would be improved brain function assessment, miniaturisation, weight reduction and small increase in data quality.

Given the high proportion of combat deaths caused by haemorrhage, effective bleeding management arguably holds the greatest potential benefit out of the subsystems discussed. The most promising technologies out of those reviewed are the SAM-JT (TRL 9) for junctional wounds and the ResQFoam for abdominal wounds (TRL 6). Both of these technologies would function independently from a smart stretcher, however in the future they could be augmented by monitoring and automation to optimise application.

A system that attaches to an existing stretcher in a similar way to the ACCS or MOVES SLC systems is recommended over the integrated system articulated in MACS due to the versatility of an agnostic platform. In order to maximise the potential of attached systems, it may be useful to revise the standards followed for basic stretchers in order to accommodate attachments. Consistency in attachments, power and data transfer protocols could promote greater interoperability and leaves more room for future upgradability.

An isolation capsule module could prove useful in specialised CBRN situations. A smart stretcher could be particularly suited to these situations because it could reduce the number of personnel put at risk during CBRN evacuation. A hard pod like the one pictured in the MACS concept would be heavy and cumbersome. Instead, standard casualty isolation “bags” that are already designed for use with standard stretchers would

be more practical and would not require additional development. A hard capsule may be better suited for use with cabinless vehicles however it may take just as long to deliver as conventional evacuation assets.

The next development step is to discuss the context with the end-user. Subject to refining the concept, core subsystems including integrated conventional vitals monitoring, intravenous infusion and ventilation, could be implemented in 5 years. Standards and redundancy should be implemented to allow for future modules and upgrades such as automated cannulation and automated life support that could take up to 15 years to develop and implement.

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Appendix A Concept Development Questions

- What is the purpose? How does it address current needs/weaknesses? How does it address future needs/weaknesses?
- How does it fit into the current process? What changes would be required?
- To what extent would it improve, replace or add to current capability?
- What are the constraints of the current treatment continuum?
- How would it be transported to the next stage in the continuum?
- What analogues exist?
- What injuries are likely in combat and HADR?
- What are the features and functions?
- Which equipment, sensors and modules are essential? Does essential equipment change for HADR versus combat?
- What equipment, sensors and modules would only be useful for more specific situations?
- Is it a new system or modification/attachment to an existing system?
- What is the extent of modularity?
- How are functions balanced against usability and practicality?
- Size?
- Space?
- Weight?
- Power?
- Interoperability?
- Robustness?
- Mobility?
- Signatures and cyber protection?
- Simple User Interface?
- What is the layout?
- What data will be generated? How will this be managed, stored and forwarded?
- How will data be kept high value, low volume?
- How can software, batteries and modules be designed for upgradability?
- What would happen if communications or technology fails?
- Who is the target user/operator(s)? How many/few operators are required?

- How much uses current technologies? How much relies on currently emerging and future developments?
- What are the risks?

Appendix B Technology Readiness Levels Definitions

Table 6- Technology Readiness Levels Definitions [3]

TRL Level	Definition
TRL 1	**Basic Research**: Initial scientific research has been conducted. Principles are qualitatively postulated and observed. Focus is on new discovery rather than applications.
TRL 2	**Applied Research**: Initial practical applications are identified. Potential of material or process to solve a problem, satisfy a need, or find application is confirmed.
TRL 3	**Critical Function or proof of Concept Established**: Applied research advances and early stage development begins. Studies and laboratory measurements validate analytical predictions of separate elements of the technology.
TRL 4	**Lab Testing/Validation of Alpha Prototype**: Design, development and lab testing of components/processes. Results provide evidence that performance targets may be attainable based on projected or modelled systems.
TRL 5	**Laboratory Testing of Integrated/Semi-Integrated System**: System component and/or process validation is achieved in a relevant environment.
TRL 6	**Prototype System Verified**: System/process prototype demonstration in an operational environment (beta prototype system level).
TRL 7	**Integrated Pilot System Demonstrated**: System/process prototype demonstration in an operational environment (integrated pilot system level).
TRL 8	**System Incorporated in Commercial Design**: Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration).
TRL 9	**System Proven and Ready for Full Commercial Deployment**: Actual system proven through successful operations in operating environment, and ready for full commercial deployment.

