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Eccentric Training Decreases Paratendon Capillary Blood Flow and Preserves Paratendon Oxygen Saturation in Chronic Achilles Tendinopathy

Achilles tendinopathy is associated with a certain degree of neovascularisation[15] and pain, which may be demonstrated by either color Doppler or Power Doppler ultrasound. The introduction of Laser Doppler supports imaging in soft tissue inflammation and is believed to be more sensitive than Power Doppler.[5]

The baseline Achilles tendon as well as paratendon microcirculation in healthy athletes differs from patients with either insertional or midportion tendinopathy, where capillary blood flow at the point of pain is increased as determined by laser Doppler flowmetry.[13] Combining laser Doppler flowmetry to assess capillary blood flow, with spectrophotometry to determine local oxygen saturation and postcapillary venous filling pressures, is a novel approach to evaluating tendon and paratendon microcirculation in detail.[13]

STUDY DESIGN: A controlled, randomized, prospective study.

OBJECTIVE: To assess the changes in paratendon microcirculation after 12 weeks of daily painful eccentric training in individuals with chronic Achilles tendinopathy.

BACKGROUND: Changes in tendon and paratendon microcirculation are evident in insertional and midportion Achilles tendinopathy. Whether the paratendon is involved in eccentric training response is not known.

METHODS: Twenty patients with chronic Achilles tendinopathy were recruited for a prospective, controlled trial using eccentric exercise. A laser Doppler system assessed capillary blood flow (flow), tissue oxygen saturation (SO_2), and postcapillary venous filling pressure (rHb) at 8 paratendon locations at depths of 2 and 8 mm.

RESULTS: Pain in the eccentric-training group was reduced by 48% (from a mean of 4.1 $\pm$ 2.9 to 2.1 $\pm$ 2.2, $P<.05$). Deep paratendon blood flow decreased at the midportion paratendon location ($P<.05$). Superficial blood flow at the medial distal midportion position (by 31%, $P = .008$) and the lateral proximal midportion location (by 45%, $P = .016$) were significantly decreased postintervention. No significant change of superficial or deep paratendon oxygenation was found after intervention as compared to baseline. Deep paratendon postcapillary venous filling pressures were significantly reduced following eccentric training ($P<.05$).

CONCLUSION: An eccentric-training program performed daily over 12 weeks reduced the increased paratendinous capillary blood flow in Achilles tendinopathy by as much as 45% and decreased pain level based on a visual analog scale. Local paratendon oxygenation was preserved while paratendinous postcapillary venous filling pressures were reduced after 12 weeks of eccentric training, which appears to be beneficial from the perspective of microcirculation. *J Orthop Sports Phys Ther 2007;37(5):269-276. doi:10.2519/jospt.2007.2296*

KEY WORDS: microcirculation, rehabilitation, tendon, ultrasound

An adjunct inflammatory involvement of the paratendon might be expected in tendinopathy. Authors of recent animal studies[4,20] found that paratendinous injections of substance P following surgical repair of the Achilles tendon in rats appears to provide a stimulus to the initial stages of healing and significantly accelerate the reparative phase of the healing process. Peritendinous injections of proinflammatory prostaglandin PGE_1 produce acute inflammation of the Achilles tendon, with prolonged PGE_1 administration leading to both peritendinous and intratendinous degeneration.[21] These data suggest a role of the paratendon in individuals with Achilles tendinopathy.

The use of eccentric calf muscle training has resulted in good clinical short-term and midterm outcomes in patients with chronic painful midportion Achilles tendinosis.[17] Using MRI techniques, both eccentric and concentric loading of the Achilles tendon was shown to increase total tendon volume and intratendinous signal immediately after strength training.[18] This increase may be explained by a higher water content and/or hyperaemia in the Achilles tendon during and/or immediately after strength training of the

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gastrocnemius-soleus complex. Good clinical midterm results were associated with decreased tendon thickness and a structurally more normal tendon, with no remaining neovessels as evaluated with ultrasound,[16] and a decreased tendon volume and intratendinous signal as seen on MRI.[19]

However, no data on the effect of eccentric training to the peritendinous part of the Achilles tendon have yet been published. Based on the results of previous studies, we hypothesized that an eccentric training intervention changes parameters of paratendon microcirculation in Achilles tendinopathy.

