Strategies for Avoiding Problems with the Use of Pneumatic Tourniquets

ABSTRACT

The Pennsylvania Patient Safety Authority has received 140 event reports associated with pneumatic tourniquets (December 2004 through December 2009). Pneumatic tourniquets are used primarily to occlude blood flow and obtain a bloodless field during limb surgery. They also facilitate intravenous regional anesthesia, an alternative to general anesthesia for surgery involving the upper or lower limbs. In this application (also known as a Bier block), the tourniquet prevents infused local anesthetic from flowing out of the limb and also provides a bloodless operating field. This article considers tourniquet problems reported to the Authority and reviews use and maintenance issues that can prevent these types of problems. (Pa Patient Saf Advis 2010 Sep;7[3]:97-101.)

In surgical applications, a pneumatic tourniquet should reliably maintain the minimum pressure necessary to stop blood flow in the limb. This minimum pressure setting is affected by repositioning the limb during the procedure, by changes in systolic pressure, and by cuff width compared to limb circumference. Pneumatic tourniquets typically consist of three basic components: (1) a cuff, (2) a means of inflating the cuff bladder, and (3) a controller (e.g., a pressure indicator, regulator). Most tourniquet controllers also have a timer or an elapsed-time meter for tracking cuff inflation time because there is a limit to tolerable ischemia time.

There are several methods for inflating tourniquet cuffs. Many models operate from compressed-gas sources: air or nitrogen is delivered from a wall outlet or a cylinder with a regulator. Several models use an electric pump to compress ambient (i.e., room) air for cuff inflation; these units are line powered and typically have backup batteries.

Cuff pressure is indicated by liquid crystal display (LCD), light-emitting diode (LED) display, or an aneroid gauge; there may also be indicators for supply pressure and/or low battery. Most of the line-powered and some of the compressed-gas units have alarms for such conditions as excessive cuff pressure, cuff pressure leaks, kinks in tubing, and mechanical failure. A few units incorporate a sensor for determining and tracking limb occlusion pressure (LOP). Tourniquet controllers should have locking connectors that secure cuff tubing to prevent leaks and inadvertent detachment. The connectors must also *be incompatible* with Luer fittings to prevent accidental connection to intravenous (IV) tubing and infusion pump administration sets.

Reusable and single-use tourniquet cuffs are available in a wide variety of lengths and are closed with Velcro™ and ribbon fasteners. Cuff selection should be made according to the patient's limb circumference; cuffs should not overlap beyond the Velcro when applied. Several studies have reported that the use of wide tourniquet cuffs reduces the pressure needed to stop blood flow; as such, it is recommended that a cuff should be wider than half the limb's diameter.[1,2] Contoured cuffs are desirable for limbs that are excessively tapered (i.e., very muscular, obese); conventional cuffs transmit pressure disproportionately to the wider section of the limb rather than uniformly across the cuff width.[3]

Intravenous regional anesthesia (IVRA), more commonly referred to as a Bier block, is performed with a dual-bladder cuff. After the limb is exsanguinated by compressing it with a spirally wrapped (Esmarch) bandage, the bladder farthest from the operating site is inflated, and the anesthetic (e.g., lidocaine) is infused into the limb through an IV cannula. After the anesthetic has been absorbed, typically within 20 minutes, the second bladder is inflated over the anesthetized tissue, and the first is deflated. This procedure requires a tourniquet controller to be interfaced with the dual bladders so that the inflating gas can be channeled to either or both bladders.

Reported Problems

From December 2004 through December 2009, 140 events associated with the use of tourniquets in surgical procedures were reported to the Pennsylvania Patient Safety Authority. The event reports are summarized as follows, accompanied by deidentified examples:

- Events associated with limb redness, bruising, or swelling (41%). Bruising and/or swelling should not occur and suggests excessive pressure.

  Bruising noted along distal section of tourniquet.

  Patient complained of discomfort of her right upper arm. Anterior site is abraded and discolored with abrasion. It appears the tourniquet was too tight.

- Events citing skin tears or blisters (19%), which respectively suggest nonuniformly-applied cuff padding and absorbed prepping solution.

