LONG-LASTING UNILATERAL MUSCLE WASTING AND WEAKNESS FOLLOWING INJURY AND IMMOBILISATION

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ABSTRACT. Quadriceps strength and size was measured in a small group of subjects ($n=7$) 1 to 5 years after full mobilisation following some form of unilateral lower limb trauma. The mean maximum voluntary isometric force (MVC) was significantly lower for the injured (I) compared to the uninjured (UI) leg (369 N ± 139 vs. 535 N ± 131, $p<0.01$). Electrical stimulation superimposed on the voluntary contractions demonstrated that all subjects were able to maximally activate the quadriceps of both legs. Mean quadriceps cross-sectional area (CSA) was significantly lower in the I (64 cm^2 ± 12.8) compared to the UI leg (80 ± 12.8, $p<0.01$). One subject with marked unilateral weakness and wasting took part in a 3-month strength training study for the injured leg. After training the I/UI ratio had been restored to nearly 100% (94% MVC; 88% CSA). These results would suggest that longer and more intensive physiotherapy is required in the immediate post-injury period to restore muscle strength and size to severely atrophied muscle.

Key words: muscle, immobilisation atrophy, strength, size, strength training.

Muscle weakness and atrophy are well-known side effects which occur with limb immobilisation. The values quoted for the loss of strength vary between 20 and 50% (4, 7, 13, 20) with 10 to 50% decreases in muscle volume, cross-sectional area and fibre area (2, 9, 18, 20, 21). Rehabilitation involves exercise to strengthen the affected muscles and once mobility has been regained it is generally assumed that the muscle has returned close to its full size and strength but there are suggestions that this may not be the case. After 14 weeks of intensive rehabilitation strength decrements of up to 35% have been reported between the injured and uninjured limb in army personnel and even six months after the resumption of military duties differences of 10–25% were still evident (6, 8). We know of no studies following this type of patient over the next few years to see whether full strength ever returns.

We report here results of quadriceps strength and size in a small group of subjects 1 to 5 years after full mobilisation following some form of unilateral lower limb trauma. A pilot study of the effect of strength training was carried out in one subject who had marked unilateral wasting and weakness.

METHODS

Subjects. Seven subjects (6 male, 1 female) were studied. Details of the injury, time of immobilisation and time since full mobilisation are given in Table I. All procedures were approved by the Committee on the Ethics of Clinical Investigation, University College Hospital.

Quadriceps strength. Maximum voluntary isometric contractions (MVC) of the quadriceps were measured in a conventional strength testing chair (1). The best of three MVCs was measured on at least two separate days. A percutaneous twitch superimposition technique was used to test whether subjects were able to maximally activate the quadriceps during the isometric contraction (for full description of method see ref. 17). The quadriceps was stimulated at 1 Hz with a voltage sufficient to activate over 50% of the muscle and the height of the twitches before and during the voluntary contraction were compared. During a truly maximum contraction no extra force is generated by the stimulation. When the contraction is submaximal the height of the superimposed twitch can be used to estimate the degree of inhibition from the known relationship between superimposed twitch height and the percentage of maximum force being generated (17).

Measurement of quadriceps size. Quadriceps cross-sectional area (CSA) was measured from a Computerised Tomography (CT) X-ray scan taken at half femur height. Scans were taken on a Philips Tomoscan 350 with a scanning time of 4.8 s and a slice thickness of 9 mm. Images were analysed off-line on a locally designed interactive medical imaging package running on a PDP 11 (13). The area of the qudriceps and femur were measured semi-automatically using a contour following programme with manual editing where necessary.

Training regime. A preliminary training study was carried out on one subject (S. W.) who trained the injured leg for three months. The exercise consisted of one-legged knee extension training on a conventional isotonic multi-gym appa-

