Ultrasound Guided Compartment Pressure Test for Chronic Exertional Compartment Syndrome: A Standard Reproducible Protocol

Part 1: Ultrasound anatomy of the lower leg compartments

Part 2: A standard reproducible protocol for ultrasound guided compartment testing

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Abstract. Compartment pressure testing for exertional leg pain remains the gold standard for diagnosing chronic exertional compartment syndrome. To date nobody has documented an ultrasound guided standard protocol for ultrasound guided compartment pressure testing. Musculoskeletal diagnostic ultrasound is a highly valuable, rapid and inexpensive tool in the armamentarium of the sports medicine physician. From 2008 to 2020, the principal author performed 235 compartment pressure tests with zero complications. A referral center for compartment pressure testing, 92.8% of tests were positive. Ultrasound anatomy of the lower leg compartments can easily be mastered with practice. Once mastered by the sports medicine clinician, patients with chronic exertional compartment syndrome can be imaged with ultrasound in the office for ultrasound guided compartment pressure testing, ultrasound evaluation for compartment swelling with exercise, and treatment with ultrasound guided botulinum toxin injections. A standard reproducible protocol for ultrasound guided compartment pressure testing is described herein yielding zero complications by the principal author over a period of 16 years.

Keywords: Chronic Exertional Compartment Syndrome; Exertional Leg Pain; Musculoskeletal Ultrasound; Ultrasound Guided; Compartment Pressure Test

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Introduction:

Part 1: Ultrasound Anatomy of the Lower Leg Compartments

Anterior Compartment

The anterior compartment of the lower leg is bordered medial by the lateral surface tibia, posterior by the interosseous membrane, and laterally by the anterior intermuscular septum and part of the medial surface fibula, and anterior by deep fascia beneath the skin and subcutaneous tissue [1] (Figure 1). The hyperechoic linear echo of the tibia cortex and interosseous membrane and the superficial nature of the hyperechoic anterior fascia serve as easy landmarks to outline the anterior compartment under transverse ultrasound imaging (Figure 2).

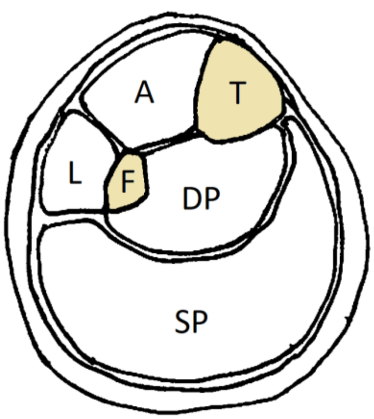

Figure 1. Lower Leg Compartments A. Anterior, L. Lateral, DP. Deep Posterior, SP. Superficial Posterior, T. Tibia, F. Fibula.

The muscles of the anterior compartment, the tibialis anterior muscle, extensor hallucis longus, and extensor digitorum longus muscle can also be differentiated and seen under dynamic imaging. The neurovascular bundle made up of the anterior tibial artery and veins and deep peroneal nerve are located deep along the interosseous membrane close to the tibia (Figure 3). The pulsatile nature of the small anterior tibia artery, allows the neurovascular bundle to be been, even without Doppler.

