Intramuscular pressures during exercise

Comparison of measurements with and without infusion

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Our objective was to compare two techniques for measuring intramuscular pressures during dynamic exercise. In 20 volunteers muscle contraction and relaxation pressures were recorded with a noninfusion method (slit catheter) and with a microcapillary infusion method (Myopress catheter). Relaxation pressures measured by noninfusion were higher than those measured by infusion. The dynamic properties of the infusion method were higher as compared with the noninfusion method. The dynamic properties of the noninfusion method increased when microcapillary infusion was connected. This resulted in a lower recording of the muscle-relaxation pressure than without infusion. We concluded that the microcapillary infusion technique and the design of the tip of the Myopress catheter are better suited for pressure recordings during exercise.

History and clinical signs alone are in many cases not sufficient to establish the diagnosis of chronic compartment syndrome of the lower leg (Styf and Körner 1987). Therefore, intramuscular pressure recordings during exercise and at rest after exercise are helpful in diagnosing the causes of exercise-induced pain in the lower legs. Pressure recordings during exercise are also useful in the study of ergonomics and in mechanical studies of muscle tissue (Baumann et al. 1979, Mubarak 1981, McDermott et al. 1982, Körner et al. 1984, Sejerstedt et al. 1984).

We have studied catheter measurements, with and without infusion, for recording intramuscular pressures during exercise and at rest after exercise.

Subjects and methods

Pressure in the anterior tibial muscle was recorded unilaterally in asymptomatic legs of 6 women and 14 men with a mean age of 29 (17–56) years. Eleven subjects were healthy volunteers, and 9 had periostitis over the anterior margin of the tibia on the contralateral leg. Following a diagnostic pressure recording on the symptomatic leg, the subjects volunteered to participate in the present study. The study was approved by the ethics committees of the Universities of Gothenburg and California.

Pressure recordings. A dual-pressure recording system was employed for all the comparisons (Figure 1). The subjects were investigated at rest, during exercise, and at rest after exercise. All the subjects lay supine with the feet attached to an ergometer. The experimental setup, introduction of catheters, and the exercise test were described by Styf and Körner (1986). Subjects were allowed to exercise at a constant contraction frequency of 0.5–1.0 Hz until they experienced muscle fatigue. The minimum exercise time was 10 min in all but 1 subject, who developed muscle fatigue after 7 min.

The two catheters were introduced parallel to each other and 10–15 mm apart at the same depth into the anterior tibial muscle. The distance from the skin to the tip of the catheter was 45 mm. The first catheter was introduced 2 cm lateral to the tibial tuberosity, in a distal direction and parallel to the muscle fibers. The second catheter was introduced 10–15 mm lateral to the first catheter. The slit catheter was introduced via a 2.0-mm-diameter sheathed Venflon needle (Viggo, Helsingborg, Sweden). The Myopress catheter was introduced via a 1.7-mm-diameter sheathed Venflon needle. Both catheters were taped to the skin and via a transducer line connected to an electromagnetic transducer (Siemens-Elema 746 or Hewlett-Packard 1280) with low volume displacement and a multichannel ink recorder (Siemens-Elema, Mingograph 82).

Pressures were taken at rest without infusion and without injection of the catheters. Before the start of

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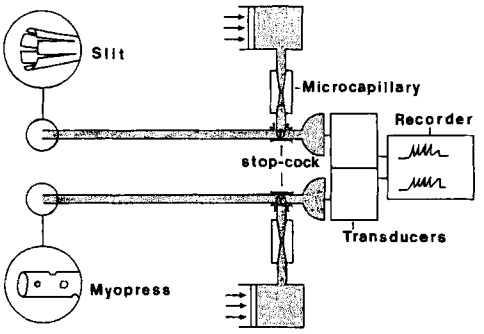

Figure 1. Schematic drawing of the pressure recording system showing the tips of the slit and Myopress catheters. The arrows indicate the pressure applied over the microcapillary, which gives the nonconstant infusion during exercise.

