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Bone Mass in the Calcaneus after Heavy Loaded Eccentric Calf-Muscle Training in Recreational Athletes with Chronic Achilles Tendinosis

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Abstract. In an ongoing prospective study of 14 recreational athletes (12 males and 2 females, mean age 44.2 ± 7.1 years) with unilateral chronic Achilles tendinosis, we investigated the effect of treatment with heavy-loaded eccentric calf-muscle training. Pain during activity (recorded on a VAS scale) and isokinetic concentric and eccentric calf-muscle strength (peak torque at 90°/second and 225°/second) on the injured and noninjured side were evaluated. In this group of patients, we examined areal bone mineral density (BMD) of the calcaneus after 9 months (range 6–14 months) of training. BMD of the injured side (subjected to heavy-loaded eccentric training) was compared with BMD of the noninjured side. Before onset of heavy-loaded eccentric training, all patients had Achilles tendon pain which prohibited running activity, and significantly lower concentric and eccentric plantar flexion peak torque on the injured compared with the noninjured side. The training program consisted of 12 weeks of daily, heavy-loaded, eccentric calf-muscle training; thereafter the training was continued for 2–3 days/week. The clinical results were excellent—all 14 patients were back at their preinjury level with full running activity at the 3 month follow-up. The concentric and eccentric plantar flexion peak torque had increased significantly and did not significantly differ from the noninjured side at the 3 and 9 month follow-up. There were no significant side-to-side differences in BMD of the calcaneus. There was no significant relationship between BMD of the calcaneus and calf-muscle strength. As a comparison group, we used 10 recreational athletes (5 males and 5 females) mean age 40.9 years (range 26–55 years), who were selected for surgical treatment of chronic Achilles tendinosis localized at the 2–6 cm level. Their duration of symptoms and severity of disease were the same as in the experimental group. There were no significant side-to-side differences in BMD of the calcaneus preoperatively, but 12 months postoperatively BMD of the calcaneus was 16.4% lower at the injured side compared with the noninjured side. Heavy-loaded eccentric calf-muscle training resulted in a fast recovery in all patients, equaled the side-to-side differences in muscle strength, and was not associated with side-to-side differences in BMD of the calcaneus. In this group of middle-aged recreational athletes, BMD of the calcaneus was not related to calf-muscle strength.

A high bone mass in the calcaneus has been demonstrated in several cross-sectional studies of athletes participating in weightbearing sport activities [1–7], but athletes participating in sports with partial weightbearing (bicycling) and nonweightbearing (swimming) have been shown to have a bone mass not differing from nonactive controls [2, 8]. Nonweightbearing loading such as immobilization after injuries [9, 10] and prolonged bedrest [11, 12] is associated with a rapid loss of trabecular and cortical bone. From experimental studies [13–16], it has been suggested that loadings that produce high strains in unusual patterns during short periods that are repeated regularly have the greatest osteogenic effect. Torsional loadings have been proposed to be more osteogenic than axial loadings [17].

Relationships between muscle strength and bone mineral density (BMD) of the weightbearing adjacent bones have been demonstrated in female nonathletes [18–21], but in female athletes participating in sports with intense weightbearing loading such as soccer [18] and volleyball [19] no such relationships have been shown. In a longitudinal study on young (25 years old) female students, 12 months of unilateral high resistance strength training showed an increase in isometric elbow flexion strength, but no changes in bone mineral content (BMC) of the proximal humerus [22]. However, recently, Nordström et al. [23] showed a significantly higher BMD of the tuberositas tibia, but not proximal tibia, in adolescent, male ice hockey players on a high activity level, compared with referents. The authors suggested this to be a very local site-specific skeletal response, associated with the strong muscle contractions in the quadricep muscles during skating.