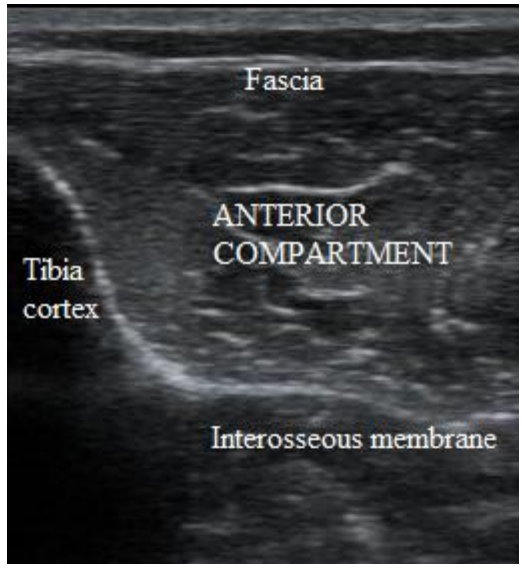

Figure 2. Anterior Compartment

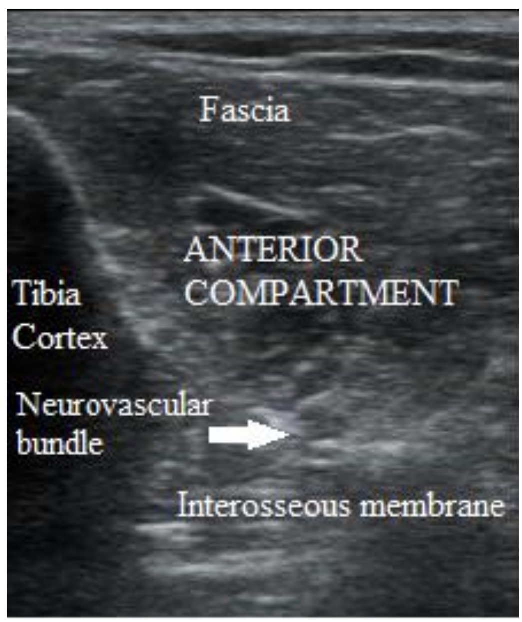

Figure 3. Anterior Compartment Neurovascular Bundle.

Lateral Compartment

The lateral compartment of the lower leg is bordered medially by the fibula, posterior by the posterior intermuscular septum, laterally by fascia, beneath the skin and subcutaneous tissue, and anteriorly by the anterior intermuscular septum [1] (Figure 1). The hyperechoic linear echo of the peroneal surface of the fibula cortex can be easily identified under longitudinal and transverse ultrasound imaging (Figure 4, 5). The peroneal brevis deep along the fibula cortex and the more superficial peroneal longus muscle can be easily identified under ultrasound examination as well in both transverse and longitudinal views. The superficial peroneal nerve lies within the lateral compartment.

Figure 4. Lateral Compartment Transverse Ultrasound View.

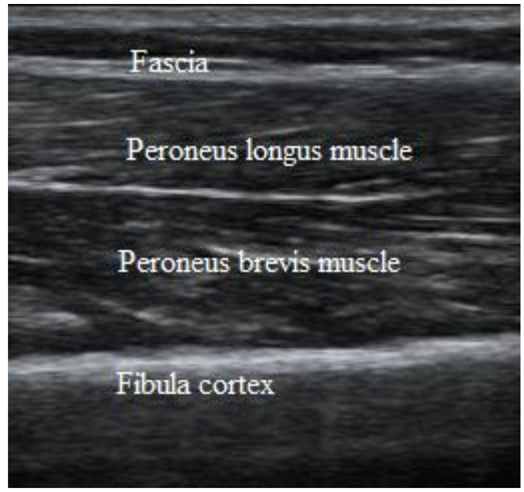

Figure 5. Lateral Compartment Long View.

Superficial Posterior Compartment

The superficial posterior compartment of the lower leg, the largest compartment, contains the gastrocnemius muscle (medial and lateral belly), soleus muscle, and the small plantaris tendon and muscle [1] (Figure 6). The hyperechoic, linear echo of the gastrocnemius and the deeper, more hypoechoic soleus muscle can be easily seen in both long and transverse ultrasound imaging, with a hyperechoic linear fascial echo separating the two muscles and another hyperechoic linear echotexture separating the superficial compartment from the deep posterior compartment (Figure 7).

Figure 6. Superficial Compartment.

