MAGNETIC RESONANCE IMAGING OF LOWER EXTREMITY MUSCLES AND ISOKINETIC STRENGTH IN FOOT DORSIFLEXORS IN PATIENTS WITH PRIOR POLIO

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ABSTRACT. The thigh and lower leg of six patients with prior polio were examined using magnetic resonance imaging (MRI), and the strength of their weak foot dorsiflexors was measured isokinetically. Spin-echo images of the lower extremities were visually evaluated on a semi-quantative four-point scale, and T1 and T2 relaxation times of the lower leg anterior compartment were analysed. There were prominent MRI signs of randomly distributed muscle degeneration. The high signal intensity changes in the affected muscles on T1-weighted images and T1 and T2 values indicated replacement of muscle fibres with fat and the accumulation of tissue water, respectively. MRI findings were compared with isokinetic strength in foot dorsiflexor muscles. Foot dorsiflexor peak torque values at 30 deg/s ranged from 6 to 29 Nm. There was no significant correlation between MRI visual scoring, T1 and T2 relaxation times and peak torque values at 30 deg/s. However, the most severe MRI changes with visual scoring and T2 relaxation times were observed in the patients with the most pronounced muscle weakness.

Key words: isokinetic strength, magnetic resonance imaging, prior polio.

INTRODUCTION

Magnetic resonance imaging (MRI) in neuromuscular disorders has proved its usefulness in studies of muscle in patients with lower motoneuron disorders (39) and myopathies (29, 34, 35, 38, 47, 48). The method may demonstrate oedema-like abnormalities in acute (34) and in chronic disease (7), and selective fatty degeneration changes in chronic disease (24, 25, 28). The changes observed are, however, non-specific and not diagnostic for separate diseases (25, 28). A selective muscle involvement has been suggested in some disorders, such as late-onset distal myopathy of Welander (48) and tibial muscular dystrophy (46). Few studies include MRI findings related to biopsy-confirmed skeletal muscle diseases (7, 25, 34, 48). There are few clinical studies of denervation (15, 33, 39, 42) and, to our knowledge, no previous systematic MRI study of prior polio patients.

In patients with prior polio after a stable period of at least 15 years, a late deterioration including loss of muscle strength has been reported as the "post polio syndrome" (6, 10). The cause of impaired muscle function is not known but several mechanisms have been suggested, including loss of motoneurons and decreasing motor unit size within the muscle (1). The relation between isokinetic strength and MRI findings has not been studied in chronic neurogenic disorders.

The aims of this study were to describe MRI findings in the thigh and lower leg muscles of patients with prior polio, and to compare these with isokinetic strength in weak foot dorsiflexor muscles.

SUBJECTS AND METHODS

Patients

Six patients (I–VI), four women and two men, with weak foot dorsiflexors due to prior polio were studied. Their mean age was 64 (range 47–75) years. The mean latency between the acute illness and the investigation was 45 (range 27–58) years. All were ambulatory. Two patients used two crutches for ambulation indoors and otherwise wheelchairs, one patient used one crutch and another one stick; the others needed no walking aids. The patients were selected from a group of previously studied patients exhibiting slight to moderate weakness (at least antigravity strength) of the foot dorsiflexor muscles, excessive use of the tibialis anterior muscle (TA) studied during locomotion and a predominance of hypertrophic type I muscle fibres (3, 43). Right-foot dorsiflexor muscles were studied in patient II and left-foot dorsiflexors in the others. The patients gave their informed consent and this investigation was approved by the ethics committee of the Karolinska Institute.

Magnetic resonance imaging (MRI)

