JBJS ESSENTIAL Surgical Techniques

Continuous Intracompartmental Pressure Monitoring for Acute Compartment Syndrome

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Introduction

We recommend that all patients at risk for acute compartment syndrome undergo continuous intracompartmental pressure monitoring.

A permutation of clinical signs and/or intracompartmental pressure monitoring is routinely employed for diagnosing acute compartment syndrome following a tibial diaphyseal fracture. There are advocates for both methods. However, some still argue that the diagnosis should be based on clinical assessment alone, questioning the usefulness and validity of intracompartmental pressure monitoring. The use of monitoring as the primary diagnostic tool ranges from 12% to 100% in the literature[1-3].

The literature has clearly documented the poor diagnostic performance characteristics of the clinical symptoms and signs of acute compartment syndrome, which lead to a delay in making a prompt diagnosis[3-9]. This, in turn, can delay treatment, which can result in irreversible and devastating complications in a young patient population[10-14] as well as an increased rate of legal compensation proceedings against the treating surgeon[15]. Ulmer calculated the diagnostic accuracy of clinical assessment for the diagnosis of acute compartment syndrome[8], concluding that the symptoms and signs alone were unreliable. He found that the probability of accurately diagnosing acute compartment syndrome was above 90% only when three or more symptoms or signs were positive, with the third sign being paralysis. Paralysis is associated with irreversible complications for the patient[16], and it is unacceptable to wait for this to occur.

Our previously published study was, to our knowledge, the first to document high diagnostic performance characteristics for continuous intracompartmental pressure monitoring in the diagnosis of acute compartment syndrome complicating a fracture of the tibial shaft[17]. We found that continuous intracompartmental pressure measurement with a differential pressure (ΔP) of <30 mm Hg for more than two hours considered to be the threshold for decompression was superior to clinical assessment alone for all performance criteria. On the basis of this study, we recommended that all patients at risk for acute compartment syndrome undergo continuous intracompartmental pressure monitoring.

Our technique for continuous intracompartmental pressure monitoring involves the following steps.

Step 1: Patient Consent

Provide thorough explanations so that the patient can give informed consent to undergo catheter placement and continuous compartment pressure monitoring.

- Explain the procedure thoroughly and communicate clearly with the patient throughout the informed-consent process.
- Explain the risk of acute compartment syndrome following a tibial diaphyseal fracture, along with the potentially devastating complications if it is missed.
- Explain the benefits of continuous intracompartmental pressure monitoring, including early diagnosis.
- Ensure that the patient has no known allergies.

Step 2: Position the Patient

Perform the procedure with the patient supine, in either the recovery room (post anesthetic care unit) or with adequate assistance on the ward.

- The patient is supine and in a comfortable position on a trolley or bed. An above-the-knee cast is routinely applied in the emergency department prior to the insertion of the catheter.
- Estimate the fracture level from initial radiographs, and determine the level of

insertion of the catheter (either proximal or distal to the fracture) on the basis of the estimated fracture level.

- Then window the above-the-knee cast to allow adequate access to this area of the anterior compartment.

Step 3: Preparation

Have all required items for the slit catheter technique for continuous intracompartmental pressure monitoring with placement under a strict aseptic technique.

- A dressings set including swabs, sterile drape, and sterile gloves.
- Antiseptic skin preparation.
- A needle, syringe, and suitable local anesthetic (e.g., 1% lidocaine).
- A slit catheter (14-gauge, central venous catheter) and trocar (Fig. 1). The catheter is prepared by placing two small longitudinal slits in the end to give it a “castellated” appearance (Fig. 2). This increases the surface area and prevents blockage of the end of the catheter.
- A standard blood pressure transducer and a standard pressure manometry tubing that should be filled with normal saline solution, providing a continuous static column of fluid.

Step 4: Insert the Catheter

At the time of admission to the hospital, insert a slit catheter into the anterior compartment with the catheter tip within 5 cm of the fracture level and 1 to 2 cm lateral to the tibia.

- Prepare and drape the skin site of the affected leg in the standard fashion.
- Inject a small volume (1 to 2 mL) of local anesthetic agent into the planned entry site, which should be proximal or distal to the fracture site and 1 to 2 cm lateral to the lateral subcutaneous border of the tibia (Fig. 3).
- Make a small stab incision in the anesthetized area through the skin and underlying fascia, sufficiently proximally to allow for an adequate length of the catheter to be placed within the compartment, with the tip within 5 cm of the fracture level as this level of the fracture has been shown to be the area where the pressure is highest[18] (Fig. 4).
- As the trocar and catheter are passed through the superficial tissues, penetration through the deep fascia is confirmed by a change of resistance. When this has occurred, withdraw the trocar slightly and advance the catheter to the appropriate level.
- A similar technique is used for other compartments that are easy to access (e.g., the lateral and superficial posterior compartment of the leg, interosseous compartments in the hand and foot, and volar and dorsal forearm compartments).
- For the deep posterior compartment in the leg, insert the catheter from distal to proximal. Stand at the foot of the supine patient. The entry point is behind the distal third of the subcutaneous border of the tibia. Introduce the catheter aiming toward the posterior aspect of the tibia and then “walk it off” the tibia until a characteristic “give” is felt as the trocar goes through the deep fascia. Then withdraw the trocar slightly and advance the catheter.

