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Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg*

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ABSTRACT

One hundred fifty-nine patients were referred to the authors for evaluation of chronic exertional leg pain from 1978 to 1987. The records of 131 patients were complete and available for retrospective review. Forty-five patients were diagnosed as having a chronic compartment syndrome (CCS) and seventy-five patients had the syndrome ruled out by intramuscular pressure recordings. The only significant difference found between the two groups on history and physical examination was a 45.9% incidence of muscle herniae in the patients with CCS, compared to a 12.9% incidence in those without the syndrome. One-third of the patients with the syndrome and over one-half of those without it reported persistent, moderate to severe pain at 6 month to 9 year followup.

Modified, objective criteria were developed for the diagnosis of CCS. The criteria were based upon the intramuscular pressures recorded with the slit catheter before and after exercise in 210 muscle compartments without CCS. In the presence of appropriate clinical findings, we consider one or more of the following intramuscular pressure criteria to be diagnostic of chronic compartment syndrome of the leg: 1) a preexercise pressure ≥15 mm Hg, 2) a 1 minute postexercise pressure of ≥30 mm Hg, or 3) a 5 minute postexercise pressure ≥20 mm Hg.

Chronic compartment syndrome is defined as a condition in which exercise induces high pressure within a closed space bounded by bone and/or fascia, resulting in decreased tissue perfusion and ischemic pain.[11] However, exercise-induced pain in the lower extremity may be related to a wide variety of conditions, including periostitis and other inflammatory processes, stress fracture, arterial insufficiency, and central or peripheral nervous system disease.[22] Some investigators have reported that CCS can be diagnosed on clinical grounds,[7,16] but most recent studies have emphasized the need for intramuscular pressure measurement in the diagnostic process.[3,19,22]

Although a variety of techniques have been described for the measurement of intramuscular pressure, there is no current consensus regarding the specific criteria for the diagnosis of CCS. Some investigators advocate the use of intramuscular pressures recorded during exercise: for example, the mean muscle pressure,[15] muscle contraction pressure,[10] or muscle relaxation pressure.[24,26] Other investigators support the use of resting pressures before and after exercise.[3,8,11,16,19] The purpose of this study is to review our experience with patients referred for the evaluation of chronic exertional leg pain, in order to improve the criteria for objective diagnosis of CCS.

MATERIALS AND METHODS

Between 1978 and 1987, 159 patients were referred to the Division of Orthopaedics, University of California, San Diego, for evaluation of possible CCS of the leg. One hundred thirty-one of these patients' records were considered complete enough for retrospective analysis. Of these patients, there were 65 females and 66 males, with a mean age of 29 (range, 14 to 80 years). Thirteen of the patients in the present study had been included in a previous review by Fronek and coworkers.[3]

At the time of the pressure study, a pertinent history and

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physical examination were recorded by the evaluating physician. Intramuscular pressures were monitored before, during, and after exercise in the appropriate leg compartments, using the slit catheter (Howmedica, Rutherford, NJ) as described previously,[11] and the pressures recorded on a chart recorder (Hewlett Packard, Waltham, MA). The preexercise resting pressure was recorded with the patient in a relaxed, supine position. Patients then exercised in a sitting position, with the catheters in place, by alternating ankle plantar flexion and dorsiflexion on an isokinetic exercise device (Orthotron, Lumex, Bayshore, NY). Exercise was continued until either reproduction of leg symptoms or muscle exhaustion.

Following exercise, patients returned to the supine position and intramuscular pressures were monitored for at least 5 minutes. The 1 minute and 5 minute postexercise pressures were recorded for each patient. Thirty-seven patients (28.2%) did not have adequate reproduction of their symptoms during the exercise protocol. In these patients, the catheters were removed and the patient either ran or performed calisthenic exercises in order to elicit symptoms. The catheters were then replaced for a repeat measurement of the 5 minute postexercise resting pressure.

An elevated resting pressure or an elevated 5 minute postexercise pressure were considered diagnostic for CCS. Before 1981 we considered a resting pressure of ≥10 mm Hg consistent with a diagnosis of CCS. This threshold was adjusted to a resting pressure of ≥15 mm Hg during later studies as our experience increased. A 5 minute postexercise pressure of ≥25 mm Hg was considered diagnostic of CCS throughout the study. By these criteria, we diagnosed CCS in 80 compartments in 45 patients. Patients who did not meet either of these pressure criteria were considered not to have a compartment syndrome. There were 210 compartments in 75 patients in which CCS was ruled out. Eleven patients had technically inadequate or equivocal pressure studies; these borderline cases were not used for subsequent comparisons.

