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**Research article**

# Pre, during, and post exercise anterior tibial compartment pressures in long distance runners

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**Abstract**
The aim of the study was to assess pre, during, and postexercise compartment pressures in the anterior tibial compartment in asymptomatic long distance runners (5000 m) and recreational athletes. Forty-eight participants (n = 48, 24 females and 24 males) underwent the experimental procedures. The participants were assigned into 4 groups of 12 volunteers. Intracompartmental pressures measurements were recorded 1 minute before, at the 1st minute after the onset of exercise, and finally 5 minutes after the completion of the exercise on treadmill. The wick catheter technique was the method of choice for measuring intracompartmental pressure values. Post hoc analysis of the groups by measures interaction indicated that all pairwise comparisons among pre-test (1 minute before exercise), during-test (1st minute during exercise), and post-test measures (5 minutes after exercise) were statistically significant for male controls ($p < .001$), male athletes ($p < .001$), female controls ($p < .001$) and female athletes ($p < .001$). The results confirm the correlation between long distance runners and the increased risk of chronic exertional compartment syndrome (CECS) development.

**Key words:** Compartment syndrome, athletes, wick catheter, intracompartmental pressures, runners.

## Introduction

Compartment syndrome is a condition characterised by increased intracompartmental pressure within the inelastic fascia that surrounds muscular compartments (Hargens and Mubarak, 1998; Kostopoulos et al., 2004; Rorabeck et al., 1988). During strenuous exercise, increase up to 20% may occur in muscle volume and weight due to the increased blood flow and edema (Bong et al., 2005; Mohler et al., 1997). The muscular adaptations to chronic running exercise leading to local hypertrophy, reduce the compliance of the available volume within the fascial compartment (Hutchinson and Ireland, 1994; Tzortziou et al., 2006; Winston et al., 2004). Although normal fascial compartment can accommodate increased muscular volume during strenuous exercise, in chronic exertional compartment syndrome (CECS) a noncompliant compartment leads to abnormally elevated tissue pressures (Blackman, 2000).

CECS pathophysiology is not fully understood but there is a general agreement that abnormally raised compartment pressures during exercise, lead to vascular occlusion, ischaemic pain and possibly muscle damage (Birtles et al., 2002; Dayton et al., 1990). This may occur during or after exercise and may last minutes to hours after exercise cessation. Positive diagnosis for leg compartment syndrome is established using as pathological compartment tissue values resulting in CECS: 1) a pre-exercise pressure of ≥15 mmHg, and/or 2) a 1 minute post-exercise pressure of ≥30 mmHg, and/or 3) a 5 minute post-exercise pressure of ≥20 mmHg (Pedowitz et al., 1990). Of note, radiographic findings typically are normal in cases of chronic CECS (Blackman et al., 2000).

Repeated episodes of CECS may lead to compartment fascia thickening and concomitant fibrosis, which increasingly affects the ability to return to its normal state of yield (Birtles et al., 2002; Bong et al., 2005).

The aim of the present study was to assess pre, during, and postexercise compartment pressures in the anterior tibial compartment in asymptomatic long distance runners (5000 m) and recreational athletes, with the use of the treadmill at a specific, predetermined speed and inclination for each participant individually.

## Methods

Forty-eight participants (n = 48, 24 females and 24 males) underwent the experimental procedures. The mean age of the subjects was 27.5 years (age range, 19.5 to 33.5 years). All participants were familiarised with testing procedures. The latter included 2 practice sessions where participants became fully confident of running on a motorised treadmill. Participants also became familiarised with collection of expired air samples. All the procedures described in this study were performed after approval had been granted by the School of Health and Social Care Ethics Committee with participants being informed about the research procedures and potential risks. No participant had received any foot or ankle surgery. Participants were free from any foot and ankle pain for at least 1 year prior to the study. Adittionally, all the participants were free of health problems, non smokers without receiving any medication during the experimental period.