Step 5: Attach the Transducer

Once the catheter is in position, fill it with normal saline solution and attach it to the transducer and pressure manometry tubing, providing a continuous column of saline solution between the compartment and the transducer.

- Use only enough saline solution to fill the catheter. Do not inject large volumes as this will increase the intracompartmental pressure.
- Secure the the pre-prepared blood pressure transducer into position using tape at the level of the tip of the catheter and zero it to atmospheric pressure.

Step 6: Attach the Transducer to the Monitor and Check Reading

Once assembly is complete, you must check that the catheter is working properly and providing accurate readings; then measure the patient’s blood pressure at the initial and every subsequent reading.

- The transducer is attached to a standard monitor, providing continuous pressure readings within the compartment.
- To ensure the catheter is within the anterior compartment, lightly squeeze the anterior compartment of the leg distal to the catheter tip. There should be an immediate increase in the pressure reading.
- Falsely high readings can occur if:

- The transducer is allowed to drop below the tip of the catheter as it was zeroed at the level of the tip.
- There is external compression on the leg—e.g., from positioning.

- Falsely low readings can occur if there is blockage of the catheter. The most common reason for this is that a bubble of air has been allowed to obstruct the continuous column of saline solution. If blockage has occurred, the squeeze test will be negative.
- Measure the patient's blood pressure at the initial and every subsequent reading. The differential pressure (ΔP) is equal to the patient's diastolic blood pressure minus the intracompartmental pressure.

Step 7: Continuous Monitoring

Perform continuous monitoring for twenty-four hours or until the pressure is consistently dropping and the ΔP is consistently rising, whichever is the longer.

- Commence continuous monitoring in all patients at risk on admission, when acute compartment syndrome is suspected, and after intramedullary nailing of the tibia.
- Assess the patient's clinical signs, including pain, swelling, and the neurovascular status of the affected leg every hour (see Appendix).
- Assess the differential pressure every hour or as indicated—e.g., more regularly if there is heightened clinical concern (see Appendix). Perform continuous monitoring for twenty-four hours or until the pressure is consistently dropping and the ΔP is consistently rising, whichever is the longer. Observing the trend of readings over time is essential. Do not depend on a single reading, as this will lead to overdiagnosis of acute compartment syndrome.
- Make a diagnosis of acute compartment syndrome if the ΔP is <30 mm Hg for more than two hours[19]. When the trend of pressure readings demonstrates an imminent entry into the "safe zone" then you can allow an additional short time for observation, especially since it has been shown that intracompartmental pressure monitoring allows the diagnosis at an average of sixteen hours before clinical findings[11].

Results

In our previously published study, we examined 850 patients who underwent continuous intracompartmental pressure monitoring following a fracture of the tibial diaphysis[17]. The mean age was thirty-eight years (range, twelve to ninety-four years), and 598 (70.4%) were male.

One hundred and fifty-two patients (17.9%) underwent fasciotomy for acute compartment syndrome, with 141 diagnosed as having acute compartment syndrome (true-positive results) and six considered not to have acute compartment syndrome (false-positive results). In five patients, normal differential pressure readings were recorded but fasciotomy was performed on the basis of clinical signs; those patients had operative findings consistent with acute compartment syndrome (false-negative results). Six hundred and ninety-eight patients (82.1%) did not have a fasciotomy, with 689 having no evidence of any late sequelae of acute compartment syndrome at the time of follow-up (true-negative results). Four patients had normal continuous differential pressure readings and did not have a fasciotomy, but at the time of follow-up they were noted to have developed late sequelae of acute compartment syndrome (false-negative results). Five patients had diagnostic differential pressures due to a low diastolic blood pressure but did not have any clinical signs. These patients did not undergo fasciotomy and had no long-term sequelae of acute compartment syndrome (false-positive results).

On the basis of these findings (Table I), the estimated sensitivity of intracompartmental pressure monitoring for suspected acute compartment syndrome was 94%, and the estimated specificity was 98%. The estimated negative predictive value was 99%, and the estimated positive predictive value was 93%.

What to Watch For

Indications[20]

- Tibial diaphyseal fractures
- High-energy pilon and plateau fractures of the tibia
- Soft-tissue swelling suggestive of compartment syndrome, irrespective of age, sex, or causality, especially if the patient is being treated with anticoagulants or has a bleeding diathesis
- Young patients with high-energy forearm or femoral injuries, with or without an associated fracture

- Patients who are unable to cooperate with clinical assessment—e.g., polytrauma patients, ventilated patients, and children

Contraindications

- No absolute contraindications
- Patients with obvious clinical signs consistent with acute compartment syndrome, including those determined intraoperatively, should progress to fasciotomy without delay.