The patients in this study were referred to the authors by a large number of orthopaedic surgeons who suspected CCS on clinical grounds. The specific treatment plans were determined by the individual physicians after completion of the pressure study. The surgical treatment of CCS by fasciotomy has been described previously.[3,8,11]

Using a questionnaire, we obtained followup ranging from 6 months to 9 years in 21 (46.7%) patients with CCS and in 31 (41.3%) patients in whom CCS was ruled out. Patients described their pain level, activity level, and the presence of weakness or numbness before and after their pressure study. They also reported whether surgery had been recommended or performed.

RESULTS

The historical data for the 45 patients with CCS and 75 patients in whom it was ruled out are presented in Table 1. There were no significant differences in age, sex, duration, location, or nature of symptoms, or in the activities that induced symptoms among both groups.

Data obtained on physical examination are presented in Table 2. There were no differences in the incidence of tenderness to palpation or of abnormalities in distal pulses between the two groups. Of the patients with and without CCS, 19.7% and 17%, respectively, were noted to have either a sensory or motor deficit. A palpable muscle hernia was found in 45.9% of patients with CCS, compared to a 12.9% incidence in the patients without CCS ($P < 0.001$, chi square).

Two hundred ten compartments were studied before and after exercise in the patients ruled out for CCS (Table 3). In these patients, the resting pressure was 7.4 ± 3.6 mm Hg, the 1 minute postexercise pressure was 10.7 ± 7.2 mm Hg,

TABLE 1
Historical data in patients with chronic exertional leg pain

	CCS+[a] (45 Patients)	CCS−[b] (75 Patients)
Mean age (range, years)	26.8 (15–61)	30.8 (14–80)
Sex	55.6% Male	43.8% Male
Mean duration symptoms in months (range)	21.5 (0.8–98)	26.4 (0.2–98)
Symptomatic compartments		
Anterior	60.0%	47.3%
Lateral	34.5%	17.1%
Sup. post.	21.1%	13.0%
Deep post.	32.2%	28.8%
Bilateral pain	15.6%	20.5%
Pain description		
Sharp	20.0%	34.2%
Dull	24.4%	20.5%
Pressure	20.0%	16.4%
Ache	31.1%	43.8%
Cramp	8.9%	15.1%
Fullness	20.0%	13.7%
Unknown	17.8%	12.5%
Symptoms induced by:		
Running	71.1%	57.5%
Other sports	24.4%	27.4%
Walking	24.4%	32.9%
Working	4.4%	6.8%
Pain at rest	17.8%	12.3%
Other/unknown	6.6%	6.8%
Change in activity caused by symptoms	97.0%	94.2%

[a] Patients who had chronic compartment syndrome diagnosed.
[b] Patients who had chronic compartment syndrome ruled out.

TABLE 2
Physical examination in patients with chronic exertional leg pain

	CCS+[a] (45 Patients) (%)	CCS−[b] (75 Patients) (%)
Tender to palpation	73.3	64.8
Distal pulses not normal (not 2+)	11.5	13.9
Motor deficit only	4.4	5.5
Sensory deficit only	8.9	5.5
Motor and sensory deficit	4.4	6.8
Muscle herniae	45.9[c]	12.9[c]

[a] Patients who had chronic compartment syndrome diagnosed.
[b] Patients who had chronic compartment syndrome ruled out.
[c] Chi square, $P < 0.001$.

TABLE 3
Intramuscular pressures before and after exercise[a]

Compartment (No. studied)	Before exercise	After exercise	
		1 minute	5 minutes
CCS−[b] compartments			
Anterior (102)	7.9 (3.4)	12.2 (8.0)	8.9 (4.9)
Lateral (30)	6.8 (4.0)	8.2 (6.1)	5.9 (4.9)
Sup. post. (24)	7.1 (3.8)	7.3 (4.6)	7.0 (3.4)
Deep post. (54)	6.8 (3.5)	10.5 (6.2)	7.9 (5.1)
Mean (210)	7.4 (3.6)	10.7 (7.2)	8.0 (4.9)
CCS+[c] compartments			
Anterior (45)	15.5 (6.8)	44.3 (16.5)	32.5 (13.4)
Lateral (16)	17.1 (4.3)	25.4 (16.0)	18.7 (11.0)
Sup. post. (4)	17.5 (4.2)	22.0 (22.0)	18.5 (1.7)
Deep post. (15)	15.8 (7.2)	25.6 (13.0)	27.0 (16.7)
Mean (80)	16.0 (6.3)	36.9 (18.0)	28.1 (14.4)