Overuse injuries with painful conditions localized in the achilles tendon are common, especially among male runners, and occur at a higher rate in older athletes than most other overuse injuries [24–27]. Conservative treatment is

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not always successful and surgery is required in about 25% of these patients [27]. In a prospective study of recreational athletes surgically treated for chronic Achilles tendinosis, we have recently demonstrated a prolonged, progressive, calcaneal bone loss of the injured side despite early weight-bearing rehabilitation [28]. Also, in two prospective studies on middle-aged recreational athletes with chronic Achilles tendinitis/tendinosis [29, 30], we have recently reported the results of surgical treatment followed by 6 weeks of immobilization [29] and of surgical treatment followed by 2 weeks of immobilization [30]. The results showed that it took a long time to recover calf-muscle strength, and the postoperative immobilization time, 6 weeks compared with 2 weeks, did not seem to have any influence on the time of recovery in calf-muscle strength and the time of resumption of previous activity level. Stanish et al. [29] have reported good results with an eccentric training regimen on patients with chronic tendinitis. However, no scientific data on these patients have been reported. At our clinic, we have recently started to treat patients with chronic Achilles tendinosis with heavy-loaded, eccentric calf-muscle training [32].

The aims of this study were to investigate if side-to-side differences in BMD of the calcaneus were associated with this treatment, and whether BMD of the calcaneus was related to calf-muscle strength in middle-aged recreational athletes with chronic Achilles tendinosis. In the comparison group, there were no significant side-to-side differences in BMD of the calcaneus preoperatively. The patients in the comparison group were in the same age group, had degenerative changes at the same level of the Achilles tendon, and also had had symptoms for a long time. Therefore, we think it is reasonable to assume that before the eccentric training regimen was started there were no side-to-side differences in BMD of the calcaneus in the group of patients included in this study.

Material and Methods

Fourteen recreational athletes (12 males and 2 females, mean age 44.2 ± 7.1 years) were diagnosed with chronic Achilles tendinosis and selected for treatment with heavy-loaded, eccentric calf-muscle training. They had a long duration of symptoms (17.8 months, range 3–100 months), had pain during running activity, and had tried conventional treatment (rest, NSAIDs, changes of shoes or orthoses, physiotherapy, and ordinary training programs) with no effect on the achilles tendon pain.

As a comparison group, 10 recreational athletes (five males and five females), mean age 40.9 years (range 26–55), were selected for surgical treatment for chronic Achilles tendinosis. The patients in this group had a long duration of symptoms (28.6 months, range 6–84), had pain during running activity, and had tried conventional treatment (rest, NSAIDs, changes of shoes or orthoses, physiotherapy, and ordinary training programs) with no effect on the achilles tendon pain.

All patients in both groups had degenerative changes (tendinosis) at the 2–6 cm level. The diagnosis was based on a unilateral painful condition located in the Achilles tendon and with a duration of at least 3 months. In all patients, localized degenerative changes in the tendon, corresponding to the painful area, were seen on ultrasonographs. All ultrasonography examinations were done by the same radiologist. All patients in both groups had morning stiffness in the Achilles tendon. All patients were in good health, on no medication, and were not smoking. All females had regular menses. Patients with bilateral symptoms, and with restricted ankle joint motion due to other injuries or diseases were excluded.

Bone Mass Measurement

Total body BMD was measured using a Lunar DPX-L (Lunar Co. WI), dual energy X-ray absorptiometer (DXA). The accuracy and precision of this method have previously been discussed in detail by others [33–35]. In our laboratory, the coefficient of variation (CV) for a total body scan is 0.7% [35]. BMD of the calcaneus was derived using the Orthopaedic program and region of interest option. To scan the left calcaneus the subject was placed on his left side with the foot fixated by rice bags. The angle between the collimeter opening and a proximal-distal aspect of calcaneus was approximately 90°. Two standardized boxes were placed, one to measure BMD in the Achilles tendon insertion site of the calcaneus, and one to measure BMD in a more central site of the calcaneus (Fig. 1). Each scan was performed with a 150 mm-long plexiglass rod in collimeter opening. This rod was developed by the Lunar Corporation as an alternative to rice bags in regions where lack of soft tissues interferes with BMD measurements. The precision was evaluated by having one of the investigators scan the same person eight times, with repositioning between the scans, during a short period of time. The CV value for the calcaneus was 3.6% for the Achilles tendon insertion site, and 4.9% for the more central site.