  Removed tourniquet at end of case. Noted bruised area anterior right thigh approximately 5 to 6 inches in length, probably from tourniquet and cast padding.

  18" tourniquet placed on left upper arm for surgery. Upon removal at end of procedure, patient was noted to have a blood blister approximately 8 inches around and 2 inches wide.

  After removal of the underpadding, it was noted that the patient had a 3 cm x 18 cm reddened area that began at the edge of the tourniquet underpadding. The area had Betadine solution present, which was wiped off with a warm, damp towel.

- Events citing unintended deflation or "tourniquet failure" (14%), suggesting a system leak, an unsecured cuff, a controller malfunction, or a surge in blood pressure.

  Tourniquet was plugged in, and it deflated in the middle of the case. Lost all of the block anesthesia.

  Unexpected amount of bleeding occurred. Pressure increased to 400. Unusual bleeding continued, and Velcro noted to have detached on cuff.

  "BATT FAIL" after working well for 38 minutes. The alarm went off, and the tourniquet released. All the connections were checked and found to be intact. Another tourniquet was obtained and put into service.

  A tourniquet failed after 150 mg lidocaine bolus IV, Bier block was delivered, giving a subsequent risk of seizure and cardiovascular complications.

- Events citing a cuff inflation time for more than two hours (8%); some reports also mentioned limb tingling and/or numbness.

  Patient has had ongoing pain since block wore off, along with a numbness in certain parts of the foot.

  Physician was informed that tourniquet was up for 120 minutes. He asked for 10 more minutes. When 10 minutes were up, he asked for 10 more minutes. When 10 minutes were up [again], he asked for 10 more minutes. Tourniquet was up for a total of 145 minutes.

- Events in which the opposite limb was prepped and, in some cases, the cuff was applied (6%).

  A patient was admitted for right knee arthroscopy. A tourniquet was placed on the left leg and inflated by RN [registered nurse] at the request of the surgeon. The RN began to prep the left leg. The physician did time-out and said "right knee." Tourniquet was deflated and immediately removed.

- Events describing "partial occlusion" (4%), which suggests a system leak, insufficient pressure setting, incorrect cuff size and/or application, or a surge in intravascular pressure within the operative limb from injection of the block.

  A patient experienced bradycardia and decreased responsiveness after administration of lidocaine in the form of a Bier block. The patient was treated with medications (atropine, epinephrine, ephedrine, Narcan®, and Romazicon®), intubated, and transferred to the intensive care unit. [The patient's] mental status is much improved. A question was raised regarding the fit of the tourniquet.

  Doctor asked nurse to check tourniquet on right thigh because he did not have hemostasis intraoperatively. The tourniquet was found to have "unvelcroed." [They] reapplied a tourniquet one size bigger.

- Events citing that the cuff was not removed immediately after deflation (4%).

  [When a] patient returned from the postanesthesia care unit, an operative tourniquet was found on the patient's arm. The patient had complained of numbness and tingling, which was relieved when the tourniquet was removed.

  Patient complained that upper thigh hurt more than the surgery area. [Staff] discovered that the leg tourniquet was intact but deflated.

- Events citing that the opposite limb was injected or incised (4%).

  Patient placed in prone position for left leg popliteal posterior block. Block performed by the anesthesiologist on left posterior popliteal area. Patient was then put in supine position, and approximately a half hour later the anesthesiologist returned to perform the tourniquet block on the front of the leg. The anesthesiologist blocked the right front leg.

  A tourniquet was placed on the incorrect knee. The incision was made on the incorrect knee by the surgeon. Time-out procedures were not followed; site ID was already marked. The surgeon noted the lack of marking and stopped the procedure.

- Event citing use of an Esmarch bandage as a tourniquet for more than two hours, which produced blistering (0.7%).

  Surgeon using 4-inch esmark (sic) as tourniquet was advised of tourniquet time at 60, 90, 105 minutes and repeatedly at 120 minutes [and] did not release esmark until 132 minutes tourniquet time. Surgeon states he is in charge. Circulator advocating for patient.

