Trauma Surgery & Acute Care Open

Formula One: a 'crash' course in motorsports medicine

James Michael Kempema

Surgery and Perioperative Care, University of Texas at Austin Dell Seton Medical Center, Austin, Texas, USA

Correspondence to
Dr James Michael Kempema; jkempemaMD@gmail.com

Received 1 February 2024
Accepted 27 March 2024

To cite: Kempema JM. *Trauma Surg Acute Care Open* 2024;**9**:e001402.

There is no question that motorsports are inherently dangerous. In particular, Formula One (F1) has long been associated with this risk, tallying a large number of major injuries and fatalities throughout the history of the sport. Traveling at excessively high speeds in open-wheel and open-cockpit vehicles in very close proximity to each other puts the drivers at major risk of track incidences and crashes. These high speeds convey incredibly high forces onto the driver, often resulting in serious consequences. To a certain degree, this risk enhances the appeal of the sport, however measures must be taken to enhance driver safety, both preventively through track, car, and safety equipment, as well as improved medical interventions and care.

Many of these advances in safety and medical care are exemplified by an incident that occurred at an F1 event in Bahrain in 2019. Near the start of the race, Romain Grosjean was involved in an incident in which his vehicle had contacted another competitor, ultimately forcing his car off the track and into the Armco barrier. His vehicle penetrated the barrier, severing the car in half and immediately erupting in flames. There is no question that without recent advances in auto safety enhancements and the immediate response of medical rescue personnel, this would have been a fatal accident. Instead, the vehicle's halo protected his head, the survival cell remained intact, and fire-resistant race gear minimized his thermal injuries.

Over the last 20–30 years, increased focus on car safety and medical response has greatly decreased the risk of major injury and death to the competitors. This article is intended to highlight some of the more recent improvements in both vehicle safety and provided medical care.[1–3]

SAFETY ADVANCES IN FORMULA ONE CARS

Survival cell

The survival cell, or 'Monocoque' has continued to evolve and improve since its implementation in the early 1980s. It is essentially a 'safety capsule' surrounding the driver and made up of incredibly strong composite structure. The capsule is surrounded by more energy-absorptive materials, while the survival cell itself is made up of thin layers of carbon fiber and epoxy, sandwiching layers of an aluminum honeycomb, with an internal lining of Kevlar. The shell then undergoes a series of heating sessions in an autoclave under negative pressure, resulting in a composite structure reported to be five times lighter than steel, but twice as strong. The structure is incredibly protective for the driver as essentially becoming impenetrable as well as fire resistant. Internally, the structure includes a fire suppression system which the driver or first responder can activate. The protective nature of the survival cell was exemplified by the Grosjean crash in Bahrain, as his vehicle was completely separated in half and subsequently engulfed in flames. The cell remained intact despite the incredibly high impact force and assisted in protecting the driver from the associated fire.[4–6]

Fuel cell

Fire is always significant concern among motorsports participants, and improvements have continued to decrease this risk. F1 fuel cells are located directly behind the driver and in front of the engine, and are now made of lightweight, military-grade ballistics material; essentially a type of molded Kevlar and are considered to be leak-proof. Hoses feeding the engine with fuel are equipped with a specific dry-break coupling. In the event of a major incident with damage or separation between the chassis and engine, fuel is prevented from leaking and increasing the risk of fire.

Head and Neck Support device: frontal head restraint

Motorsport incidents often results in extensive rapid deceleration and rotational forces, frequently resulting in severe head and cervical spine injures. These forces have been implicated in several fatalities with secondary traumatic brain injuries, basilar skull fractures, atlanto-occipital dislocations, and cervical spine injuries. In the early 1980s, biomechanical engineer Dr Robert Hubbard developed the first prototype of the Head and Neck Support ('HANS') device. The device was designed to prevent the head from 'whipping' in a crash and minimize the rotational forces on the head without interfering or restricting normal head and neck movement.

The HANS device is made of a polymer reinforced with carbon fiber, so it is lightweight and easily tolerated by the user. It is in the shape of a large 'U' surrounding the neck with the arms lying flat on the patient's chest. The posterior portion extends behind the driver's head, with quick-release tethers connected to the driver's helmet.