[a] Mean pressure in mm Hg (SD).
[b] Patients who had chronic compartment syndrome ruled out.
[c] Patients who had chronic compartment syndrome diagnosed.

and the 5 minute postexercise pressure was 8.0 ± 4.9 mm Hg (mean ± SD). One minute after exercise, the mean intramuscular pressure in the anterior and deep posterior compartments tended to be slightly higher than that in the lateral and superficial posterior compartments.

Eighty compartments in the patients with CCS demonstrated elevated intramuscular pressure (Table 3). The compartments that did not demonstrate abnormally elevated pressure in these patients were excluded from the study (for example, asymptomatic compartments that were studied for reference purposes). In the compartments of patients with CCS, the resting pressure was 16.0 ± 6.3 mm Hg, the 1 minute postexercise pressure was 36.9 ± 18.0 mm Hg, and the 5 minute postexercise pressure was 28.1 ± 14.4 mm Hg (mean ± SD). The pressure in the anterior compartment tended to be higher than in the other compartments 1 minute after exercise. Five minutes after exercise, the anterior and deep posterior compartment pressures tended to be higher than in the other two leg compartments.

The distribution of intramuscular resting pressure before exercise and 1 and 5 minutes postexercise for compartments of both groups are presented graphically in Figure 1, A through C, respectively. In each figure, the mean intramuscular pressure and mean plus two standard deviations are noted for the compartments in which the syndrome was not diagnosed.

Followup was obtained in a total of 52 patients (Table 4). Of the patients with CCS, 61.9% considered themselves very active prior to the pressure study. Another 14.3% reported minimal or no activity, while 36.6% of patients who had the syndrome ruled out described little or no activity before referral. Virtually all of the patients felt that their symptoms limited sports activity. Eighty-one percent of the patients with the syndrome underwent surgery upon one or both legs. Of the patients who had the syndrome ruled out, 25.8% had surgery; however, half of these procedures were for specific diagnoses unrelated to CCS (e.g., "fibrositis," "periostalgia," "vascular insufficiency," and "Baker's cyst," by patients' reports). After the pressure study and surgical procedure (if performed), 60% of patients with CCS returned to their highest level of sports activity, whereas 33.3% of patients without the syndrome felt that they had returned to this degree. One-third of the patients with the syndrome and 52.6% of those without it reported persistent, moderate to severe pain.

DISCUSSION

All patients in this study were referred to us for evaluation because of clinical suspicion of CCS. Using intramuscular pressure criteria, we diagnosed CCS in 45 (34.4%) of the 131 cases reviewed. In recent reports, CCS diagnoses were made after intramuscular pressure monitoring in 26.5%[22] and 70%[19] of patients suspected of having CCS by clinicians experienced with the evaluation and treatment of compartment syndrome. In our study, the only clinical difference between patients who had CCS and those who did not was a 45.9% incidence of muscle herniae among patients who had CCS diagnosed. This is in agreement with previous reports of a 20% to 60% incidence of fascial defects in patients with CCS.[3,11,17]

Although most investigators recognize the need for intramuscular pressure monitoring in the evaluation of CCS, there is no consensus regarding the optimal method of measurement or the diagnostic criteria that should be applied. A number of monitoring techniques have been described, including the needle manometer,[1] wick catheter,[13] slit catheter,[20] microcapillary infusion,[24] and microtip pressure methods.[10] Varying degrees of technical expertise and equipment investment are necessary in order to use these methods. Simple and reliable techniques, such as the slit catheter method, are appropriate for most physicians evaluating patients with chronic exertional leg pain.

