Negative interstitial pressure in the peritendinous region during exercise

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Langberg, Henning, Dorthe Skovgaard, Jens Bülow, and Michael Kjaer. Negative interstitial pressure in the peritendinous region during exercise. J. Appl. Physiol. 87(3): 999–1002, 1999.—In the present study, tissue pressure in the peritendinous area ventral to the human Achilles tendon was determined. The pressure was measured during rest and intermittent isometric calf muscle exercise at three torques (56, 112, and 168 Nm) 20, 40 and 50 mm proximal to the insertion of the tendon in 11 healthy, young individuals. In all experiments a linear significant decrease in pressure was obtained with increasing torque [e.g., at 40 mm: −0.4 ± 0.3 mmHg (rest) to −135 ± 12 mmHg (168 Nm)]. No significant differences were obtained among the three areas measured. On the basis of these observations, microdialysis was performed in the peritendinous region with a colloid osmotic active substance (Dextran 70, 0.1 g/ml) added to the perfusate with the aim of counteracting the negative tissue pressure. Dialysate volume was found to be fully restored (100 ± 4%) during exercise. It is concluded that a marked negative tissue pressure is generated in the peritendinous space around the Achilles tendon during exercise in humans. Negative tissue pressure could lead to fluid shift and could be involved in the increase in blood flow previously noted in the peritendinous pressure could lead to fluid shift and could be involved in the increase in blood flow previously noted in the peritendinous space ventral to the human Achilles tendon at rest and during graded workloads. This was done during intermittent isometric contractions with the triceps surae muscles. Furthermore, it was hypothesized that, if tissue pressure was found to decrease during exercise, the addition of colloid osmotic substances to the perfusion fluid would result in counteracting fluid loss when microdialysis is performed during muscle contraction.

METHODS

Subjects

A group of healthy volunteers with no previous history of Achilles tendon symptoms or injuries were included in the present study. The group consisted of 11 subjects (4 women and 7 men) with a median age of 28 yr (range 23–35 yr) and a median body weight of 78 kg (range 55–93 kg). All but one volunteer participated in recreational endurance sports (mean training: 6 h/wk). Subjects were told not to undertake any kind of exercise 24 h before the experiment, except for ordinary daily working activities. The study was approved by The Ethical Committee of Copenhagen ([KF] 01-164/97).

Procedures

In all subjects, both pressure measurements and microdialysis were performed. At least a 2-wk period was allowed between the measurements to ensure that the results were not influenced by a potential previous trauma due to insertion.

Pressure measurements. To measure the pressure in the peritendinous space, the subjects were positioned in a specially constructed experimental setup (Fig. 1), with the trunk perpendicular to the seat and the knee extended. The extension of the knee ensured that the torque moment registered was generated by the calf muscles only and that activity in the extensor muscles of the thigh was excluded. One foot at the time was positioned on a vertical sheet with the axis of the sheet aligned with the axis of flexion in the ankle joint. The torque moment developed by triceps surae muscle in the plantar direction could be registered by a precalibrated (range 0–2,000 N) strain gauge (lever arm: 280 mm). The torque was amplified by a custom-made instrumental alternating-current amplifier and displayed online to the subject (Fig.

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determined when the torque had stabilized, and the same strain gauge corresponded to 200 N. Interstitial pressure was generated to register, the subject was asked to generate a plantar flexor torque by which the force at the position in the tissue. The subject was subsequently told to position the cannula (OD 0.8 mm) was inserted at a depth of 10–20 mm. To control that the cannula was ready to register, the subject was asked to generate a minor torque in the plantar direction, resulting in a change in interstitial pressure. To measure the resting tissue pressure the subjects were asked to relax (≥ 20 s) with the cannula positioned in the tissue. The subject was subsequently told to generate a plantar flexor torque by which the force at the strain gauge corresponded to 200 N. Interstitial pressure was determined when the torque had stabilized, and the same procedure was performed with a plantar torques that corresponded to 400 and 600 N. The experiment was terminated by a recovery measurement with relaxed triceps surae muscle. In all cases the interstitial pressure returned to resting values.

Microdialysis measurements. One microdialysis catheter (membrane 30 × 0.62 mm, 20,000-molecular-weight cutoff; model CMA 60, CMA/Microdialysis, Stockholm, Sweden) was placed on the peritoneal space ventral to each Achilles tendon with the active part of the catheter covering the area from 20 to 50 mm above the insertion of the tendon on the calcaneus (equal to the area where the pressure measurements had been performed). One additional catheter (membrane 30 × 0.62 mm, 20,000-molecular-weight cutoff; model CMA 60, CMA/Microdialysis) was placed in the gastrocnemius lateralis muscle. The dialysis catheters were perfused, via a high-precision syringe pump (model CMA 100, Carnegie Medicine, Solna, Sweden), at an infusion rate of 1 µl/min. The precision of the pump was verified by weighing samples collected from tubing attached to syringes in the pump. The perfusion fluid was a Ringer acetate solution supplemented with 0.1 g/ml of Dextran 70 (71,000 mol wt; D-1537, Sigma Chemical, St. Louis, MO). The colloid osmotic pressure of that perfusion fluid was calculated to be 27 mmHg. Microdialysis was performed with the subjects resting supine for 60 min. After this, intermittent isometric contractions (1.5-s contraction/1.5-s rest) in plantar direction were performed with both legs for 30 min with a total torque of one times body weight (Fig. 1). A mean torque for the “exercising cycle,” consisting of a rest period (1.5 s) and a contraction period (1.5 s), was calculated by using the area under the curve (Fig. 2). The study was completed by an additional resting period of 60 min. The dialysate was collected in capped microcuvirs (CMA/Microdialysis), and the collected dialysate volume was determined immediately by weighing all samples on a high-precision weight.