Deep Posterior Compartment

The deep posterior compartment of the lower leg lies beneath the soleus muscle, and is bordered deep by the fibula bone laterally, the interosseous membrane centrally, and the tibia bone medially [1] (Figure 1). The hyperechoic, linear echotexture of the smaller fibula bone and then larger tibia bone can be easily identified under ultrasound examination in transverse imaging with a hyperechoic linear interosseous septum connecting the two (Figure 8). The deep posterior compartment contains the tibialis posterior muscle, the flexor digitorum longus muscle, and the flexor hallucis longus muscle, along with the popliteus muscle proximally. The muscles can be easily differentiated under ultrasound examination using the hyperechoic linear echoes of the fibula, septum, and tibia as anatomical guidance. The deep posterior compartment neurovascular bundle, which contain the posterior tibial artery, veins, and tibial nerve, can be seen under ultrasound guidance, with or without Doppler, due to the pulsatile nature of the posterior tibial artery especially post exercise.

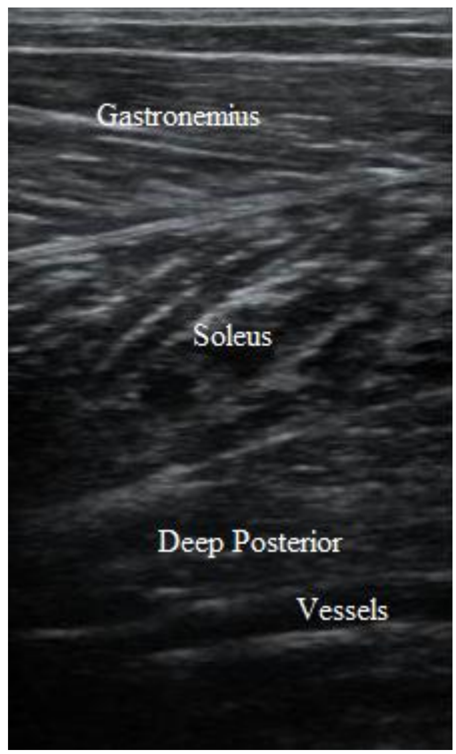

Figure 7. Deep Posterior Compartment Long View.

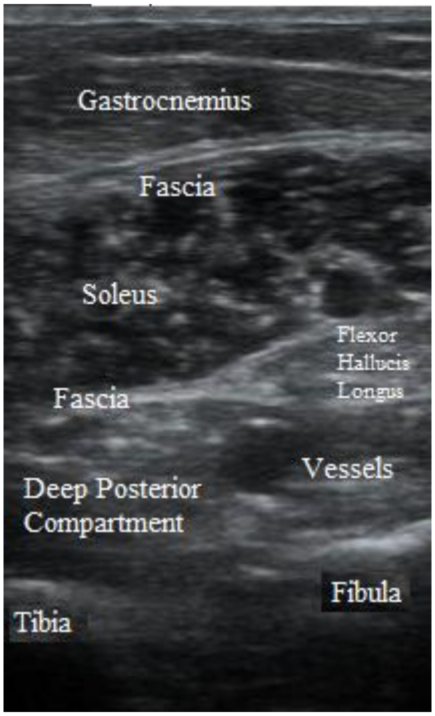

Figure 8. Deep Posterior Compartment Transverse View.

Discussion:

Musculoskeletal diagnostic ultrasound is a highly valuable, rapid and inexpensive tool in the armamentarium of the sports medicine physician. However, there is a dearth of scientific articles on ultrasound examination of the lower leg, especially scarce in relation to evaluating exertional leg pain.

Ultrasonography of medial gastrocnemius muscle tears, referred to as 'tennis leg', a common cause of posterior calf pain, has been well documented in the literature [2]. Crural fascia herniations have been previously illustrated in the literature with dynamic ultrasound demonstrating fascial defects upon standing and provocation [3].

The normal crural fascia under ultrasound examination should appear as a thin lamina of hyperechoic connective tissue estimated to have a mean thickness of 1.1mm in healthy subjects [4].

Webborn [5] in 2014 demonstrated with ultrasound an acute tear of the fascia cruris at the attachment to the Achilles tendon. Silberman reported in 2017 via ultrasound imaging, thickening of the fascia between the medial gastrocnemius muscle and soleus, present in a high school runner diagnosed with exertional compartment syndrome [6] (Figure 9) and in a separate case, thickening of the superficial fascia between the medial gastrocnemius and the subcutaneous tissue [6] (Figure 10).

