Come Fly With Me: The story of taking intensive care medicine and critical care above the clouds.

By Dr Sam Fosker

The C-17 Globemaster, with its 4 PW-100 turbofan engines, touches down at RAF Brize Norton carrying more of its specialist cargo. At 174 feet this is the largest aircraft in the RAF's fleet but it's what is on the inside that makes it even more unique. The C-17 Globemaster contains a fully staffed and functioning Intensive Care Unit capable of transporting up to 36 patients and providing full critical care support on its transcontinental journey(1). In only the last 100 years has the medical world been able to take the highest level of medical care it can offer and package this into the clouds, creating a service capable of resuscitating and transporting patients, military and civilian, from many remote areas to definitive care.

1917, a hundred years ago this year, marked a pivotal time in aeromedical medicine in the United Kingdom. Lance-corporal MacGregor serving with the 2nd Battalion Imperial Camel Corps Brigade was shot in the ankle, wounding him and leaving him stranded. Fortunately this year marked the unveiling of the first British Air Ambulance that was able to transport him to care within 45 minutes, instead of the 3 hours it would have taken by foot(2).

The systems and technologies now available allow for patients almost anywhere in the world to be stabilized and transported back to a UK hospital within 24 hours(3). In this essay I will look at the technologies and pioneering people that have allowed us to take Intensive Care medicine above the clouds, and then safely back down to earth again.

Origins

The origins of transfer and retrieval medicine stretch back to biblical times when The Good Samaritan aids an injured traveler and transports him to the nearest town on his donkey to receive further medical care. Animals continued to aid in the development of aeromedical medicine when in 1783 a sheep, duck and rooster were the pioneers of flight, and were sent up in one of the original Montgolfier balloons. This also led to the first aeromedical injury when the agitated sheep kicked the rooster mid flight(4).

The first aeromedical patients were for years thought to be during the Franco-Prussian War, when it was reported balloons were used to evacuate wounded soldiers from the front line. This has been discredited however, as although reports show the use of many balloons during the war, this was only for navigational and logistic purposes and not for medical reasons at any point(5). Later in the 1800s a Dutch military doctor DeMooy proposed the idea of transporting patients in balloons tied to horses, however this appears to be more a hypothesis and there is no evidence to suggest he managed to make this a reality. The first doctor in the air was a Dr John Jeffreys who crossed the English channel with Frenchman Jean Blanchard in a hydrogen-filled balloon(6). During these early years, with flight itself very much in it's infancy, medical interest in aviation was minimal and restricted to a few dedicated individuals. The French medical journal Le Caducee summed up the world's view on aeromedicine in 1912 when it stated "the use of the aeroplane for medical evacuation is, for the moment, in the realm of fiction"(7). During the 1900s war was the main driving force necessitating mass casualty evacuation over large distances and the need to bring intensive care out of the realms of the hospital.

Military Beginnings

World War I brought about a rapid expansion in the use of aeromedical services, and with it an exponential increase in the speed and effectiveness at which critical patients could be transferred and treated in hospitals. The first dedicated air ambulance, the modified Dorand ARII, was developed by the French, at the time leaders in the field, in 1917 and soon other countries were following suit. The US developed the Curtiss JN-4D "Jenny", capable of transporting a stretchered patient at the rear of the aircraft. Still, aircraft were more for transport of patients and to assist search and rescue operations rather than in-flight monitoring and treatment(8).

After the First World War countries across the world began to develop their own aeromedical units with many following the French lead. These were now being used outside of the military environment as well. In Australia, the idea of aircraft to access and treat the people in the outback was proposed to the Superintendent of the Australian Inland Mission, Reverend John Flynn. However, it wasn't until 1928 that enough funds were found to establish the scheme properly. The scheme flourished and soon the system was developed from taking doctors to remote areas to deliver clinics, to a service that was able to transport patients out of remote environments to regional centres. This led to the first flight nurses who developed a skill set not only to assist in clinics on the ground, but also to escort patients in need of further treatment. The service was taken over by the Aerial Medical Service in 1942 and then became the world renowned Royal Flying Doctor Service (RFDS) in 1955. The RFDS has now become a benchmark in aeromedical retrieval and covers over 70 000km daily to stabilize and transfer acutely unwell patients. (9,10)