The participants were assigned into 4 groups of 12 volunteers at each group. A1 group consisted of recreational male athletes (control men group) that participate in sport activities (football, basketball, tennis, running) 1-3 times per week. A2 group included long distance (5000m) high level male runners (athlete men group)competing at national and international level (6 training sessions per week). W1 group consisted of recreational female athletes (control women group) that participate in sport activities

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**Table 1.** $VO_2$ max values and somatometric characteristics of the participants. Data are means (±SD).

| | MEN Athletes (n=12) | MEN Control (n=12) | WOMEN Athletes (n=12) | WOMEN Control (n=12) |
|---|---|---|---|---|
| **$VO_2max$ (ml·kg$^{-1}$·min$^{-1}$)** | 67 (5) | 52 (9) * | 58 (2) | 43 (4) * |
| **Height (m)** | 1.75 (.15) | 1.76 (.12) | 1.62 (.18) | 1.65 (.09) |
| **Weight (kg)** | 71.5 (2.4) | 79.3 (1.1)* | 53.3 (1.4) | 57.2 (.8) * |

* $p < 0.05$ compared with athletes.

(tennis, running, jogging) 1-3 times per week and W2 group with long distance (5000m) high level female runners(athlete women group) of the same sport level and exercise training frequency as A1.

Measurements of the intracompartment pressures of the anterior tibial compartment were recorded 1 minute before, at the 1st minute after the onset of exercise, and finally 5 minutes after the completion of the exercise on the treadmill.

The wick catheter technique (Barnes, 1997) was the method of choice for all testing procedures. Dexon suture fibers protrude from the bore of a nylon catheter with an external diameter of 1mm and an internal diameter of 0.6 mm. The catheter was filled with sterile heparinized saline (0.3 cm$^3$ of normal saline solution (0.9%) was flushed through the catheter), prior to the insertion with calibration to zero hydrostatic fluid pressure being performed. Catheter was connected via a 3-way stopcock to a transducer and a magnetic tape recorder and introduced into the anterior tibial compartment of the participants through a 16-gauge needle. The pressure transducer was cushioned in foam rubber to eliminate shock and secured to the the leg at the level of the catheter insertion. All pressure measurements were performed with participants in supine position, with feet and heart on the same horizontal plane (Brennan and Kane, 2003). The ankle and foot were maintained at neutral position (90$^o$). All participants used the same type of running shoes.

To define exercise intensity, two preliminary tests were carried out in order to determine: a) the relationship between oxygen uptake and running speed, and b) the maximum oxygen uptake ($VO_2max$). The oxygen uptake test involved 16 minute continuous submaximal running. Initial speed was set between 2.5 and 3.5 m/sec, depending on subject's training level, increased every four (4) minutes by 0.4-0.5 m/sec depending also on subject's fitness. Heart rate was monitored throughout the test. A regression equation relating oxygen uptake to running speed was obtained, and running speeds at 80% $VO_2max$ could be predicted further. The maximal oxygen uptake test ($VO_2max$) involved inclined treadmill running employing a continuous incremental test to fatigue (Baumgartl, 1990).The speed was maintained constant throughout the test, whereas the inclination of the treadmill increased by 2.5% every three minutes from an initial 3.0%. Expired air samples were collected throughout the test. Verbal encouragement was given to subjects during this test. The peak 1 min $VO_2$ value was considered to be the $VO_2$ max value of the subject.

Based on the findings of the premilinary tests, experimental exercise intensity was set at 80% $VO_2max$ of each participant individually for 16 minutes running on the treadmill. Treadmill inclination was set at 3% throughout running. Between preliminary tests and final experimental procedure, seven (7) days interval was apparent to avoid any residual effects. At the days of exercise testing, participants had no other sporting activities prior to the experimental procedures. Patients' somatometric data and $VO_2max$ values are presented in Table1.

The experimental design used for analysing intracompartment pressures was a 4×3 (groups by measures) design with repeated measures on the last factor. The assumptions associated with the aforementioned design were tested (Keppel, 1991).

## Results

The alpha level of significance was set at 0.05 for all statistical and Scheffe post hoc analyses. Data are presented in Table 2.

All 48 subjects successfully completed data collection with no drop out. The results revealed normal intracompartmental pressure values at 1 minute before exercise, although athlete men group was presenting higher compartment pressure values compared to the other three groups. At the 1st minute of exercise , six participants (12.5%), one (1) man from the control group, three (3) athlete men , and two (2) athletes women, presented pathological intracompartmental pressure values. Pathological intracompartmental pressure values were noted in two (2) athlete men and one (1) athlete woman, 5 minutes after exercise completion.