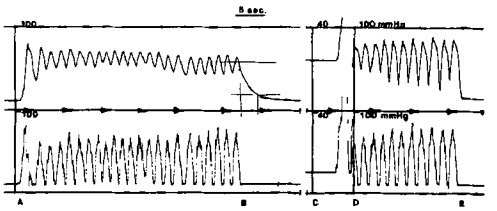

Figure 2. Original recording of intramuscular pressures. Upper trace: slit catheter without infusion. Lower trace: Myopress catheter with a microcapillary infusion rate of 1.5 mL/h. A. Intramuscular pressure after 6 min of exercise. B. Intramuscular pressure at rest after exercise. The rise time for the slit catheter is about 2 s. C. Intramuscular pressure at rest before exercise. An infusion rate of 1.5 mL/h is turned on in the slit catheter. Scale for pressure recording is changed from 100 mmHg to 40 mmHg. D. Intramuscular pressure during constant exercise. The infusion rate is 1.5 mL/h in both catheters. Scale for pressure recording is changed from 40 mmHg to 100 mmHg. E. Intramuscular pressure at rest after exercise.

Table 1. Results of simultaneous intramuscular pressure recordings with the Myopress (microcapillary infusion) and slit (noninfusion) catheters in the anterior tibial muscle of 9 subjects. Values are in mmHg. Mean *SD*

	Myopress		Slit[a]	
Intramuscular pressure at rest	7.2	*1.7*	6.6	*1.9*
Muscle contraction pressure				
at the beginning of exercise	110	*27*	93	*34*
after 10 minutes of exercise	119	*24*	105	*32* [a]
Muscle relaxation pressure				
at the beginning of exercise	7.4 *	*1.1*	16.9 *	*12.4*
after 10 minutes of exercise	16.8 **	*3.2*	42.8 **	*16.7* [a]
Mean muscle pressure				
at the beginning	59	–[b]	55	–[b]
after after 10 minutes	76	–[b]	74	–
Intramuscular pressure				
after exercise	16.1	*3.1*	19.7	*4.1*
6 minutes after exercise	8.1	*1.5*	9.6	*2.9*
Pressure amplitude				
at the beginning of exercise	103	–[b]	76	
at the end of exercise	102	–[b]	62	–[b]

* $P < 0.05$ ** $P < 0.025$.
[a] Data from three occluded slit catheters were omitted.
[b] Mean values of mean.

exercise, the microcapillary infusion (1.5 mL/h) was turned on to the Myopress catheter, and resting pressures were taken again. The slit catheter was flushed once with 0.1 mL of sterile physiologic saline at the start of exercise. The function of the catheters was checked by response to external compression and to active muscle contraction.

Muscle-contraction pressure and muscle-relaxation pressure were recorded during exercise. Mean muscle pressure was calculated by adding the relaxation pressure to half the pressure amplitude. Dynamic properties of the pressure recording system were evaluated by *rise time*, which was defined as the time period required for the pressure to pass through the range of 10 to 90 percent of the final pressure value recorded at external compression.

In the first 14 subjects, recordings with the slit catheter noninfusion technique (Rorabeck et al. 1981) were compared with those of the Myopress catheter microcapillary infusion technique (Styf and Körner 1986). Microcapillary infusion at 1.5 mL/h was turned on to five of the slit catheters that showed decreased dynamic properties at the end of the exercise test.

In the second part of the study, the influence of infu-

Table 2. Results of simultaneous intramuscular pressure recordings with one infused and one noninfused Myopress catheter in 6 healthy subjects. Values are in mmHg. Mean *SD*

	Infusion		Noninfusion	
Intramuscular pressure at rest	8.7	*1.7*	8.3	*1.9*
Muscle contraction pressure	105	*26*	88	*24*
Muscle relaxation pressure at the end of exercise	14.3	*3.2*	12.3	*2.9*
Mean muscle pressure at the end	60	–	50	–
Intramuscular pressure at rest after exercise	14.4	*3.9*	12.7	*2.7*

sion on pressure recordings was studied in 6 healthy subjects. Pressures were recorded with two Myopress catheters—one with microcapillary infusion (1.5 mL/h) and the other without infusion. The minimum exercise time on a Cybex foot ergometer was 30 min with at most 5 min of rest.

Pressure values are given as means with 1 SD. Significance ($P < 0.05$) testing was performed by using the Student's *t*-distribution.

Results

Intramuscular pressure at rest without infusion was 5.9 (0.9) mmHg with the Myopress catheter and 6.6 (1.9) mmHg with the slit catheter in the first part of the study. Intramuscular pressure was 7.2 (1.7) mmHg using the Myopress catheter and 6.6 (1.9) mmHg using the slit catheter when the infusion rate was 1.5 mL/h into the Myopress catheter (Table 1). During constant submaximal exercise, muscle-contraction pressures were the same with the two techniques. However, the muscle-relaxation pressure recorded with the slit catheter was higher at the beginning and after 10 min of exercise. In all, 3/14 slit catheters occluded during the exercise test, whereas none of the Myopress catheters occluded. Of the remaining 11 slit catheters, 8 showed decreased dynamic properties at the end of exercise (Figure 2). The dynamic properties of 4/5 slit catheters increased when the microcapillary infusion was switched on after 6–10 min of exercise (Figure 2). Three of nine slit catheters that were not infused maintained their dynamic properties during the exercise test.