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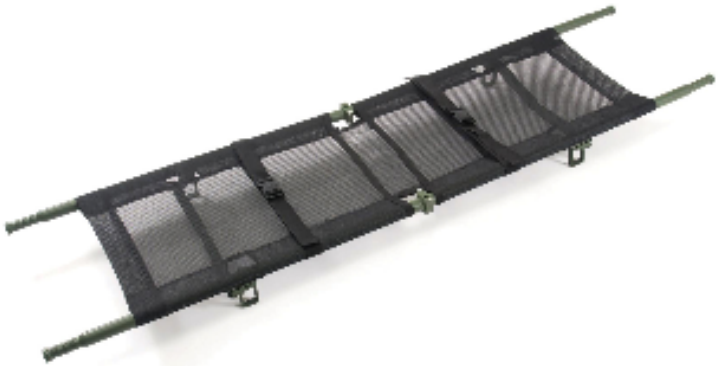
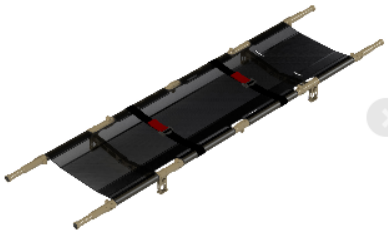
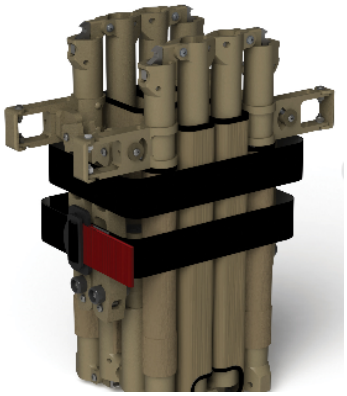
Appendix C Existing Systems

C.1. Existing Standard Stretchers

Table 6-7. Examples of NATO Standard Stretchers

Talon II Model 90C Collapsible Handle Litter[52]	
ProMIL 217 NATO Field Stretcher[53]	 

Golden Season Single Fold STANAG 2040 NATO Stretcher [57]	
Ferno Disaster Litter[58]	
Ferno Tactical Litter[59]	
Ferno Special Operation Forces Litter[60]	 

C.2. Automated Critical Care System (ACCS)

The Automated Critical Care System (ACCS) is a smart stretcher system under development by the Office of Naval Research with Athena GTX [20]. The self-contained and foldable system is designed to attach underneath a standard evacuation litter. The system is modular and is capable of smart controllable ventilation, IV fluid delivery and storage, suction, decision support and oxygen generation. The system itself has not been approved by the FDA; however the majority of the modules and subsystems are FDA approved. The system is relatively light (12 kg including 1.5L of fluid, batteries and clamps).

C.2.1. Questions for further investigation

- Is there redundancy to allow for future hardware and software upgrades?
- Is practical to use without a litter if required?
- Once attached to a NATO standard stretcher, does the resulting system maintain physical interoperability?
- Does the bidirectional communication capability allow remote communication with the casualty?
- What were the results of the user feedback sessions and evaluations?
- Could it be scaled up for use as a surgical bed?

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Appendix D Casualty Care and Evacuation Procedures

D.1. Casualty Lifting Techniques

D.1.1. Vertical (Straddle) Lift

- 5 first responders
  - Most secured way (produces vertical movement only).
  - Head, shoulders, hips, legs lifted vertically.
  - 5th responder moves the stretcher underneath.
- 4 first responders
  - Head + neck + shoulders, hips, legs.
  - 4th responder moves stretcher underneath.
  - Dangerous in case of spine trauma suspicion.
- 2 first responders
  - For no specific trauma.
  - Slide little by little: one responder lifts while the other slides.

D.1.2. Handling Strap Assisted

- Handling strap used to create handles.
- Protects lifters by allowing better lifting posture.

D.1.3. Translation Lift

- Used when stretcher can't be pushed.
- 3/4 responders used for lifting.
- Vertical and horizontal movement.

D.1.4. Log roll

- Only usable when casualty doesn't have unstable trauma.
- Requires less effort and more comfortable position for lifters.
- Roll onto side, place spine board/flexible stretcher on back.