The period before the Second World War saw the development of aircraft and systems that allowed patients to be monitored in-flight and signified the shift from solely transfer missions to retrieval and treatment. The US modified the British De Havilland DH-4A, to enable it to transport 2 patients with an attending doctor(11). The French had formed a squadron of 6 aircraft assisting them in transporting over 2000 patients during the Moroccan Riffian War and it wasn't long before the UK followed suit. Three years after the release of the first air ambulance in 1917, the then War secretary Winston Churchill authorized the formation of a new squadron code-named "Zed Expedition" to assist with aeromedical retrievals in their Somaliland campaign. This squadron, although formally a bomber squadron, consisted of one converted DH-9 designed to carry casualties back to the nearest field hospital (12). The aircraft themselves had been adapted to carry a coffin like structure at the rear of the plane in order to transport the patient, this came with the added benefit of the pilot still being able to use the front mounted machine gun, should the need arise. Due to the success of the dedicated DH-9 aircraft, further dedicated air ambulances were developed and by 1925 the RAF were flying regular flights from their Middle East bases(8).

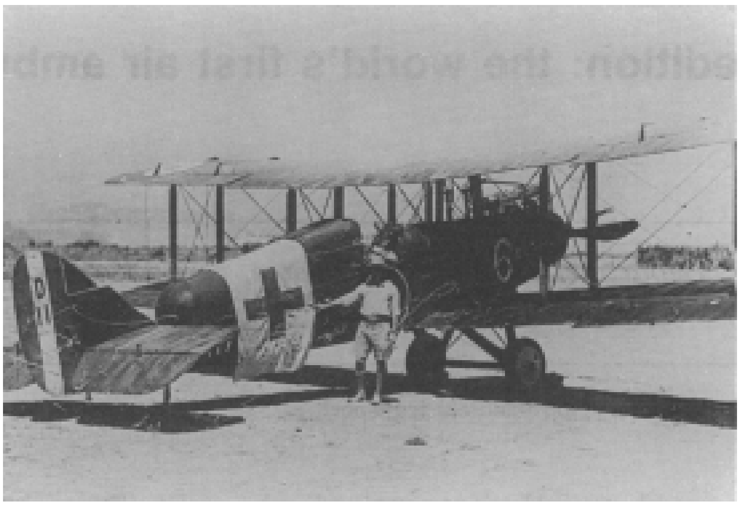

Figure 1 - The DH-9 plane with its rear mounted patient container (12).

By the Second World War aeromedical units were now commonplace, and regular missions transported patients back to larger hospitals. The RFDS had proven the system to work and had shown how large patient networks could be developed in the civilian setting. Flight nurses were soon to become more widespread, the US seeing their first nurses graduate in 1943, allowing patients to be transferred and have continued in-flight care. (8). The Germans had also refined their squadrons having transported many patients during the Spanish Civil War of 1936-1939. Their Luftwaffe squadron pioneered the art of long distance high altitude evacuation, escorting patients for up to 10 hours and at an altitude of 18 000 feet. With planes now travelling faster and longer the stress put on the patient's bodies was ever increasing. This drove developments to reduce any harm to patients with new technologies introduced to combat the cold, hypoxia and pressure changes(7,13). The technological advancements occurring within the planes will be discussed in more detail later in the essay, however one advancement would change the field of aeromedicine completely. The invention and mass production of the helicopter transformed aircraft as a method to transport patients, to a new system allowing access to patients at the point of injury.

Birth of the Helicopter

It wasn't until the 1940s that a commercially viable vertical flight design was found. Igor Sikorsky, a Russian born engineer living in America developed his R-4. The success of this design led the US army to put in a large order, intended to be used predominantly in a search and rescue environment, however by the end of the Second World War over 400 Sikorsky helicopters were in use. However aeromedical history was to be made when a young American soldier shot himself in the hand whilst serving in Burma (now Myanmar). The now well established R-4 helicopter was dispatched to him and safely returned him to a local hospital marking the first trauma patient extricated from the point of injury(7,14).

After the war the RAF used helicopters to evacuate some patients out of some of the more austere locations, however it wasn't until the Korean War that the helicopter truly showed its full potential. Named "Combat Cargo", the aerial support network during the Korean War revolutionised patient transport and was so effective it remains mostly unchanged even today. Dedicated medical aircraft were transporting patients in huge numbers to large hospitals in Japan and America, with dedicated nurses and doctors escorting them and providing in-flight care. As well as this, helicopters were deployed to the front line to bring injured personnel to a facility that could resuscitate and stabilise them. The patients could then be transferred on further, using the fixed wing aircraft. This also marked to introduction of helicopters that had the ability to mount patients inside the helicopter. Previously due to the helicopters being used solely for extrication purposes, patients were tied to the outside, much like in the original fixed wing aircraft. With patients now brought inside the helicopter the onboard medic could start to provide resuscitative treatment whilst in flight. Overall, during the war over 300 000 patients were successfully transferred. These quicker transport networks, as well as new antibiotics and surgical techniques, meant that the death rate of wounded soldiers was half that of World War II(15–17).