Despite demonstrating early success, the device was slow to be universally adopted due to driver reluctance and lack of sanctioning body support. The device was extensively tested by the FIA (Federation Internationale de l'Automobile) in the 1990s and found to be superior to other safety measures and ultimately mandated

Figure 1 Formula One driver extrication exercise. Photo courtesy of Dr James Michael Kempema.

its use for international events in 2009. Statistically it is difficult to measure the success of the device, however since the HANS device has been mandated by major motorsports organizations including the FIA, NASCAR (National Association for Stock Car Auto Racing), and CART (Championship Auto Racing Teams), there has not been a single fatality related to a cranial vertebral junction injury.[7 8]

Head/Side impact

To further minimize head motion and protect the driver from side impacts, a removable head surround has evolved over the years. The surround must be high enough on the side to protect the driver yet have minimal impact on visibility. Currently, the head surround is made of a carbon fiber skin for aerodynamics and filled with impact absorbing foam. The foam hardens somewhat with impact and provides a small amount of rebound. The density is variable based on ambient temperature and most F1 teams will carry two to

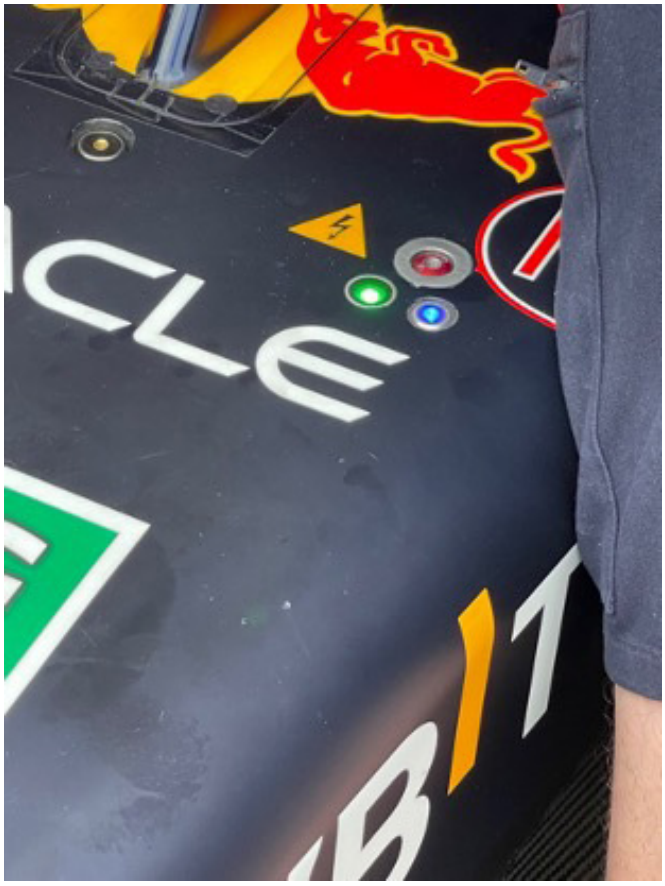

Figure 3 Formula One car with blue medical warning light and energy recovery system status light. Photo courtesy of Dr James MichaelKempema.

Figure 2 Formula One medical car Aston Martin DBX 707. Photo courtesy of Dr James Michael Kempema.

Figure 4 Biometric data monitoring. Photo courtesy of Dr James Michael Kempema.

three versions of the surround with different densities based on the environmental condition.

Helmet

In 2009, Felipe Massa was involved in a significant incident at the Hungarian GP. During a qualifying event, he was struck in the head by a spring that had broken loose from a competitor's vehicle. The spring struck Massa in the head while traveling around 170 mph, penetrating his helmet, and knocking him unconscious. Both the accelerator and brake pads were pressed simultaneous due to his level of consciousness, and he subsequently crashed directly into the tire barrier at a high rate of speed. He suffered a significant head injury and was forced to retire for the remainder of the season.