The MRI examination was performed with whole-body superconductive MR equipment (1.0 T Siemens Magnetom, software D1). The patients were imaged on the body coil. Transaxial images at two locations—in the thigh (10 cm superior to proximal patella) and in the lower leg (between the upper and middle third of the distance from tuberositas tibiae to the lateral malleolus) were performed in both legs. Spin-echo sequences with different repetition times (TR = 300, 500, 750, 1,500 and 3,000 ms) combined with a short echo time (TE = 17 ms) were used for T1 evaluation and spin-echo sequences with TR = 1,500 ms in combination with different echo times (TE = 30, 60, 94 and 134 ms) for T2 evaluation. One single 10 mm slice with a 256 × 256 matrix and a 500 mm field of view, yielding a pixel size of 1.95 × 1.95 mm, was scanned for each sequence. From the anterior muscle compartment in the lower leg, regions of interest (ROI) were analysed from both T1 and T2 maps. The longitudinal relaxation time estimates (T1) were obtained from irregularly shaped ROIs, corresponding to the whole anterior compartment, outlined on T1 maps computed according to Sperber et al. (41). The transverse relaxation time estimates (T2) were obtained on T2 maps from circular ROIs, the area being approximately 2.5 cm^2. The T2 maps were computed according to the implementation in our MR equipment. From the frequency distributions of pixel values in these ROIs, specific T1 and T2 values were obtained. The shapes of the distributions, their mean values and standard deviations for patients were compared with data from healthy subjects studied earlier at the same centre (48). Values deviating more than 2 SD from the data obtained in healthy subjects were considered abnormal.

In TA, muscle atrophy was graded semi-quantitatively according to Damian et al.: no or mild atrophy = 0, marked atrophy = 1, severe atrophy = 2 (11).

Individual muscles or muscle groups with synergistic function were evaluated visually from images with TR 300 ms and TE 17 ms. The signal intensity (SI) of the muscles was evaluated on a semi-quantitative four-point grading scale, with the SI of subcutaneous fat as reference (12): *Grade 1.* Normal muscle with homogeneous hypointensive signal. *Grade 2.* Muscle with irregular, patchy hyperintense areas, but not isointensive with fat. *Grade 3.* Muscle with marked irregular, patchy hyperintense areas, isointensive with fat. *Grade 4.* Muscle totally isointensive with fat.

