MUSCLE HYPOTHROPHY: LESSONS FROM SPACE

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Since the beginning of the space-flight era, weightlessness was shown to lead to substantial changes of muscle function, similar to those brought about by ageing or long term immobilisation. These changes consist mainly of loss of muscle mass, force and power, increased muscle fatigability, and abnormal reflex patterns. They are due to a combination of factors among which an increased degradation of muscle proteins, and substantial changes of the neuromuscular control of movement, both brought about by the absence of the constant pull of gravity, play a major role.

In humans, during simulated microgravity (bed rest), the muscle mass decreases exponentially towards an asymptotic value of about 70 % of the initial one, which would be attained after about 270 days. Most animal studies reported preferential atrophy of slow twitch fibres whose mechanical properties change towards the fast type. However, in humans, at the end of a 42-days bed rest study, a similar atrophy of slow and fast fibres was observed. After microgravity, the maximal force of several muscle groups showed a substantial decrease (6 to 25 % of pre-flight values) accompanied by an even greater fall of maximal muscle power.

Indeed, data obtained, before and after the Euromir 94, 95, Mir 97 and Euromir E missions on 9 astronauts, by means of a specially developed instrument, have shown that the maximal explosive power of the lower limbs, as determined during maximal "all-out" pushes on a force platform was reduced to about 67 % after 31 days and to about 45 % (of pre-flight values) after 180 days. At variance with these data, the maximal power of the lower limb muscles developed during 6 - 7 seconds all-out bouts on an isokinetic cycloergometer was reduced to a lesser extent, attaining about 75 % of pre-flight, regardless of the flight duration. Since in the same subjects, lower limb muscle mass decreased only by 9 - 13 %, irrespective of the flight duration, these data suggest that a large fraction of the decline of the maximal power, at least during the very short "explosive" efforts, may be due to the effects of weightlessness on motor unit recruitment pattern (Antonutto et al., 1999).

The large fall of maximal explosive power seems to be a specific characteristics of space-flight that cannot be easily reproduced by bed rest. Indeed, after 42 days of bed rest, the maximal explosive power produced during a vertical jump on a force platform was reduced to 76 % of preflight (average of 6 subjects) (Ferretti, 1997; Ferretti et al. 2001), to be compared with 67 % after 31 days spaceflight (see above). It is also noteworthy that the data reported by Ferretti were obtained after 42 days of bed rest without countermeasures, to be compared with a space-flight of 31 days with 2 hours of exercise per day. These observations support the hypothesis that the absence of gravity, favouring smooth and delicately balanced muscle actions, brings about a substantial rearrangement of the motor control system that is responsible, at least to a large extent, for the observed decline in the maximal explosive power during all-out short lasting actions of the lower limbs extensor muscles . This rearrangement does not seem to manifest itself or, if it does, to be markedly less effective after bed rest wherein the pull of gravity is not abolished, but simply shifted by 90 degrees.

Besides the functional characteristics of the lower limbs muscle, also the tendon mechanical properties are affected by microgravity. Indeed, Goubel et al. (1997) observed a decrease of the stiffness of the series elastic elements of the plantar flexors of the ankle after space-flight of 1 to 6 months duration. This observation was recently confirmed by Reeves et al. (2002) who reported a 32% decrease in Achille's tendon stiffness following 90 days of bed rest. However, these results are in apparent contrast with the findings of Lambertz et al. (2001) showing an increase in musculo-tendineous stiffness after prolonged space-flight. Such discrepancy may conceivably originate from the different conditions of space-flight and bed rest; whereas during bed rest, subjects are not engaged in any form of exercise, in space-flight, astronauts perform daily countermeasures aimed at mitigating the effects of prolonged disuse.

In conclusion, simulated and actual microgravity lead to profound alterations of skeletal muscle structure and function. Knowledge of the underlying mechanisms and of the countermeasures to avoid them seems a necessary prerequisite not only for prolonged manned space-flight, but also for preventing muscle damage due to immobility and ageing on Earth.

References in P.E. di Prampero, M.V. Narici. Muscles in microgravity: from fibres to human motion, J. Biomechanics 36: 403 – 412, 2003.