Intramuscular pressure varies with depth

The tibialis anterior muscle studied in 12 volunteers

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Pressures in the tibialis anterior muscle were recorded at rest and during exercise with transducer-tipped catheters in 12 volunteers while they were supine or standing. The recordings were repeated with venous stasis created by an inflated tourniquet cuff on the thigh. Catheters were placed at 3 different sites in the muscle: catheter I adjacent to the deep surface of the fascia over the anterior compartment; catheter II between the fascia and the central tendon; and catheter III deep in the muscle close to the interosseous membrane. In both the supine and standing positions the intramuscular pressure at rest and the muscle relaxation pressure during exercise, obtained by catheter II, were greater than the corresponding pressures measured by the superficially located catheter I in the normal as well as in the volume loaded limb. The same conditions for pressure measurement consistently revealed lower pressures recorded by catheter III compared to II, but the difference was not significant. Our results indicate that intramuscular pressure increases centripetally, as the centrally lying tendon is approached. We conclude that pressure measurements for diagnosis of acute and chronic compartment syndromes and in ergonomic studies should be based on recordings from a standard location of the catheter within the muscle and a standard posture of the subject.

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Recording of intramuscular pressures is a valuable adjunct in diagnosis of acute and chronic compartment syndromes (Reneman 1975, Rorabeck and McNab 1976, Hargens et al. 1977, Styf and Körner 1987). Intramuscular pressure during contraction has been used to estimate the force generation from a specific muscle in ergonomic studies (Körner et al. 1984, Sejerstedt et al. 1984, Järvholm et al. 1988). Pressure at rest in the rat calf muscle is reported to be higher in the central zone than in the periphery (Kirkebo and Wisnes 1982), and muscle contraction pressure declines linearly with decreasing distance from the insertion site in the human vastus medialis muscle (Sejersted et al. 1984). However, the influence of depth of the recording catheter on pressures at rest and during exercise in the human tibialis anterior muscle has not been investigated. If intramuscular pressure recordings depend on the location of the catheter in the muscle, this would influence the interpretation of pressure recordings in muscle compartments.

We have determined intramuscular pressures at rest and during exercise with 3 catheters located at 3 different sites in the tibialis anterior muscle. We also studied the influence of posture as well as venous stasis on intramuscular pressures. Our hypothesis was that intramuscular pressure would be higher the deeper the catheter was inserted.

Subjects and methods

Pressures in the tibialis anterior muscle were recorded in 12 healthy volunteers, 7 men and 5 women, with a mean age of 28 (22–32) years. Pressure recordings were made while the subject was supine with the knees flexed 90 degrees and with the feet in neutral position attached to a foot ergometer (Cybex II). To examine the effects of posture, the volunteer stood on the floor, put the weight on the contralateral leg and exercised the tibialis anterior muscle by dorsiflexing the ankle of the experimental leg with the heel on the floor.

Intramuscular pressure recordings. After preparation of a sterile field the skin was anesthetized with 2 mL of 1% Xylocain injected 2 cm lateral to the tibial tuberosity. A 14-gauge (2.1 mm) needle was introduced in a distal direction. The fascia of the anterior tibial muscle was penetrated while the subject maintained the foot actively dorsiflexed. The tip of the nee-

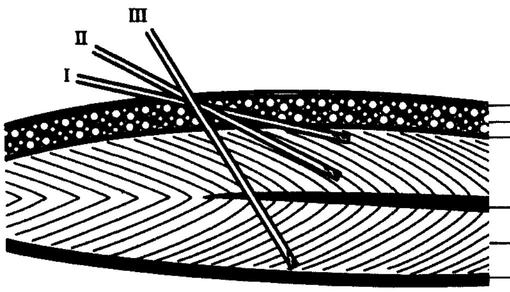

Figure 1. Longitudinal section of the tibialis anterior muscle showing placement of catheters.

dle was retracted into the sheath which was bluntly introduced into the relaxed muscle (Styf and Körner 1986). Then the sheath of the needle was filled with saline while removing the needle was removed. A calibrated transducer-tipped catheter (Camino Labs, San Diego, CA, U.S.A.) was introduced into the sheath. The catheter was taped to the skin and connected to an amplifier (model 421, Camino Labs), a digital monitor (model 420, Camino Labs) and a multichannel chart recorder (Hewlett Packard 7754 A). We used transducer-tipped catheters to obviate the need to adjust the transducers to the level of the catheter tip. The catheters were introduced at 3 different sites in the tibialis anterior muscle (Figures 1 and 2): catheter I adjacent to the deep surface of the overlying fascia of the anterior compartment, catheter II parallel to the muscle fibers between the fascia and the centrally located tendon, and catheter III deep in the muscle close to the interosseous membrane.