The analysis of variance indicated significant main effects for groups ($F_{3,44} = 25.33$, $p < 0.001$) and measures

**Table 2.** Means (Standard Deviations) of the intra- compartment pressures (mmHg) for the athletes and the control groups.

| Groups | | | Pre-test (1 minute) 1 | During-test (1st minute) 2 | Post-test (5 minute) 3 |
|---|---|---|---|---|---|
| **MEN** | **Control** | **(n=12)** | 6.72 (.90) $^{2,3}$ # | 24.73 (3.31) $^{1,3}$ # | 17.82 (1.23) $^{1,2}$ |
| | **Athletes** | **(n=12)** | 11.05 (1.63) $^{2,3}$ * # | 27.81 (2.74) $^{1,3}$ * # | 17.88 (1.76) $^{1,2}$ |
| **WOMEN** | **Control** | **(n=12)** | 6.87 (1.23) $^{2,3}$ | 18.80 (2.32) $^{1,3}$ | 16.71 (1.23) $^{1,2}$ |
| | **Athletes** | **(n=12)** | 8.57 (.85) $^{2,3}$ * | 22.10 (4.86) $^{1,3}$ * | 17.13 (1.44) $^{1,2}$ |

Superscripts indicate the differences ($p < 0.05$) between the occasions.
* indicate $p < 0.05$ between control and athletes.
# indicate $p < 0.05$ between men and women
Numbers refer to the different study periods.

($F_{2,88}$ = 561.61, $p < 0.0001$) and groups by measures interaction ($F_{6,88}$ = 8.99, $p < 0.001$). Scheffe post hoc analysis for groups main effect indicated that (a) control men (M = 16.42, SD = 1.37) had lower intra-compartment pressure from athlete men (M = 18.91, SD = 1.37), and higher from control women (M = 14.13, SD = 0.88), (b) athlete men had higher intra-compartment pressure than control and athlete women, and (c) control women had lower intra-compartment pressure than athlete women.

Post hoc (Scheffe) analysis for the measures main effect revealed that overall intra-compartment pressure differed significantly from measure to measure. All participants had the lower intra-compartment pressure one minute before the beginning of exercise (M = 8.30, SD = 2.11) and the highest at the first minute during exercise (M = 23.36, SD = 4.73), lowering back (M = 17.39, SD = 1.47) five minutes after test completion.

Post hoc analysis of the groups by measures interaction indicated that all pairwise comparisons among pretest (1 minute before exercise), during-test (1st minute during exercise), and post-test measures (5 minutes after exercise) were statistically significant for control men ($p < 0.001$), athlete men ($p < 0.001$), control women ($p < 0.001$) and athlete women ($p < 0.001$). Moreover, one minute before exercise control men (M = 6.72, SD = 0.90) had significantly lower intra-compartment pressure than athlete men (M = 11.05, SD = 1.23) and athlete women (M = 8.57, SD = 0.85), athlete men had higher intra-compartment pressure than control (M = 6.87, SD = 1.23) and athlete women (M = 8.57, SD = 0.85), and control women had lower intra-compartment pressure than athlete women. One minute after the beginning of exercise control men (M = 24.73, SD = 3.31) had significantly higher intra-compartment pressure than control women (M = 18.80, SD = 2.32), and athlete men (M = 27.81, SD = 2.74) had higher intra-compartment pressure than control and athlete women (M = 22.10, SD = 4.86). Five minutes after exercise and the rest of the pairwise comparisons did not reach statistical significance.

## Discussion

The incidence of CECS in the general population is unclear, however, in one study of patients with undiagnosed lower leg pain (Qvarfordt et al., 1983), the incidence was 14%. On the other hand, in a study of patients with chronic exercise-induced anterior lower leg pain the incidence was 27% (Styf, 1988). Initial CECS symptomatology is not clear and increases gradually (García-Mata et al., 2001). The hallmark diagnostic tool to confirm CECS has been reported to be intracompartmental pressure testing. Objective criteria for diagnosis of chronic exertional compartment syndrome of the leg were defined by Pedowitz et al. after review of 131 pressure studies in patients with chronic exertional leg pain (Pedowitz et al., 1990).

In this study, all participants , men athletes and controls, women athletes and controls, were asymptomatic. The use of the wick catheter technique revealed normal intracompartmental values in the anterior tibial compartment prior to exercise. All subjects were presenting the lowest intracompartment pressure value one minute before exercise initiation while the highest value was recorded at the first minute during exercise. This finding is in accordance with those of a previous study (Mcdermott et al., 1982), supporting that exercise-induced changes in the intracompartment pressure occur rapidly at the start of exercise, while Logan et al. (1983) study advocates that both average and peak to peak pressures measured during exercise are elevated compared to those recorded at rest, and that intracompartmental pressures raise with increasing speed.