METHODS

A total number of 20 patients with chronic (as determined by greater than 3 months Achilles tendon pain, tenderness with or without swelling, and grey-scale conventional ultrasound) participated in this prospective randomized controlled study after signing an informed consent. The patients were recruited by advertisements in the medical school and several fitness clubs in the local city. Patients seeking medical attention due to Achilles tendinopathy in the Medical School Hannover were also informed about the study and offered to participate. All subjects were required to be older than 18 years. Patients with both unilateral and bilateral Achilles tendinopathy were included. The diagnosis of Achilles tendinopathy was made if patients had pain and tenderness with or without swelling at the tendon at rest or with exercise, either at the insertional zone on the calcaneus or in the midportion area of the Achilles tendon 2 to 6 cm proximal to the distal insertion. Individuals with prior Achilles tendon surgery were excluded as well as individuals with vascular occlusive disease or venous congestion. Pregnancy was also an exclusion from the study. None of the patients included had received prior therapy with eccentric exercise training prior to the study. The protocol for this study was approved by the Institutional Review Board of Hannover Medical School, Germany.

Detailed patient characteristics such as age, body mass index, sports activities, medication, and anthropometric data are provided in **TABLES 1**, **2**, and **3**. Subjects were allocated and randomized in a control group (n = 5: chronic insertional tendinopathy, n = 3; chronic midportion tendinopathy, n = 2) and the eccentric-training group (n = 15: chronic insertional tendinopathy, n = 9; chronic midportion tendinopathy, n = 6).

The eccentric-training group performed eccentric training of 3 sets of 15 repetitions daily over at least 12 weeks. For the eccentric training, subjects were instructed to stand on the forefoot of both the involved and uninvolved lower extremity at the edge of a step with the ankle in full plantar flexion. They were then asked to slowly lower their body by progressively lowering their heel as far as possible below the edge of the step to full ankle dorsiflexion. Both eccentric and concentric parts of the exercise had to last over 2 seconds. The patients were instructed to perform the eccentric training in socks or bare feet to maximize foot and ankle flexibility and available range of motion. The participants were in-

TABLE 1 Patient Characteristics for the Eccentric Training and Control Groups

	Training (n = 15)	Control (n = 5)
Male	8	3
Female	7	2
Age (y)*	33 ± 12	32 ± 10
Height (cm)*	177 ± 7	176 ± 8
Body mass (kg)*	71 ± 12	78 ± 10
Body mass index (kg/m^2)*	22.5 ± 2.0	25.2 ± 4.0

Values are mean ± SD. There was no difference between groups for any of the variables (P>.080).

TABLE 2 Subjects' Training History Before and During the Intervention*

	Eccentric Training (n = 15)		Control (n = 5)	
	Before	During	Before	During
Aerobic sport	10 (67%)	9 (60%)	2 (40%)	3 (60%)
h/wk	4 (1-20)	2 (1-15)	4 (1-7)	6 (1-7)
Ball game	6 (40%)	6 (40%)	1 (20%)	1 (20%)
h/wk	2 (1-14)	3 (2-12)	2	2
Biking	4 (27%)	3 (20%)	4 (80%)	3 (60%)
h/wk	2 (1-9)	2 (1-9)	4 (1-24)	4 (4-7)
Gymnastics	2 (13%)	1 (7%)	0	0
h/wk	1.5 (1-2)	2	...	...
Fitness training	1 (7%)	1 (7%)	2 (40%)	2 (40%)
h/wk	3	3	2 (1.5-3.0)	2 (2-3)
Water sports	1 (7%)	1 (7%)	1 (20%)	2 (40%)
h/wk	5	2	3.0	3.5 (3-4)
Horseback riding	1 (7%)	1 (7%)	0	0
h/wk	5	2	...	...

**Across subject group data are number (%) of subjects in the group doing a particular activity; h/wk data are presented as median (range).*

formed about the possibility of pain during the exercise in the Achilles tendon region. Furthermore, the participants were informed that after initiation of the eccentric training program, calf soreness might be evident during the first 2 to 3 days. The control group used conventional repetitive cryotherapy (crushed ice for 10 minutes) and relative rest in case of pain to relieve symptoms over the 12-week study period. Both patients in the control and the eccentric-training groups were instructed not to change their usual and regular physical activities throughout the study period.

Pain Assessment

Pain was assessed on an 11-point visual analogue scale (VAS) prior to the training and after completion of the 12-week program. The lower and upper limits for the VAS were 0 for no pain and 10 for the highest imaginable pain. In case of bilateral symptoms the side with worse pain was chosen for pain assessment.