Based on this event and similar incidents, modifications have been made to better protect the competitors. Several advancements have taken place since then including narrowing the aperture for the drivers' eyes to provide added protection. In addition, Zylon has been added to the helmet, primary directly above the aperture. Zylon is a high-strength synthetic polymer, boasting fibers that have a tensile strength that exceeds Kevlar, yet is very lightweight. Simulated studies completed by the FIA and helmet manufacturers have demonstrated it provides significantly more protection from flying projectiles.

High speed cameras located in the vehicles have demonstrated it was common for driver's helmet visors to become dislodged and open spontaneously, particularly during rollover incidents. Latching mechanisms to keep the visor closed have demonstrated efficacy from further exposing the driver's face to potential direct impacts.

Halo: frontal head protection

Several incidents have occurred in F1 events that have led to a push for improved driver head protection, both from flying debris such as tires as well as impacts with other vehicles or track structures. The last fatality in F1 occurred in 2015, when Jules Bianchi collided with a large, mechanized recovery vehicle that had lifted and was moving another F1 car that had gone off track and collided with the barricade. The race was yellow-flagged, meaning no passing is allowed and speed should be controlled. Despite this, many drivers attempt to move forward in the queue to become closer to the race leaders once racing resumes. Bianchi maintained a high rate of speed, especially dangerous considering the wet, rainy weather. He subsequently lost control and collided with the recovery vehicle, lifting a multi-ton crane off the ground as his car slid underneath it. He subsequently suffered a catastrophic head injury which proved to be fatal.

This led to renewed push to improve protection of the driver's head. Multiple solutions were proposed including completely enclosing the driver cockpit. Ultimately, the 'halo' was accepted and mandated for use by the FIA in 2018. It is made of titanium and weighs approximately £20 yet is strong enough to withstand the force of five times the vehicle's overall weight. The device has a halo-type appearance to it, encircling the space above the driver's head with three attachment points, one directly in front of the driver and two behind and each side of the driver's seat.

Again, the device was met with much skepticism by both drivers and fans alike, citing concerns for the drivers to be able to egress from the vehicle rapidly as well as the general aesthetics and potential to impact aerodynamics. Since implementation, approval has grown and include several drivers crediting it to their survival. Statistically, the FIA used the data from 40 real incidents prior to implementation and estimate at least a 17% increase in driver survival rates if the device had been used.[9 10]

RACE WEEK AND MEDICAL RESCUE COORDINATION

Most F1 races occur over a weekend with the current schedule including 24 races globally over the year. The race itself typically occurs on Sunday of race week with practice sessions and qualifying occurring on Friday and Saturday. A few events each year also include a Sprint race, essentially a shorter duration race.

For FIA medical coverage, extensive planning and preparation begins earlier in the week. FIA medical coverage includes two medical delegates at each event, one for medical rescue coordination and the other manning and assisting race control in determining the need and type of medical rescue response during on-track activities.

The two medical delegates spend the earlier portion of the week studying the circuit and medical facilities, ensuring the medical center at the circuit is appropriately staffed and medically prepared. There is also a designated regional trauma center to accept any injured drivers and steps are taken to confirm they adhere to appropriate best-practice.

Medical rescue coordination involves multiple steps. On-track response teams are made up of a combination of physicians, paramedics/emergency medical technicians, and firefighting personnel. Most circuits also provide medical intervention vehicles, which can assist in track response. A medical response briefing is held by the FIA medical delegates with participation of all medical personnel potentially involved in driver care, including track and medical center representatives. The briefing includes a review of safety measures associated with F1 vehicles, appropriate extrication techniques, criteria for medical center evaluation, and overall track safety (figure 1).