Muscle strength measurements

Maximal foot dorsiflexor strength was measured in isokinetic

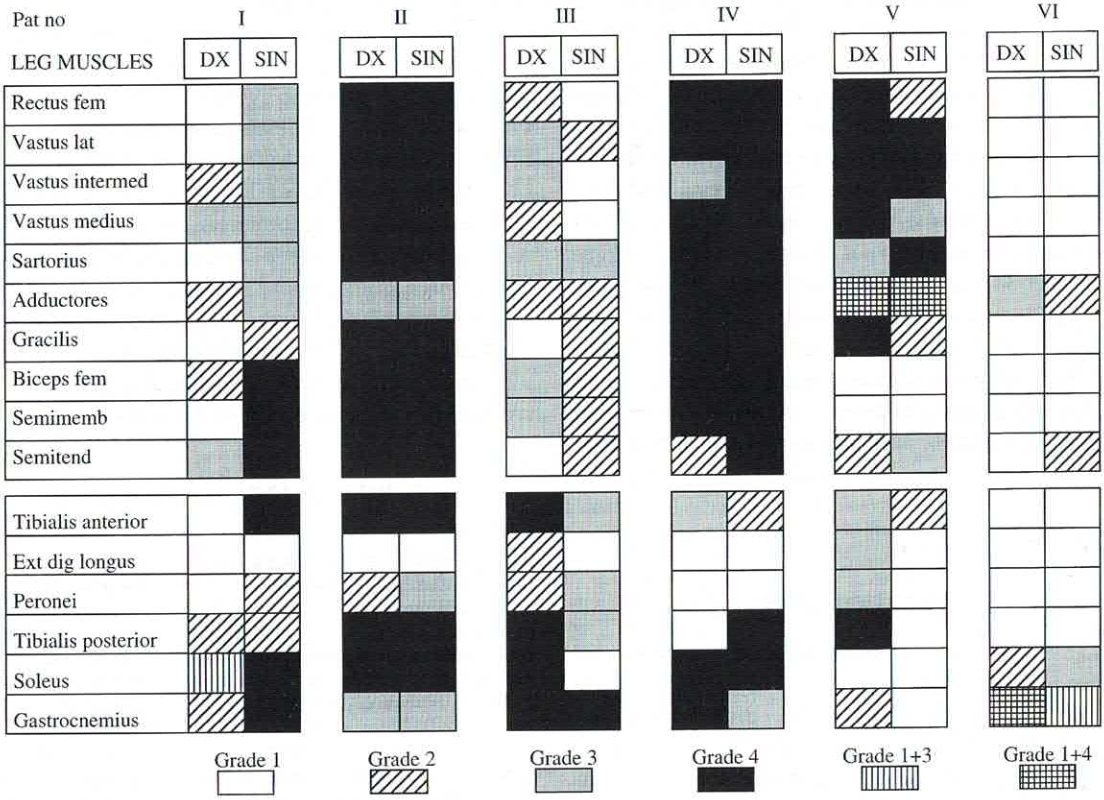

Fig. 1. Distribution of visual semi-quantitative MRI (TR/TE 300/17) findings in six prior polio patients (I–VI). *Grade 1*: Normal muscle with homogeneous hypointensive signal. *Grade 2*: Muscle with irregular, patchy hyperintense areas, but not isointensive with fat. *Grade 3*: Muscle with marked irregular, patchy hyperintense areas, isointensive with fat. *Grade 4*: Muscle totally isointensive with fat. *Grade 1 + 3*: Muscle with focal affection where half of the muscle appears with normal SI and the rest of the muscle with SI corresponding to grade 3. *Grade 1 + 4*: Muscle with focal affection where half of the muscle appears with normal SI and the rest of the muscle with SI corresponding to grade 4.

movements with a dynamic dynamometer (KIN-COM 500H, Chattecx Corp., Chattanooga TN, USA) (43). Peak torque was determined at 30 deg/sec.

Statistics

The Spearman rank-order correlation coefficient was used for statistical analysis. $p < 0.05$ was considered statistically significant.

RESULTS

MRI findings

Distribution of muscle involvement. There were no difficulties in identifying the major muscles and muscle compartments in the thigh or the muscle compartments in the lower leg.

The subcutaneous fat layer was prominent in four patients (I–III and V), occupying about half of the thigh diameter (Figs. 2–5), while in two (IV and VI) it was of ordinary thickness.

The semi-quantitative observations of the distribution of degenerative changes in different muscle groups in the thigh and lower leg are shown in Fig. 1.

On T1-weighted spin-echo images (TR/TE 300/17 ms) the signal abnormalities varied from patchy to homogeneous, resembling the SI of subcutaneous fat. Parts of muscles, whole muscles or muscle groups were affected. Spared muscles were easily demarcated from affected ones by the difference in SI and by different T1 relaxation times (Figs. 6–8). No specific pattern in the distribution of the muscle involvement was noted (Fig. 1).

Five of the patients (I–V) had widespread grade 2–4 MRI abnormalities in the thigh muscles (Figs. 2–5). In one patient (VI) there were grade 2–4 abnormalities restricted to the adductor and semitendinosus muscles of both thighs. A relatively symmetrical distribution was noted in five patients (II–VI), while an asymmetrical distribution was seen in one (I).

In the lower leg there were widespread grade 2–4 MRI abnormalities in five patients (I–V), while one (VI) had changes in soleus and gastrocnemius muscles. A relatively symmetrical distribution was seen in patients II, IV and VI, and an asymmetrical distribution in patients I, III and V.

In the anterior compartment it was possible to distinguish between TA and extensor digitorum longus muscles in four of the six patients. There was a difference in muscle affection between tibialis anterior and extensor digitorum longus in patients II–V.

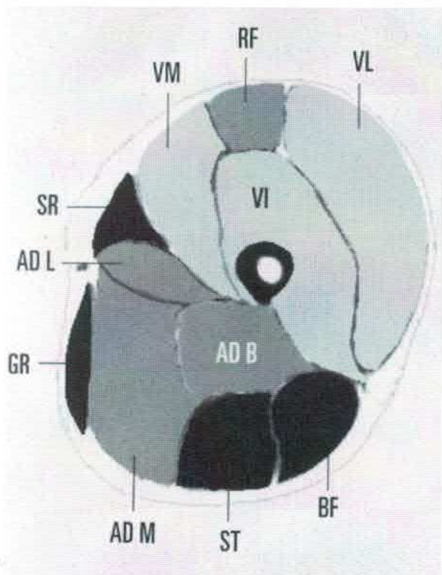

Fig. 2. Cross-section of lower thigh. AD B = Adductor brevis. AD L = Adductor longus. AD M = Adductor magnus. BF = Biceps femoris. GR = Gracilis. RF = Rectus femoris. SR = Sartorius. ST = Semitendinosus. VM = Vastus medialis. VL = Vastus lateralis. VI = Vastus intermedius. (From P. A. Tesch: *Muscles meet magnet*, 1993. With permission from the author.)

