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Measuring Intracompartmental Pressures in the Lower Leg

Assessing the Use of Unilateral Measurements in Patients with Bilateral Symptoms

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Background: The purpose of the present study was to evaluate whether unilateral intracompartmental pressure (ICP) measurements correctly represent the contralateral ICP value in patients suspected to have bilateral chronic exertional compartment syndrome (CECS) in the anterior compartment of the leg.

Methods: A retrospective cohort study was performed that included military service members who had been referred to a secondary care department for bilateral anterolateral exercise-related leg pain. The obtained ICP values were utilized to assess 2 possible measurement strategies to perform unilateral ICP measurements: the right-leg strategy (i.e., always testing the right leg) and the most-symptomatic-leg strategy (i.e., always testing the most symptomatic). The diagnostic cutoff value for CECS in this cohort was 35 mmHg in the first minute after provocation. Four outcome categories were created to describe the pressure classification of the second leg if only 1 leg would have been measured: correct (category 1: both values ≥35 mmHg; category 2: both values <35 mmHg) or incorrect (category 3: measured leg, ≥35 mmHg and contralateral leg, <35 mmHg; category 4: measured leg, <35 mmHg and contralateral leg, ≥35 mmHg).

Results: A total of 442 patients (884 legs) were included. In 88% of patients, the unilateral value would have correctly diagnosed the other symptomatic leg, whereas in 12% of patients, the contralateral leg would have been diagnosed incorrectly. The right-leg strategy had a slightly smaller proportion of cases in which the contralateral leg would have been incorrectly diagnosed (7% compared with 8% for the most symptomatic leg strategy). In 89% of the 390 patients in categories 1 and 2, the ICP values deviated by >5 mmHg from the 35-mmHg cutoff value compared with 40% of the 52 patients in categories 3 and 4.

Conclusions: In military service members with bilateral chronic anterolateral exertional pain, a unilateral ICP measurement seems to be justified, especially among those with pressure values >5 mmHg above or below the diagnostic cutoff value. When a unilateral pressure measurement is within 5 mmHg above or below the cutoff value, a bilateral ICP measurement may be warranted.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Chronic exertional compartment syndrome (CECS) is an overuse injury with a transient and reversible character, responsible for exercise-induced symptoms in both civilian athletes and military service members. Although CECS can affect all muscle compartments of the body, the anterior compartment of the lower leg is most frequently affected, accounting for 40% to 77% of CECS cases[1-4]. The symptoms, typically described as pain and tightness, are thought to result from a disruption in blood flow or nerve impulses secondary to a pathological increase in intracompartmental pressure (ICP) inside an osseofascial compartment[5,6]. The diagnosis of CECS in a muscle compartment is confirmed by measuring ICPs after symptom provocation, utilizing invasive needle manometry[7,8]. However, there is no consensus in the international literature regarding the execution of an ICP measurement and the diagnostic cutoff value for CECS[7-10].

The execution of an ICP measurement is considered a user-dependent investigation because a universally accepted protocol is absent and variations exist in the use of commercially available pressure monitors[11,12]. Hislop and Tierney[12] found discrepancies in the number of legs tested in these protocols, as half of the interviewed specialists would routinely test both limbs. Specifically, 77% would measure the

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symptomatic compartments in only 1 leg. A potential argument in favor of limiting ICP measurement to 1 limb seems to be the invasive and painful nature of the test together with the risk of incorrect placement of the catheter[13,14]. On the contrary, a study by Zimmermann et al.[4] examined the potential needle pain and concluded that limiting the number of ICP measurements for this reason seemed unjustified. The question whether a positive ICP measurement in 1 limb can confirm the existence of bilateral CECS represents a long-standing gap in clinical knowledge.

Despite the flaws of ICP testing for the diagnosis of CECS reported in the international literature, clinicians may consider the use of measurements made at 1 minute after exercise and utilize locally established protocols for the execution of diagnostic testing[7]. In fact, a study among military orthopaedic surgeons revealed that 85% would recommend this invasive test to confirm the presence of CECS[15]. Also, only 39% would recommend surgical treatment on clinical examination alone. For this reason, ICP measurement is often still part of standard care and is performed in 1 or both limbs according to the preference of the practitioner. In cases of bilateral symptoms, however, it is unknown whether a positive ICP measurement in 1 limb can confirm with certainty the existence of bilateral CECS.