Why Problems Occur

Extended application time and/or excessive cuff pressure can cause tissue bruising, limb swelling, muscle ischemia, compartment syndrome, and extremity paralysis from peripheral nerve damage. However, swelling and nerve damage may also result from or be exacerbated by other aspects of a procedure. Temporary nerve damage is a frequently reported tourniquet-related adverse event. Although nerve damage can be permanent, it frequently resolves within a year. Compartment syndrome is a relatively rare tourniquet complication; when it occurs, it is likely to require a fasciotomy.

The literature generally indicates that muscle ischemia occurs within one to three hours. Accordingly, there is no rule to determine how long a tourniquet may remain safely inflated; the length of time may vary with the age of the patient and the vascularity of the extremity.[4]

Applying padding under the cuffs of pneumatic tourniquets is a well-established and recommended practice.[2] However, a chemical burn can occur if a skin preparation solution (e.g., Betadine, chlorhexidine) runs beneath the tourniquet and is absorbed by the padding. Padding may also produce uneven pressure distribution if it overlaps or has areas of nonuniformity under the tourniquet cuff. The disadvantage of cast padding, which is commonly used for tourniquet cuff padding, is that its fibers adhere to Velcro and may eventually comprise cuff closure. As an alternative, consider using a stockinette-stitch bandage for cuff padding.

When cuff pressure is between systolic and diastolic levels, blood can flow into the limb, but constriction of the veins will limit or prevent blood return, which may cause venous congestion and edema. Insufficient LOP and unintended cuff deflation can also result in blood entering the surgical site, subsequently interrupting and lengthening the procedure, and in blood loss. Although less common, nerve damage from hemorrhagic infiltration can also result from inadequate cuff pressure.[4]

Another potential for injury with pneumatic tourniquets occurs when they are used to provide intravenous regional anesthesia. High concentrations of anesthetic can enter the systemic circulation and cause such adverse events as cardiovascular collapse, seizures, cardiac arrest, and coma if either of the following occurs before the injected bolus is absorbed: cardiovascular pressure in the operative limb exceeds cuff pressure (e.g., from the injected bolus), or cuff falls below diastolic pressure. Unintentional pressure loss can result from a damaged tubing connector, deteriorated tubing and cuff bladders, and failed or improperly engaged cuff closures. It can also occur when cuff deflation is inadvertently activated. Although some tourniquet models have an alarm that signals cuff pressure loss, alarm activation is also likely to signal the release of a toxic anesthetic bolus from the limb.

In the past, some manufacturers of pneumatic tourniquets provided fittings that allowed connection of oxygen and nitrous oxide as inflation sources, which is hazardous. Tourniquets inflated with oxygen or nitrous oxide can catch fire and burn violently upon contact with ignition sources present in the OR (e.g., electrosurgical units, surgical lasers, fiberoptic light sources). ECRI Institute has reported an event in which leaked oxygen from a tourniquet connector was trapped under a surgical drape; the drape was ignited by a disconnected fiberoptic cable, and a flash fire severely burned the patient's legs.[5] Tourniquets that can be connected to oxygen or nitrous oxide should be removed from service.[6]

Risk Reduction Strategies for Avoiding Tourniquet Complications

The Association of periOperative Registered Nurses' (AORN) "Recommended Practices for the Use of the Pneumatic Tourniquets" includes 18 categories of detailed recommendations for nurses and physicians who use pneumatic tourniquets.[2] The following risk reduction strategies for tourniquet use are derived from AORN's recommended practices unless otherwise noted. (For additional information, see "Strategies for Pneumatic Tourniquet Use.")

Cuff Selection and Application

A complete selection of reusable or disposable cuffs needs to be available in each location where pneumatic tourniquets are used. Cuff lengths of 8 or 10, 12, 18, 24, and 34 inches are typically stocked. It is desirable to also have contoured cuffs, especially in the larger sizes, for the limbs of very muscular or obese patients.

