ORIGINAL ARTICLE

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

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Br J Sports Med 2004;**38**:422–425. doi: 10.1136/bjsm.2002.003996

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. Only a few cases of CECS of the forearm flexor muscles have been reported.
Objectives: To determine pressure levels inside the deep flexor compartment of the forearms during a sport specific stress test.
Method: 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 and 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.

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Accepted 20 May 2003

Chronic exertional compartment syndromes (CECS) are well known in sports medicine. Most commonly affected is the tibialis anterior muscle compartment in runners and walkers.[1 2] 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[3–10] 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,[3 5 11] climbing,[4] heavy manual labour,[6 7 12] and gymnastics and field hockey.[10] Diagnostic and therapeutic criteria varied; even the anatomical bases were the subject of discussion. Although van der Zypen[13] described 10 different compartments in the forearm, other authors only reported about three.[14] Froeber and Linss[14] finally defined five different compartments through injection of different liquid gelatins (ulnar extensor compartment, dorsal extensor compartment, radial compartment, superficial flexor compartment, deep flexor compartment). Seiler *et al*[15] measured pressure in the normal forearm.

Although extreme forearm stress is not specific to sports such as motor cycling and to heavy manual labour, it is surprising that only one report on CECS among sport climbers has been published.[4] Sport climbing puts extreme stress on the deep forearm flexor muscles,[16 17] their exhaustion being performance limiting in the sport. As overuse syndromes in sport climbing are generally in the upper extremities,[18–20] only a few cases of CECS are known. We diagnosed one climber with bilateral CECS, presenting with pressures of more than 50 mm Hg after climbing. After fasciotomy he was pain free and regained full performance level. G Straub (personal communication 1999) reported that two climbers with CECS of the first dorsal interosseous muscle were treated successfully with surgery. Climbers usually report "pumped" forearms (hard swollen forearms) when succeeding in a climb, so the question of physiological standard pressures during the sport arises. The objective of this study was to determine these standard pressure levels inside the deep flexor compartment of the forearms during a sport specific stress test (climbing ergometry). In addition, further criteria for clinical procedure and treatment need to be found.

METHODS

Ten healthy, high level climbers were enrolled in a prospective study. Mean age was 26.5 years (range 18–37), with a mean height of 179 cm (range 173–193) and a mean body weight of 73.4 kg (range 65–90). The average redpoint climbing level was 10− (UIAA) or 5.13c (USA). The range in redpoint level was 9+ to 10+ (UIAA) or 5.13a to 5.14a (USA). All had more than five years climbing experience (mean 10.6, range 6–23) as well as experience in indoor and competition climbing. All participants gave written informed consent before the test.

The climbers underwent a sports specific climbing ergometric test using a rotating climbing wall (Rockn Roll; Entreprises France; step test, total climbing time 9–15 minutes; fig 1). The test profile was in accordance with the standards for climbing ergometry,[16 17] only slightly modified. The test route was built with holds requiring first fingers only, in order to concentrate the stress on the deep flexor muscles. The climber started on a 5° overhanging angle, with three minutes climbing time on the test route. A one minute 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℃, 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 Froeber and Linss.[14] 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.

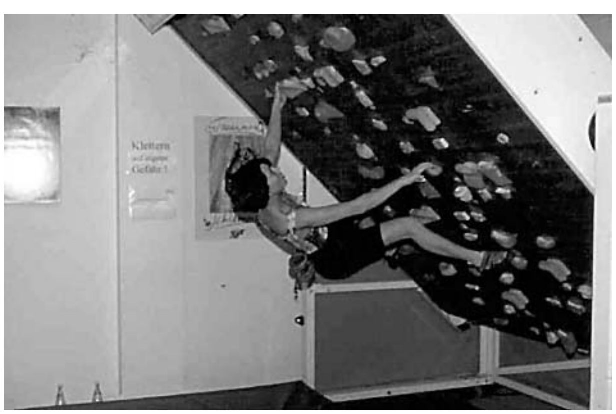

Figure 1 Rotating climbing wall used for climbing ergometric test.

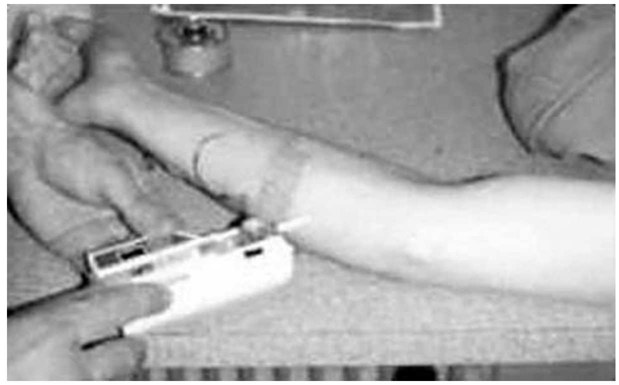

Figure 2 Insertion of slit catheter for measurement of pressure.