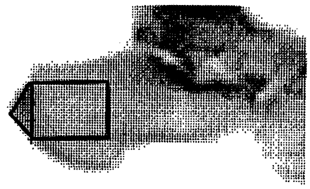

Fig. 1. BMD of the calcaneus was derived using the Orthopaedic program and region of interest option. Two boxes were placed: one to measure BMD in the Achilles tendon insertion site of the calcaneus and one to measure BMD in a more central site of the calcaneus.

Muscle Strength Measurement

Isokinetic calf muscle strength was measured in Newton meters (Nm) using a Biodex isokinetic dynamometer (Biodex Co, NY, USA). Peak torque, presented as the best repetition, was evaluated before start of eccentric training regimen and at follow-up after 3 and 9 months.

Concentric plantar flexion peak torque was measured at 90°/second (five repetitions) and 225°/second (10 repetitions) of angular velocity. Eccentric plantar flexion peak torque was measured on 90°/second (three repetitions). All tests were done at about the same time of the day in all patients and at all testing times (between 9 a.m. and 12 noon). The warm-up procedure consisted of 10 minutes of bicycling. The patients were seated with the knee positioned at 40° of flexion and with a hip angle of 110°. The axis of rotation in neutral position passes through the body of talus, the fibular malleolus, and through or just below the tibial malleolus. Strength was measured between 20° of dorsal flexion and 30° of plantar flexion. The strength of the injured side was compared with the strength of the noninjured side. All tests were performed by the same physiotherapist.

To our knowledge, there are no studies on the test-retest reliability of the Biodex for ankle flexion/extension. Therefore, in our laboratory we determined the test-retest reliability for ankle flexion/extension peak torque on six healthy and noninjured individuals (four males and two females), age 34.4 ± 7 years (mean ± SD). Statistical analysis of data showed the following intraclass correlation coefficients: eccentric plantar flexion 90°/second ($r = 0.98$), concentric plantar flexion 90°/second ($r = 0.89$), concentric plantar flexion 225°/second ($r = 0.55$), concentric dorsal flexion 90°/second ($r = 0.59$) and dorsal flexion 225°/second ($r = 0.77$).

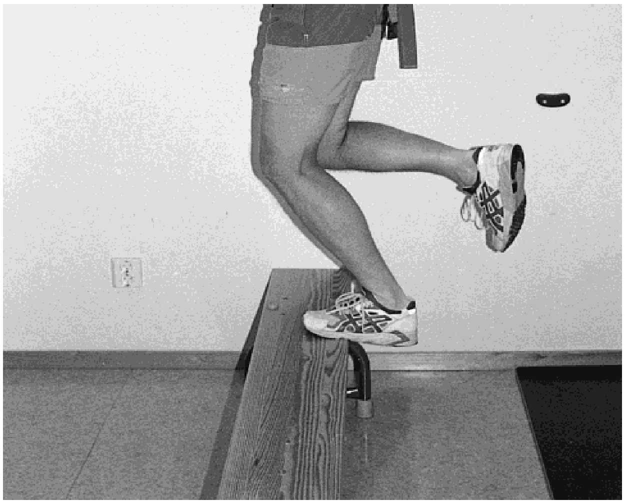

Fig. 2. From an upright body position and standing with all body weight on the ventral half-part of the foot, with the ankle joint in plantar flexion, the calf muscle was eccentrically loaded by having the patient lower the heel beneath the lever.

Eccentric Training Model

To get good patient cooperability, a training intervention was constructed for the purpose of easy performance, and that could be done at home. The patients were told to do their exercises standing on a staircase, and gradually increase the load by adding weights in a backpack. At the end of the training intervention, when heavier weights were needed, a weight machine at the physiotherapy clinic was used. All patients were practically instructed and given a written manual on how to perform and progress their training. The patients were instructed to do their eccentric exercises twice daily, 7 days/week for 12 weeks, and thereafter once daily, 2–3 days/week. During the training regimen, jogging-running activity was allowed if it could be performed with only mild discomfort and no pain.

Eccentric Exercises. The calf muscle was eccentrically loaded with the knee straight and to maximize the activation of the soleus muscle also with the knee bent. Each of the two exercises included 15 repetitions done in three sets (3×15 reps). The patients were told that muscle soreness during the first 1–2 weeks of training was to be expected.