Weak foot dorsiflexor muscles—isokinetic strength and MRI findings. An overview of the isokinetic strength measurements and MRI findings of foot dorsiflexor muscles is shown in Fig. 9.

Peak torque values at 30 deg/s angular velocity ranged from 6 to 29 Nm. Corresponding values from healthy subjects ranged from 18 to 39 Nm (43).

The calculated T1 and T2 values of the anterior muscle compartment are shown in Table I. Individual mean T1 values were within the same range as in the controls, with a tendency towards lower values, except for one patient (IV) with a mean value more than 2 SD below the control data. The SDs of the individual

Table I. *T1 and T2 mean values (± SD) from* lower *leg anterior compartment*

Patient no.	T1	T2
I	1,045 ± 519	61.3 ± 18.4
II	795 ± 404	57.2 ± 4.8
III	877 ± 312	35.7 ± 6.2
IV	803 ± 428	56.9 ± 9.0
V	992 ± 336	55.6 ± 8.1
VI	1,094 ± 326	—
Normal values	1,143 ± 141	35.0 ± 3.3

mean values were large. Individual mean T2 values were high in four patients (I, II, IV, V), with mean values more than 2 SD above the control data.

There was no significant correlation between MRI findings (T1, T2 values, MRI scoring) and peak torque values, although the correlation coefficient for the MRI scoring was 0.8 and the level for statistical significance ($p < 0.05$) was >0.886. In the two patients (I and II) with the highest degree of muscle affection on the visual grading scale (grade 4), isokinetic strength was 7 Nm, i.e. among the lowest. Further, these patients exhibited marked (1) or severe (2) muscle atrophy according to Damian, and their T2 values were the highest, i.e. 61.3 (I) and 57.2 (II).

DISCUSSION

The most common MRI findings were patchy changes in muscles involving varying amounts of muscle tissue, as previously described in other neuromuscular disorders (15, 25). This is interpreted as fatty infiltration and accumulation of water (15, 28, 34, 48). Fatty atrophy has been confirmed with computer tomography (17, 47). In our study the distribution of T1 and T2 relaxation times (Table I) in the anterior compartment of the lower leg agreed with previously reported short T1 and long T2 relaxation times in a dystrophic patient (45), and prolonged T2 relaxation times in patients with lumbar root lesion and neuropathy (39) and nerve entrapment (16).

In MRI the signals arise mostly from the hydrogen atoms of water molecules. The water content of the muscles and its distribution between the extra- and intracellular space is thought to be particularly important for the MRI relaxation times. T2 relaxation times provide contrast permitting visualization of an increase in tissue water, since extracellular fluid has a greater effect on increased SI due to its longer relaxation time (5, 8, 18, 28). T1 relaxation times of normal muscle and fat show a considerable difference, fat having a short relaxation time and a high SI, whereas normal muscle tissue has a moderate T1 relaxation time and a moderate SI (8, 4). There are conflicting data concerning the influence on relaxation times of different muscle fibre type compositions (21, 22, 23, 30, 32) (for further discussion cf below). MRI