Statistics

Friedman’s test was used to test whether significant changes occurred with increasing torque (16), and such changes were then located by the multiple-comparison procedure (16). Differences between the regions at the same torque were determined by the Mann-Whitney ranking test for unpaired data (16). A significance level of 0.05 (2-tailed testing) was chosen a priori.

RESULTS

At rest no significant difference was found between the pressures measured in any of the three regions (P > 0.05) (Fig. 3). Furthermore, a nearly linear decrease in pressure was found with increase in torque in all the three regions (Fig. 3), and no significant difference was found among the regions (P > 0.05).

On the basis of the calculated average torque for an exciting cycle (Fig. 2) and the linear relationship between torque and tissue pressure (Fig. 3), the average negative pressure generated during one exercising cycle was calculated to be 25–30 mmHg. On the basis of these calculations 0.1 g/ml of Dextran 70 was added to the perfusate during microdialysis. With the addition of Dextran 70, a 100 ± 4% recovery of dialysate volume was achieved during exercise (Fig. 4). However, a net gain of ~10% in the dialysate volume was found during both rest and recovery.

**Fig. 1.** Schematic drawing of experimental setup. Subject is seated with trunk perpendicular to seat, knee extended, and foot positioned on vertical sheet with axis of sheet and axis of plantar flexion and dorsiflexion in ankle joint aligned. Torque moment developed by triceps surae muscle in plantar direction is registered by a precalibrated (range 0–2,000 N) strain gauge (lever arm: 280 mm). Torque is amplified by a costume-built instrumental alternating-current amplifier and displayed online to the subject.

**Fig. 2.** Graphic presentation of generated torque as shown on the display to the subject. Shown is an example of intermittent contractions (contraction 1.5 s, resting 1.5 s) in performance of a load equal to 1 × body weight (60 kg).
The addition of Dextran 70 to the perfusate resulted in a net gain of fluid of 10% during rest and almost 20% during exercise.

**DISCUSSION**

A marked decrease in peritendinous tissue pressure ventral to the Achilles tendon was found during intermittent static contractions of the triceps surae muscle in humans (Fig. 3). In a recent paper a method for measuring negative intramuscular pressure similar to the one used in the present study was evaluated, and it was shown that the method was suited for recording negative pressures over a wide range (5). This is to our knowledge the first time changes in the interstitial pressure around the human Achilles tendon have been measured in relation to exercise. The negative interstitial pressure found in the present study is in contrast to changes in muscle tissue pressure, where exercise is found to cause a rise in intramuscular pressure in a variety of muscle groups (1, 11, 13, 18, 19). The fact that peritendinous pressure decreased severalfold during exercise can explain why collected dialysate volumes were lower than expected when microdialysis technique was attempted in that region. The decreased peritendinous pressure could be created as a result of the muscles contracting, expanding the dense structures surrounding the Achilles tendon. The role of this marked negative pressure during exercise could be of importance for fluid shift and microvascular flow appearing during exercise and as such involved in the increase in blood flow in the peritendinous area around the human Achilles tendon previously determined during exercise (8, 9).

It is well described in muscular tissue that changes in intramuscular pressure influence blood flow through the region and that chronic elevated intramuscular pressure is associated with decreased venous outflow (18) and with clinical symptoms (3, 12). In the peritendinous tissue of the Achilles region, blood flow has been shown to increase during exercise (8), and this is in accordance with the present observed decrease in tissue pressure.

On the basis of the obtained correlation between exercise load and tissue pressure (Fig. 3), the average negative pressure during one exercising cycle in our protocol (Fig. 2) with the exercise done at a resistance of one times individual body weight would be equivalent to 25–30 mmHg. With this background as the basis, 0.1 g of Dextran 70 was added per milliliter of perfusate, resulting in increase in osmotic pressure of 27 mmHg in the perfusate. It was found that the dialysate volume was restored to 100% and, although the addition of Dextran 70 resulted in a dialysate volume at rest of 110%, the loss of dialysate volume when individuals shifted from rest to exercise was counteracted. This supports the hypothesis that the loss in dialysate volume during exercise is a result of changes in pressure. In addition to this, microdialysis in the muscle resulted in an increase in collected dialysate from rest to exercise, which is most likely a result of increased colloid osmotic pressure and a small increase in tissue pressure from rest to exercise. We chose in the present study to perfuse the microdialysis probes at a flow rate of 1 µl/min with a membrane length of 30 mm, which have been found to give the best relationship between recovery (concentration) and volume (unpublished ob-
servations). However, other flow rates, membrane lengths, and exercising intensities could markedly influence the fluid loss and as such the need for modifying the composition of the perfusate to counteract dialysate loss (14).

In summary, the present study shows that the interstitial pressure decreased during exercise. The decrease in pressure along the Achilles tendon was linear with increasing torque. Addition of a colloid osmotic active substance to the perfusate counteracted the negative tissue pressure and resulted in a complete recovery of the dialysate volume (100% ± 4%). On the basis of the present findings, it is concluded that the negative tissue pressure in human peritendinous space around the Achilles tendon during exercise requires the addition of a colloid osmotic substance to the perfusate when the microdialysis technique is used.

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