In the beginning, the loading consisted of the body weight with the patients standing with all their body weight on their injured leg. From an upright position and standing with all body weight on the ventral part of the foot, with the ankle joint in plantar flexion, the calf muscle was loaded by having the patient lower the heel beneath the lever (Fig. 2). They were only loading the calf muscle eccentrically; no following concentric loading was done. Instead, the noninjured leg was used to get back to the start position. The patients were told that they were allowed to experience pain during the exercise, however, no training with disabling pain was encouraged. When they could perform the eccentric loading without experiencing minor pain or discomfort, they were instructed to elevate the load by adding weight. This could easily be done by using a backpack that was successively loaded with weight. In this way the eccentric calf-muscle loading was gradually increased. If very high weights were needed, the patients where told to use a weight machine.

After the initial 12-week training regimen, the patients were told to continue the heavy loaded eccentric training with added weights 2–3 times/week in addition to their running activity.

Statistical Evaluation

The SPSS package for personal computer was used for the statistical analyses. A nonparameteric test for two related samples (Wilcoxon) was used. Bivariate correlations were measured using Pearson's coefficient of correlations. A P-value < 0.05 was considered significant.

Results

Basic data on 24 patients with chronic Achilles tendinosis are shown in in Table 1.

Side-to-side differences in areal BMD (g/cm^2) between the calcaneus of the injured and noninjured leg 9 months (range 6–14) after instituted eccentric calf-muscle training, and preoperatively in the comparison group, are shown in Table 2. After 9 months of eccentric calf-muscle training, there were no significant differences between the injured and noninjured leg in BMD of the Achilles tendon insertion site and BMD in the more central site of the calcaneus. In the comparison group, there were no significant differences between the injured and noninjured leg, preoperatively in BMD of the Achilles tendon insertion site and BMD in the more central site of the calcaneus.

Concentric and eccentric calf-muscle strength (peak torque in Nm) in the injured and noninjured leg before onset of eccentric training and after 3 and 9 months of training are shown in Figure 3. Concentric plantar flexion strength at 90°/second and 225°/second and eccentric plantar flexion strength at 90°/second was significantly lower on the injured compared with the noninjured side before onset of training (week 0). After 3 and 9 months of eccentric calf-muscle training, there were no significant differences in concentric and eccentric calf-muscle strength between the injured and noninjured side. There were no significant correlations between bone mass (BMD g/cm^2) of the calcaneus and calf-muscle strength in the injured leg and noninjured leg at the 3 and 9 month follow-up (not shown).

The clinical results were evaluated on a 10 cm visual analog scale (VAS), describing the amount of pain during activity (running). The results are shown in Figure 4. There was a significant decrease in VAS score (70.5 ± 21.9–3.5 ± 5.6) from onset of training to the 3-month follow-up. At the 9-month follow-up the VAS score was 7.4 ± 14.1.

Discussion

The results of this study showed that in middle-aged recreational athletes with chronic Achilles tendinosis there were no side-to-side differences in BMD of the calcaneus after 9 months of unilateral, heavy-loaded, eccentric calf-muscle training, despite a progressive increase of the muscle strength. There is always a possibility that the BMD values might have been lower on the injured side compared with the noninjured side at the time when the eccentric training regimen was started. However, in a comparison group consisting of recreational athletes with chronic Achilles tendinosis that were selected for surgical treatment, there were no side-to-side differences in BMD of the calcaneus (Achilles tendon insertion site and in a more central site in the calcaneus) preoperatively. The patients in the comparison group were in the same age group, had tendinosis at the same level of the Achilles tendon, and had had symptoms for a long time. Therefore, we think the patients in the reference group and the patients in the present study are comparable.