D.2. Vitals Monitoring and Diagnostics

D.2.1. Primary and Secondary Survey

Casualty monitoring typically follows a process that is similar across the civilian and defence sectors. The process is usually separated into two stages: the primary and secondary survey [61].

The goal of the primary survey is to identify and treat immediate life-threatening conditions. This stage is often structured by DRABC (danger, response, airway, breathing circulation). The first responder checks for any danger, to themselves or the patient, before seeking to determine the patient's level of consciousness. The responder then inspects the patient's airway to confirm patency or identify obstructions. C-spine immobilisation, simple airway manoeuvres, suction and airway adjuncts are used as required. The responder also determines whether the patient is breathing and oxygen or intermittent positive pressure ventilation (IPPV) are applied if needed. The responder also checks the patient for an adequate response and applies defibrillation, haemorrhage control, leg elevation or intravenous fluid therapy if required.

After the casualty has been stabilised during the primary survey, the secondary survey is conducted to identify and treat injuries that are significant but not immediately life threatening. Where possible, casualty history is considered, including onset, provocation, severity, signs and symptoms, allergies, medications, past injuries. The patients' vital signs are then surveyed and a more comprehensive physical examination is conducted. Traditionally, "vital signs" refers only to temperature, pulse, breathing rate and blood pressure; however broader cardiovascular and respiratory metrics such as peripheral oxygen saturation (SpO2) and electrocardiogram (ECG) are also standard practice. Diagnostic metrics and their significance are summarised in *Table* 6-8.

Table 6-8. Casualty Monitoring Metrics: significance and measurement techniques

Metric	**Significance**	**Standard Measurement Techniques**
Heart rate The number of contractions of the heart per minute.	• General indicator of physiological state. • Considered in defibrillation decisions. • Indicator for disease diagnosis.	• Peripheral pulse palpitation. • ECG R-R interval.
Respiratory Rate The number of breaths per minute.	• General indicator of physiological state. • Indicator of airway obstruction or damage. • Indicator for disease diagnosis. • Indicator of tissue oxygen supply. • Considered in airway and breathing management decisions.	• Manually counting chest rises over set period. • Stethoscope. • ECG. • Photoplethysmography. • Accelerometry.

<u>Blood Pressure</u> Pressure of circulating blood on arterial walls. Systolic – peak pressure, occurs during ejection. Diastolic – minimum pressure, occurs during filling.	• Indicator of physiological state. • Indicator of blood loss. • Indicator for disease diagnosis. • Indicator of cardiac function. • Indicator of cardiac stress.	• Sphygmomanometer (non-invasive cuff).
<u>Body Temperature</u> The temperature of the casualty's body. Usually core temperature rather than peripheral temperature for accurate reflection of critical organ state.	• Indicator for infection. • Indicator for primary (environmental) and secondary hypothermia/hyperthermia. • Informs patient temperature regulation decisions. • Indicator of cardiac and circulatory function.	• Thermometer (oral, rectal, axillary, aural, epidermal).
<u>Oxygen Saturation</u> Relative proportion of oxygen saturated haemoglobin compared to unsaturated haemoglobin. SaO_2 – arterial oxygen saturation. SpO_2 – peripheral oxygen saturation (approximation of SaO_2). SvO_2 – venous oxygen saturation. StO_2 – tissue oxygen saturation.	• Indicator of respiratory function. • Indication of circulatory function. • Indicator of critical delivery of oxygen to tissue/organ. • Informs administration of oxygen.	• Oximetry (relative light absorption of oxygenated/ deoxygenated haemoglobin) – typically applied to finger.