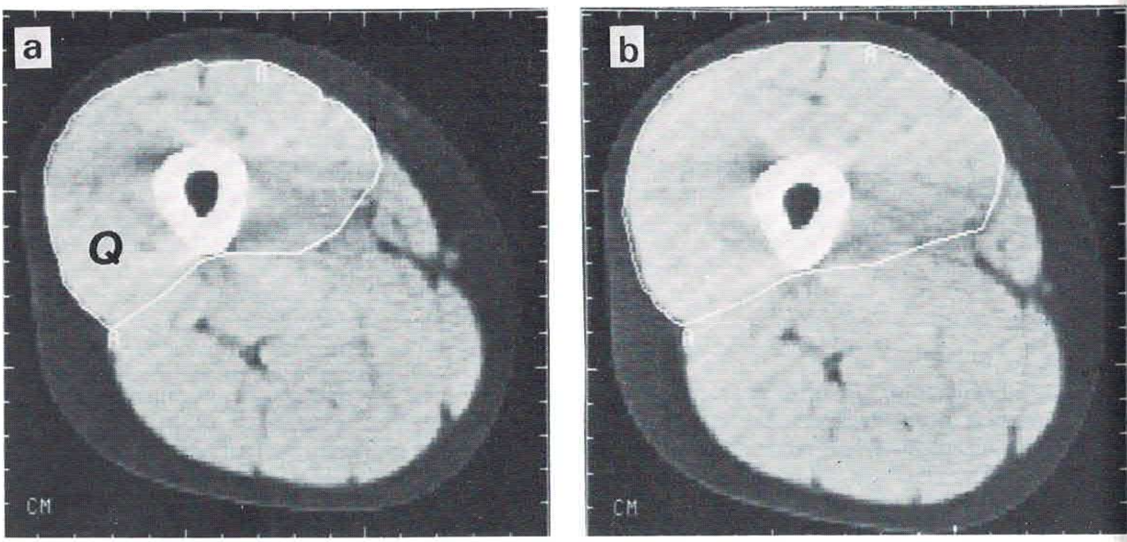

Fig. 1. Computerised tomography (CT) scans taken at half femur height in the injured leg before (*a*) and after (*b*) six months strength training. Q = quadriceps.

ratus. Each training session consisted of 4 sets of 6 repetitions at a weight that could just be lifted 6 times. The weight was progressively increased as the subject improved. Before and after the 3 months of training, measurements were made of quadriceps CSA and isometric force. CT scans of the mid thigh for this subject before and after training are shown in Fig. 1.

RESULTS

Isometric strength. The mean quadriceps isometric strength for the injured limb (369 N ± 139; mean ± SD) was significantly lower than the uninjured leg (535 N ± 131; mean ± SD; $p<0.01$, Wilcoxon's paired rank sum test). Electrical stimulation superimposed on the

Table I. *Details of injury, time since injury and time immobilised for each subject*

Individual values for quadriceps maximum isometric force (MVC) and cross-sectional area (CSA) are given for the injured (I) and uninjured (UI) leg. Subject S. W. took part in a 3-month strength training regime and values for post-training are also given

Subject	Injury	Years post	Time immobilised (months)	MVC (N) I	MVC (N) UI	CSA (cm^2) I	CSA (cm^2) UI
MH	Mutiple fractures	5	13	300	436	50	68
NK	Torn anterior cruciate	2	1	630	760	71	93
DM	Fractured femur	1	3	430	555	64	83
KM	Fractured femur	2	5	420	545	73	78
PM	Fractured femur	1	1	288	468	78	85
SW	Fractured femur/torn anterior cruciate	1	2	204 366	360 390	43 56	39 Pretraining 64 Posttraining
GM	Multiple femur fractures	3	8	312	620	70	93

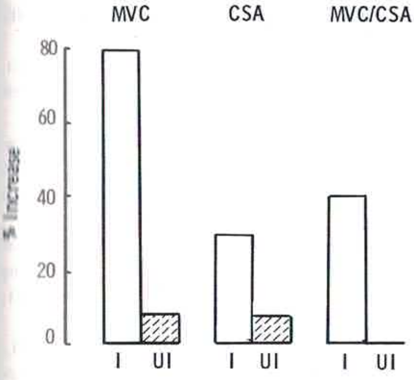

Fig. 2. Percentage changes in maximum isometric force (MVC), cross-sectional area (CSA) and force per unit area (MVC/CSA) of the quadriceps after 3 months strength training of the injured leg in one subject (S. W.). I = injured, UI = uninjured.

Table II. *Group mean values for quadriceps isometric strength (MVC), cross-sectional area (CSA) and force per unit area (MVC/CSA) for the injured and uninjured leg and the injured value as percentage of uninjured (Mean, SD)*

	MVC (N)	CSA (cm^2)	MVC/CSA (Ncm^{-2})
Injured (I)	369 (139)	64 (12.8)	5.7 (1.7)
Uninjured (UI)	535 (131)	80 (12.8)	6.6 (0.8)
I/UI %	67.7 (12.1)	80 (8.7)	85 (16)

voluntary contractions demonstrated that all subjects were able to maximally activate the quadriceps muscle of both the injured and uninjured leg. The I/UI ratio (%) of strengths was 68% (range 50–83). Individual and group mean results are given in Tables I and II respectively.