Compliance and Supervision

All participants were provided with the e-mail and telephone information of the members of the study team in case they had questions. Four weeks after the initiation of training each participant was contacted by phone by the investigator and asked about training performance, pain during the exercises, possible problems encountered, and any other questions they might have had. Twelve weeks after the initial laser Doppler assessment a second evaluation was performed under exactly the same environmental conditions by the same experienced investigator (R.K.), who was blinded to the randomization results. All 20 patients completed the study.

Paratendon Microcirculatory Mapping

A noninvasive, real-time combined laser Doppler and spectroscopy system (Oxygen-to-See; LEA Medizintechnik, Giessen, Germany) was used to perform detailed realtime paratendon microcirculatory mapping in 16 locations of the Achilles tendon.[12]

A combined laser-Doppler and flowmetry system was used to evaluate microcirculation at 2 distinct tissue depths noninvasively.[6,7] We have recently described increased capillary blood flow at the point of pain in patients with insertional and midportion tendinopathy of the Achilles tendon compared to healthy subjects.[13]

Blood flow and blood flow velocity are measured in arbitrary units (AU). These units were chosen by the developer of the device. The measured signals for blood flow are electrical values of frequencies and amplitudes, so that the unit is a combination of electrical units. To calculate the blood flow in milliliters per minute, it would be necessary to compare the electrical signals with a method that measures the blood flow in milliliters per minute (eg, plethysmography, microspheres) for each organ (or organs with similar optical properties). This calibration has not been done.

The reproducibility of blood flow values determined with the Oxygen-to-See has been tested in a test-retest design in 20 healthy, nonsmoking adults (22-39 years of age). Multivariate analysis of variance for repeated measures did not reveal significant differences in the mean blood flow values within and between different days. An average 5% intrasubject variability was calculated.[8]

TABLE 3 Patient-Related Medical History

	Eccentric Training (n = 15)	Control(n = 5)
Smoking		
Never	13 (87%)	3 (60%)
Cigarettes, <5/d	1 (7%)	1 (20%)
Cigarettes, >5/d	1 (7%)	1 (20%)
Medication during the last 6 mo		
None	9 (60%)	3 (60%)
Antibiotics	1 (7%)	1 (20%)
Chinolones	0	1 (20%)
Other antibiotics	1 (7%)	0
Inhalative corticoids	1 (7%)	0
Non steroidal antirheumatic drugs	0	2 (40%)
Oral contraceptives (% in females)	4 (57%)	1 (20%)
Medical history		
No significant history	12 (80%)	4 (80%)
Arterial hypertension	2 (13%)	1 (20%)
Renal insufficiency	0	0
Others (allergy)	1 (7%)	0

Statistics

The data are presented as median and range for continuous variables or number and percentages for dichotomous variables of patients' characteristics. As there was nonsignificant skewness in microcirculatory variables, but a high skewness in percentual change of the microcirculatory variables preintervention to postintervention, we chose a presentation of the data as median values for the percent change of parameters of microcirculation and mean (±SD) for the raw values of microcirculation preintervention and postintervention. Univariate analysis of categorical data was carried out using the chi-square or Fisher exact tests. Multivariate analysis of metrical data was carried out by 2-way ANOVA for comparison of preintervention to postintervention microcirculatory changes between groups. An independent-samples t test was applied for parametric, ordinal variables of independent samples regarding biometrical, sports activity, and pain level data. Student's t test for paired samples was used for parametric, ordinal, and metrical variables of repeated samples. A chi-square test was applied on nominal patient characteristics regarding smoking, history, and medication.

A P value less than .05 was considered to indicate statistical significance. The SPSS statistical software package 11.5 for Windows (SPSS Inc, Chicago, IL) was used for statistical analysis.

RESULTS

Sport Activity Prior to and After the Intervention

We found no significant changes in the amount of aerobic exercise or participation in ballgames, gymnastics, biking, swimming, and horseback riding during the study.

No change in concomitant medical therapy due to other health conditions besides Achilles tendinopathy was found in a detailed evaluation that was performed throughout and at the end of the 12-week training intervention.

VAS

The eccentric-training group had a mean (±SD) of 4.1 ± 2.9 on the VAS prior to the training, which was reduced by 48% to 2.1 ± 2.2 ($P<.05$) after 12 weeks of eccentric training (**FIGURE**). The pain level in the control group decreased from 8.0 ± 0.5 to 5.5 ± 0.5 (P = .123) after 12 weeks. The difference in pain level at baseline between the 2 groups was large but not statistically significant (P = .086).