Despite increase of intracompartmental pressure values during and post exercise, no participant reported any symptoms that either affected or ceased exercise. At the first minute of exercise six participants, one male athlete, three male controls, and two female controls presented pathological values without reporting any symptoms. This finding comes into agreement with Padhiar and King (1996) results who reported that CECS arises as a result of a series of events , characterized by an increase of the muscle volume caused by the increased exercise- related blood flow.

As a matter of fact and although raised intracomparmental pressure values are usually used in the diagnostic procedure, it seems that they are not the sole cause of CECS symptoms (Barnes, 1997). Indeed, as referred in a study of a consecutive operative series of 100 patients (Detmer et al., 1985) there is no definite correlation between the intramuscular pressure and the severity of symptomatology or the rate of recurrence. In addition, Hargens and Mubarak (1998) claim that after the exercise completion symptoms usually subside, but they typically reappear either at the same interval and intensity or even sooner with worst symptoms at the next athletic session (Potteiger et al., 2002).

This finding requires physicians and physiotherapists attention as pathological intracompartmental values in asymptomatic athletes may be overlooked and thus, result in irreversible damage of the tissues leading to surgical treatment (Brennan and Kane, 2003; Fronek et al, 1987; Howard et al, 2000).

As it has been suggested (Barnes,1997), increased intracompartmental pressure values are related to a less extensible fascia preventing the normal increases in muscle size during exercise leading so to a raised intramuscular pressure. Referring to the subgroups, one minute before exercise, control men group presented lower intracompartmental pressure than athlete men and women groups, as well as athlete women group recorded higher intra-compartment pressure than control women group,providing a correlation between long distance runners and the increased risk of chronic exertional compartment syndrome (CECS) development.This observation is in accordance with Kostopoulos et al. (2004) where non-athletes presented lower intracompartmental pressures at rest, compared with basketball athletes.

As more women have become involved in competitive athletics, it appears that the incidence of CECS in men and women is similar (Qvarfordt et al., 1983, Pedowitz et al., 1990). However, in this study it has to be noted that no woman athlete revealed intracompartmental pressure values above the normal limits before exersice. Because CECS is produced by exercise, it is most useful to examine the compartment during and after vigorous exertion of the muscles in the anterior tibial compartment. Comparing further the men and women subgroups, at the first minute during the exercise, control men group showed higher intra-compartment pressure than control women group, while athlete men group showed higher intra-compartment pressure than athlete women group. The finding could be indicative of a sex difference both for athletes and controls, possibly explained by the limitation of circulation in the smaller female unyielding compartment, which especially in women athletes susceptible to CECS canno accommodate the associated 20% increase in muscle mass that typically occurs with intense exercise. (Schissel and Godwin, 1999).

CECS of the lower extremity is often misdiagnosed, requiring repeated visits to the physician and subsequent delay in definitive treatment. Early suspicion of the condition is paramount, because the definitive treatment is fasciotomy. Family physicians and general medical officers caring for otherwise healthy people and athletes should be aware of the syndrome so that prompt orthopaedic referral for evaluation and definitive treatment will not be delayed.

## Conclusion

Initial CECS symptomatology is not clear and increases gradually (García-Mata et al., 2001).Although the majority of the CECS surgeons confirm the diagnosis by intracompartmental pressure (ICP) measurements (Tzortziou et al., 2006), the physician cannot assure that during or after exercise non-normal intracompartmental values will develop.

Further studies on predisposing factors of CECS, such as increased intracompartmental pressure values in asymptomatic athletic population is needed to establish the diagnosis in a proper time. The development of non-invasive techniques for intracompartmental pressure measurements, with sensitivity clinically equivalent to that of invasive ones, (Van den Brand JG et al., 2005) may let physicians early diagnose CECS and prevent surgical treatment.

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## Key points

- Compartment syndrome is a condition characterised by increased intracompartmental pressures within inelastic fascia which surrounds muscular compartments
- Initial CECS symptomatology is not clear and increases gradually
- All the study participants presented the lowest intracompartment pressure values one minute before the beginning of exercise (at rest) with the highest value being recorded at the first minute of exercise.
- Control population had lower intra-compartment pressure than professional runners.
- One minute after the beginning of exercise control and athlete men group showed higher intracompartment pressure than control and athlete women group, indicating a probable sex difference both for athletes and controls.
- Further studies on predisposing factors of CECS, such as increased intracompartmental pressure values in asymptomatic population is needed to establish the diagnosis in a proper time.

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