Quadriceps CSA. The group mean quadriceps CSA was significantly lower for the injured limb (64 ± 12.8 cm^2) compared to the uninjured limb (80 ± 12.8 cm^2; $p < 0.01$). The I/UI ratio of areas was 80% (range 73–94%).

Force per unit area. The mean force per unit area was calculated. The value for the injured limb (5.7 ± 1.7 Ncm^{-2}) was lower than that of the uninjured leg (6.6 ± 0.8 Ncm^{-2}), the difference not quite reaching significance at the 5% level.

Training study. Measurements before and after training in the one subject SW are given in Table I and the changes in muscle size, strength and force per unit area are illustrated in Fig. 2. After three months training the quadriceps strength had increased by 79% in the injured leg while the uninjured leg, which had not been trained, was 8% stronger. Quadriceps CSA increased by 30 and 8% respectively in the injured and uninjured leg. The resulting change in force per unit CSA was 40% (I) with no change in the uninjured leg. After training the I/UI ratios became 94% (MVC), 88% (CSA) and 108% (MVC/CSA).

DISCUSSION

In a group of young healthy, active subjects significant decrements in muscle strength and size still remained up to 5 years after full mobilisation following lower limb trauma. Differences in strength between the injured and uninjured leg ranged from 17–50% with accompanying muscle atrophy of 6–27%. There was no relationship between the degree of weakness or atrophy and the time since the injury.

Although none of the subjects reported any discomfort or pain from the injured leg, some did experience a reduction in the range of movement of the knee. In normal every-day activities the subjects were not aware of any limitation caused by the unilateral weakness, but several did report difficulty during more strenuous activities such as running up stairs.

The extent of weakness and atrophy was very similar to that previously reported in the immediate post-injury period (6, 8). In human investigations it is most unlikely that measurements will be made before the injury so the uninjured limb is generally used as a control. It is possible that the uninjured leg could either be (i) over-used and subject to compensatory hypertrophy; or (ii) underused and atrophied as a result of immobilisation. In healthy subjects there is a close relationship between the area of bone and surrounding muscle (11), the normal ratio between quadriceps and femur CSA being 12.6 ± 1.7. In our subjects the ratio for the uninjured legs was 12.7 ± 1.7, suggesting that they had suffered neither atrophy nor hypertrophy. The ratio and for the injured legs was 10.1 ± 1.5, indicative of muscle wasting.

In the injured legs force was reduced to a greater extent than would be expected from the loss of cross-sectional area. Maximum voluntary force was measured and this depends on the subject being able to fully activate the muscle. Long-lasting inhibition from the trauma, or fear of making a maximal contraction may inhibit the subject (19). In the present study the evidence from superimposed electrical stimulation showed that the subjects were able to fully activate their quadriceps on both injured and control sides. Another possibility is that the muscle on the injured side may have a high fat or connective tissue content, the latter as a result of damage to the muscle during the original trauma.

After 3 months strength training in one subject the injured muscle was restored to a similar strength, size and force generating capacity as the uninjured leg. The pattern of change with a greater increase in force than in cross-sectional area is similar to that reported for the same training regime in young uninjured people (12, 16). The extent of the change was however much greater than observed in uninjured subjects. Although the stimuli for increased muscle strength and hypertrophy are unknown, they are generally thought to involve high force contractions (3, 14). Clearly the activities of every-day life do not require contractions of sufficiently high force to stimulate muscle hypertrophy. This has important implications for the design of rehabilitation programmes indicating that much more intensive strength training may be necessary.

The slowness of recovery from immobilisation-induced atrophy is in sharp contrast to the much more rapid recovery which occurs following muscle damage, such as that induced by eccentric exercise. In the latter situation muscle strength and fibre size is restored to normal within about four weeks in the absence of any specific training stimulus (10, 15). After exercise-induced damage the affected fibres degenerate and subsequently regenerate from satellite cells and these new fibres have a greater potential for growth since every-day activities appear to provide a sufficient stimulus. In contrast, during recovery from immobilisation-induced atrophy, growth probably occurs in mature fibres and these require a much greater stimulus before they return to their original size.

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