Two training simulation exercises are completed prior to race activities. An on-track scenario is completed with a simulated F1 crash and is used to evaluate the rescue team response, coordination and communication, driver transport as well as care provided by medical center. In addition, each extrication team located on the circuit must complete a driver extrication exercise. A specific F1 team is required to provide one of their actual cars for the testing. The teams are evaluated on vehicle safety, as well as quality and timing of driver extrication, including rapid driver removal and controlled extrications. Each vehicle is equipped with an anatomically molded, carbon fiber driver's seat held in place by four pins to the floor of the car. For drivers that are otherwise stable but at high risk for spine or lower extremity injury, the driver is extricated via the seat. The head surround, helmet, and HANS device are removed, and cervical spine immobilization is completed with a collar and Kendrick Extrication Device (KED). Extrication straps are then attached to points on the driver's seat, and the driver must be removed attached to the seat to minimize any further movement of the spinal column considering the very high risk of an unstable vertebral injury. Teams are graded on the efficiency of the extrication, with remedial training provided when necessary.

Lastly, prior to any racing events, the FIA medical staff are involved in track inspections and testing, including high speed tests, to become familiar with the circuit and plan for any potential race-related events including multivehicle incidents, aborted starts, and yellow and red flag events.

FORMULA ONE MEDICAL CAR

Currently, the F1 medical car is either an Aston Martin DBX 707 or a Mercedes AMG GT 63 S. The manufacturers supply the

cars and all maintenance, and both Mercedes and Aston Martin maintain a rotation for providing both the safety and medical cars for each event. Each car is retrofitted with upgraded suspension, engine enhancements, and auto racing seat configurations. Responding to an incident must occur as quickly as possible and both vehicles can reach a top speed of nearly 200 mph, yet must be large enough to carry the required personnel and equipment (figure 2).

The car is staffed by two FIA personnel, a professional driver, and the FIA medical delegate/medical rescue coordinator. Considering the limitation and restrictions of medical licensing in each country, each circuit must provide a 'national doctor' as a third member of the medical car staff. This doctor must be trained in trauma and emergency care, with out-of-hospital medical experience. The national doctor is the primary physician responsible for any on-track medical care with guidance from the FIA medical rescue coordinator and must provide the required equipment. This involves first response care including airway intervention equipment, intubation and pain medications, and appropriate emergent life-saving interventions and medications, such as oxygen supply, tourniquets, and intraosseous access.

The medical car is also equipped with redundant similar equipment and emergent burn care measures. There is significant variability in the training and experience of the national doctor, and the FIA medical rescue coordinator may be required to assist with any of the necessary interventions. All the necessary medical equipment is duplicated from the national doctors responsibilities; however, medications are not carried due to restrictions in transporting them globally, particularly narcotics. The medical car also carries two different types of fire extinguishers depending on the type of fire. A heavy duty Holmatro cutting tool is carried to assist in extrication in the event the driver is entrapped, or the halo is obstructing removal.

iPads are mounted on the dashboard as well as a small rear facing camera screen. The iPads are receiving continuous input and data including live video input of the event, plus ongoing data collection including driver's position, lap and sector times. Each race-related vehicle including all race cars, safety car, and the medical car are equipped with GPS telemetry monitoring. An electronic map of the circuits displayed on the iPad reflects each car's current position and location. Each race car is also equipped with multiple accelerometers to determine the severity of any impact. These data are immediately relayed to both Race Control and the medical car.

During race practice and qualifying events, the medical car is staff and positioned at a rapid response location, most commonly at the pit lane exit or nearby. For the actual F1 race, the process differs. The medical car will be dispatched to leave pit lane in front of the F1 cars formation lap. Before the race, the cars initially line up on their respective pole position location on the starting grid for the prerace activities and ceremony. To begin the race, they complete a formation lap which is a full 'warm-up' lap, and then return to their standing starting position on the grid. The medical car stays in front of the cars until the last turn, then exits to a safe location while the F1 cars pass and line up. The medical car then pulls up behind the cars on the grid.

Statistically, the cars are at highest risk for collision/crash during the first lap as all the cars are closely grouped together and attempting to establish position near or at the lead. Because of this, the medical car completes a full, high-speed lap directly behind the cars to immediately be available to respond to any significant events. The necessity of this has been demonstrated multiple times, including the Grosjean incident. If no major incidents occur, the medical car will return to its standby position for the remainder of the race.