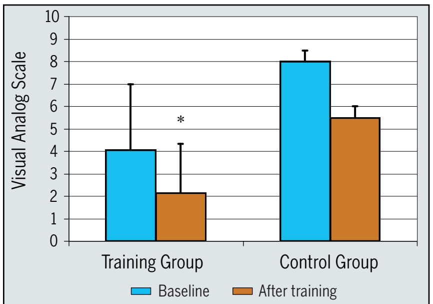

FIGURE. Achilles tendon pain at peak exercise in the eccentric-training group (including both insertional and midportion tendinopathy) at baseline and after 12 wk of eccentric training versus the control group. Pain was measured with a 0-to-10 visual analog scale, with 0 representing no pain and 10 representing highest imaginable pain. Data presented as means ± SD. *$P<.05$.

Paratendon Microcirculation

The superficial capillary blood flow at the distal medial midportion (–31%, P = .008) and the lateral proximal midportion (–45%, P = .04) of the tendon were found to be significantly reduced after 12 weeks of eccentric training. We found no further significant changes in capillary blood either in the superficial or deep medial and lateral paratendon of Achilles tendons in both groups, as noted in **TABLES 4** through **7**. There was no significant difference in capillary blood flow between the control and the eccentric-training group.

Tendon and Paratendon Oxygen Saturation

No significant change of superficial and deep-tissue oxygen saturation, as compared to baseline, was found in the train-

TABLE 4 TISSUE OXYGEN SATURATION*

	2 mm		8 mm	
	Training	Control	Training	Control
Tissue oxygen saturation baseline (%)				
Medial insertion	35 ± 21	37 ± 20	72 ± 5	72 ± 3
Medial distal midportion	32 ± 12	36 ± 10	68 ± 5	69 ± 4
Medial proximal midportion	35 ± 12	37 ± 32	70 ± 6	68 ± 3
Medial musculotendinous junction	33 ± 14	36 ± 22	70 ± 7	69 ± 3
Lateral insertion	30 ± 18	30 ± 14	69 ± 4	70 ± 4
Lateral distal midportion	32 ± 11	46 ± 14	68 ± 3	68 ± 5
Lateral proximal midportion	37 ± 13	56 ± 22	66 ± 6	67 ± 4
Lateral musculotendinous junction	39 ± 15	47 ± 19	67 ± 7	65 ± 6
Tissue oxygen saturation after 12 wk (%)				
Medial insertion	35 ± 12	42 ± 15	119 ± 12	69 ± 3
Medial distal midportion	35 ± 13	44 ± 15	68 ± 4	69 ± 4
Medial proximal midportion	36 ± 14	38 ± 10	69 ± 5	69 ± 2
Medial musculotendinous junction	36 ± 14	38 ± 8	69 ± 5	71 ± 5
Lateral insertion	34 ± 11	40 ± 13	67 ± 5	68 ± 4
Lateral distal midportion	33 ± 8	45 ± 6	67 ± 5	69 ± 3
Lateral proximal midportion	37 ± 13	44 ± 11	67 ± 5	67 ± 3
Lateral musculotendinous junction	33 ± 11	41 ± 5	67 ± 7	69 ± 4
Tissue oxygen saturation median change (%)				
Medial insertion	37	2	–4	–3
Medial distal midportion	11	24	–2	–3
Medial proximal midportion	23	3	–5	2
Medial musculotendinous junction	12	6	–10	3
Lateral insertion	26	33	–6	–2
Lateral distal midportion	28	–3	7	2
Lateral proximal midportion	4	–21	–1	0
Lateral musculotendinous junction	–16	12	5	6

Absolute values (mean ± SD) and median percent change (%) in Achilles paratendon microcirculation variables for the eccentric-training group (n = 15) and the control group (n = 5) at 8 paratendon locations at 2 tissue depths. No significant preintervention-to-postintervention change (P>.05) ing and control groups at any of the 8 paratendon positions after 12 weeks.

Tendon and Paratendon Postcapillary Venous Filling Pressures

There was a significant increase of the superficial postcapillary venous filling pressures at the 2-mm depth in the training group at the medial (27 arbitrary units, $P<.036$) and lateral insertion (9 arbitrary units, $P<.006$) after 12 weeks. At all other midportion paratendon locations no further significant changes regarding superficial and deep postcapillary venous filling pressures were noted after the intervention.