Pitfalls & Challenges

- It is essential to appreciate that the prevalence of acute compartment syndrome in the literature is well below 30% and there is no gold-standard reference for diagnosing acute compartment syndrome[2,3,21].
- Low-prevalence situations lower the probability that a positive test will correspond with a true-positive result, as false-positive results are nearly as common as true-positive results.
- The anterior compartment is recommended for measurement as it has been proven to be most frequently involved, is thought to be representative of the other compartments in patients with tibial diaphyseal fractures, and is easily accessible[19,22].
- Other compartments can be involved in isolation, and if this is thought to be the case, they should be measured. If the symptoms and signs indicate acute compartment syndrome in the absence of a critical ΔP then the pressure in other compartments should be measured. Ultimately, any compartment should be measured if there is a clinical suspicion of acute compartment syndrome.
- Beware of the isolated deep compartment acute compartment syndrome[10,18].
- Much of the research on continuous intracompartmental pressure monitoring has been done in adults with tibial diaphyseal fractures. The efficacy of this technique for other causes and at other sites of acute compartment syndrome, as well as in children, is unknown.

Clinical Comments

- We acknowledge that the optimal diagnostic test would achieve 100% accuracy; however, as in many facets of clinical practice, this is not often seen and both the patient and the surgeon have to accept a small risk with any diagnostic tool.
- In the diagnosis of acute compartment syndrome, we believe that the risk should be weighted toward false-positive rather than false-negative results. We recognize the morbidity associated with fasciotomy[23] but believe that this is less than the morbidity associated with a missed acute compartment syndrome.
- Further work is needed in this area, especially long-term outcome studies analyzing the efficacy of intracompartmental pressure monitoring.
- Data on children with acute compartment syndrome as well as data on acute compartment syndrome in other regions of the body would aid in determining the usefulness of intracompartmental pressure in these patients as well as the critical differential pressure in these clinical scenarios.
- Level-I diagnostic evidence requires adequately powered prospective randomized controlled trials of clinical signs versus continuous intracompartmental pressure monitoring but the logistics of performing such studies is highly complex and unlikely to be achievable[20].

Appendix

The Compartment Monitoring and Pain Assessment chart used in our unit is available with the online version of this article as a data supplement at jbjs.org.

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Figures

Fig. 1
A fourteen-gauge central venous slit catheter and trocar.
Fig. 2
Preparation of the slit catheter, with longitudinal slits made in the end to give it a “castellated” appearance.
Fig. 3
Estimation of the entry point (arrow) on the anteroposterior radiograph of a midshaft tibial diaphyseal fracture. The entry point should be proximal to the fracture site and 1 to 2 cm lateral to the lateral subcutaneous border of the tibia.
Fig. 4
Confirmation of slit catheter placement with use of dye, with the tip within 5 cm of the fracture level.

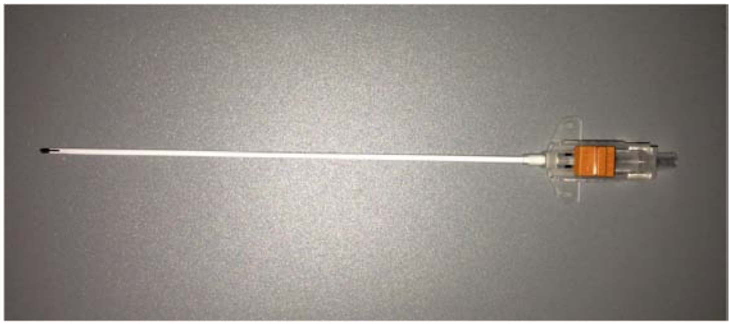

Fig. 1

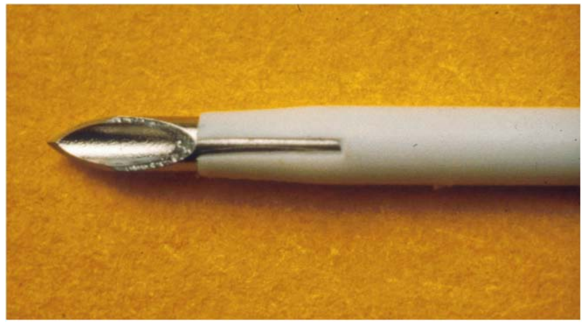

Fig. 2

Fig. 3

Fig. 4

Tables

TABLE I The Estimated Diagnostic Performance Characteristics of Compartment Pressure Monitoring in the Diagnosis of Acute Compartment Syndrome Following a Tibial Diaphyseal Fracture*	
Diagnostic Performance Characteristic	Value†
Sensitivity	0.940 (0.890 to 0.968)
Specificity	0.984 (0.972 to 0.991)
Positive predictive value	0.928 (0.875 to 0.959)
Negative predictive value	0.987 (0.976 to 0.993)
Positive likelihood ratio	59.818 (33.236 to 107.661)
Negative likelihood ratio	0.061 (0.032 to 0.115)

*Reprinted from: McQueen MM, Duckworth AD, Aitken SA, Court-Brown CM. The estimated sensitivity and specificity of compartment pressure monitoring for acute compartment syndrome. J Bone Joint Surg Am. 2013 Apr 17;95(8):673-7.
†The value is given as the ratio of the estimated diagnostic performance characteristic, with the 95% confidence interval in parentheses.