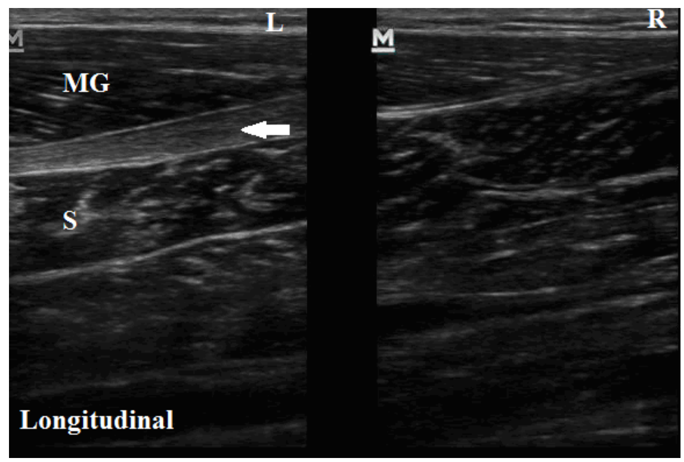

Figure 9. Thickening of fascia between the medial gastrocnemius (MG) and soleus (S) muscle.

If you want to learn something new, read something old. As far back as 1982, Gerhsuni reported on ultrasound examination of the anterior compartment of the lower leg following exercise [7]. Two recent studies suggest that ultrasound may show promise as a useful tool in the assessment of CECS of the anterior compartment [8, 9]. Both studies revealed a significant increase in anterior compartment depth as measured on ultrasound post exercise to symptoms in those with anterior compartment syndrome. This was easily reproduced in our experience (Figure 11) with a significant increase in the post exercise measurement of the anterior compartment depth, in an athlete with anterior exertional symptoms and a positive elevated anterior compartment pressure test. In a little known study from 1983 [10], only one of its kind found in the literature, Christensen et al. reported on five middle-aged men with chronic compartment syndrome who were successfully treated with diuretic medication. Based on Christensen's work and the hypothesis that exercise is associated with fluid accumulation in muscle as a result of osmosis and filtration [11], we too have had success prescribing low dose diuretics in treating our athletes with CECS, with or without symptom swelling, based on ultrasound examination of increased anterior compartment depth post exercise.

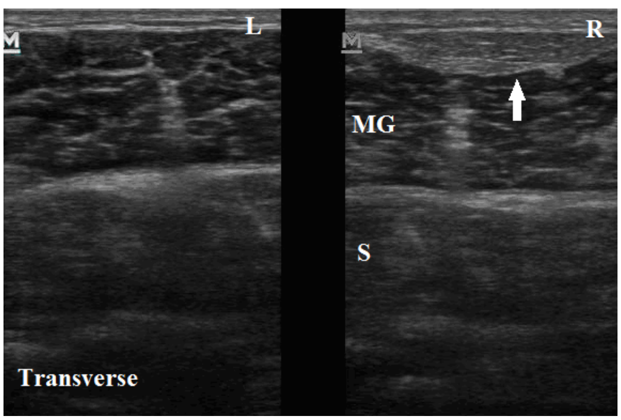

Figure 10. Thickening of superficial fascia between medial gastrocnemius muscle (MG) and subcutaneous tissue.

