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CURRENT CONCEPTS IN TOURNIQUETS

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ABSTRACT

Pneumatic tourniquets are used many thousands of times per day in orthopaedic and non-orthopaedic surgical procedures throughout the world, facilitating operations by reliably establishing a bloodless surgical field with a high level of safety. Within the last thirty years, there have been important improvements in the technology of tourniquet instruments and tourniquet cuffs, leading to greater safety and efficacy in surgical procedures and non-surgical settings. This paper provides an overview of current concepts in tourniquets in the following six areas: 1) Safety features integrated into modern tourniquet systems; 2) The use of Limb Occlusion Pressure (LOP) to enable individualized, optimal tourniquet pressure settings to be achieved; 3) Personalization of tourniquet cuffs through the use of variable contour design and availability of cuffs to fit pediatric and bariatric patient populations; 4) Reduction of soft tissue injuries through the use of limb protection sleeves matched to the limb size and cuff size; 5) Non-pneumatic tourniquets, developed for stopping arterial blood flow simply and rapidly in pre-hospital military and emergency settings, but with less safety and less accuracy than surgical tourniquet systems; and 6) Ongoing innovations to automatically maintain tourniquet pressures near ongoing optimal limb occlusion pressure for individual patients throughout a surgical procedure.

INSTRUMENT SAFETY FEATURES

The modern microcomputer-based tourniquet system was invented in 1981 by one of us, Dr. James McEwen[1]. Modern electronic tourniquet instruments include a pressure regulator that maintains cuff pressure at the level set by the user and an automatic timer to provide an accurate record of tourniquet inflation time and alarm if the inflation time exceeds a limit set by the user. A block diagram of a typical modern tourniquet system is shown in Figure 1. Tourniquet instruments also typically include audiovisual alarms to prompt the operator if hazardously high or low cuff pressures are present in the cuff. Other safety related features and alarms that may be present in a tourniquet instrument include:

- Self-test capabilities to provide automatic checks of system operation and calibration at each start-up of the instrument.
- Self-monitoring capabilities to continuously monitor the operation of the instrument.
- A backup battery to allow instruments to continue to operate normally during an unanticipated power interruption or during patient transport.
- Alarms to detect potentially hazardous air leakage from pressurized tourniquet cuffs.
- Alarms to detect occlusions of the tubing connecting the instrument to the cuff.
- Alarms to detect failure of a cuff to depressurize when deflation is intended.
- A cuff hazard interlock to prevent the instrument from being inadvertently powered off while a cuff is still inflated.

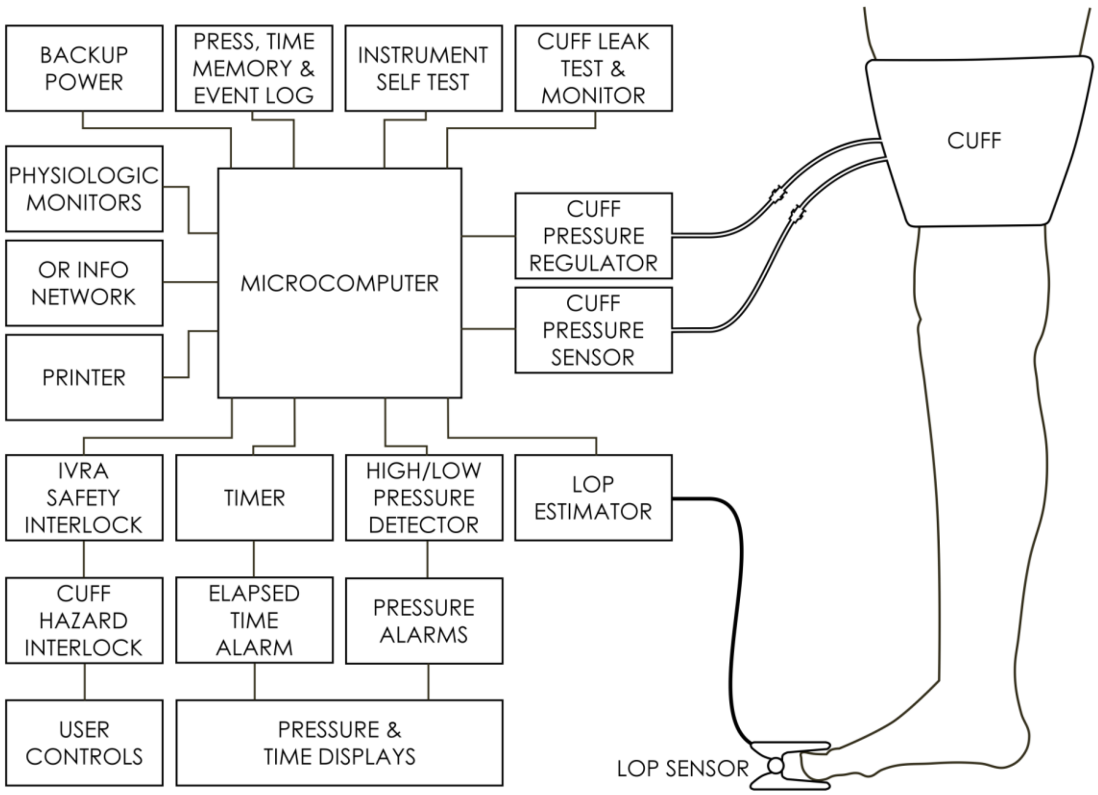

Figure 1: Block diagram of a typical modern tourniquet system containing elements that have improved safety, accuracy and reliability [2]

- Interlocks to help prevent inadvertent cuff deflation during intravenous regional anesthesia (Bier Block) procedures and bilateral limb procedures.