The aim of the present study was therefore to assess whether unilateral ICP measurements could correctly represent the ICP value of the contralateral leg, thereby evaluating the need to routinely perform bilateral ICP measurements in patients suspected of having bilateral anterior CECS.

Materials and Methods

Study Design

This study was a retrospective evaluation of standard care provided to military service members in a secondary, multidisciplinary setting (i.e., surgery, sports medicine, and psychiatry). National law does not require ethical approval for this type of study. All patients gave informed consent, agreeing to the scientific and anonymous use of relevant clinical data.

Study Population

Military service members with bilateral exercise-related leg pain on the anterolateral side of the leg (i.e., suspected anterior CECS) were eligible. Patients with concomitant presence of posteromedial tibial pain (i.e., indicative of medial tibial stress syndrome) were eligible for inclusion as well. At the time of intake, all patients were screened and bilateral ICP measurement of the anterior compartment was performed. All patients underwent a locally standardized symptom provocation test and pain scoring system, both described previously (Fig. 1)[4].

Patients were included if subjective exertional pain scores over the anterolateral side of the leg were ≥2 (on a 0-to-10 scale) in both legs. If ≥1 pain score or ICP value of the anterior compartment was missing, patients were excluded.

ICP Measurements

As recommended in the literature, the diagnosis of CECS was made with use of a locally developed protocol for the execution of ICP measurements and according to locally established cutoff values[7]. The ICP measurements were performed by a single senior sports physician with use of a Stryker pressure monitor device[4,16]. Immediately before the standardized provocation test on a treadmill, patients were given subcutaneous anesthetics (1 to 2 mL xylocaine 1.0%) at a marked location for ICP measurement, centrally in the anterior compartment (approximately 10 cm distal to the tibial tubercle and 2 cm lateral to the anterolateral border of the tibia). The table for ICP measurement was placed immediately adjacent to the treadmill, so that transfer of the patient from the treadmill to the table to assume the position for ICP measurement was completed within 10 seconds. The patient was placed in the supine position with the legs hanging vertically off of the edge of the table in order to ensure that the muscles of the lower leg were relaxed during ICP measurement. A single ICP measurement was performed in each leg, in the same order for every patient: right leg first, left leg second. The time to complete the ICP measurement in 1 leg was approximately 20 seconds. Steps for ICP measurement included introduction of the needle, 15 seconds for the device to show a stable measurement, needle retraction, and placement of a simple bandage. By 1 minute after exercise, ICP measurement in both legs was completed. The procedure described here has been the same for many years and has been reported in several publications[4].

Fig. 1

The Running Leg Pain Profile scores exertional pain minute by minute during a treadmill provocation test in running shoes, for 4 regions of the leg: the right anterolateral (region 1), right posteromedial (region 2), left posteromedial (region 3), and left anterolateral (region 4) region. Patients are asked every minute to give a pain score of 0 to 10 for 4 regions of the legs. The resulting pain profile can assist the clinician in determining a detailed diagnosis, with region 1 and 4 indicative of anterior CECS or biomechanical overload syndrome and region 2 and 3 of medial tibial stress syndrome.

Data Collection

Patient data were aggregated in an encoded electronic database and included the patient age (in years), gender (female = 0,

TABLE I Outcome Categories

	Contralateral Leg ≥35 mmHg*	Contralateral Leg <35 mmHg*
Measured leg ≥35 mmHg	Category 1 (both elevated)	Category 3 (only measured leg is elevated)
Measured leg <35 mmHg	Category 4 (only contralateral leg is elevated)	Category 2 (both normal)

*The contralateral leg is the left leg for measurements made with use of the right-leg strategy and the least symptomatic leg for measurements made with use of the most-symptomatic-leg strategy.

male = 1), and concomitant presence of posteromedial pain (none = 0, unilateral = 1, bilateral = 2). The ICP values of the anterior compartments were retrieved, as well as the subjective exertional pain scores (Fig. 1) at intake.

Diagnostic Applicability

A unilateral ICP measurement can be performed according to various protocols. Two measurement strategies were evaluated in the present cohort. For the first measurement strategy, the unilateral ICP measurement would always be performed in the right leg (right-leg strategy), and for the second measurement strategy, the unilateral ICP measurement would always be performed in the most symptomatic leg (most-symptomatic-leg strategy). The most symptomatic leg was determined by means of the highest patient-reported exertional pain score during the standardized exercise test.