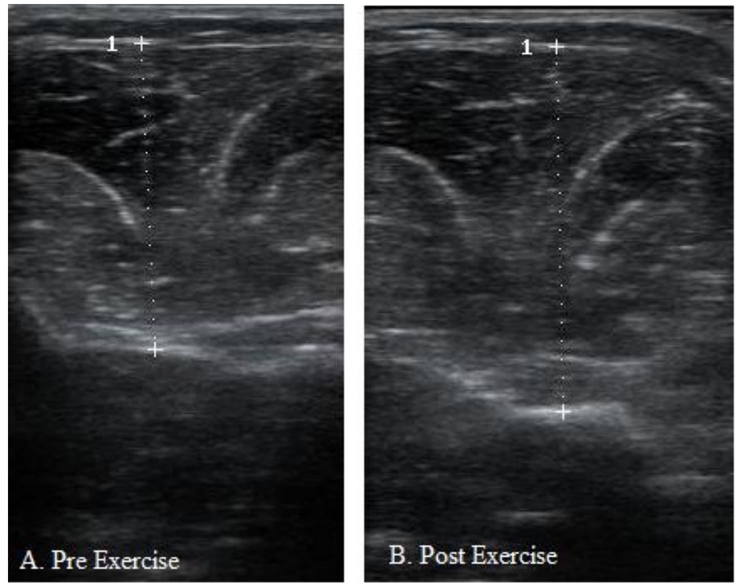

Figure 11. Anterior compartment depth measurement pre and post exercise. A. Pre-exercise depth 3.07 cm. B. Post-exercise depth 3.66 cm.

Conclusion:

Once the normal anatomy is mastered by the physician ultrasonographer, a standard reproducible ultrasound guided compartment testing protocol can be implemented in clinical practice as outlined in Part 2.

Part 2: A standard reproducible protocol for ultrasound guided compartment testing

Introduction:

Between 2008 and December 2020, the principal author performed 235 muscle compartment tests for the evaluation of exertional leg pain. Compartment pressures were measured using the Stryker Intra-Compartmental Pressure Monitor System (Kalamazoo, Michigan). Manufacturer's instructions were followed.

There were zero complications.

The assertion that compartment testing is painful, invasive, and risky is unfounded [9, 12, and 13].

When compartment testing is performed by an experienced physician with the standard protocol used below, the procedure is no more painful, and often said by our patients to be less painful, than orthopedic injections they had received at outside institutions.

The current gold standard for diagnosing compartment syndrome is direct measurement of intramuscular pressure and the protocol outlined in this article has been found to be reproducible when performed by an experienced physician.

Protocol:

Only two needle insertion points are used to test the four compartments (Figure 12). Lateral marked site for anterior compartment and lateral compartment. Medial marked site for superficial compartment and deep posterior compartment.

Figure 12. Two needle entry points for testing of all four compartments.

Local 1% lidocaine is used for creating a skin wheal at each entry point and is then injected further under US guidance with a 25g needle down to the fascia but not penetrating the fascia.

All four compartments are tested in both legs, both at rest and post running exercise to symptoms.

Testing of all four compartments in both legs is performed at rest and post exertion to symptoms after a treadmill stress test unless the athlete specifically states that a certain activity would bring their symptoms on more, such as the addition of jumping for a basketball player, and then that activity is specifically added to the treadmill run. Plantar and dorsiflexion is not sufficient of a stress.

The anterior compartment is tested via a horizontal needle entry laterally with an in-plane approach (Figure 13).

Figure 13. Anterior compartment test.

The lateral compartment is tested via a vertical needle entry, through the same entry site used for the anterior compartment, also with an in-plane approach (Figure 14).

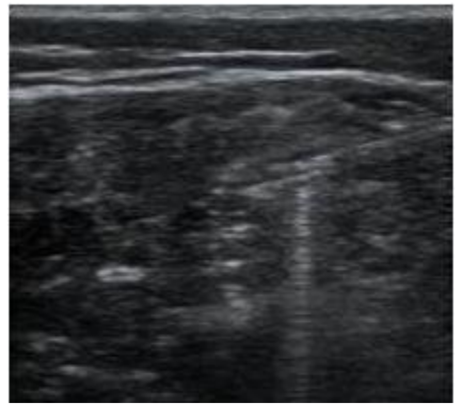

Figure 14. Lateral compartment test.

The superficial compartment is tested via a horizontal or slightly angled entry medially with an in-plane approach (Figure 15).