Electrocardiogram Electrical activity of the heart. P wave (atrial depolarisation). QRS complex (ventricular depolarisation). T wave (ventricular repolarisation).	• Indicator of cardiac function. • Provides specifics about health of different functional regions in the heart. • Particularly relevant in heart disease or cardiac arrest.	• 12-lead ECG using skin electrodes placed on chest and limbs (5 around heart, 1 on right side of chest, 1 on each limb). • "less than 12 lead" ECG using various combinations of fewer electrodes than the 12-lead ECG setup. •
Glasgow Coma Scale A defined set of criteria for assessing consciousness by eye opening, verbal response and motor response.	• Indicator of casualty mental function. • Indicator for depth of sedation.	• Set criteria/questionnaire.
Melbourne Ambulance Stroke Score A defined set of criteria to diagnosis stroke in pre-hospital settings. Assesses facial drooping, arm strength, handshake and speech.	• Indicator for stroke severity.	• Set criteria.
Coagulopathy of Severe Trauma (COAST) score A defined set of criteria for identifying patients likely to develop acute traumatic coagulopathy (excessive or continuous haemorrhage).	• Assessment of severity of bleeding wounds.	• Set criteria.
Sedation Assessment Tool (SAT) A scale for assessing a patient's degree of agitation or sedation. Usually reported along with GCS, HR, BP, SpO2, RR.	• Assessment of depth of sedation for sedation control.	• Set criteria.

D.3. Cannulation Procedure

Current best practice cannulation procedures follow a large number of manual steps [62]:

1. Establish adequate lighting.
2. Gather and open supplies.
3. Select location (usually dorsum of non-dominant hand, volar aspect of forearm, dorsum of foot, great saphenous vein at ankle).
4. Apply tourniquet.
5. Apply splint if practical (preferred for children).
6. Decontaminate skin.
7. Apply topical anaesthetic.
8. Palpate and observe site to select target vein.
9. Insert along the line of the vein (angle of 10-15 degrees, distal to proximal).
10. Advance needle and cannula.
11. Withdraw needle from cannula.
12. Secure hub of cannula (usually with tape).
13. Attach a connector to the cannula hub.
14. Fix the connector.
15. Apply clear plastic dressing.