Additional features that may be found in some of the most modern tourniquet systems include:

- Automated estimation of Limb Occlusion Pressure, permitting individualized setting of safer tourniquet pressures;
- Integrated cuff testing, the capability to test cuffs, tubing and connectors for potentially hazardous leakage during surgery as well as before and after procedures; and
- Interfaces to OR information systems to remotely capture cuff pressures and inflation times and potentially hazardous events.

In addition to the safety features listed above, the user interface of certain tourniquet instruments, such as those employing touchscreen user interfaces, may also include special safety features to suppress hazardous changes in cuff pressure that may have been triggered inadvertently by a user during surgery. Some new surgical tourniquet systems have been developed to permit a extended (higher) pressure range if required to stop bloodflow in individual bariatric patients, while maintaining a lower and safer normal pressure range for most patients.

LIMB OCCLUSION PRESSURE

It is well established by evidence in the clinical literature that higher tourniquet pressures are associated with higher probabilities of tourniquet-related injuries.[3] As a result, modern tourniquet systems aim to use the minimum pressure required to stop blood flow in a limb over the duration of a surgical procedure. A new method based on Limb Occlusion Pressure (LOP) has been shown to allow individualized, optimal tourniquet pressure settings to be achieved. LOP can be defined as the minimum pressure required, at a specific time in a selected tourniquet cuff applied to an individual patient's limb at a desired location, to stop the flow of arterial blood into the limb distal to the cuff.[3][4] Some advanced surgical tourniquet systems include means to measure LOP automatically, although LOP can also be measured non-automatically by users

PERSONALIZATION OF TOURNIQUETS

A recent introduction of personalized tourniquet cuffs has also resulted in safer and more effective tourniquet use. Personalized cuffs are designed to better match patient limb size and shape and thus provide more efficient application of cuff pressure to the limb, allowing lower and safer tourniquet pressures to be used. The improved fit is a result of the arrival of new types of tourniquet cuff designs, in addition to the traditional tourniquet cuff design. The traditional 'straight' tourniquet cuffs are best suited to cylindrical limb shapes. New types of cuffs include 'variable contour cuffs' that allow the user to adapt the shape of the tourniquet cuff to any of a wide range of non-cylindrical (or tapered) limb shapes. In addition to the introduction of new cuffs that allow better matching of cuff shapes to individual limb shapes, other advances in tourniquet cuff design have been made for pediatric and bariatric patient populations. Tourniquet cuffs are now available that are matched specifically to pediatric and bariatric limb sizes and shapes, with comparative effectiveness established in published literature.

MATCHING LIMB PROTECTION SLEEVES

High pressures, high pressure gradients and shear forces applied to skin and soft tissues underlying a tourniquet cuff can cause injuries to the skin and soft tissues. To reduce the nature and extent of these injuries, studies have been published to determine the relative effectiveness of no protective material, underlying padding, underlying stockinette, and underlying limb protection sleeves that are matched to specific limb sizes and cuff sizes.[5][6][7] Study results present evidence that limb protection sleeves improve safety by protecting the skin underlying tourniquet cuffs during tourniquet use, and further provide evidence that greatest safety is achieved through the use of limb protection sleeves consisting of two-layer material specifically matched to the limb size and cuff size.

EMERGENCY AND MILITARY TOURNIQUETS

Investigations performed by the US Army's Institute for Surgical Research has led to the introduction and widespread use of tourniquets in combat settings. It has been proven convincingly that many lives have been saved that would have been lost without the use of tourniquets. As a result of these successes in combat settings, the same types of tourniquets are now being used increasingly by police, paramedics and other first responders in non-military settings with similar benefits. Also, based on the proven safety and efficacy of pneumatic tourniquets in surgical settings over many years, new types of compact pneumatic tourniquets are being developed and used in emergency and military settings. For example, a recent study of comparative effectiveness[8] led to the introduction and use of pneumatic tourniquets by NATO forces.

ONGOING INNOVATIONS

Although some existing commercial tourniquet systems allow LOP to be automatically estimated preoperatively, these measurements are limited by the fact that LOP is known to vary intraoperatively, especially in response to changes in blood pressure and other physiologic variables.[3][4]

Investigations are ongoing to develop a tourniquet system that intraoperatively minimizes the required tourniquet pressure to occlude blood flow into the limb. Two approaches are being investigated:

1. An algorithm that incorporates an initial LOP measurement as well as intraoperative blood pressure and heart rate data to estimate intraoperative LOP.[9]

2. A system that incorporates sensors at the tourniquet cuff to measure and control the depth of penetration of arterial blood beneath a tourniquet cuff. This system would eliminate the need for an initial LOP measurement and would require less operator attention and skill, while providing more safety and reduced risk of intraoperative breakthrough bleeding.[10]

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