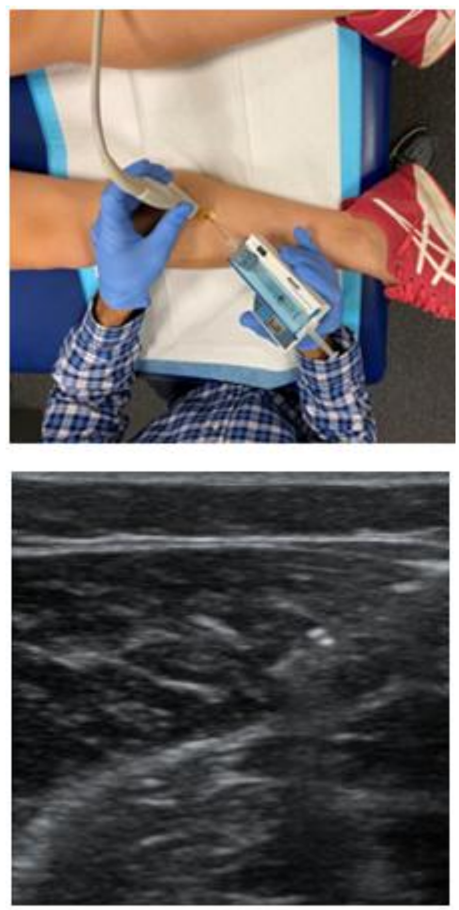

Figure 15. Superficial compartment test.

The deep posterior compartment is tested via a more angled needle entry, through the same entry site used for the superficial compartment, also with an in-plane approach (Figure 16). For those with larger muscular girth, prone positioning with probe in transverse position may be used for in plane medial to lateral approach.

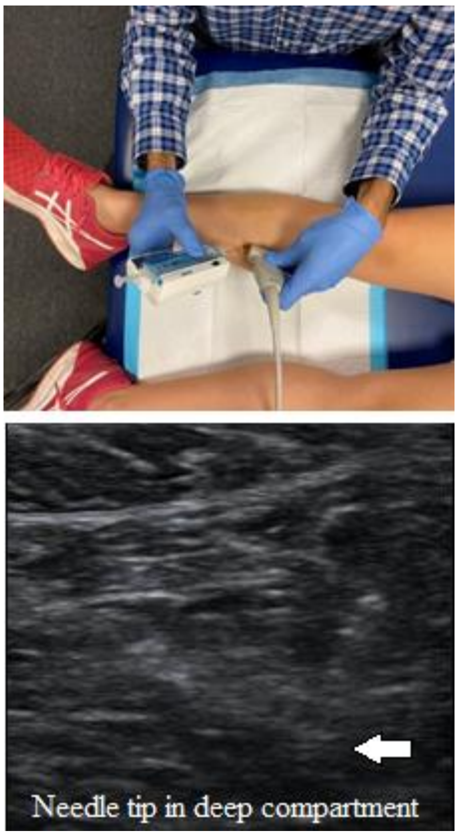

Figure 16. Deep posterior compartment test. Due to obliquity of needle angle away from transducer, continuous direct visualization during the procedure allows needle tip to be seen advancing into the deep posterior compartment.

The reference criteria used for the diagnosis of chronic exertional compartment syndrome is that of Pedowitz et al. from their classic article [14].

"In the presence of appropriate clinical findings", Pedowitz considered one or more of the following intramuscular pressure criteria to be diagnostic of chronic exertional compartment syndrome of the leg: 1) a pre-exercise pressure greater than or equal to 15 mm Hg, 2) a 1 minute post-exercise pressure of greater than or equal to 30 mm Hg, or 3) a 5 minute post-exercise pressure greater than or equal to 20 mm Hg [14].

A five minute post exercise test is not performed by the author and need not be performed in the author's experience.

Results:

Between 10/10/2008 to 12/14/2020 a total number of 235 compartment tests were performed by the principal author with zero complications. There were zero infections, zero hematoma or bleeding events, and zero nerve injuries.

The percentage of positive cases was 92.77% (218/235).