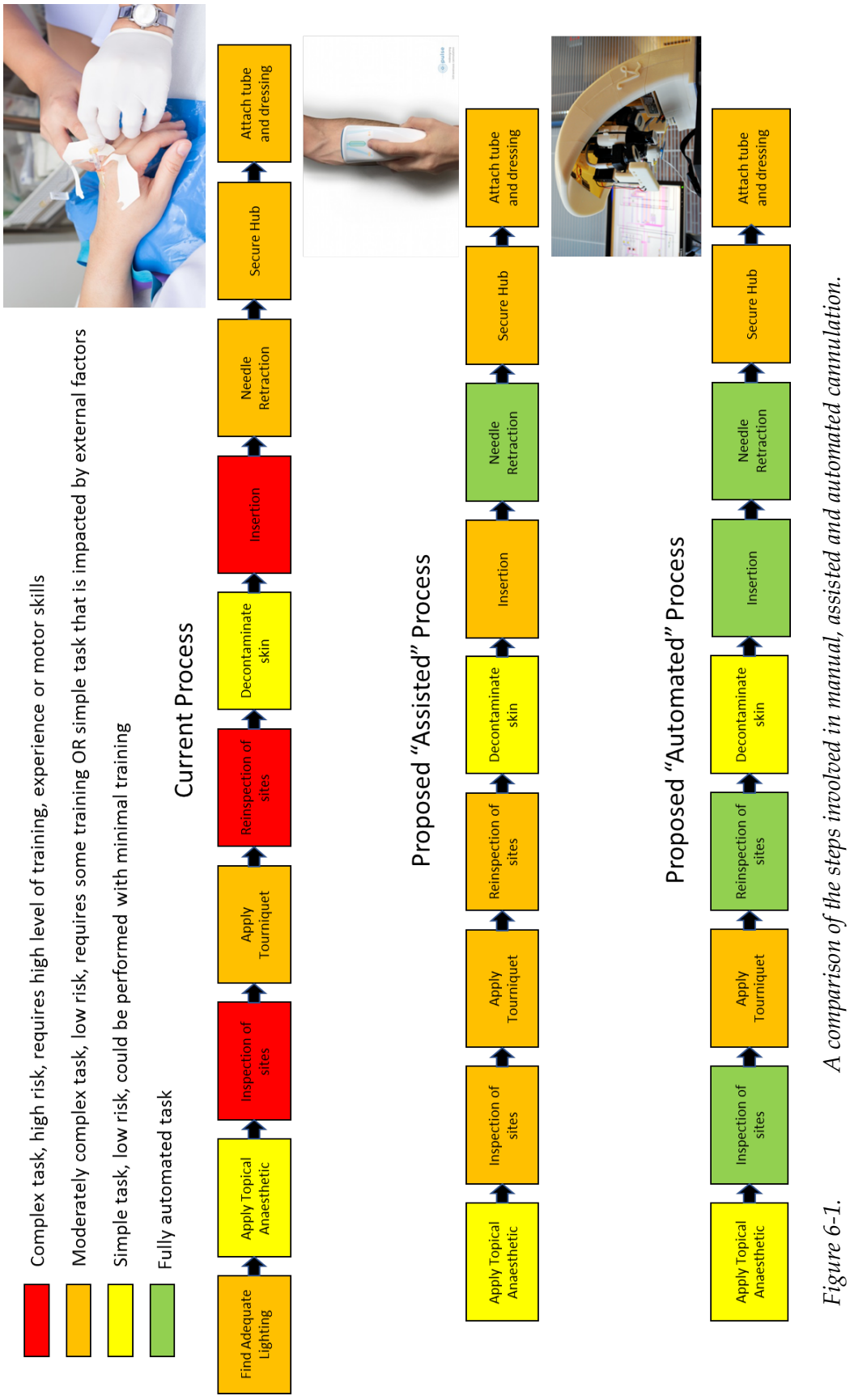

Figure 6-1. A comparison of the steps involved in manual, assisted and automated cannulation.

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Appendix E Relevant notes from the NATO "Safe Ride Standards for Casualty Evacuation" Technical Report

In 2012, NATO Science and Technology Organisation published a technical report on "Safe Ride Standards for Casualty Evacuation Using Unmanned Aerial Vehicles" [63]. Relevant notes and findings from this report are listed below:

- Future cargo-carrying UAVs will likely have capability for carrying a reclining casualty.
- UAVs for CASEVAC should follow an agreed set of physiological, flight, and materiel parameters.
- UAVs for CASEVAC is ethically, legally, clinically and operationally permissible only if the relative risk for the casualty favours moving by UAV over not moving by UAV.
- Concluded that UAV MEDEVAC (en-route treatment) is not technologically feasible due to a lack of inflight medical equipment (n.b. published in 2012).
- Challenges for UAV CASEVAC:
    - Not all aircraft are suitable for casualty transport (internal carriage space, normal flight profile).
    - Acceleration forces generated by flight may create physiological stresses.
- The current risk to air ambulances is high (e.g. American MEDEVAC in Afghanistan often not allowed to launch without an accompanying gunship).
- Aircraft suitable for carrying casualties are representative of common multi-use aircraft, typically at lower end of performance envelope.
- On-board pilots can typically maintain flight profiles within the tolerance limits of casualties (however no set of standards exist for development of flight profiles for UAVs).
- History and Development of Aerial Evacuation:
    - Nearly every animal or vehicle used by an army has been adapted to medical and evacuation use to fill a gap in capability.
    - Historically, CASEVAC developments were driven by necessity rather than doctrine.
    - During and after WWII there was an increased emphasis on en-route treatment with specialised equipment and trained transport personnel.
    - Doctrine recognises that not every casualty can be provided with modern intensive-care during transportation and allows for fall back to vehicles of opportunity that are not capable of en-route care.
    - NATO policy now demands best medical practice for operations with fewer expected casualties (e.g. peace-keeping, crisis response).

    - Israel raised the need for smaller, more agile evacuation platforms which can evacuate (at least to a safe area) from scene of injury, in zones too hazardous or small for manned aircraft.

- Development of mechanisms for using new concepts and equipment for benefit of patient should be guided by principle of "First of all, do no harm".
- Proposes that remotely Piloted Aircraft are more likely to succeed as evacuation platforms in the near-term.
- Advantages of UAVs for CASEVAC:
    - UAVs may already be present for logistics support.
    - UAVs could serve to supplement air ambulances and other evacuation capabilities.
    - Crewed CASEVAC places additional lives at risk.
    - UAVs may be better suited to asymmetric/urban warfare.
    - UAVs may allow medical mission execution in weather beyond safe crewed flight limits.
    - UAVs may allow medical mission execution when the en-route or terminal environment is contaminated or under heavy threat.
    - UAVs can potentially provide faster medical resupply and casualty rescue.
- Possible Operational Use of UAVs for Evacuation:
    - Providing a time-critical response.
    - Reducing threat to aircraft crews.
- Doesn't advocate total replacement of manned evacuation vehicles with UAVs.
- Medical Equipment recommendations for future CASEVAC UAVs:
    - litters
    - litter straps
    - IV fluids
    - blankets
    - better, smaller, smarter monitoring capability
    - interior lighting for safe loading and patient comfort:
        - low light source close to casualty's head
        - bright light source at head and at lower body (post-boarding/pre-unloading care)
    - communication with evacuee
    - spine immobilisation
    - padded floors