Previous investigators have emphasized the value of dynamic intramuscular pressure measurements made during exercise in the evaluation of CCS. They have demonstrated differences in the mean muscle pressure,[15] muscle contraction pressure,[10] and muscle relaxation pressure[24,26] in patients with CCS. Muscle contraction pressure is affected by the effort exerted by the subject[6,11,21] and by the depth of catheter insertion.[5] Thus, the muscle contraction pressure, and therefore the mean muscle pressure, may be difficult to control and interpret in the clinical setting.[23]

During exercise, muscle is normally perfused between contractions, similar to cardiac muscle perfusion during diastole.[2] The pathophysiology of CCS should therefore be related to changes in the resistance to inflow during this period. Styf and coworkers[26] have shown that decreased muscle blood flow is correlated with increased muscle relaxation pressures between 35 and 55 mm Hg in patients with CCS. However, accurate assessment of muscle relaxation pressure requires considerable technical expertise and a monitoring system with a high response frequency, making these measurements relatively impractical in general orthopaedic application.

Static intramuscular pressures are relatively easy to meas-

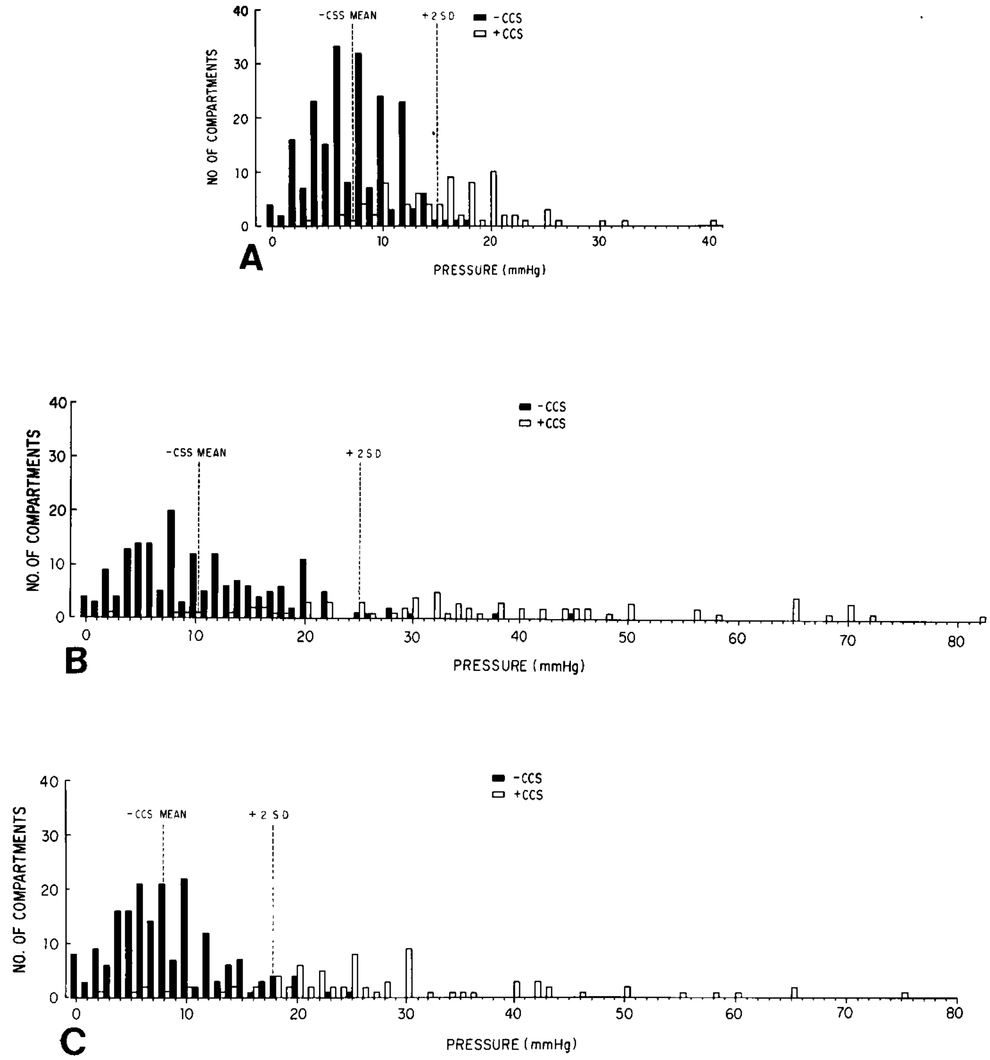

Figure 1. Intramuscular pressures recorded before and after exercise in the compartments of patients who had CCS and those who had it ruled out. In each histogram, the mean and mean plus two standard deviations are noted for the patients who had the syndrome ruled out (95% confidence intervals). A, at rest before exercise; B, 1 minute after exercise; C, 5 minutes after exercise. CCS+ indicates compartments diagnosed with CCS; CCS− indicates those ruled out for CCS.