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 forearms[3–10] are case reports including only one or two patients. Only one study used climbing for stress induction of CECS of the forearms.[4] 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*,[21] Schoeffl *et al*,[16 17] and Watts *et al*.[22] 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 al*[21] 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

Table 1 Blood lactate concentration and heart rate in 10 climbers during ergometric test

	AW	CS	HQ	HS	OD	SH	EH	TK	VS	SK
Blood lactate (mmol/l)										
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˚	–	–	–	2.4	3.3	2.6	3.3	3.3	4.1	4.3
20˚	–	–	–	–	–	–	–	3.7	5.3	5.4
3 min after	3.0	3.2	1.8	2.6	5.0	2.0	1.6	3.3	5.5	6.4
Heart rate (beats/min)										
Start	85	95	87	100	67	90	92	63	84	71
5˚	146	144	175	164	147	172	166	138	120	128
10˚	178	186	192	177	162	187	183	166	154	157
15˚	–	–	–	187	177	197	188	180	174	192
20˚	–	–	–	–	–	–	–	180	183	183
3 min after	75	98	90	138	117	118	100	92	107	95

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,[23 24] the pressures in the forearm are low.[3–10] For the tibialis anterior compartment, Styf *et al*[24] recommend a borderline of >35 mm Hg for the muscle relaxation pressure, and Mannarino and Sexson[23] 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*[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 14 mm Hg for the left 10 minutes after stress. Wasilewski *et al*[10] found values of only 25 mm Hg for the right and 31 mm Hg for the left after stress and 46 mm Hg for the right and 36 mm Hg for the left during recovery. Allen and Barnes[3] also recorded pressures of above 40 mm Hg, whereas Del Cerro *et al*[4] 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 used for the arm. Furthermore the different positioning of the compartment with respect to the body centre is of importance, changing the hydrostatic pressure. For further evaluation, a more sensitive method of analysing compartment pressures with a piezoresistive microtip probe is desirable.

Ferguson and Brown[25] studied arterial blood pressure and forearm vascular conductance responses to sustained and rhythmic isometric exercise and arterial occlusion in trained rock climbers and untrained sedentary subjects. The stress induction was achieved with a handgrip exerciser which provides stress that is comparable to that in climbing ergometry, as climbing involves complex changes in isometric handholding positions. They found no difference in the time to fatigue of climbers and 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[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

Table 2 Compartment pressure (mm Hg) in 10 climbers during ergometric test

	AW	CS	HQ	HS	OD	SH	EH	TK	VS	SK
Start	11	9	14	8	1	0	8	8	3	11
5˚	13	28	20	8	3	11	11	7	13	10
10˚	20	28	20	10	15	10	11	10	10	11
15˚	–	–	–	14	12	33	19	14	20	10
20˚	–	–	–	–	–	–	–	17	25	10
3 min after	30	35	12	11	17	36	13	13	10	7

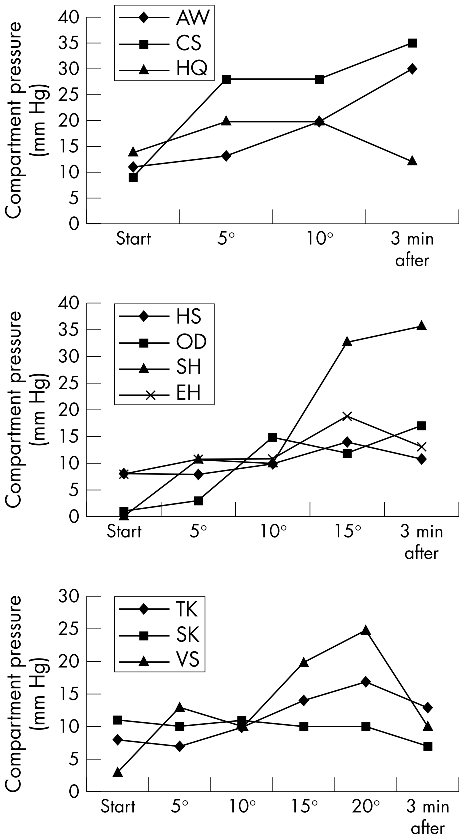

Figure 3 Compartment pressures measured in 10 climbers and grouped according to the number of steps performed.

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.[10 23 24]

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 normal after climbing; all climbers in our study reported it. In climbing, it cannot be seen as indicative of CECS unless it is prolonged (more than 15 minutes after stress). In conclusion, aware that this is only tentative, we are proposing an algorithm for diagnostic criteria (fig 4). This algorithm is based on the current literature on CECS[1 2 23 26 27] (adjusted to the guidelines of CECS in the tibialis anterior compartment, with its higher peak pressures) as well as on the case reports of forearm compartments[3–12 15 24] and our findings. It is to be considered only in addition to clinical findings and symptom reports. Treatment can be either conservative or surgical. We prefer a conservative approach initially, especially in cases of overuse syndrome or "high risk". Only if strongly indicated and wanted by the athlete should surgery be considered.

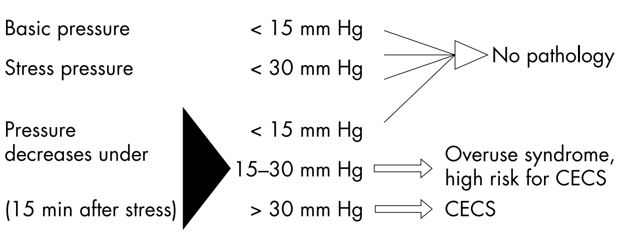

Figure 4 Algorithm for suspected chronic exertional compartment syndrome (CECS) of the forearm flexor muscles.

Take home message

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

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