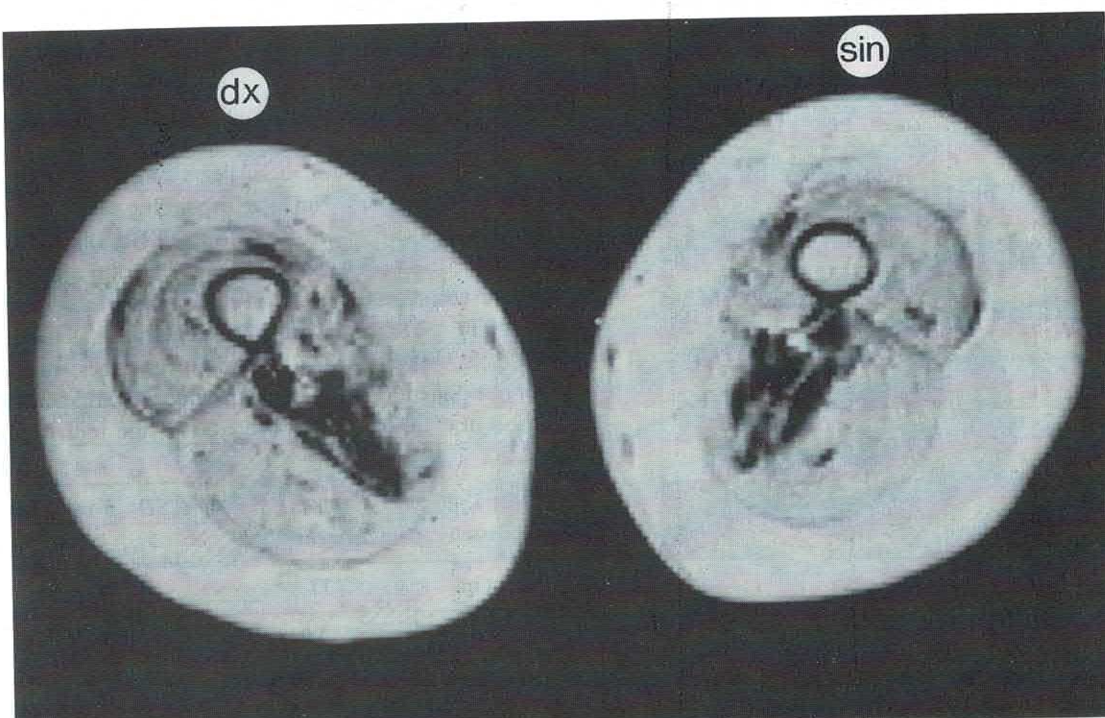

Fig. 3. Pat II. 10 mm axial MR section, TR/TE 300/17, of both thighs (low-level). Bilateral involvement of extensor and flexor muscles with hyperintense SI grade 4 resembling the SI of subcutaneous fat. Selective relative sparing of adductor muscles. Note the prominent subcutaneous fat layer.

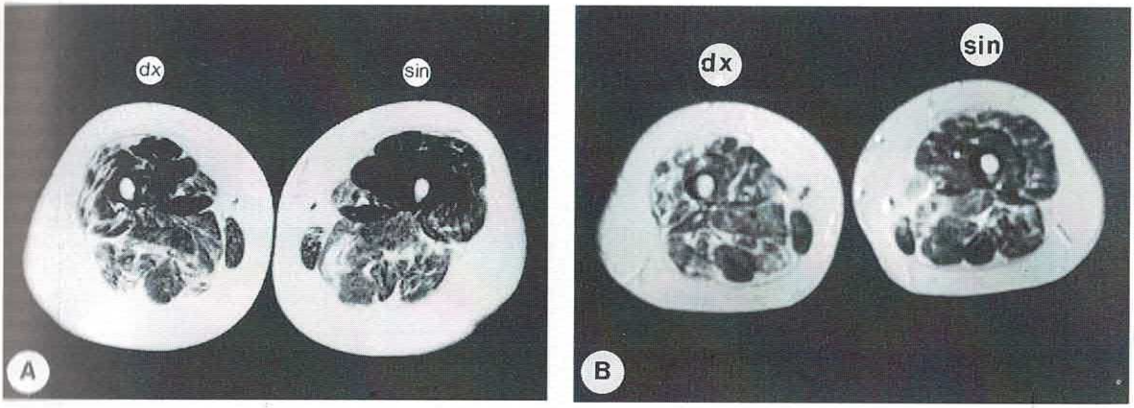

Fig. 4. Pat III. 10 mm axial MR section, (A) TR/TE 300/17 (T1) and for comparison (B) TR/TE 1500/94 (T2), of lower thigh. Widespread involvement of muscles of grade 2–3 in the right leg. In the left leg, involvement of grade 2 mainly in the posterior muscle groups and sparing of vastus medialis, vastus intermedius and rectus femoris muscles. Note the prominent subcutaneous fat layer.