In a study by Nordström et al. [23], adolescent, male ice-hockey players were found to have a significantly higher

Table 1. Basic data on 24 patients with chronic Achilles tendinosis

Variable	Eccentric training (n = 14)	Surgical treatment (n = 10)
	No. of patients	
Sport		
Jogging	14	8
Soccer		1
Basketball		1
Duration of symptoms (months)	17.8 (3–100)	28.6 (6–84)
Symptom		
Morning stiffness	14	10
Pain during walking	11	5
Pain preventing running	14	10
Earlier treatment		
Previous ordinary training program	14	10
NSAID[a]	13	8
Local cortison injection	3	4
Biomechanical faults		
Cavus feet	6	3
Body characteristics		
Age (years)	44.2 ± 7.1	40.9 ± 10.9
Height (cm)	177.3 ± 8.2	172.7 ± 9.7
Weight (kg)	77.6 ± 10.0	74.3 ± 11.6

[a] NSAID, nonsteroidal antiinflammatory drug

Table 2. Bone mineral density (BMD in g/cm^2) in the Achilles tendon insertion site and in a more proximal site of the calcaneus after 9 months of heavy-loaded eccentric calf-muscle training in 14 patients with chronic Achilles tendinosis, and preoperatively in 10 patients with chronic Achilles tendinosis selected for surgery

	Eccentric training (n = 14)			Surgical treatment (n = 10)		
	A		B	A		B
BMD (g/cm^2)						
Calcaneus						
Insertion site	1.09 ± 0.18	ns	1.08 ± 0.22	0.89 ± 0.17	ns	0.96 ± 0.17
Central site	0.76 ± 0.11	ns	0.74 ± 0.15	0.72 ± 0.13	ns	0.75 ± 0.14

ns = nonsignificant
Injured side (A) is compared with noninjured side (B)

BMD in the tuberositas tibia compared with moderately active controls. However, in their study, adolescent boys that had been playing ice-hockey for many years were investigated. In the present study, the middle-aged men and women had been subjected to heavy-loaded, eccentric calf-muscle training for an average of only 9 months (range 6–14); initially they trained twice/day for 12 weeks, and thereafter the eccentric training was continued 2–3 days/week. According to the theories of Lanyon [13–15], loadings that produce high strains in unusual patterns are suggested to have the greatest osteogenic effect. Maybe, during eccentric calf-muscle training, the strain on the calcaneus is insufficient to create an osteogenic response. Another explanation might also be the difference in age between the groups (i.e., the skeleton in the younger athletes is more prone to give an osteogenic response upon muscle stress compared with the skeleton in the middle-aged athletes) [36].

In the present study, we found no significant relationship between BMD of the calcaneus and calf-muscle strength on either the injured side (subjected to heavy-loaded eccentric training) or the noninjured side (not subjected to strength training). Site-specific relationships have been demonstrated between muscle strength and BMD of the adjacent weightbearing bones in non-athletes [18–21, 23], but to our knowledge, no such relationships have been demonstrated in athletes. In the study by Nordström et al. [23], there was no significant relationship between thigh muscle strength and BMD of the adjacent bones in the adolescent ice-hockey players.

Overuse injuries affecting the Achilles tendon are common, and in 25% of these patients surgery is required [24–27]. Surgery is followed by total or partial immobilization for different periods of time [29, 30, 37–39], however, immobilization has negative effects on the skeleton [9–12]. A calcaneal bone loss of around 1% per week has been demonstrated during prolonged bedrest [12], and in a recent prospective study, we found a prolonged progressive calcaneal bone loss despite early weightbearing rehabilitation in patients surgically treated for chronic Achilles tendinosis [28]. Twelve months postoperatively, BMD of the calcaneus at the injured side was found to be 16.4% lower than