  - head towards front (to avoid head down take-off and landing)
  - space and weight requirements must account for casualty, support equipment, IC fluids, oxygen supplementation, hypothermia prevention
  - equipment restraints
  - monitoring (blood pressure, EtCO2, thermometer, urine, chest/NG drains, 12 lead ECG, intracranial pressure monitoring, heart rate variability/complexity monitor, accelerometers)
  - treatment (oxygen supplementation, mechanical ventilation (remote control if possible), infusion pumps, suction, analgesia, intermittent sequential pneumatic compression devices)
  - pressurised cabin, food and drinking fluids, climate control, head rise, padded floor/mattresses, strapping
  - supplies to reinforce/replenish ground.
- Technical details for desirable equipment:
  - airworthy
  - certified by national body
  - space for wiring required
  - equipment locked in patient chamber when not in use
  - redundant pulse oximetry, 3-lead ECG, ventilation capability to allow function for at least half duration of longest flight planned – backup system connected to UAV's communication systems
  - "all in one" systems and "closed loop" systems to save space and allow autonomous control/output
  - single screen to display data
  - medical data stored on board and in black box
  - urine and drain output lower than the casualty's trunk (allow drainage), scale for output measurement
  - analgesia administration should include patient controlled analgesia and automatic (remote/automated) infusion pump – requires pre-determined algorithms + EEG/anesthesia depth sensors)
  - oxygen and suction sockets near the head of the evacuee
  - probe for ICP monitor and EtCO2 near head
  - blood pressure probe and invasive blood pressure probes near upper half of evacuee's body
  - minimum wiring: maximum use of wireless without interference with UAV operation/joining of sensors' wiring
  - powersockets for additional medical equipment

  - three points for affixing equipment (head, mid-body, lower extremities)
  - casualty carried via internal carriage
  - Compartment with environmental controls that meet or exceed passenger compartment environment conditions of manned helicopters for casualty movement.
- Current NATO Doctrine and the how it affects CASEVAC via UAVs:
  - NATO doctrine (as of 2012) doesn't address UAVs for CASEVAC directly.
  - Medical care should be highest quality possible.
  - Demand for rapid evacuation.
- Casualty evacuation vulnerabilities:
  - nonlinear/urban battlefields (e.g. Afghanistan):
    - increased threat to aircraft crews and evacuees
    - large distances.
  - difficult and time consuming casualty movement
  - varied environments, rugged terrain, various obstacles
  - IED attacks
  - potential capability to add capacity with reduced risk to piloted aircraft in:
    - operations in high threat areas, poor weather, hazardous terrain, hostile environments
    - units operating in dispersed or remote locations
    - immature/developing theatres of operation
    - expeditionary operations which require quick global response.
- Assumptions for UAV CASEVAC to succeed:
  - protocols to define casualties that can/can't be safely evacuated
  - UAVs meet crashworthiness/safety standards and operate with similar flight parameters to man-carrying Rotary Wing aircraft
  - adequate training to provide an aid in correct selection/non-selection of UAVs for CASEVAC use and preparation of the casualty for evacuation (decision making training for commanders, initial combat trauma care training, operational safety training for field personnel.
- Medical and Clinical Considerations:
  - clinical benefit vs harm
  - does the casualty condition allow movement by this means?
  - degradation in the level of care is not acceptable