Medical warning light

As mentioned, each F1 car is equipped with accelerometers to determine the force potentially imparted on the driver with any impact. The data are instantaneously transferred to race control as well as the medical car. If there is an impact of 15 g or greater in the horizontal plane, or 25 g or greater in the vertical plane, the medical car is immediately dispatched to assess the driver and bring to the medical center for evaluation. Each car also has a small light located in front of the driver. Prior to any impact, it is a slow pulsating blue light. If the impact on the car meets the above listed parameters, the light begins to blink rapidly and rescue personnel can recognize that the driver sustained a significant impact and will require medical evaluation (figure 3).

Biometric monitoring

There have been several instances where the drivers are not immediately assessable after an incident. For example, in 2022 Zhou Guanyo was involved in a collision shortly after the race started at the British GP in Silverstone. He was involved in a minor side swipe type contact which caused his car to ultimately flip, slide on the halo, and then roll again multiple times; ultimately jumping the stacked tire barrier and coming to rest on the vehicle's side, sandwiched between the tires and fence barricade. It was not until responders were able to get below the vehicle that they could actually communicate with him. A few years earlier, Dr Ian Roberts developed a biometric monitoring system to assist in evaluating drivers prior to being extricated.

The drivers now all wear fire-resistant driving gloves that include a small sensor at the left index fingertip and a battery/transmitter near the driver's wrist. The sensor is continually monitoring the driver's heart rate, pulse oximetry, and include a small accelerometer to determine any movement. The data are transmitted confidentially via an advanced Bluetooth-type communication to a small receiver in the medical car, providing the physicians with some idea of the driver's hemodynamic condition and level of consciousness (figure 4).

Energy recovery system

F1 cars are hybrid vehicles and maintain a supplemental battery system to augment the power of the engine. Kinetic energy from braking is converted to electrical energy and stored in a battery system, as is heat generated from engine exhaust. This extra energy can be used to enhance the engine power, increasing horsepower by an estimated extra 160 horsepower. When an F1 vehicle is damaged, there is the small possibility of a ground fault disruption, potentially 'electrifying' the vehicle. This then puts the rescue personnel at risk of electrical injury, just by touching the vehicle.

The electrical status of the vehicle is signaled by an electrical warning light, located above the driver's head on the roll hoop near the engine air intake. This is intended to signal to both race team personnel as well as rescue workers the status of the system. A green light indicates the system is turned off and the vehicle is safe to touch, while a yellow light signals the system is activated, however still considered safe. A red light conveys that this system and vehicle are potentially dangerous to touch. The same information is displayed on a repeater light near the front of the driver if the vehicle has more extensive damage.

To minimize the risk to rescue providers, initial assessment of the driver and vehicle must be done wearing thick, insulated

gloves until they can ensure the vehicle is safe. Each vehicle contains a neutral button located in front of the driver to turn off the system.

Driver extrication

Very little assessment can be completed while the driver is still in the vehicle due to the confined space. On medical car and other rescue personnel arrival, initial assessment primarily is focused on the status of the vehicle and potential for further injury to the driver. Many drivers will self-extricate when possible if injuries do not prohibit it or they are not entrapped. If the driver is still in the vehicle, assessment will include determination of the driver's level of consciousness and the potential further risk to them, including fire or vehicle positioning.

If the driver's condition appears critical, including unresponsiveness, or if there is potential danger to the driver from something like fire, the primary objective is to remove the driver as quickly as possible from the risk of further injury. Vehicle fires will be addressed with supplied fire extinguishers as well as the built-in fire suppression system in the vehicle's driver compartment. A four-man to six-man team will attempt to stabilize the head and neck as much as possible while lifting the driver out of the vehicle and removing him from this additional threat. He then can be placed outside the vehicle in a safer environment for further assessment.

In addition to the medical car, rescue and extrication teams maintain hydraulic and battery powered extrication tools to quickly cut and divide any portion of the vehicle that is impeding driver removal.

Occasionally, the driver will be alert, however, there is evidence of a lower extremity or spinal injury. The driver will be extricated in a much more controlled manner using the seat of the vehicle to maintain current anatomical alignment. This procedure is described above.