ure by well-established and reliable techniques.[9, 13] However, intramuscular pressure measurements may be affected by joint position[4] and resting muscle tension.[23] Therefore, care must be taken to place the limb in a relaxed and consistent position for accurate, reproducible pressure assessment. The static measurements that have been suggested for diagnostic purposes include the preexercise rest pressure, the immediate, 1 minute, 5 minute, and 15 minute postexercise pressures, and the time to normalization of intramuscular pressure.[19] In our study, the immediate postexercise pressure was not evaluated because a variable amount of time was required to return the patient to a supine position at the end of exercise. The 1 minute postexercise pressure was believed to be the first well-defined postexercise measurement.

In this study, we applied relatively empirical pressure criteria for the diagnosis of CCS, criteria based upon previous studies performed in normal, asymptomatic volunteers.[3, 5] It would be inappropriate to compare statistically the intramuscular pressures recorded in the patients who had CCS and those who had it ruled out, because these groups were defined by pressure criteria set before the study. This limitation has been recognized in previous reviews of CCS diagnosis and treatment.[3, 19]

In our study, the intramuscular pressures recorded in the patients who had CCS ruled out provide a helpful data base for establishing diagnostic pressure criteria in patients with chronic exertional leg pain. The group which did not have the syndrome probably includes some patients who should have had CCS diagnosed; inclusion of these patients may result in a false elevation of the range of pressures in the group without the syndrome. However, by including these patients, a higher and therefore more conservative estimate

TABLE 4
Questionnaire data in patients with chronic exertional leg pain[a]

	CCS+ (21 Patients)	CCS− (31 Patients)
PRESTUDY		
Activity Level:		
Very active	61.9% [21]	30.0% [30]
Moderately active	23.8%	33.3%
Minimally active	14.3%	23.3%
Inactive	0.0%	13.3%
Pain level:		
Very painful	66.7% [21]	46.7% [30]
Moderately painful	9.5%	43.3%
Minimally painful	19.0%	10.0%
No pain	4.8%	0.0%
Weakness or numbness	68.4% [19]	67.7% [31]
Symptoms limit sports	100% [21]	96.6% [29]
TREATMENT		
Surgery recommended	85.7% [21]	36.7% [30]
Underwent surgery	81.0% [21]	25.8% [31]
POSTSTUDY		
Activity level:		
Very active	61.1% [18]	20.0% [20]
Moderately active	16.7%	55.0%
Minimally active	16.7%	5.0%
Inactive	5.6%	20.0%
Return to highest activity level	60.0% [15]	33.3% [27]
Pain level:		
Very painful	11.1% [18]	36.8% [19]
Moderately painful	22.2%	15.8%
Minimally painful	27.8%	26.3%
No pain	38.9%	21.1%
Weakness or numbness	22.2% [18]	50.0% [20]

[a] Numbers in parentheses refer to the number of patients responding to the questionnaire. Brackets indicate number of patients responding to the question.

of the pressure threshold for patients with the syndrome has been chosen. Application of these pressure criteria should therefore minimize the incidence of false positive CCS diagnoses.

In the group of patients without the syndrome, mean intramuscular pressure at rest was 7.4 mm Hg (mean resting pressure + 2 SD = 14.6 mm Hg). Previous investigators have reported mean preexercise resting pressures between 5.1 and 10.9 mm Hg in normal volunteers[3,14,19] and 6.2 ± 2.2 mm Hg in symptomatic muscle compartments in patients without the syndrome.[23] In our patients who did have CCS, the mean 1 minute postexercise pressure plus two standard deviations was 25.1 mm Hg. The mean 5 minute postexercise pressure plus two standard deviations was 17.8 mm Hg. These values represent the 95% confidence intervals for a normally distributed population of patients without the syndrome whose intramuscular pressures were measured using the slit catheter technique.