  - advanced trauma life support: control catastrophic bleeding, control airway, ensure adequate breathing, maintain circulation to ensure perfusion, disability (neurological status), exposure
  - standard of care affects outcome
  - immediate care should not be compromised by conditions of evacuation
  - physical restraint of casualty while unattended is required
  - time is fundamental in effectiveness of care
  - the risk of inflight vomiting may warrant using recovery position
  - airway management/equipment could become dislodged during flight
  - hypothermia is likely in trauma
  - requirements for UAV evacuation:
    - active moderate to severe bleeding must be controlled
    - field dressings and tourniquets securely applied prior to flight
    - casualty breathing spontaneously, able to survive journey without supplemental oxygen but may benefit from oxygen
    - able to be placed in recovery position if unconscious
    - internal compartment or secure external structure with sufficient restraint to prevent casualty falling out or moving in turbulence
    - risk caused by UAV evacuation must be less than remaining at current location or waiting for another platform.
- Safety and operational issues:
  - safety, flight characteristics, flight capabilities, user support
  - weather performance
  - anticipate failure modes
  - platform sensors and robust intelligent software
  - crashworthiness
  - reliable electrical generators, hydraulic pumps and fly-by-wire transducers
  - ease of maintenance: line replaceable units, integrated health monitoring systems
  - high operational readiness
  - low failure rate
  - hover Out of Ground Effect capability desirable
  - temperature, power margins
  - environmental/weather safe design

  - not undue G force, vibration or roll-rate
  - decision making, navigation and GPS
  - high threat survivability
  - no exposed sharp edges or high temperature surfaces
  - NATO/national air regulation safety rating
  - air quality in compartment,
  - noise limit, vibration below UH-60, acceleration <2 Gs in any axis while carrying casualty, <0.25 G/sec G-onset rate.

- En Route Care Medical RDT&E Gaps and Status:
  - focus areas for en-route care research:
    - patient stabilisation
    - patient preparation for movement
    - patient staging
    - impacts of the in-transit environment on patient physiology AND medical attendant performance
    - occupational concerns for medical staff
    - human factors and patient safety
    - medical personnel training and equipment
    - environmental health issues
    - infectious disease
    - cabin infection control
    - burn and pain management
    - resuscitation
    - lifesaving interventions
    - nutrition
    - alternative medicine
    - organ system effects (neurologic, psychological, orthopaedic, pulmonary, cardiovascular, gastrointestinal, renal, respiratory)
    - biodynamic evaluations for new aircraft
  - environmental considerations for patient compartment in a UAV:
    - noise
    - nibration
    - turbulence

- acceleration
- temperature
- humidity
- altitude
- electromagnetic interference
- air quality

- other considerations:
  - auxiliary power for equipment
  - oxygen delivery
  - suction
  - closed-loop medical systems
  - infectious control
  - litter mounting systems (immobilisation)
  - psychological effects of confined spaces
  - communications
  - data connectivity
- research gaps
  - casualty stabilisation
  - casualty preparation for movement
  - impacts of in-flight environment on patient physiology
  - human factors and patient safety
  - environmental health issues
  - infections disease and cabin infection control
  - burn and pain management
  - resuscitation
- casualty movement environments and functional limitations:
  - mission equipment noise levels (voice recognition, obscure audible physiological and technological signals)
  - vibration may exacerbate casualty condition OR damage medical equipment (or impair stability and accuracy)
  - turbulence can lead to unpredictable G-forces
  - environmental temperatures not always well regulated as altitude changes
  - relative humidity may increase breathing difficulty

- cabin pressure at altitude and impact on casualty and equipment (ventilators)
- acceleration effects (take-off and landing particularly)
- EM environment – avoid interference with/from aircraft, ship, ground vehicle electronics, radars and transmitters
- power distribution outlets/systems
- on-board oxygen capacity (has driven development of portable systems)
- uration of transport affects physiology and treatment of casualty
- "The constantly-developing suite of multiple critical care medical devices needed for patient care is heavy and not necessarily integrated or interoperable, which requires intensive monitoring by medical staff and continuously challenges their situational awareness and decision making."

- en route care research is dependent on enhancements in:
  - portable medical equipment
  - adaptation of clinical capabilities for employment on any available and appropriate AE transportation platform
  - patient management and regulating systems
  - clinical and operational training
  - knowledge of physiological effects of flight stresses
  - safe clinical management and transport of patients with head and spine injuries

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