As the Authority reports illustrate, it is essential to verify the correct surgical site before applying a tourniquet cuff. AORN provides extensive guidance to help ensure proper cuff selection and application. Select a cuff that will overlap between three and six inches when applied.[7] In addition to selecting the correct length cuff, the recommended practices state that the cuff should be wider than half the limb diameter where it is to be applied. If the limb is grossly tapered, a wider, contoured cuff will apply pressure to the limb more uniformly, and limb occlusion can be obtained at a lower inflation pressure. Before the cuff is inflated, the limb should be exsanguinated with an Esmarch bandage.

Inflation Time

AORN recommends that tourniquet inflation time "be kept to a minimum" and notes that "safe inflation time has not been precisely determined" and that "the surgeon should be informed of the duration of tourniquet time at regular, established intervals." Factors such as the patient's age and limb size or the presence of vascular disease may also be relevant when determining safe tourniquet time. For pediatric patients, an inflation time less than 75 minutes for lower extremities has been recommended.[8] It also has been recommended that the final decision of when to deflate a tourniquet be made by the surgeon based on the risks and benefits of delaying deflation until closure is complete.[3]

Limb Occlusion Pressure

Proper cuff inflation pressure is frequently defined as the minimum pressure above systolic that produces a bloodless field. However, rather than simply referencing systolic pressure, it is desirable to base cuff pressure on actual LOP. AORN states that LOP can be determined with a Doppler stethoscope located on an artery distal to the cuff while the cuff bladder is gradually inflated. LOP is equivalent to the cuff pressure at which the pulse stops and remains silent for several beats. AORN also recommends setting cuff inflation pressure for adults at LOP *plus* the following pressures:

- 40 mm Hg *if LOP is less than 130 mm Hg*
- 60 mm Hg *if LOP is between 131 mm Hg and 190 mm Hg*
- 80 mm Hg *if LOP is greater than 190 mg Hg*

For pediatric patients, adding 50 mm Hg to LOP is recommended.[9] The additional pressure allows for any likely increase in blood pressure during the surgical procedure and/or for increased venous pressure from injected anesthetic volume. The anesthetic for a Bier block is injected slowly (e.g., over 90 seconds); both cuffs of a double cuff tourniquet should not be deflated for at least 20 minutes.[10]

Verifying Tourniquet Performance

Prior to each procedure, AORN recommends that users visually inspect cuffs, tubing, connectors,

Strategies for Pneumatic Tourniquet Use

Before Patient Use

- Maintain an adequate selection of cuffs.
  - — Contoured cuffs are desirable for excessively tapered limbs.
  - — Do NOT reuse single-use cuffs.
- Ensure electronic controllers are connected to line power and/or have adequate battery capacity; perform self-test.
- Select the proper size cuff, and look for cracked tubing and loose connectors.
- Keep tubing off the floor and routed to avoid accidental contact by personnel.
- Apply a soft padding uniformly to the operative limb cuff site.

After Applying a Tourniquet Cuff

- Do not allow prepping solution to migrate under cuff.
- Determine minimum limb occlusion pressure (LOP).
  - — Place a Doppler stethoscope on a distal arterial pulse.
  - — Increase cuff pressure until the pulse stops.
- Set cuff inflation pressure for *adult* patients at LOP plus:
  - — 40 mm Hg if LOP is less than 130 mm Hg,
  - — 60 mm Hg if LOP is between 131 and 190 mm Hg, or
  - — 80 mm Hg if LOP is greater than 190 mm Hg.
- Set cuff inflation pressure for *pediatric* patients at LOP plus 50 mm Hg.
- Minimize cuff inflation time.
- Notify the surgical team of elapsed inflation time at regular intervals.
- Monitor cuff pressure during the procedure, especially when repositioning the limb.
- Remove cuff and padding immediately after completing procedure.
- Indicate the following in patient record:
  - — Times of inflation and deflation
  - — Inflation pressure(s)
  - — Site of cuff placement
  - — Controller ID number

Include Tourniquet Controllers in the Facility's Technology Management Program

- Inventory tourniquet controllers so that they can be identified and located in the event of hazard and recall notices.
- Schedule units for routine inspection and preventive maintenance.