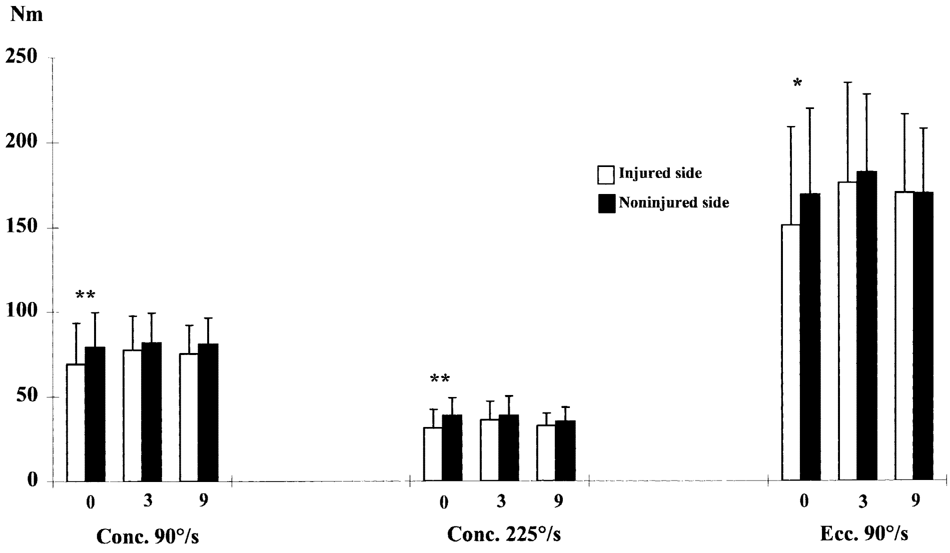

Fig. 3. Isokinetic concentric and eccentric peak torque (Nm) in 14 patients with chronic Achilles tendinosis. Values before start of eccentric training regimen, and values after eccentric training (3 and 9 months). Injured side is compared with noninjured side. *Statistical significance $P < 0.05$. **Statistical significance $P < 0.01$.

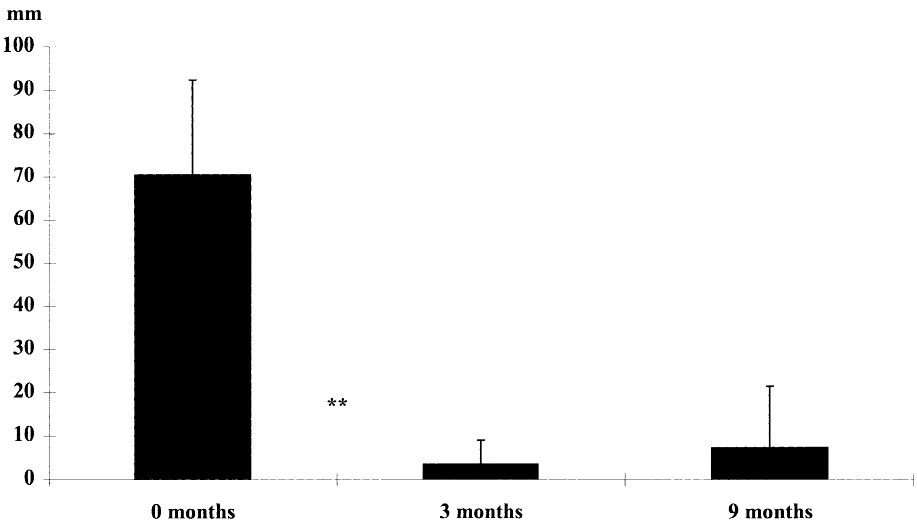

Fig. 4. Scores from a 10-cm visual analog scale that reported the amount of pain during activity (running) before and after (3 and 9 months) eccentric calf-muscle training. **Statistical significance $P < 0.01$ compared with previous measurement.

at the noninjured side. At our clinic we have started to treat patients with chronic Achilles tendinosis with heavy-loaded, eccentric calf-muscle training. The short-term results are good [32]. In this study, the clinical results were good; all patients were back at their previous activity level (before injury) after 3 months of eccentric training. Nine months after eccentric training was instituted there were no signs of the negative effect on calcaneal BMD seen after surgical treatment [28]. The calf-muscle strength increased significantly, and at the 3 and 9 month follow-up there were no side-to-side differences in concentric and eccentric plantar flexion strength. In our previous studies on patients surgically treated for chronic Achilles tendinosis [29, 30], we demonstrated that it took a long time to recover in plantar flexion strength, and the patients were back at their previous activity level around 6 months postoperatively.

In conclusion, in patients with chronic Achilles tendinosis, heavy-loaded, eccentric calf-muscle training seems to be a good treatment model. The clinical results are good with a fast recovery and return to previous activity level. Nine months of unilateral heavy-loaded, eccentric calf-muscle training is not associated with side-to-side differences in BMD of the calcaneus, compared with surgical treatment where there is a significant calcaneal bone loss at the injured side postoperatively. In this group of middle-aged recreational athletes, there was no significant relationship between calf-muscle strength and bone mass of the calcaneus.

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