DISCUSSION

A 12-week daily eccentric training program changed paratendon microcirculation in individuals with Achilles tendinopathy. Deep paratendon capillary blood flow decreased significantly between the training groups versus the control group at 2 midportion paratendon positions. Neovascularisation has been found to be evident in tendinopathy. Öhberg and Alfredson[16] demonstrated during heel drop eccentric training a stop of the flow of the pathologic neovessels and raised the theory that the positive clinical results obtained with painful eccentric calf muscle training might be mediated through regional changes in the neovascularisation. In this study we demonstrate a significant decrease in paratendinous capillary blood flow at 2 distinct midportion locations in the Achilles tendon. This change was associated with a significant 48% decrease of pain. The repetitive occlusion of the supporting neovessels during the daily repetitions of the eccentric training might therefore somehow resolve or occlude the neovessels. Based on our data, the microcirculatory level, showed no increase in postcapillary venous filling pressures after 12 weeks of eccentric training; therefore, a capillary thrombosis as the pathomechanical principle behind this phenomenon appears unlikely.

The decrease of postcapillary venous filling pressures shown at 2 paratendinous locations after 12 weeks of eccentric training might facilitate clearance of local metabolic end products in the postcapillary system. An increased postcapillary venous filling pressure is seen in inflammation with venous congestion, thus disrupting the local metabolic system, which could be demonstrated at the paratendon insertional level superficially only. Decreased postcapillary venous filling pressure at the paratendon therefore, facilitates venous outflow and clearance of local metabolic end products. Overall, the effects of the eccentric training on this microcirculatory parameter seem to be favorable and furthermore rule out a local thrombosis as mechanism for the resolution of capillary flow, as indicated before.

A 12-week eccentric-training program does not impair local paratendinous oxygenation of the Achilles paratendon, neither at superficial- nor at deep-tissue depths. The preservation of tissue oxygen saturation throughout the 12-week period is a positive finding, because a

TABLE 5 Postcapillary Venous Filling Pressures*

	2 mm		8 mm	
	Training	Control	Training	Control
Postcapillary venous filling pressures baseline (arbitrary units)				
Medial insertion	41 ± 12	46 ± 12	105 ± 15	108 ± 32
Medial distal midportion	58 ± 10	61 ± 6	99 ± 14	111 ± 14
Medial proximal midportion	57 ± 10	57 ± 7	80 ± 22	90 ± 17
Medial musculotendinous junction	54 ± 9	54 ± 5	53 ± 8	51 ± 9
Lateral insertion	46 ± 14	51 ± 17	101 ± 17	97 ± 31
Lateral distal midportion	58 ± 12	59 ± 10	93 ± 14	96 ± 12
Lateral proximal midportion	62 ± 9	57 ± 9	94 ± 44	75 ± 15
Lateral musculotendinous junction	59 ± 7	58 ± 6	75 ± 17	73 ± 7
Postcapillary venous filling pressures after 12 wk (arbitrary units)				
Medial insertion	50 ± 9	51 ± 8	104 ± 21	114 ± 28
Medial distal midportion	57 ± 9	59 ± 9	88 ± 17	102 ± 24
Medial proximal midportion	55 ± 7	55 ± 13	75 ± 17	88 ± 23
Medial musculotendinous junction	81 ± 24	79 ± 11	79 ± 18	80 ± 22
Lateral insertion	59 ± 7	56 ± 11	107 ± 14	104 ± 14
Lateral distal midportion	59 ± 8	60 ± 12	94 ± 18	86 ± 25
Lateral proximal midportion	58 ± 8	61 ± 9	85 ± 24	120 ± 75
Lateral musculotendinous junction	58 ± 9	58 ± 6	75 ± 17	90 ± 17
Postcapillary venous filling pressures median change (%)				
Medial insertion	27†	11	–12	5
Medial distal midportion	–8	–3	–28	–9
Medial proximal midportion	–2	–4	–7	–1
Medial musculotendinous junction	–3	–4.5	–13	2
Lateral insertion	9†	11	–18	6
Lateral distal midportion	–4	2	0	–10
Lateral proximal midportion	–11	6	–9	59
Lateral musculotendinous junction	–22	1	0	23

Absolute values (mean ± SD) and median percent change (%) in Achilles paratendon microcirculation variables for the eccentric-training group (n = 15) and the control group (n = 5) at 8 paratendon locations at 2 tissue depths.
†P<.05 indicates a significant preintervention to postintervention change within a group for that location and depth.

decrement of tissue oxygen saturation is encountered, for example, in case of ischemia associated with impaired local oxygen supply and tissue acidosis.[14] Taking all the microcirculatory effects found in this study together, we could not find any negative effect of eccentric training on the paratendinous tissue. But we found beneficial effects related to the decreased capillary blood flow as well as the facilitated venous capillary outflow, due to decreased postcapillary venous filling pressures with preserved local oxygen supply.