The Vietnam conflict saw further development of the systems from Korea. Helicopter evacuation teams, under the name "Operation Dust-off" were now so successful they were able to transport patients to definitive medical care within 20 minutes of injury. Although only limited medical equipment was available in the helicopters, the quick nature of the "scoop and run" approach led to minimal deaths during transfer. The Vietnam War also saw far greater media coverage than any war previously, and this drew the public attention to the use of helicopters and the daring rescues being performed by the crews. It wasn't long before people were developing the systems used in War to civilian life (11,17).

Civilian Adaptations

The use of helicopters to aid retrieval of patients in the civilian environment grew across the world from the 1950s. Early systems were developed in Switzerland, Germany and Belgium to access patients in austere environments and transfer them to definitive medical care. The development of helicopters allowed far greater range of access, and soon teams were making regular trips to highly mountainous areas, unreachable by other means. Polytrauma was known to be the leading cause of death in the younger population and helicopters provided a quick new alternative to reaching and treating these patients.

Great Britain developed its first dedicated Emergency Medical Service helicopter unit in the 1980s. Alongside initial help from the Royal Navy, the Cornwall Air Ambulance developed it's service to help patrol the local coastline and provide medical assistance both on land and from the air(18). It wasn't long before the London Helicopter Emergency Medical Service (HEMS) was introduced to serve the dense urban population. Much discussion had previously been had into what was the best team to equip these HEMS units with. Early flight nurses had been changed to doctors and then across to paramedics during the Vietnam War. However the

HEMS teams serving the civilian population changed to both a doctor and paramedic onboard, creating a team with complementary skills that enabled them to bring more intensive care medicine out of the hospital and onto the roadside. Now there are over 20 similar teams across the UK providing this service to all areas of the country and catering for both the adult and paediatric populations.

Fixed wing aircraft still have a role in the civilian setting as well. With more people travelling across the world, there are increasing demands for people to be escorted back to the UK when they fall ill. As well as this, fixed wing aircraft are still required in some of the more geographically restricted areas of the UK including the surrounding islands, for example the Isle of Man Air Ambulance service.

Technological advancement

With all the advancement of aircraft to reach the critically ill patient at point of injury, the technology housed within these aircraft has had to keep up in order to provide the best treatment when on scene. This has also now developed to a point where techniques previously thought only safe in large intensive care units are being provided in the streets before patients are transferred.

Long before patients had been put into aircraft, issues with altitude had been noted when the first pioneering people had first travelled in balloons, and ascending up to more than 25 000 feet. Paul Bert is widely renowned as the father of Aviation medicine and he began his studies after reading about the balloon flight of Glaisher and Coxwell in 1862. As they ascended, they began to note multiple worsening symptoms; first difficulties with their ears and eyes, and then progressive paralysis of their arms and legs. Luckily Coxwell had the presence of mind to pull the cord with his teeth before he became unconscious and the balloon transported both men safely to earth. Bert's subsequent experiments focused on the effects of changes in barometric pressure and the altered levels of both oxygen and carbon dioxide within the blood(6).

Further scientific interest was taken in the First World War, when there were reports of pilots losing consciousness and having difficulty navigating due to the hypoxia at higher altitudes. This led to pilots undergoing rigorous medical testing, and the further discovery of the effect that these changes had on patients led to the recognition of Aviation Medicine as a separate field of its own.

These technological challenges pushed new technologies to combat the physiological stresses put on the pilots and patients. Hypoxia has long been a significant issue for the polytrauma patient needing rapid transfer. The ability to store oxygen in large quantities has only been achieved recently due to safe development of liquid oxygen systems. Due to its volatile nature, liquid oxygen has long been used in the space industry as a propellant for their rockets. However now systems are in place to store and safely convert liquid oxygen to the gaseous form, enabling patients to be supported on their transcontinental journeys. 10 litres of liquid oxygen will supply 8600 litres of gaseous oxygen and can all be stored in a container the size of a suitcase, providing over 14 hours of oxygen for a patient requiring a flow rate of 10 litres a minute (19,20).

Alongside the use of oxygen in an intensive care environment, is the ability to deliver this to patients who require mechanical ventilation. A review of the injuries and deaths from the Vietnam War showed the one intervention with the greatest potential lifesaving benefit was the early availability of ventilators. Without the use of reliable mechanical ventilation patients would often deteriorate before they reached definitive care. Over the past 30 years ventilators have become lighter and more portable, allowing the delivery of ventilation in small aircraft. The algorithms used to modify the pressure and volumes delivered have also developed and become more advanced to compensate for the changes in barometric pressure when taking ventilated patients in aircraft (21–23).

