Evaluation of physiological standard pressures of the forearm flexor muscles during sport specific ergometry in sport climbers

V Schoeffl, S Klee, W Strecker

Background: Chronic exertional compartment syndromes (CECS) are well known in sports medicine. Most commonly affected is the tibialis anterior muscle compartment in runners and walkers. Diagnostic and therapeutic criteria for this group have been widely discussed. There are very few documented cases of chronic compartment syndrome of the forearms and hands. Scientific reports are mostly case reports only. Diagnostic and therapeutic criteria for CECS in the forearm flexor muscles, pronator quadratus, anconeus, thenar, hypothenar, and first dorsal interosseous muscle. CECS in these cases was caused by motorcycling, climbing, heavy manual labour, and gymnastics and field hockey. Diagnostic and therapeutic criteria varied; even the anatomical bases were the subject of discussion. Although van der Zypen described 10 different compartments, only three representing CECS in the forearm flexor muscles, pronator quadratus, anconeus, thenar, hypothenar, and first dorsal interosseous muscle. CECS in these cases was caused by motorcycling, climbing, heavy manual labour, and gymnastics and field hockey. Diagnostic and therapeutic criteria varied; even the anatomical bases were the subject of discussion. Although van der Zypen described 10 different compartments, only three representing CECS in the forearm flexor muscles, pronator quadratus, anconeus, thenar, hypothenar, and first dorsal interosseous muscle. CECS in these cases was caused by motorcycling, climbing, heavy manual labour, and gymnastics and field hockey. Diagnostic and therapeutic criteria varied; even the anatomical bases were the subject of discussion. Although van der Zypen described 10 different compartments, only three representing CECS in the forearm flexor muscles, pronator quadratus, anconeus, thenar, hypothenar, and first dorsal interosseous muscle. CECS in these cases was caused by motorcycling, climbing, heavy manual labour, and gymnastics and field hockey.

Methods: Ten healthy, high level climbers were enrolled in a prospective study. All underwent climbing specific ergometry, using a rotating climbing wall (step test, total climbing time 9–15 minutes). Pressure was measured using a slit catheter placed in the deep flexor compartment of the forearm. Pressure, blood lactate, and heart rate were recorded every three minutes during recovery.

Results: In all the subjects, physical exhaustion of the forearms defined the end point of the climbing ergometry. Blood lactate increased with physical stress, reaching a mean of 3.48 mmol/l. Compartment pressure was related to physical stress, exceeding 30 mm Hg in only three subjects. A critical pressure of more than 40 mm Hg was never observed. After the test, the pressure decreased to normal levels within three minutes in seven subjects. The three with higher pressure levels (>30 mm Hg) required a longer time to recover.

Conclusions: For further clinical and therapeutic consequences, an algorithm was derived. Basic pressure below 15 mm Hg and stress pressure below 30 mm Hg as well as pressures during the 15 minute recovery period below 15 mm Hg are physiological. Pressures of 15–30 mm Hg during recovery suggest high risk of CECS, and pressures above 30 mm Hg confirm CECS.
break followed, during which the participant was allowed to step off the wall, and pressure, blood lactate concentration, and heart rate were recorded. During the break, the angle of the endless rotating climbing wall was increased by 5°. The test then continued until physical exhaustion of the forearm flexor muscles resulted in the climber falling off the wall. Pressure, blood lactate concentration, and heart rate were recorded every three minutes and during recovery. The standards for scientific ergometry (temperature 18–24°C, relative humidity 30–60%) were followed, and a sufficient recuperative interval from specific stress levels before the test (>48 hours rest) was required. On a scale of 1–10, all climbers indicated the subjective maximum level of pumped forearms at the end of the test (forearm pump level, in comparison with Borg scale).

A Polar belt and receiver was used to record heart rate. To signify total physical exhaustion, the theoretical maximum heart rate (beats/min; maximum = 220–age) had to be achieved. Blood samples were taken from the hyperaemic ear lobe, and blood lactate was analysed using the ESAT 6661 lactic acid analyser (Eppendorf, Hamburg, Germany). Pressure was measured using a slit catheter (Stryker Trauma, Geneva, Switzerland), placed in the deep flexor compartment of the forearm and analysed through the Stryker unit. The catheter tip was positioned in the deep flexor compartment as described by Froebel and Linss.24 A line from the epicondylus humeri ulnaris to the processus styloideus ulnae was divided into three equal parts. The puncture was made under sterile conditions using local anaesthesia at the spot where the proximal third met the middle third, pointing 45° horizontal. The needle was pushed forward until it made contact with the ulna and was then retracted for 1 cm (fig 2).