is especially sensitive in detecting oedema-like abnormalities, i.e. increased muscular water content or enlarged extracellular fluid space (34). Differences in muscle relaxation times have been observed after exercise (13, 14, 40). Processes such as abscess, oedema, inflammation and tumour typically cause an increase in extracellular fluid (5, 8, 34, 36). In muscle disorders, the changes in SI have been interpreted as mainly due to oedema-like abnormalities in acute and in chronic forms and a varying amount of fat infiltration in chronic forms (28, 34). Thus, in inflammatory myopathies, the increased SI on T2-weighted, but not on T1-weighted, images was interpreted as indicating oedema-like abnormalities

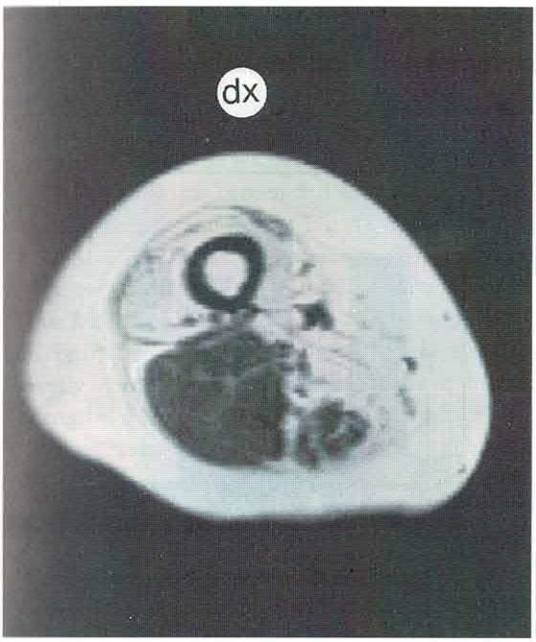

Fig. 5. Pat V. 10 mm axial MR section, TR/TE 300/17, of lower thigh. Right leg. Grade 2–4 involvement of the anterior muscle group and of the adductor muscle group with sparing of hamstrings muscles. Note the prominent subcutaneous fat layer.

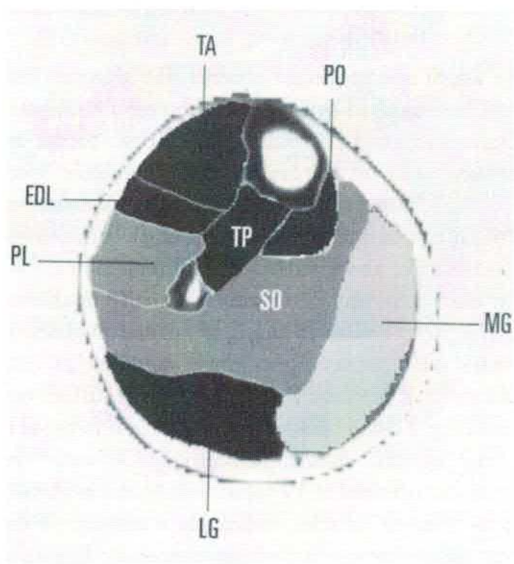

Fig. 6. Cross-section of left lower leg. SO = Soleus. MG = Medial gastrocnemius. LG = Lateral gastrocnemius. TA = Tibialis anterior. TP = Tibialis posterior. PO = Popliteus. EDL = Extensor digitorum longus. PL = Peroneus longus. (From P. A. Tesch: *Muscles meet magnet*, 1993. With permission from the author.)