Orientation of catheters in cadavers

In 4 cadaver limbs catheter I was inserted a distance of 45 mm from the skin as superficially and as parallel to the fascia as possible; this was achieved by elevating the tip of the needle after penetration of the fascia. Catheter II was inserted 45 mm at an angle of 30 degrees to the plane of the skin. After penetration of the fascia the tip of the needle was retracted within the plastic sheath of the introducer. The introducer was lowered to an angle of about 20 degrees to the plane of the skin and introduced parallel to the muscle fibers (Styf and Körner 1986). This method of catheter insertion has been used in hundreds of pressure recordings during exercise and was regarded as a reference catheter in our study. Catheter III was placed 5 mm distal to the first and introduced 45 mm at an angle of 45 degrees to the skin. The localization of the catheter tips within the anterior compartment was determined by careful dissection.

The reference catheter II was located between the overlying fascia and the centrally located tendon whereas catheter I was situated adjacent to the deep surface of the fascia. The tip of catheter III was positioned close to the interosseous membrane (Figure 1).

Catheter II and III pressures

In 5 subjects reference catheter II was compared to catheter III, because we hypothesized that the former would record lower pressures (Figure 1). Both catheters were inserted as described above. 3 types of pressure measurements were made: 1) resting pressure; 2) muscle relaxation pressure; 3) muscle contraction pressure and each pressure was obtained while the volunteer was alternately in one of the following positions: 1) supine, 2) standing, 3) supine with venous stasis, 4) standing with venous stasis. Muscle contraction pressure was measured during concentric contractions of the tibialis anterior muscle during dorsiflexion of the ankle at a frequency of between 0.5 and 1.0 Hz. There was some variation of frequency between individuals, but each individual maintained a rather constant contraction frequency. Muscle relaxation pressure was the pressure obtained in the relaxed muscle between contractions. The recordings were made in turn—first while the subject was supine with the knees flexed 90 degrees and with the feet attached to a foot ergometer (Cybex II). Then the volunteer stood on the floor on the contralateral leg. Finally, to simulate a compartment syndrome a thigh tourniquet was inflated to 60 mm Hg on the experimental leg. This obstructed venous return and thus increased the blood and interstitial volumes of the leg. Measurements under the condition of stasis were performed with the volunteer supine and then standing.

Catheter I and II pressures

In 7 subjects reference catheter II was compared to catheter I (Figure 2). Catheter I was inserted a distance of 45 mm as superficially and as parallel to the fascia as possible. The correct positioning of the needle was facilitated by the fact that at this location the tibialis anterior muscle presents a convex bulge during a concentric contraction. Catheter II, the reference catheter,

Table 1. Intramuscular pressures (mmHg) in the tibialis anterior muscle at rest and during exercise in 5 subjects. Catheter locations, see Figure 1. Muscle relaxation pressure is the pressure between contractions during dynamic muscle contractions. Mean *SD*

	Catheter II		Catheter III	
Pressure at rest				
Supine	5.2	*2.4*	4.2	*1.6*
Standing	13.2	*5.6*	12.8	*6.1*
Supine and stasis	12.7	*3.8*	9.0	*2.6*
Standing and stasis	26.0	*4.3*	21.7	*5.3*
	P 0.19			
Muscle relaxation pressure				
Supine	4.4	*1.5*	4.0	*1.6*
Standing	9.0	*3.9*	8.2	*2.5*
Supine and stasis	7.2	*1.5*	4.5	*1.3*
Standing and stasis	16.0	*1.6*	11.0	*2.0*
	P 0.14			
Muscle contraction pressure				
Supine	115	*50*	125	*41*
Standing	170	*62*	160	*67*
Supine and stasis	203	*47*	187	*42*
Standing and stasis	200	*69*	187	*91*
	P 0.23			

Table 2. Intramuscular pressure (mmHg) in the tibialis anterior muscle at rest and during exercise from 7 subjects. Catheter locations, see Figure 1. Mean *SD*

	Catheter I		Catheter II	
Pressure at rest				
Supine	3.6	*2.2*	6.4	*2.7*
Standing	13.4	*13.0*	17.8	*11.2*
Supine and stasis	11.6	*9.1*	17.2	*8.2*
Standing and stasis	18.3	*12.9*	26.8	*9.8*
	P 003			
Muscle relaxation pressure				
Supine	2.9	*2.3*	6.6	*3.2*
Standing	7.1	*5.5*	14.6	*13.0*
Supine and stasis	7.0	*6.0*	10.9	*6.3*
Standing and stasis	12.8	*12.0*	7.3	*9.8*
	P 0.02			
Muscle contraction pressure				
Supine	127	*51*	172	*96*
Standing	143	*41*	194	*68*
Supine and stasis	163	*72*	193	*68*
Standing and stasis	190	*67*	238	*65*
	P 0.09			

was placed 5 mm distal to the first, as described above. A series of pressure recordings was made in the various positions, as described above.