Statistical Analysis

Statistical analysis was performed with use of SPSS (version 26; IBM). The characteristics of the study population were presented with appropriate measures of central tendency and dispersion. The effect of the delay (a maximum 30 seconds) between the ICP measurements in the right and left legs was evaluated with use of a paired-samples t test. P values (2-sided) of ≤0.05 were considered significant.

Each value was classified as elevated (≥35 mmHg) or normal (<35 mmHg) according to the locally established cutoff value of 35 mmHg. Subsequently, all obtained ICP values were plotted to evaluate the magnitude of pressure variation. Next, 4 different outcome categories were created to evaluate the 2 possible unilateral measurement strategies (Table I): (1) patients with ICPs of ≥35 mmHg in the anterior compartments of both legs, (2) patients with ICP values of <35 mmHg in both legs, (3) patients with an ICP of ≥35 mmHg in the right or most symptomatic leg and an ICP of <35 mmHg in the contralateral leg, and (4) patients with an ICP value of <35 mmHg in the right or most symptomatic side and ≥35 mmHg in the contralateral leg. In outcome categories 1 and 2, the value of a unilateral ICP measurement would also correctly indicate the pressure group of the contralateral side, whereas in outcome categories 3 or 4, the pressure group of the contralateral leg would be indicated incorrectly. The allocation of patients among these outcome categories was performed once for each of the 2 measurement strategies defined in the Diagnostic Applicability section.

Source of Funding

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Results

From 2013 through 2019 (7 calendar years), a total of 719 military service members with chronic exercise-related leg pain were evaluated in a secondary, multidisciplinary setting (i.e., surgery, sports medicine, and psychiatry). In this cohort, 442 patients were diagnosed with bilateral exertional pain on the anterolateral side of the leg. The remaining 277 patients were excluded for the following reasons: no or unilateral anterolateral leg pain (n = 234) or missing ICP values or Running Leg Pain Profile scores (n = 43). Baseline characteristics of the study population are shown in Table II.

Results of Bilateral ICP Measurements

ICP values were obtained in the anterior compartments of both legs of 442 patients (884 legs) (Fig. 2), and ranged from 7 to 140 mmHg. The mean ICP (and standard deviation) in the right leg was 55 ± 26 mmHg, compared with 54 ± 26 mmHg in the left leg (p = 0.03).

A total of 390 patients (88%) had ICP values of ≥35 mmHg in both legs (n = 305, outcome category 1) or ICP values of

TABLE II Patient Characteristics (N = 442)*

Age *(yr)*	23, 21-27
Male gender	377 (85%)
Concomitant posteromedial tibial pain	
None	208 (47%)
Unilateral	40 (9%)
Bilateral	194 (44%)
Anterior compartment ICP values at intake *(mmHg)*	54 ± 26

*Values are given as the mean and interquartile range, the count with the percentage in parentheses, or the mean ± standard deviation.

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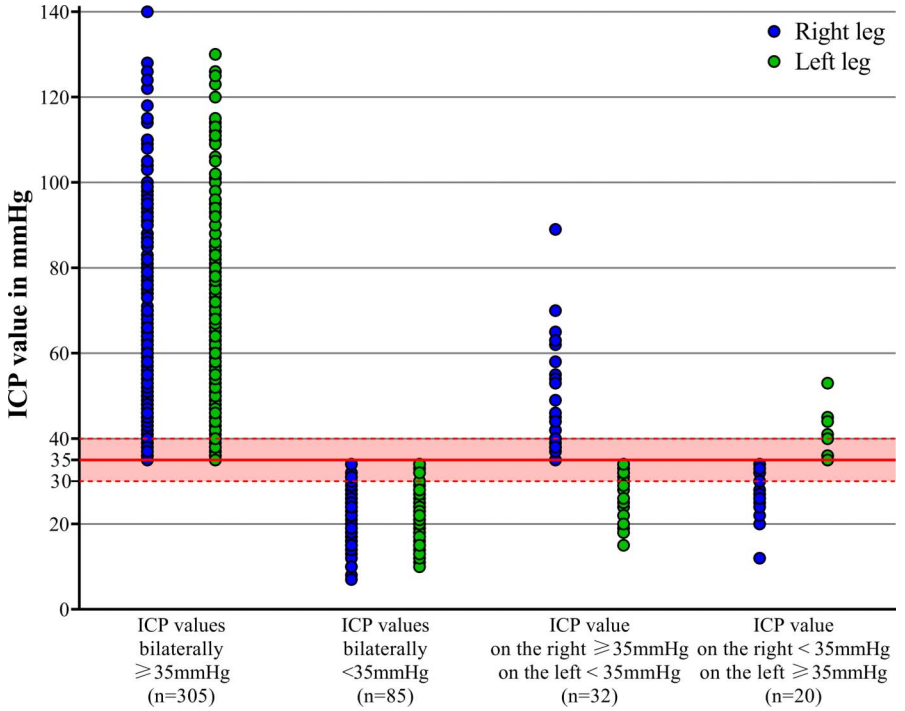

