Atrophy of the Intrinsic Muscles of the Foot Associated with Diabetic Neuropathy

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Introduction

Atrophy of the intrinsic muscles of the foot secondary to distal symmetric diabetic polyneuropathy has been implicated in the etiology of plantar ulceration and foot deformity. More specifically, intrinsic muscle atrophy has been hypothesized to cause clawing and/or hammering of the toes leading to prominent metatarsal heads (MTHs) and subsequent elevated plantar pressure during walking through the process of anterior migration of the protective sub-metatarsal head fat tissue cushions (Coughlin, 1984; Myerson and Sheriff, 1989). Experimental evidence for this hypothetical link and its components is lacking. The purpose of this study was to use magnetic resonance imaging (MRI) to examine intrinsic foot muscle status in patients with diabetic polyneuropathy and age-matched healthy control subjects.

Methods

Eight subjects (6 males) with peripheral sensory-motor polyneuropathy (mean (sd) age: 51.6 (11.1) yrs., body mass: 87.8 (16.2) kg, height: 177.7 (8.8) cm, diabetes duration: 22.1 (11.0) years) and nine age and gender matched non-diabetic healthy controls (age: 53.0 (8.6) yrs., body mass: 82.5 (11.4) kg, height: 172.7 (9.8) cm) participated. Sensory-motor polyneuropathy in the diabetic subjects was confirmed by vibration and touch-pressure perception and sural sensory and peroneal motor nerve conduction velocity measures. Vascular insufficiency was excluded (ABI index < 0.75 or absent pulses), as was significant lower extremity injury, fracture (including Charcot fracture), or surgery, neurological diseases (other than diabetic neuropathy), active disc disease, symptoms of radiculopathy, hallux abducto-valgus, pes planus or pes cavus, and conditions precluding MRI assessment.

A MEDSPEC S300 3.0T research whole body imager (Bruker Instruments, Inc., Karlsruhe, Germany) was used to acquire high resolution (256x256 pixels) T2-weighted fast spin-echo frontal plane images (40-46 slices) from the metatarsal region of the foot (see figure 1a), with TE = 11ms, effective TE = 66ms, TR = 6.0 – 9.0s and slice thickness = 3 mm. In addition, a set of eleven T2 parametric spin-echo images with variable TE (12-132 ms) and TR = 1.8s from each of 6 frontal plane slices were collected (see figure 1b). In order to improve visualization, both datasets were zero-filled to a 512 x 512 image resolution prior to Fourier transformation. From these six T2 slices, one representative slice of a cross-section through MTH 5 was selected for quantitative T2 analysis. Using CHIPS software (Dardzinski et al, 1999), a T2 map with T2 times between 0 and 255 milliseconds was generated from the signal intensity levels of the 11 spin-echo images (figure 1c). From the T2 map, a histogram was generated showing the number of volume elements (voxels) as a function of T2 value (Figure 3). A multi component segmentation analysis subsequently determined the amount of muscle tissue and other tissues in the image (Figure 2c). Since skin tissue has the same T2 value range as muscle tissue, the skin was excluded from the analysis.
Figure 1. Orientation of the T2 weighted (a) and T2 (b) frontal plane images in the foot. An example of a T2 map generated from the representative slice of a healthy control subject (c). Warm colors represent muscle and skin tissue, black indicates tendon and cortical bone, gray and blue represent fat tissue and trabecular bone.

Results and Discussion

Our original intention was to segment the T2 weighted images by manually defining the outlines of the intrinsic muscles in each slice and calculating the volumes of individual muscles similar to the approach of Fukanaga et al. (1992). However, muscle segmentation in the neuropathic subjects proved impossible since many of the structures were not clearly defined (Figure 2a,b).

A subjective analysis of the T2 weighted images revealed a striking absence of definable muscle tissue in the majority of the slices for the neuropathic subjects. This can be seen in Figure 2 where corresponding T2-weighted images from an age-matched healthy control and neuropathic patient are shown. The areas where clear muscle bundles appear in the control subjects are occupied by somewhat disorganized tissue with fatty infiltration in the neuropathic subjects which has a different signal intensity than that for muscle. Not only are the interossei absent but only remnants of the other major intrinsic muscles such as flexor hallucis brevis and adductor hallucis are visible.

Figure 2. T2-weighted frontal plane images through MTH 5 of a healthy control (a) and a neuropathic subject (b). Results of a 5 component (3 gray levels, black and white) segmentation (c) of the image in figure 2c with the skin excluded and muscle tissue outlined in blue.
These subjective observations were confirmed by the histograms derived from the parametric T2 maps (Figure 3) in which all control subjects (a) have a bimodal distribution with the first large peak indicating muscle tissue in the region of 35-65 ms while this peak is absent in all of the neuropathic subjects (b). The number of elements around a T2 of zero represent tendon and cortical bone (black in figure 1c). The large peak at about 100 ms represents fat tissue and trabecular bone. The amount of intrinsic muscle tissue, expressed as a percentage of total foot area, was 30.7 (3.7) % in the healthy subject group and only 8.3 (2.9) % in the diabetic neuropathic group. All neuropathic subjects had muscle tissue volumes that differed more than 5 standard deviations from that of the normal average, demonstrating the large amount of intrinsic muscle atrophy in these patients.

Discussion

These data show that normal intrinsic muscle tissue is largely absent from the forefoot in diabetic patients with distal symmetric polyneuropathy. The results extend the findings of Brash et al. (1999), who reported reductions in muscle and changes in connective tissue adjacent to the first metatarsal and of Suzuki et al. (2000) who demonstrated an increase in fat-to-water ratio and biochemical changes representative of muscle atrophy in the plantar foot muscles using MRI techniques in similar subjects. The observed changes can be expected to have important consequences for the structure and function of the foot, severely compromising the normal mechanics of the foot and possibly playing a significant role in plantar ulceration in neuropathic patients. The interossei and lumbricals are believed to play a major role in controlling the position of the proximal phalanx in relation to the respective metatarsal (Myerson and Sheriff, 1989) and thus the atrophy noted here can be expected to contribute to clawing of the toes and subsequent elevated sub-metatarsal head pressures, which has been shown to be a major contributing factor in the development of plantar ulcers in diabetic patients with neuropathy (Veves et al., 1992).

While some actions of the intrinsic muscles are duplicated by extrinsic muscles, others are generated only by intrinsic muscle action. Level walking on even ground may not be compromised by such loss of force actuators, but balance on uneven terrain may have to rely on more proximal muscle groups acting at the ankle rather than at the foot.

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References

Figure 3. Histograms showing the number of voxels at each value of T2 derived from the parametric T2 maps for all 9 control subjects (a) and all 8 neuropathic subjects (b).