Based upon the pressures recorded in the 210 compartments of patients who were determined not to have CCS, we have redefined our intramuscular pressure thresholds for CCS diagnosis. We now consider a resting pressure ≥15 mm Hg and/or a 1 minute postexercise pressure ≥30 mm Hg and/or a 5 minute postexercise pressure ≥20 mm Hg, in the presence of appropriate clinical findings, to be consistent with the diagnosis of CCS. Application of these criteria should result in less than a 5% incidence of false positive diagnoses. However, these criteria may also result in missed diagnoses of CCS (false negatives). In borderline situations, clinical judgement, repeat static pressure measurements, or perhaps recording of the intramuscular relaxation pressures during exercise would be important.[23]

A 1 minute postexercise diagnostic pressure threshold has not been defined in previous studies. A 30 mm Hg value was designated for the resting pressure because the anterior compartment pressure tended to be higher than those in the other leg compartments of the patients without the syndrome at 1 minute after exercise (mean + 2 SD = 28.2 mm Hg, Table 3). This observation reflects differences between the compartments in their propensity for the development of CCS.[18] For example, variable compartment compliance caused by different osseofascial anatomy may affect the magnitude of intramuscular pressure generation during exercise. Alternately, these pressure differences may be related to the specific pain producing mechanisms in our patients with chronic exertional leg pain who did not have the syndrome.

It should be noted that a 1 minute postexercise pressure was not recorded in approximately 15% of the patients in our study. Technical problems in the period immediately after exercise, such as catheter clotting or difficulty in repositioning the patient, precluded accurate pressure measurement. If a clot must be flushed from the pressure catheter with a very small volume of fluid, adequate time must be allowed for pressure equilibration. In these situations, the pressures at rest before exercise and 5 minutes postexericse should be used for diagnostic purposes.

The relatively elevated 1 minute postexercise anterior and deep posterior compartment pressures may have been related to increased effort in these muscle groups during our exercise protocol. Ankle plantar flexion and dorsiflexion with the knee flexed may not induce sufficient activity of the lateral and superficial posterior musculature. In fact, 28% of our patients did not adequately reproduce their symptoms using this protocol and needed to run or perform calisthenic exercises. Definitive diagnosis may be difficult in these situations because low or borderline intramuscular pressures in the absence of pain may be related either to a noncompartment syndrome condition or to the lack of adequate muscle exertion during the exercise routine. This problem emphasizes the importance of inducing patients' symptoms with exercises that are similar to their normal, pain-producing activities. Such protocols may be simplified by the use of preexercise and postexercise pressure criteria, without focusing upon the intramuscular pressures during exercise.

Followup was obtained by questionnaire in 43% of the patients in our study. We believe this rate of response to be inadequate to allow for statistical comparisons between the patients who had CCS and those in whom it was ruled out. However, it should be noted that 33.3% of patients with the syndrome reported persistent, moderate to severe pain (81%

of these patients underwent surgery). Of 19 CCS patients in a previous study, 47% reported dissatisfaction at a mean of 8 months after fasciotomy. Dissatisfaction decreased to 26% after a mean of 25 months, in part because of reoperation in two patients.[25] Pain and submaximal activity level were not specifically correlated with recurrence of compartment syndrome in our study but have been reported previously.[15, 17, 18] Other processes, for example periostitis, stress fracture, or medial tibial syndrome, may have been responsible for the persistent pain in these patients.[12, 25]

In followup after their pressure study, only one-third of the patients who had the syndrome ruled out returned to their highest level of activity, with more than half reporting moderate to severe pain. Half of this group reported persistent weakness or numbness. The pathophysiology of pain and dysfunction in these patients is poorly understood. Controlled studies in which specific diagnostic criteria and treatment protocols are used should improve the prognosis for patients with chronic exertional leg pain.

CONCLUSIONS

The diagnosis of chronic compartment syndrome is extremely difficult to establish on clinical criteria alone. Intramuscular pressure monitoring before and after exercise may be easily performed using safe and reliable techniques. The objective criteria have been modified for the diagnosis of CCS. These pressure thresholds are based upon the review of slit catheter studies performed in 210 compartments of 75 patients with chronic exertional leg pain in whom chronic compartment syndrome had been ruled out. In the presence of appropriate clinical findings, we consider a preexercise resting pressure ≥15 mm Hg and/or a 1 minute postexercise pressure ≥30 mm Hg and/or a 5 minute postexercise pressure ≥20 mm Hg to be consistent with the diagnosis of CCS.

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