Twelve weeks of daily eccentric training reduced pain by 48% in individuals with chronic Achilles tendinopathy ($P<.05$). Therefore, an eccentric-training regimen has its role in the therapeutic toolbox for people with chronic Achilles tendinopathy, which is in agreement with previous reports of the successful application of eccentric training for individuals with Achilles tendinopathy. Interestingly, significant reductions in pain have also been reported for individuals with patellar tendinopathy (jumper's knee VAS, 7.3-2.3; $P<.005$)[10] and chronic painful impingement syndrome of the shoulder (VAS, 6.2-1.8, $P<.05$)[11] when using an eccentric-training intervention.

The analysis of 118 symptomatic heels in 73 patients in the UK[9] revealed that 81% had evident ultrasound abnormalities, with 109 Achilles tendons with disease in the proximal two thirds of the tendon. Interestingly, 91% of them (99/109) had only medial involvement and 19% also had lateral proximal tendon involvement, but no lateral tendon involvement was seen in isolation. It has been suggested that the medial involvement may be associated with foot hyperpronation due to an increased longitudinal tension within the medial tendon and paratendon fibers. Of patients with insertional tendinopathy, 64% had paratendinitis. We found the significant decrease in superficial- and deep-capillary blood flow in the medial midportion as well as the musculotendinous part of the Achilles tendon to be different from that of the control group. This supports eccentric training as targeting not only the tendon itself, but exerting beneficial effects on the Achilles paratendon.

A recent study[2] found nerve-related components such as protein gene product 9.5 (PGP9.5) as a general nerve marker, as well as sensory markers such as substance P and calcitonin gene-related protein (CGRP), to be present in association with blood vessels in the peritendinous part of the midportion Achilles tendon in healthy and in diseased tendons localized in the paratendinous loose connective tissue.[2,3] Supporting the importance of the paratendinous tissue are the data[1] regarding the sclerosing therapy in chronic Achilles tendinopathy, which are performed from the medial side of the tendon just outside the ventral part of the tendon with polidocanol as well as the peritendinous injection of steroids, demonstrating a significant effect in reducing pain and thickening of Achilles tendon in a randomized controlled trial. Thus, the paratendinous tissue is involved in the pathogenesis of Achilles tendinopathy.

TABLE 6 Capillary Blood Flow*

	2 mm		8 mm	
	Training	Control	Training	Control
Capillary blood flow baseline (arbitrary units)				
Medial insertion	32 ± 23	41 ± 31	135 ± 72	219 ± 109
Medial distal midportion	25 ± 15	29 ± 27	127 ± 47	152 ± 77
Medial proximal midportion	23 ± 16	22 ± 12	106 ± 43	150 ± 76
Medial musculotendinous junction	30 ± 24	29 ± 17	110 ± 37	129 ± 60
Lateral insertion	29 ± 11	35 ± 21	135 ± 40	175 ± 78
Lateral distal midportion	28 ± 18	32 ± 14	124 ± 37	151 ± 28
Lateral proximal midportion	26 ± 14	23 ± 17	110 ± 44	124 ± 63
Lateral musculotendinous junction	23 ± 12	26 ± 17	98 ± 36	116 ± 70
Capillary blood flow after 12 wk (arbitrary units)				
Medial insertion	30 ± 24	42 ± 45	133 ± 54	181 ± 81
Medial distal midportion	14 ± 6	12 ± 5	106 ± 34	105 ± 31
Medial proximal midportion	16 ± 8	15 ± 6	88 ± 27	115 ± 41
Medial musculotendinous junction	19 ± 10	17 ± 7	92 ± 27	96 ± 53
Lateral insertion	24 ± 14	22 ± 12	119 ± 37	104 ± 32
Lateral distal midportion	20 ± 9	17 ± 4	118 ± 47	118 ± 32
Lateral proximal midportion	16 ± 7	17 ± 7	107 ± 52	121 ± 47
Lateral musculotendinous junction	18 ± 8	20 ± 13	90 ± 40	100 ± 24
Capillary blood flow median change (%)				
Medial insertion	10	2	–4	–17
Medial distal midportion	–31†	–58	–33	–32
Medial proximal midportion	–3	–32	–27	–24
Medial musculotendinous junction	–30	–42	–25	–26
Lateral insertion	–37	–39	–36	–41
Lateral distal midportion	–37	–47	–32	–22
Lateral proximal midportion	–45†	–26	–36	–2
Lateral musculotendinous junction	–18	–2	–12	–14

**Absolute values (mean ± SD) and median percent change (%) in Achilles paratendon microcirculation variables for the eccentric-training group (n = 15) and the control group (n = 5) at 8 paratendon locations at 2 tissue depths.*

†$P<.05$ indicates a significant preintervention to postintervention change within a group for that location and depth.