Alongside the use of ventilators, portable monitoring devices have allowed the critically ill patient to be taken up to 30 000 feet and have all the necessary monitoring at their bedside. These technologies have largely developed thanks to improved battery lives allowing long trips without mains power. Injury pattern knowledge has also helped with transfer, such as the recognition of traumatic brain injuries and the physiological changes this can have on the body during transfer (24). Patients are now able to travel with capnography and invasive arterial and intracranial monitoring as well as the standard monitoring needs. The recent development of telemedicine has meant that this information can now be transmitted to hospitals and facilities whilst the patient is in flight allowing for safer and more effective handover of care (25,26).

The ability to bring coronary support to patients in outside of a hospital setting was largely due to work done by Frank Pantridge in Belfast. In 1967, he was able to develop the first portable defibrillator allowing cardioversion to take place outside of a hospital setting. Before his new machine defibrillators weighed in excess of 70kg, however his simplified design brought this to a mere 3.2kg allowing for much easier transportation(27,28). Other recent developments in imaging have meant portable ultrasound can be used at the roadside, or whilst in the air to help with the management of the critically unwell patient. Although not as detailed as other imaging modalities, ultrasound has been shown to be very effective in assessment of fluid status and with lung pathology, allowing a quick assessment if anything changes mid-flight(29,30).

Figure 2 - The Pantridge defibrillator allowing debrillation outside a hospital setting.

Acute kidney injuries are commonly seen in polytrauma patients as well as those with burns, crush injuries or sepsis. Initial management of these patients is based around resuscitation with fluids and stopping further insult. If the injury gets so severe it progresses to failure of the kidneys, dialysis will be required to help the body remove the toxins. Although this has been used in some mobile or temporary units, mostly in a military or when supporting large level catastrophes, it is uncommon. This owes much to the speed at which patients can now be transferred to higher level units and the initial management and resuscitation of patients with renal damage is sufficient until this can occur(22,31).

With techniques for trauma care advancing at such a rapid rate there is always a push to provide better care in the pre-hospital environment. The HEMS teams working all over the world are continually innovating to provide world-class critical care and stabilisation to the patient to allow for safe and effective transfers. London HEMS were the first to perform thoracotomies at the roadside, and produced one of the world's first survivors in 1993, and recently they performed the world's first roadside Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)(32). Rapid blood loss can kill a patient before they reach hospital, even with the speed at which HEMS teams can get on scene. REBOA lets teams control this blood loss and stabilise patients before transfer. Rapid blood loss is often seen in pelvic injuries, an injury group seen commonly by the London HEMS team due to large numbers of cycling injuries and falls from height they attend.

All these new developments and technologies require intense teaching and training in order to provide a workforce capable of using them efficiently. This is now at the level where transfer, aeromedical, retrieval and catastrophe medicine are all widely recognised subspecialties within medicine. As well as this, the Anaesthetic and Emergency Medicine speciality training programs now have the option of adding in an extra year of Pre-Hospital medicine to help train prospective doctors. With a wider base of people interested in these fields it has led to increases in the amount of research and audit looking at the practices and new technologies or techniques that can widen the field further. This has also led to the production of many guidelines now available to help with the assessment and transport of critically unwell patients. With care in the UK moving towards a more "hub and spoke" model, some specialties are only available at large tertiary centres. This brought the world of transfer medicine from its military beginnings, to movement between local hospitals. The logistics of transfers is often the most time-consuming aspect of the transfer. Deciding where to take the patient, who will be travelling with them and what equipment will be needed, all needs to be considered in order to make the transfer as efficient as possible. Luckily this no longer has to be done over a single radio and technology means notes, scans and details can be sent anywhere in the world at the click of a button.

Commercial airlines have started to use the technologies developed in the military world into their own fleet. Lufthansa now have capacity for a small scale intensive care unit on their larger aircrafts (33).

In a relatively short period of time humans have developed the power of flight and the ability to transport people anywhere in the world. This has necessitated medicine to innovate to be able to continue to bring safe and effective care alongside this. From the early patients strapped to the outside of a small biplane with a tarpaulin wrapped around them for comfort, today's patient is integrated into a seamless chain of pre-hospital and retrieval medicine, allowing world class critical care to be provided at the roadside and then whilst being transported through the air in the flying intensive care units. Medicine has always proved that it has the ability to keep up with other technological advancements and constantly adapt to provide the best care anywhere in the world.

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