Once the driver is extricated, a quick but more thorough assessment can be completed by medical staff. Drivers with no obvious injuries but at risk due to the measured impact force are brought directly to the circuit medical center by the medical car staff. The medical center staff will then perform a much more comprehensive evaluation and determine if the driver is 'fit' for further racing events. If the driver does show evidence of significant injury, they will then determine whether treatment can be completed there or if transport to a regional trauma center is needed.

For drivers displaying evidence of more significant injuries during or immediately after extrication, only the necessary immediate procedures will take place on track, such as airway intervention and hemorrhage control. These participants will be brought to the circuit medical center as quickly as possible by an on-track ambulance crew and accompanied by the national doctor. The emergent procedures take place immediately before, during, and on arrival to the medical center, minimizing the time to receive more definitive care.

Each F1 circuit is required to have a medical rescue helicopter on scene and events are not allowed to be run unless the helicopter is on-scene and staffed. This allows for more rapid transport to definitive care at a trauma center, especially considering the proximity of many F1 circuits and the typical excessive traffic associated with each event.

SUMMARY

Motorsports will always carry an inherent amount of risk. Commitment to continued advancements in track, vehicle, and driver safety measures will assist in minimizing the risk to these competitors, as well as spectators. Our commitment to continued improvement to prehospital and trauma care can only assist in improving outcomes for these drivers, allowing them to return to the sport so many of us enjoy.[11]

Acknowledgements I would like to thank Dr Ian Roberts, FIA Formula One CMO/FIA Medical Delegate who generously supplied much of this information and has made countless contributions to advancing safety and medical care in motorsports.

Contributors No other contributors involved in the production of this manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Disclaimer I am employed by the FIA as a medical delegate/medical rescue coordinator. This summary is of my own research and experience and not intended to be representative of the FIA.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

ORCID iD

James Michael Kempema http://orcid.org/0009-0002-7262-6347

REFERENCES

1 Formula One Accident Investigations. Section 6: JOURNAL OF PASSENGER CARS: MECHANICAL SYSTEMS JOURNAL. 2000: 2531–9.
2 Seedhouse E. Formula one. In: *Pulling G: Human Responses to High and Low Gravity*. 2013: 89–104.
3 Lamsam K, Maron K. 2013 Motorsports safety.
4 Savage G. Formula 1 composites engineering. *Engineering Failure Analysis* 2010;17:92–115.
5 Kamble M, Shakfeh T, Moheimani R, Dalir H. Optimization of a composite Monocoque chassis for structural performance: a comprehensive approach. *J Fail Anal and Preven* 2019;19:1252–63.
6 Frömmig L. Safety in Motorsport. In: *In Basic Course in Race Car Technology: Introduction to the Interaction of Tires, Chassis, Aerodynamics, Differential Locks and Frame*. Springer Fachmedien Wiesbaden, Wiesbaden. 2023: 429–54.
7 Weerappuli P, Prasad P, Barbat Saeed. Effectiveness of the head and neck support (Hans1) device in frontal impacts of CART cars: a CAE analysis. *IJVS* 2005;1:129.
8 Newman JA, Withnall C, Wonnacott M. An integrated helmet and neck support (iHANS) for racing car drivers: a Biomechanical feasibility study. No.2012-22-0013. [SAE Technical Paper]. *Stapp Car Crash J* 2012;56:469–84.
9 Lin M, Papadopoulos P. Effect of halo protection device on the aerodynamic performance of formula Racecar. *International Journal of Mechanical and Mechatronics Engineering* 2014;14:13–8.
10 Rosalie SM, Malone JM. Effect of halo-type frontal cockpit protection on overtaking. *BMJ Case Rep* 2018;2018:bcr2018225427:bcr–2018.:.
11 Sabra JP, Cabañas JG, Bedolla J, Borgmann S, Hawley J, Craven K, Brown C, Ziebell C, Olvey S. Medical support at a large-scale Motorsports mass-gathering event: the Inaugural formula one United States grand Prix in Austin, Texas. *Prehosp Disaster Med* 2014;29:392–8.