Limitations

The training intervention of the eccentric and stretching training was thoroughly introduced by oral and written instructions as well as by a live demonstration of the exercises after randomization. Nevertheless, it cannot be excluded that the home-based rehabilitation program was not performed every day with the exact number of instructed repetitions. We attempted to maximize compliance by providing a thorough information package, making follow-up telephone calls, and by providing a second clinical evaluation with a detailed interview of how often and why any exercises were missed. Interestingly, the subjects reported that the daily program of about 5 minutes was easy to implement in their daily activities.

CONCLUSION

In this study, we found that daily eccentric training for 12 weeks reduced the increased paratendinous capillary blood flow seen with Achilles tendinopathy by up to 45%. This was consistent with a 48% decrease in pain based on a VAS. Local paratendinous oxygenation is preserved while paratendinous postcapillary venous filling pressures are reduced at determined locations after 12 weeks of eccentric training.

TABLE 7 CAPILLARY BLOOD FLOW VELOCITY*

	2 mm		8 mm	
	Training	Control	Training	Control
Capillary blood flow velocity baseline (arbitrary units)				
Medial insertion	14 ± 4	16 ± 6	21 ± 6	27 ± 10
Medial distal midportion	14 ± 3	13 ± 4	20 ± 4	20 ± 6
Medial proximal midportion	13 ± 3	13 ± 2	17 ± 3	21 ± 6
Medial musculotendinous junction	14 ± 3	14 ± 3	18 ± 2	19 ± 5
Lateral insertion	14 ± 2	16 ± 4	20 ± 3	23 ± 8
Lateral distal midportion	14 ± 2	15 ± 2	20 ± 4	21 ± 3
Lateral proximal midportion	14 ± 2	14 ± 3	20 ± 4	21 ± 5
Lateral musculotendinous junction	14 ± 3	15 ± 4	18 ± 2	19 ± 5
Capillary blood flow velocity after 12 wk (arbitrary units)				
Medial insertion	15 ± 5	18 ± 10	22 ± 6	28 ± 10
Medial distal midportion	12 ± 2	12 ± 1	20 ± 4	23 ± 8
Medial proximal midportion	13 ± 2	14 ± 3	18 ± 3	22 ± 7
Medial musculotendinous junction	14 ± 4	13 ± 1	18 ± 3	19 ± 5
Lateral insertion	14 ± 2	13 ± 2	22 ± 4	21 ± 4
Lateral distal midportion	14 ± 2	14 ± 2	23 ± 5	23 ± 6
Lateral proximal midportion	14 ± 3	14 ± 3	23 ± 6	25 ± 7
Lateral musculotendinous junction	14 ± 2	15 ± 2	20 ± 5	22 ± 4
Capillary blood flow velocity median change (%)				
Medial insertion	8	12	13	6
Medial distal midportion	–16†	–7	–10	–14
Medial proximal midportion	–2	7	1	6
Medial musculotendinous junction	–11	–5	–10	2
Lateral insertion	–12	–16	–17	–10
Lateral distal midportion	–6	–8	0	6
Lateral proximal midportion	–15	5	–19	22
Lateral musculotendinous junction	–3	–14	–8	13

**Absolute values (mean ± SD) and median percent change (%) in Achilles paratendon microcirculation variables for the eccentric-training group (n = 15) and the control group (n = 5) at 8 paratendon locations at 2 tissue depths.*
†P<.05 indicates a significant preintervention to postintervention change within a group for that location and depth.