Fig. 2

Overview of ICP values for the right and left legs of all 442 included service members. Patients were categorized according to the clinical diagnosis corresponding to the ICP measurements (i.e., CECS in both legs, CECS in neither leg, CECS in only the right leg, and CECS in only the left leg). The continuous red line represents the locally established cutoff value of 35 mmHg, and the dotted red lines represent the range of 5 mmHg above and below this cutoff value.

<35 mmHg in both legs (n = 85, outcome category 2). Ninety-five (11%) of the ICP values for patients in outcome categories 1 and 2 were found to be in the range of 30 to 40 mmHg, which is within 5 mmHg of the diagnostic cutoff value of 35 mmHg.

There were 52 patients (12%) in outcome categories 3 and 4, which represented ICPs of ≥35 mmHg in 1 anterior compartment (suggestive for CECS) and <35 mmHg in the contralateral leg (negative for CECS). The ICP values of the patients in outcome categories 3 and 4 ranged from 12 to 89 mmHg. A total of 62 (60%) of the 104 ICP values in outcome categories 3 and 4 were within 5 mmHg of the diagnostic cutoff value of 35 mmHg.

Comparing 2 Possible Measurement Strategies

A unilateral ICP measurement made with use of the right-leg strategy would have led to an incorrect clinical diagnosis in the contralateral leg in 52 patients (12%) (Table III). A unilateral ICP measurement made with use of the most-symptomatic-leg strategy would have led to an incorrect clinical diagnosis in the contralateral leg in 52 patients (12%) (Table IV).

Discussion

The primary research question for this study was whether unilateral ICP measurements could correctly represent the contralateral ICP value in the legs of military service members suspected of having bilateral anterior CECS. In the cohort of 442 patients (884 legs), it was found that a single ICP measurement would correctly predict the pressure group of the other symptomatic leg in 88% of cases. A total of 52 patients (12%) would have received an incorrect diagnosis in the contralateral leg if ICP measurement had been performed in 1 leg only. The right-leg strategy scored slightly better compared with the most-symptomatic-leg strategy (7% versus 8% of unilateral ICP measurements would incorrectly have suggested a pressure of ≥35 mmHg for the contralateral leg, respectively).

The invasive nature of ICP measurements endorses an evaluation of whether bilateral ICP measurements are necessary in patients with suspected bilateral CECS. There are few studies available in the literature that provide evidence-based

TABLE III Accuracy of the Right-Leg Strategy Involving a Single Intracompartmental Pressure Measurement*

	Left Leg ≥35 mmHg	Left Leg <35 mmHg
Right leg ≥35 mmHg	**305 (69%)**	32 (7%)
Right leg <35 mmHg	20 (5%)	**85 (19%)**

*Based on the locally established diagnostic cutoff, in which ≥35 mmHg is considered elevated, indicating CECS. Values are given as the number of patients with the percentage in parentheses. Boldface indicates that measuring only 1 leg using the "Always the right leg" strategy would have correctly diagnosed the contralateral leg as well.

TABLE IV Accuracy of the Most-Symptomatic-Leg Strategy Involving a Single Intracompartmental Pressure Measurement*

	Contralateral Leg ≥35 mmHg*	Contralateral Leg <35 mmHg*
Most symptomatic leg ≥35 mmHg	**305 (69%)**	34 (8%)
Most symptomatic leg <35 mmHg	18 (4%)	**85 (19%)**

*Based on the locally established diagnostic cutoff, in which ≥35 mmHg is considered elevated, indicating CECS. Values are given as the number of patients with the percentage in parentheses. Boldface indicates that measuring only 1 leg using the most-symptomatic-leg strategy would have correctly diagnosed the contralateral leg as well.

arguments in favor of or against the use of bilateral ICP testing. One such study was performed by Hislop and Tierney[12], who found that bilateral ICP measurements are still performed routinely approximately half of the time. At the same time, this diagnostic test is not without risk, given its invasive nature. In a study utilizing magnetic resonance imaging, Winkes et al. reported a hematoma frequency of 38% after needle puncture, although most cases remained asymptomatic[13]. Moreover, it was also demonstrated that nerves, arteries, veins, and tendons can be penetrated while performing ICP measurements[14].