Source: Association of periOperative Registered Nurses (AORN). Recommended practices for the use of the pneumatic tourniquet. In: *Perioperative standards and recommended practices*. 2007 ed. Denver (CO): AORN Inc; 2009:3753-85.

and the security of the closure mechanism; some clinicians routinely inflate the cuff and check for leaks. Pneumatic tourniquet controllers should be included on a facility's inventory of biomedical equipment. This inventory practice facilitates identification and location of units affected by a recall or other notification requiring user action. It also facilitates scheduling and documentation of routine inspection and preventive maintenance activities that ensure safe and accurate equipment operation. Tubing, cuffs, and batteries are replaced as needed during these activities.[11] Tourniquets with friction fit connectors (e.g., slip-fit Luer connectors, hose barbs) should be removed from service.[12] Units with Luer-lock connectors should also be removed from service to avoid the risk of air embolism from inadvertent connection of tourniquet tubing to an intravenous manifold or infusion pump tubing connectors.[12]

Conclusion

Pneumatic tourniquets are used to produce a bloodless field during limb surgery and frequently also to facilitate intravenous regional anesthesia. However, their failure or misuse can lead to multiple complications including muscle ischemia, nerve damage, convulsions, and coma. As part of a risk reduction strategy to reduce or eliminate adverse events related to their use, consider the following:

- Share this article with all staff responsible for applying, monitoring, removing, and maintaining pneumatic tourniquets.
- Review the procedure for determining LOP with clinicians who set cuff inflation pressure.
- Review the procedure for using a dual-bladder cuff with clinicians who deliver IVRA.
- Ensure that the facility has an adequate selection of tourniquet cuff sizes and that staff know how to properly apply them.
- Develop a policy that addresses monitoring and documenting cuff pressure and inflation time during a procedure.

Notes

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11. ECRI Institute. Inspection and preventive maintenance procedure for pneumatic tourniquets. *BiomedicalBenchmark*™ 2008 Oct; IPM procedure 443.
12. ECRI Institute. Preventing misconnections of lines and cables [guidance]. *Health Devices* 2006 Mar;35(3):81-95.

Self-Assessment Questions

The following questions about this article may be useful for internal education and assessment. You may use the following examples or come up with your own.

A tourniquet was applied to the left thigh of a hypertensive obese patient for an arthroscopic meniscectomy. 60 cc of 0.5% lidocaine was injected intravenously over approximately one minute. Less than 10 minutes after the injection, the patient's heart rhythm became irregular and she began to seize.

1. These symptoms of lidocaine toxicity are attributable to all of the following reasons EXCEPT:
   a. The cuff was inflated to 50 mm Hg above the patient's systolic pressure.
   b. The cuff was too wide.
   c. A contoured cuff was not used.
   d. The limb was not properly exsanguinated.
   e. The lidocaine bolus was injected too quickly.
2. All of the following problems associated with the use of pneumatic tourniquets have been reported to the Authority EXCEPT:
   a. Skin tears and blisters
   b. Limb tingling and numbness
   c. The wrong limb was prepped or injected
   d. Gangrene
   e. Bradycardia and decreased responsiveness during a Bier block
3. Select the practice that is unlikely to cause an adverse patient event.
   a. Select and apply a cuff that is narrower than half the diameter of the operative limb.
   b. Reuse a single-use cuff.
   c. Apply a cuff over cast padding.
   d. Allow prep solution to migrate under a cuff.
   e. Deflate both cuffs shortly after a injecting a regional block.
4. All of the following statements about selecting and applying tourniquet cuffs are accurate EXCEPT:
   a. Cuff lengths of 8 to 34 inches need to be available to accommodate a typical range of limb sizes.
   b. A cuff should be wider than half the limb diameter at the point of application.
   c. When applied, a cuff should overlap itself by at least 6 inches.
   d. Contoured cuffs are desirable for the limbs of obese patients.
   e. Dual-bladder cuffs are used to perform intravenous regional analgesia.
5. Which of the following statements about limb occlusion is accurate?
   a. It is approximately equal to diastolic pressure plus 80 mm Hg.
   b. It is approximately equal to systolic pressure plus 40 mm Hg.
   c. It is determined in the limb opposite the operative limb.
   d. It is the pressure selected on the tourniquet controller to inflate the cuff.
   e. It is likely to increase during a surgical procedure.

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