Statistics

Pressure recordings are given as mean values and 1 standard deviation (SD). Significance was tested with 2 way ANOVA. There were 2 "within" factors. The first consisted of 2 levels (catheter I versus III) and the second of 4 levels (4 experimental conditions). When testing the first factor we had 1 "between" factor whereas testing the second factor we applied the correction of Greenhouse and Geisser (Dixon 1990). Significance was accepted when $P < 0.05$.

Results

Intramuscular pressure at rest in the supine position was 5.2 (SD 2.4) mm Hg recorded by the reference catheter II and 4.2 (SD 1.6) mm Hg recorded by catheter III (n.s.). Pressures were not different between catheters with the subjects standing, with or without venous stasis (Table 1).

Reference catheter II recorded greater intramuscular pressure at rest and greater muscle relaxation pressure during exercise than the superficially located catheter I ($P < 0.05$). Catheter II recorded higher pressures, regardless of position of the subject, in the normal as well as in the volume-loaded limb (Table 2). Maximal muscle contraction pressures recorded by catheter II were only marginally greater than the superficial measurements (*P* 0.09).

Discussion

Our results show that intramuscular pressures increase with depth from a subfascial position to the centrally located tendon. Pressures increase as a function of the number of muscle fibers covering the tip between the fascia and the centrally located tendon.

Gershuni et al. (1982) reported that the distance between the fascia over the tibialis anterior compartment and the interosseous membrane connecting the tibia and fibula is about 30 mm in healthy volunteers. The interosseous membrane as well as the fascia are important structures in generation of intramuscular pressure (Mozan and Keagy 1969, Garfin et al. 1981). Hence, the interosseous membrane on the back of the tibialis anterior muscle could function similarly to the fascia on its anterior side in generation of intramuscular pressure. The tip of the catheter near the membrane is certainly located deep in the leg, but the muscle fibers might function superficially when compared to the fibers located close to the central tendon. The localization of the catheter tip could thus be defined as superficial in the tibialis anterior muscle when it is close to the fascia or close to the interosseous membrane and as deep when it is close to the centrally lying tendon. This explains why pressure recordings obtained by catheter II were greater than those obtained by catheters I or III.

The position of the investigated limb was kept constant during the experiment because intramuscular pressure in the anterior compartment varies with the position of the ankle joint (Gershuni et al. 1984). The knee was flexed 90 degrees to avoid external compression on the leg and to achieve a standard relaxed position which felt comfortable for the subject (Styf and Körner 1987, Crenshaw et al. 1992).

Although not significant, maximal muscle contraction pressure changed similarly to the other intramuscular pressures studied. Therefore, it is important to place the catheter tip at a constant depth in the muscle and to keep the patient in a standard position while recording pressure from individual muscles in ergonomic research. Our results of maximal muscle contraction pressure in the tibialis anterior muscle are in agreement with other reports (Sejerstedt et al. 1984, Styf and Körner 1986, 1987, Järvholm et al. 1988, Crenshaw et al. 1992). Intramuscular pressure at a given depth from the fascia depends on the number and thickness of the overlying muscle fibers and the magnitude of muscle fiber tension (Sejerstedt et al. 1984). Our results are in agreement with this conclusion, except that even deep fascial structures, like the interosseous membrane, function like a superficial fascia in a bipennated muscle such as the tibialis anterior.

Catheters should not be introduced close to the tendon when intramuscular pressures during exercise are recorded. The distance from the catheter tip to the tendon should allow the muscle fibers to shorten by one fifth during contraction, to prevent the tendon touching the tip of the catheter.

Muscle relaxation pressures in our series were lower than those recorded by Styf and Körner (1986, 1987). The experimental setups were similar in both series but the techniques of pressure recording were different. Although the transducer-tipped catheter records pressures that are comparable to those recorded with the microcapillary infusion technique, a piston effect (Crenshaw et al. 1992) might occur while recording muscle relaxation pressure during exercise. Muscle fibers shorten during contraction and during the following relaxation period they lengthen again. When muscle fibers slide over the tip of a large catheter, a local vacuum may be created so that the recorded muscle relaxation pressure is lower than when the readings are obtained with a smaller catheter.

Obstruction of venous return elicits increased intramuscular pressure as seen in a compartment syndrome (Jepson 1975). In our experiments the volume load in the tibialis anterior muscle was increased by the inflated tourniquet on the thigh. Deep pressure recordings in the volume loaded limb were greater than superficial readings and, in a compartment syndrome, the deep pressure readings would similarly be expected to be greater than the superficial readings. Therefore, diagnosis of compartment syndromes should be based on pressure recordings from the deep portion of a muscle as defined above.

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