RESULTS
In all athletes physical exhaustion of the forearms (causing them to fall off the wall) defined the end point of the climbing ergometry. No technical problems were reported with the test profile. Nine climbers defined their forearm pump level (in comparison with the Borg scale) as 10/10, and one climber as 9/10. A mean (SD) 3 (0.82) steps of the test could be performed, representing 44.3 (10.7) m of climbing. Heart rates of 150 (18.7) beats/min were recorded in the first step. All climbers had reached cardiac exhaustion at the end of the test (186 (6.57) beats/min). In all the climbers, heart rate decreased quickly after the test, reaching 103 (17.75) beats/min three minutes after the test. Blood lactate concentration increased in relation to physical stress, reaching 3.48 (1.13) mmol/l at the climbing end point. In five climbers, maximum lactate concentration was reached three minutes after completion of the test (5.0, 5.5, and 6.4 mmol/l). Table 1 shows blood lactate concentration and heart rate during the test.

Compartment pressure was related to physical stress, exceeding 30 mm Hg in only three climbers. A critical pressure of more than 40 mm Hg was never observed. The mean (SD) pressure was 7.3 (4.57) mm Hg at rest and 19 (7.14) mm Hg at the climbing end point. After the test, the pressure decreased within three minutes to normal values in 7/10 climbers. The three athletes with higher pressure levels (>30 mm Hg) required a longer time to recover. Table 2 shows compartment pressures of the individual climbers.

Figure 3 shows the compartment pressures of the individual climbers grouped according to the number of steps performed in the test.

DISCUSSION
The objective of this study was to determine pressure levels inside the deep flexor compartment of the forearms during sport specific stress. All papers on CECS of the forearms9–10 are case reports including only one or two patients. Only one study used climbing for stress induction of CECS of the forearms.21 Comparable and reproducible results therefore cannot be found. Normal forearm intracompartmental pressures were measured by Seiler et al.,15 who found a mean of 8.25 mm Hg in the middle of the forearm. We found a comparable standard pressure of 7.3 (4.57) mm Hg.

Our test profile shows an easy and reproducible way of performing a sport specific ergometric test and pressure measurement. All athletes reached cardiac exhaustion in accordance with the known high heart rate in climbing ergometry, as shown by Billat et al.,22 Schoeffl et al.,16 17 and Watts et al.23 In comparison with these high heart rates, blood lactate concentration was much lower. Low blood lactate concentrations have previously been shown in climbing ergometry: Schoeffl et al.,16 17 reported a maximum of 4.2 (1.25) mmol/l, and Billat et al23 found a maximum of 5.7 mmol/l. Blood lactate was not of major interest in this survey, being only a parameter of local metabolic reaction and exhaustion.

The compartment pressure was related to physical stress, exceeding 30 mm Hg in only three climbers. Within three minutes of the end of the test, the pressure decreased to normal values in 7/10 of the subjects. In three climbers, the pressure was maximum three minutes after the physical stress; here the test protocol proved to be deficient. The recovery period needs a longer follow up, as lactate concentration was maximum three minutes after the stress in 4/10 climbers as well as the compartment pressure in 3/10 climbers. For further evaluation, the follow up after the test needs to be longer. Also local compartment pressure is a function of general blood pressure, which was not monitored.
in our profile. This should be considered in further follow up studies.