Early signs of decreased dynamic properties of the pressure-recording system during exercise were 1) decreased muscle-contraction pressure during constant exercise (Figure 2), 2) muscle-relaxation pressure values that depended on the contraction frequency, and 3) different values between the recorded muscle-relaxation pressure during exercise and intramuscular pressure at rest after exercise. All of these signs correlated well with increased rise time of the pressure-recording system. The initial rise time was 60 ms for the microcapillary infusion system, and did not change during the test. The initial rise time for the noninfusion system was 110 ms, and rose in all but three catheters to values up to 2 seconds.

In the second part of the study, the need of pressure recordings during exercise was studied (Table 2). Five of the six noninfused Myopress catheters needed flushing with 0.1 mL of saline before pressures could be read during exercise. None of the catheters occluded during 30 min of exercise. All the noninfused catheters had blood clots at their distal tips following withdrawal of the catheters. The pressure recordings were not different. The results indicated that infusion is not necessary during short-term pressure recordings if catheters are flushed initially.

Discussion

Four possible explanations for recording increased muscle-relaxation pressure during exercise are 1) increased muscle-relaxation pressure that is related to a swelling (i.e., volume load) of the muscle tissue, as seen in patients with chronic compartment syndrome, 2) low dynamic properties of the pressure recording system, 3) remaining active muscle tension, and 4) volume loading by infusion.

Muscle-relaxation pressures in the anterior tibial muscle during exercise increase to 15–25 mmHg (2–3.3 kPa) in normal legs (Styf and Körner 1987) and to 34–55 mmHg in patients with chronic anterior compartment syndrome (Styf et al. 1987). The abnormal increase in muscle-relaxation pressure decreases blood flow and elicits the symptoms. Therefore, this parameter is diagnostically valuable. Pressure measurements during exercise may be erroneous if they are recorded with a method that lacks adequate dynamic response. This may result in an artificially high recording of muscle-relaxation pressure. Also, a catheter that has a clot at its tip or is occluded for some other reason records a falsely high pressure at rest after exercise.

Different values between muscle-relaxation pres-

sure and intramuscular pressure at rest after exercise recorded with the slit catheter are a consequence of its low dynamic properties. An analogous explanation is true for recordings of muscle-contraction pressure. When the dynamic properties of the recording system start to decrease during exercise, the relative duration of the contraction and relaxation times of the total cycle determines which of the pressure parameters (contraction or relaxation pressures) are less accurate. The pressure parameter with the shortest duration will be the first not to reach equilibrium. Similar results of decreased pressure amplitude with time using the slit catheter have been reported by Logan et al. (1983). Our results explain why pressure recordings during exercise with the slit catheter in other studies (Rorabeck et al. 1988), and also generally with catheter systems with low dynamic properties, are not useful in diagnosing the chronic compartment syndrome.

If the muscle is not fully relaxed between contractions, too high muscle-relaxation pressures will be recorded. This is also true for pressure recordings at rest after exercise. Simultaneous EMG recordings are helpful in excluding this possibility (Styf 1986, Järvholm et al. 1988).

The risk of volume load with a microcapillary infusion system is minimal because the compliance of muscle tissue at rest is high (Eliasen et al. 1974, Sejersted et al. 1984, Styf and Körner 1986). However, muscle compliance is lower during contraction. The risk of recording erroneously high muscle-contraction pressures is increased with a constant pump infusion technique. With the microcapillary nonconstant infusion technique, this risk is minimized (Styf and Körner 1986). In our study the infusion rate was zero when muscle contraction was 150 mmHg. For these reasons, this method is more suitable for recording muscle-contraction pressure during ergonomic studies.

The design of the tip of the catheter may be important when pressures are recorded during concentric and eccentric exercise. Several of our slit catheters were deformed. This may indicate that the petals were hooked up by the muscle tissue, causing trauma to the tissue. Therefore, the design of the tip of the slit catheter might be less suitable for recording intramuscular pressures during exercise.

We conclude that the microcapillary infusion technique and the design of the Myopress catheter are better suited for pressure recordings during exercise as compared with the slit catheter and the noninfusion technique.

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