The percentage of unilateral positive cases was 24.77% (54/218).

The percentage of bilateral positive cases was 75.23% (164/218).

The percentage of patients diagnosed with anterior compartment syndrome alone was 8.26% (18/218); the percentage of patients diagnosed with both anterior and lateral compartment syndrome was 8.26% (18/218 of total positive cases).

The percentage of patients diagnosed with both anterior (and anterior/lateral) and deep posterior (and deep/superficial posterior) compartment syndrome was 76.15% (166/218).

The percentage of patients diagnosed with deep posterior compartment alone was 5.96% (13/218).

The percentage of patients diagnosed with deep posterior compartment and superficial posterior compartment syndrome was 1.37% (3/218).

The percentage of patients diagnosed with isolated lateral exertional compartment syndrome was 0%.

The percentage of patients diagnosed with isolated superficial exertional compartment syndrome was 0%.

The average pressure in those diagnosed with chronic exertional anterior compartment syndrome was: 47.05 mm Hg.

The average pressure in those diagnosed with chronic exertional deep posterior compartment syndrome was: 33.56 mm Hg.

Discussion:

Exertional leg pain and chronic exertional compartment syndrome is a troubling problem for the athlete but need not be troubling to the clinician. When performed by an experience physician with a standard protocol, chronic exertional compartment testing is reproducible, with no more risk or pain than other sports medicine injections.

Under no circumstances should the procedure be performed without local anesthetic. Local lidocaine injection will not affect the results and will not inhibit the ability of the athlete to exercise, as reported by our patients to have been told when extremely painful CECS testing was performed at outside offices with *no* local anesthetic.

We ask that the terms invasive compartment pressure (ICP) testing [12] and the use of the term “invasive intramuscular pressure” (IMP) [9] not be used. The compartment testing needle penetrates the skin, subcutaneous tissue, and muscle, which is less invasive than an epidural injection, less invasive than a joint injection, and less invasive than a venipuncture (which directly enters a patient’s circulatory system).

In a survey of military orthopedic surgeons, 39% stated they would recommend surgical treatment without compartment testing if they were confident about the diagnosis based on clinical examination [12]. We find this troubling, given the invasiveness and permanence of a surgery with a high failure rate, more likely higher than previously published. Waterman et al reported in a large study on military personnel who underwent fasciotomy for CECS, a symptom recurrence in 44.7%, with 27.7% unable to return to full activity, surgical complications in 15.7%, with 17.3% referred for medical discharge having failed surgery [15].

The pressures referenced by Pedowitz are not to be taken as carved in stone. A resting pressure of greater than or equal to 15 mm Hg and a one minute post exercise of greater than 30 mm Hg, cited by Pedowitz as a positive test [14], are used as a reference point.

All four compartment pressures should be compared both at rest and with exertion, in addition, to their delta change from rest to post exertion, their peak opening initial pressure readings pre- and post- exercise, and whether there was a slow or rapid decline to the stable pressure reading.

By testing all four compartments, the pressures will tell a story that should support the diagnosis based on the symptom location, either anterior lateral to the tibia or posterior medial to the tibia or both.

In addition to CECS testing at our facility, all of our athletes with exertional leg pain also undergo an Ankle Brachial Index (ABI) test at rest and post treadmill stress testing along with ultrasound measurement of the anterior compartment depth at rest and post treadmill stress testing. Ankle plantar and dorsiflexion is not sufficient of an exercise challenge for ABI or ultrasound examination for swelling. Blood work should also be done all patients with exertional leg pain, to rule out anemia, low iron, thalassemia, vitamin deficiencies, and other metabolic causes or contributing factors.

Conclusion:

Compartment testing for exertional leg pain remains the gold standard for diagnosing chronic exertional compartment syndrome. When compartment testing is performed by an experienced physician with the standard protocol outlined above, the procedure is no more painful and carries less risk than routine orthopedic sports medicine injections.

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Competing Interests:

The authors declare they have no competing interests.

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