Compared with the known absolute pressure maxima, as well as the muscle relaxation pressures in the tibialis anterior compartment, the forearm pressure in the forearm are low. For the tibialis anterior compartment, Styn et al\textsuperscript{24} recommend a borderline of >35 mm Hg for the muscle relaxation pressure, and Mannarino and Sexson\textsuperscript{25} a peak pressure of more than 100 mm Hg. The forearm pressures given in case reports in the literature never reached that level. Kutz et al\textsuperscript{12} reported 42.5 mm Hg for the right forearm and 49 mm Hg for the left forearm after 30 minutes of stress, and 35.5 mm Hg for the right and 16 mm Hg for the left 10 minutes after stress. Allen and Barnes\textsuperscript{13} also recorded pressures of above 40 mm Hg, whereas Del Cerro et al\textsuperscript{11} found pressures of only 18 mm Hg for the right and 16 mm Hg for the left using climbing as stress. In conclusion, guidelines for CECS of the leg cannot be compared with other studies. Forearm conductance was higher in climbers than in non-climbers. This is consistent with other studies. Forearm conductance was higher in climbers than in non-climbers immediately after sustained exercise as well as during and after rhythmic exercise. Also after a 10 minute arterial occlusion, peak vascular conductance was significantly greater in climbers than in non-climbers. In conclusion, they showed greater forearm vasodilator capacity in the trained climbers. Our results may look contradictory at first sight, as two of the three “abnormal” responders (increased intracompartment pressure of at least 30 mm Hg after stress) were in the less fit climbing group. From a theoretical approach, the less fit climbers would be expected to have lower forearm blood conductance and less of a hyperaemic response. For our highly trained athletes, there is probably an equilibrium of blood conductance after stress and enough space for the muscle within its compartment to allow it to happen without an increase in compartment pressure. For our three “abnormal” responders, even their theoretically lower blood conductance is enough to increase compartment pressure to a level at which vasoconstriction results. When the training status of these athletes and their self reported condition is considered, this becomes even clearer, as athlete AW did not report any relevant previous history and just felt very tired and “pumped” after the test, in contrast with the situation reported by CS and SH. CS was in poor training condition for the grade at which he normally climbs. He also prefers to climb short routes (boulder problems) only. When asked about his performance on longer climbs, even those that were warm up routes, he described symptoms characteristic of CECS. Athlete SH was very well trained, a top ranking young German athlete, although he also prefers short routes. He also admitted that he has no sport specific endurance and has a tendency to get pumped forearms quickly in longer climbs. As Ferguson and Brown\textsuperscript{25} reported that well trained rock climbers have superior peripheral vascular characteristics, this may only be the case in “endurance route trained” climbers and may be less significant in “boulder route trained” climbers. This argument is strengthened by the fact that both showed low ischaemic tolerance (lactate buffer capacity). CS only reached a blood lactate concentration of 3.2 mmol/l and SH of 2.6 mmol/l, but both reached cardiac exhaustion (CS (age 37 years): maximum heart rate, 186 beats/min; SH (age 21 years): maximum heart rate

| Blood lactate concentration and heart rate in 10 climbers during ergometric test |
|----------------------------------|----|----|----|----|----|----|----|----|
| **Time** | **AW** | **CS** | **HQ** | **HS** | **OD** | **SH** | **EH** | **TK** | **VS** | **SK** |
| **Start** | 1.3 | 1.2 | 1.5 | 1.1 | 1.0 | 0.8 | 1.2 | 1.0 | 1.3 | 0.9 |
| **5'** | 2.9 | 1.0 | 2.0 | 1.3 | 2.6 | 1.2 | 3.3 | 2.4 | 2.5 | 1.3 |
| **10'** | 3.9 | 2.2 | 2.4 | 2.1 | 3.2 | 1.6 | 3.3 | 2.7 | 3.6 | 3.0 |
| **15'** | 4.2 | 3.3 | 4.1 | 3.6 | 3.3 | 3.3 | 4.1 | 4.3 | 4.3 | 4.3 |
| **20'** | — | — | — | — | — | — | — | — | 3.7 | 5.3 |
| **3 min after** | 3.0 | 3.2 | 1.8 | 2.6 | 5.0 | 2.0 | 1.6 | 3.3 | 5.5 | 6.4 |

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<th>Compartment pressure (mm Hg) in 10 climbers during ergometric test</th>
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197 beats/min). This confirms the importance of training analysis and recording of symptom presentation for diagnosis of CECS. On closer observation, both athletes can be classified as borderline or high risk for CECS. To clarify further, the follow-up monitoring needs to be longer (we monitored for only three minutes) as proposed in the literature.

Athletes presenting with CECS of the tibialis anterior complain of a dull pain as well as a hard swelling of the muscle and a pumped sensation. This pumped sensation is present.

In cases of frequent, exercise induced forearm pain in sport climbers, chronic exertional compartment syndrome may be present.

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**REFERENCES**


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