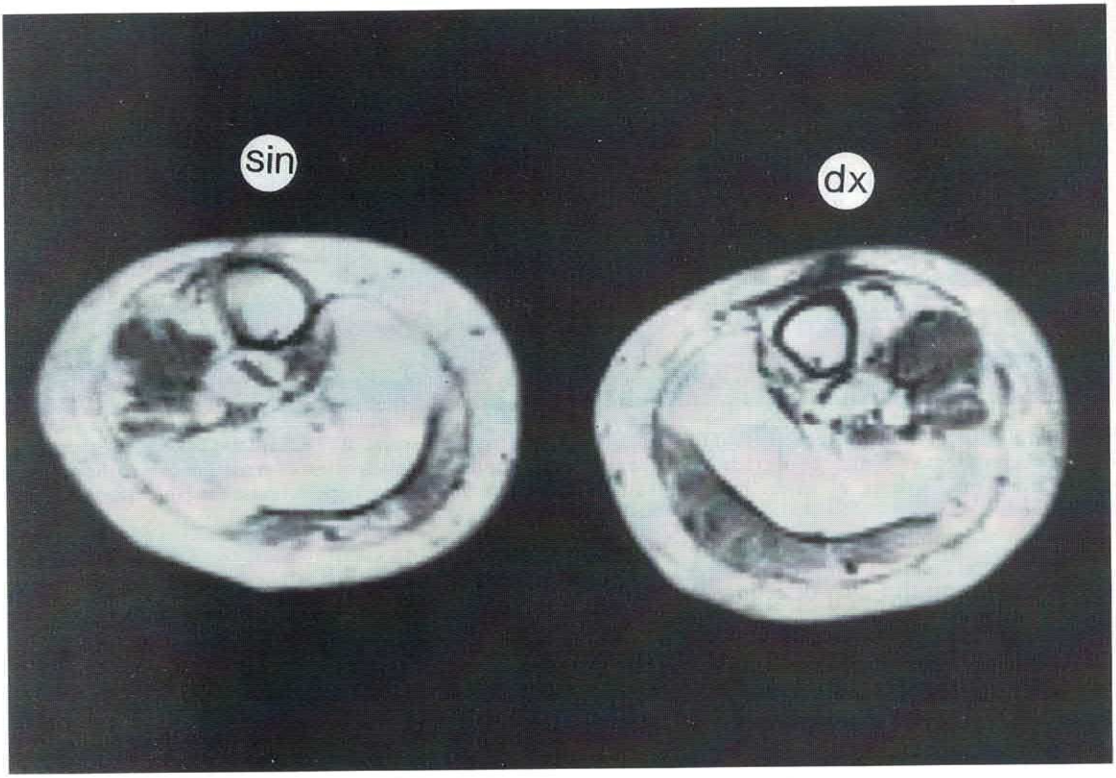

Fig. 7. Pat II. 10 mm axial MR section, TR/TE 300/17, of *lower* legs between the upper and middle third of the distance from tuberositas tibiae and lateral malleolus. In both legs a focal sparing of extensor digitorum longus and a relative sparing of peroneus (grade 2) and gastrocnemius (grade 3).

(34). Slight and moderate oedema-like abnormalities might be disguised by fat infiltration on T1-weighted images. Increased T2 values in chronic forms are consistent with an increased extracellular fluid space (15). Slightly increased T1 SI and clearly increased T2 SI have been interpreted as reflecting a combination of oedema-like abnormalities and fat replacement (34).

In our study the T1 values of visually unaffected muscles were similar to those of normal muscles. In muscles with patchy appearance, assumed as fatty infiltration, a biphasic distribution of T1 values was found (Fig. 8) with peak values of T1 close to those of fat and normal muscle, respectively. A wider frequency distribution of T1 values was found in visually patchy affected muscles, indicating a mixture of different tissues in voxels (volume elements); therefore, in these cases the amount of contractile tissue could not be differentiated from fat tissue. Thus, calculation of absolute relaxation parameters of whole muscle gave no further information about the amount of contractile elements than did visual evaluation.

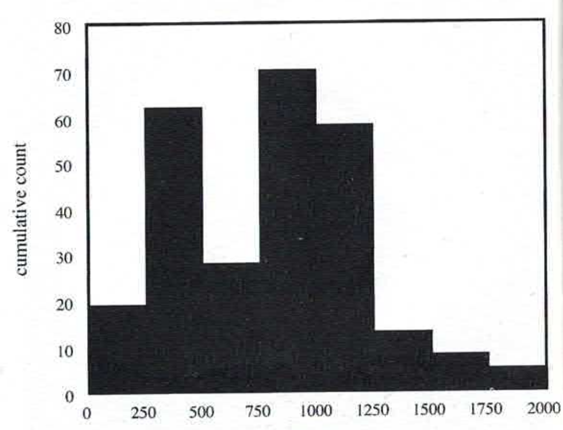

Fig. 8. Pat II. Distribution of calculated T1 values in the right *lower* leg anterior compartment, cf. fig. 4. Subcutaneous fat in healthy subjects had a mean value of 316 (SD 30) and muscle in healthy subjects 1143 (SD 141). The mean T1 value in the patient was 795 (SD 404) with a biphasic distribution interpreted as fatty degeneration of TA and normal T1 values from extensor digitorum longus.