REFERENCES

1. Alfredson H, Ohberg L. Sclerosing injections to areas of neo-vascularisation reduce pain in chronic Achilles tendinopathy: a double-blind randomised controlled trial. *Knee Surg Sports Traumatol Arthrosc.* 2005;13:338-344.
2. Bjur D, Alfredson H, Forsgren S. The innervation pattern of the human Achilles tendon: studies of the normal and tendinosis tendon with markers for general and sensory innervation. *Cell Tissue Res.* 2005;320:201-206.
3. Brain SD. Sensory neuropeptides: their role in inflammation and wound healing. *Immunopharmacology.* 1997;37:133-152.
4. Burssens P, Steyaert A, Forsyth R, van Ovost EJ, De Paepe Y, Verdonk R. Exogenously administered substance P and neutral endopeptidase inhibitors stimulate fibroblast proliferation, angiogenesis and collagen organization during Achilles tendon healing. *Foot Ankle Int.* 2005;26:832-839.
5. Ferrell WR, Balint PV, Egan CG, Lockhart JC, Sturrock RD. Metacarpophalangeal joints in rheumatoid arthritis: laser Doppler imaging--initial experience. *Radiology.* 2001;220:257-262.
6. Frank KH, Kessler M, Appelbaum K, Dummler W. The Erlangen micro-lightguide spectrophotometer EMPHO I. *Phys Med Biol.* 1989;34:1883-1900.
7. Gandjbakhche AH, Bonner RF, Arai AE, Balaban RS. Visible-light photon migration through myocardium in vivo. *Am J Physiol.* 1999;277: H698-704.
8. Ghazanfari M, Vogt L, Banzer W, Rhodius U. Reproducibility of non-invasive blood flow measurements using laser Doppler spectroscopy. *Phys Med Rehab Kuror.* 2002;12:330-336.
9. Gibbon WW, Cooper JR, Radcliffe GS. Distribution of sonographically detected tendon abnormalities in patients with a clinical diagnosis of chronic achilles tendinosis. *J Clin Ultrasound.* 2000;28:61-66.
10. Jonsson P, Alfredson H. Superior results with eccentric compared to concentric quadriceps training in patients with jumper's knee: a prospective randomised study. *Br J Sports Med.* 2005;39:847-850.
11. Jonsson P, Wahlstrom P, Ohberg L, Alfredson H. Eccentric training in chronic painful impingement syndrome of the shoulder: results of a pilot study. *Knee Surg Sports Traumatol Arthrosc.* 2006;14:76-81.
12. Knobloch K, Kraemer R, Lichtenberg A, et al. Microcirculation of the ankle after Cryo/Cuff application in healthy volunteers. *Int J Sports Med.* 2006;27:250-255.

13. Knobloch K, Kraemer R, Lichtenberg A, et al. Achilles tendon and paratendon microcirculation in midportion and insertional tendinopathy in athletes. *Am J Sports Med.* 2006;34:92-97.

14. Knobloch K, Lichtenberg A, Pichlmaier M, et al. Microcirculation of the sternum following harvesting of the left internal mammary artery. *Thorac Cardiovasc Surg.* 2003;51:255-259.

15. Kristoffersen M, Ohberg L, Johnston C, Alfredson H. Neovascularisation in chronic tendon injuries detected with colour Doppler ultrasound in horse and man: implications for research and treatment. *Knee Surg Sports Traumatol Arthrosc.* 2005;13:505-508.

16. Ohberg L, Alfredson H. Effects on neovascularisation behind the good results with eccentric training in chronic midportion Achilles tendinosis? *Knee Surg Sports Traumatol Arthrosc.* 2004;12:465-470.

17. Roos EM, Engstrom M, Lagerquist A, Soderberg B. Clinical improvement after 6 weeks of eccentric exercise in patients with midportion Achilles tendinopathy -- a randomized trial with 1-year follow-up. *Scand J Med Sci Sports.* 2004;14:286-295.

18. Shalabi A, Kristoffersen-Wiberg M, Aspelin P, Movin T. Immediate Achilles tendon response after strength training evaluated by MRI. *Med Sci Sports Exerc.* 2004;36:1841-1846.

19. Shalabi A, Kristoffersen-Wilberg M, Svensson L, Aspelin P, Movin T. Eccentric training of the gastrocnemius-soleus complex in chronic Achilles tendinopathy results in decreased tendon volume and intratendinous signal as evaluated by MRI. *Am J Sports Med.* 2004;32:1286-1296.

20. Steyaert AE, Burssens PJ, Vercruysse CW, Vanderstraeten GG, Verbeeck RM. The effects of substance P on the biomechanic properties of ruptured rat Achilles' tendon. *Arch Phys Med Rehabil.* 2006;87:254-258.

21. Sullo A, Maffulli N, Capasso G, Testa V. The effects of prolonged peritendinous administration of PGE1 to the rat Achilles tendon: a possible animal model of chronic Achilles tendinopathy. *J Orthop Sci.* 2001;6:349-357.

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