The data indicated that the contralateral leg would have been diagnosed correctly in 390 (88%) of 442 patients, who either had ICPs of ≥35 mmHg (n = 305) or ICPs of <35 mmHg (n = 85) in both anterior compartments. In the majority of patients, the performance of a unilateral ICP measurement would therefore have been sufficient, and potential risks could have been avoided. Thus, the current findings support the reduced use of bilateral ISP measurements.

Although indication for surgical treatment increasingly depends on a suggestive history in combination with failure of nonoperative interventions, some surgical protocols still warrant an ICP measurement[17]. However, it is important to note that several studies have shown that ICP values of the anterior compartment are not strongly associated with surgical outcomes[18-20]. Nevertheless, with ICP measurements still being utilized as an indication for surgical treatment, incorrect categorization could lead to an unnecessary invasive procedure. In the present study, unilateral ICP measurements performed with use of the most-symptomatic-leg strategy would have incorrectly resulted in a diagnosis of CECS in the contralateral leg (category 3) in 7% of patients, thus incorrectly indicating surgical treatment. This percentage would increase to 8% if the unilateral ICP measurement had been performed with use of the right-leg strategy. Conversely, the presence of CECS (a pressure of ≥35 mmHg) in the contralateral leg (category 4) would have been missed in 5% of patients screened with use of the right-leg strategy and 4% of those screened with use of the most-symptomatic-leg strategy. It is up to the surgeon and the patient to decide whether a 12% chance of incorrect categorization makes it acceptable to proceed without testing the other leg. Possibly, the surgeon would prefer to operate on the other compartment as well if the measured leg has an elevated pressure and the patient has bilateral symptoms, even though a measurement of the contralateral leg might have shown a pressure of <35 mmHg, instead of missing CECS as a result of the incorrect projection of an ICP of <35 mmHg on the untested contralateral leg. Of course, once a noninvasive diagnostic test is found that can be performed on both legs simultaneously, the current research question becomes obsolete.

One unexpected finding of this retrospective analysis was that in cases in which the ICP values of both legs corresponded to a similar diagnosis (outcome categories 1 and 2), the respective ICP values were typically not close to the established cutoff value of 35 mmHg. For patients in outcome categories 1 and 2, 89% of the ICP measurements deviated by >5 mmHg from this cutoff value. Only 95 (11%) of 780 ICP measurements were within 5 mmHg above or below the cutoff value. In contrast, 62 (60%) of 104 ICP measurements in outcome categories 3 and 4 were within 5 mmHg of the cutoff value. This finding implies that the following local protocol could be instated for this particular patient group: if the ICP value in the anterior compartment of the right leg is <30 mmHg or >40 mmHg, an ICP measurement of the left leg is not necessary. However, if the ICP value is between 30 and 40 mmHg, an additional ICP measurement in the left leg should be performed. This newly proposed testing protocol requires validation in greater numbers of military patients, and also in recreational and civilian athletes. Additionally, this protocol may need to be adapted if a diagnostic cutoff value other than 35 mmHg is utilized.

The present study had several limitations, the most prominent being that it was based on a locally established diagnostic protocol. A universally accepted diagnostic protocol for CECS is currently not available. Additionally, the generalizability of these results is hampered by the selection of military service members as the study population, given that they are predominantly male and subject to intense physical training. Additionally, bias may have been introduced by performing all ICP measurements in the right leg first, as the mean ICP value in right legs in this study (55 ± 26 mmHg) differed significantly from that in left legs (54 ± 26 mmHg; p = 0.03). Nevertheless, the clinical relevance was considered limited as this difference was only 1 mmHg. Finally, some studies have suggested that CECS isolated to the lateral compartment can clinically mimic CECS of the anterior compartment, and patients in the present study may therefore have received an inadequate diagnosis for their anterolateral pain[21-23]. Nevertheless, this study does suggest a novel testing protocol and suggests directions for future research.

Conclusions

Unilateral ICP measurements seem to be justified in military service members with bilateral chronic anterolateral exertional pain, as CECS would have been correctly diagnosed in the contralateral leg in 88% of cases. When pressure values in the first leg measured are within 5 mmHg above or below a cutoff value of 35 mmHg, a bilateral ICP measurement may be warranted. ■

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