Pat no	PT 30°/sec Nm	MRI grade	Atrophy score
I	7		2
II	7		1
III	6		0
IV	8		0
V	11		0
VI	29		0

Fig. 9. Foot dorsiflexor muscles. Peak torque values at 30 deg/sec, MRI score and muscle atrophy according to Damian score (see text).

The clearly increased T2 values in our patients were interpreted as an increase of fluid especially in the extracellular fluid space due to a reduction of muscle tissue (15, 34).

Several factors influence absolute T1 and T2 relaxation times (cf. above) including the technique and equipment used. Thus, each MRI unit has to create its normal data (31), although attempts have been made to correlate absolute values between different centres (9).

For the visual MRI evaluation of distribution and severity of muscle degeneration, the sequence TR/TE 300/17 ms (T1) was chosen to achieve a good contrast between muscle and fat (cf. Fig. 4). Short TR gives a high SI from fat and a moderate SI from normal muscle, while long TR (>1000 ms) gives a high SI from fluid, especially in the extracellular fluid space (8). In contrast to T2 relaxation times, T1 relaxation times greatly depend on the field strength. In high-field strengths T1 relaxation times are longer. Previous grading scales presented in the literature are too rough (48) or based on images from low-field strength systems and on different sequences (28, 24) from those used in this study. Thus, a four-point semi-quantitative grading scale was constructed.

There were widespread changes in the muscles of the thigh and of the lower leg in our patients with prior polio. No specific pattern in the distribution was detected, which accords with the diffuse distribution of the acute virus infection within the nervous system (2). Abnormal SI, confined to the area of the nerve supply, has been demonstrated in MRI studies of chronic denervation in T1- and T2-weighted images (15, 39). Thus, MRI might be useful in revealing the distribution of muscular involvement.

Owing to a prominent layer of subcutaneous fat, the cross-sectional area of the leg did not reflect the amount of muscle tissue content as previously reported (19). In healthy subjects the subcutaneous fat has been reported to be 15–26 % (20, 27) of the thigh cross-sectional area. Using ultrasound in patients with myotonic dystrophy, Schedel et al. reported a decreasing muscle diameter and an increasing subcutaneous fat layer with loss of muscle strength (37).

There was no significant correlation between MRI findings in the anterior compartment and isokinetic strength of the foot dorsiflexors, although there was a tendency to correlation between the visual scoring and isokinetic strength. This is in agreement with previous studies on nemaline myopathy, where Wallgren-Pettersson et al. (47) observed that only in *very weak* muscles was there a correlation between muscle strength and MRI pattern, whereas *slightly weakened* muscles exhibited different degrees of abnormalities. No attempt was made to relate the isokinetic strength to cross-sectional area of whole muscles since, due to fatty infiltration, the cross-sectional area did not reflect the content of contractile tissue.

Previous studies of prior polio patients with foot dorsiflexor weakness have shown significant changes in motor unit size and muscle fibre size and type related to the degree of muscle weakness in response to excessive overuse of the TA muscle during walking (3, 43, 44). Comparing the MRI findings of the present study with previously published data from macro EMG and muscle biopsy from TA muscle in the same group of patients (43, 44) showed no correlation with motor unit size or muscle fibre size or fibre type proportion.

Reported data concerning a relation between muscle fibre composition and relaxation times have been contradictory. Polak et al. (32) reported prolonged T1 and T2 relaxation times in rat and rabbit muscles with a high proportion of type I muscle fibres. Kuno et al. (22) reported prolonged T1 and T2 times associated with a high proportion of type II muscle fibres in human muscle. Jakobsson (21) found shorter T1 relaxation times in stroke patients with a high proportion of type II fibres in tibialis anterior and soleus muscles. Mardini et al. (26) found no differences between relaxation times in type II-dominated psoas muscle and type I-dominated soleus muscle in rabbits, nor did Parkkola et al. (30) in a post-mortem study find any correlation between muscle fibre type proportion and relaxation times. In our study there was no significant correlation between MRI findings and the muscle fibre type proportion (43).

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