Effects of rapid or slow body weight reduction on intramuscular protein degradation pathways during equivalent weight loss on rats

Yudai Nonaka¹, Shogo Urashima¹, Makoto Inai¹, Shuhei Nishimura¹, Kazuhiko Higashida², Shin Terada¹

1) Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, 3-8-1, Komaba, Meguro-ku, Tokyo 153-8902, Japan

2) Department of Food Science and Nutrition, School of Human Cultures, The University of Shiga Prefecture, 2500, Hassaka-cho, Hikone-City, Shiga 522-8533 Japan

Running head: Rapid and slow weight loss and muscle atrophy

All correspondence to:
Yudai NONAKA, MSc.
Department of Life Sciences,
Graduate School of Arts and Sciences,
The University of Tokyo
3-8-1 Komaba, Meguro-ku
Tokyo, 153-8902, Japan

E-mail: y-nonaka02@hotmail.co.jp
TEL: +81(Japan)-3-5465-7641
FAX: +81(Japan)-3-5454-4317
Summary
The purpose of this study was to compare the effects of short-term fasting-induced rapid weight loss with those of slower but equivalent body weight loss induced by daily calorie restriction on muscle protein degradation pathways and muscle protein content. Male Fischer rats were subjected to either 30% calorie restriction for 2 wk to slowly decrease body weight (Slow) or 3-day fasting to rapidly decrease body weight by a comparable level of that of the Slow group (Rapid). The final body weights were about 15% lower in both the Slow and Rapid groups than in the Con group (p<0.001). The total protein content and wet weight of fast-twitch plantaris muscle, but not slow-twitch soleus muscle, were significantly lower in the Rapid group compared with the control rats fed ad libitum. Substantial increases in the expression ratio of autophagosomal membrane proteins (LC3-II/I ratio) and polyubiquitinated protein concentration, used as biomarkers of autophagy-lysosome and ubiquitin-proteasome activities, respectively, were observed in the plantaris muscle of the Rapid group. Moreover, the LC3-II/I ratio and polyubiquitinated protein concentration were negatively correlated with the total protein content and wet weight of plantaris muscle. These results suggest that short-term fasting-induced rapid body weight loss activates autophagy-lysosome and ubiquitin-proteasome systems more strongly than calorie restriction-induced slower weight reduction, resulting in muscular atrophy in fast-twitch muscle.

Key words: skeletal muscle, fasting, calorie restriction, autophagy-lysosome, ubiquitin-proteasome
Introduction

Many athletes restrict their caloric intake to improve their force-to-mass ratio, to achieve a certain body mass category, or for aesthetic reasons. In particular, athletes in weight-classified sports such as wrestling and boxing usually lose body weight rapidly before competitions (Choma et al. 1998, Reljic et al. 2013). The rapid weight loss, also known as “weight cutting”, typically involves several-day fasting until the targeted weight is met. However, fasting is a recognized stimulus of skeletal muscle atrophy (Jagoe et al. 2002), which results in a significant loss of lean body mass that compromises exercise performance. Muscle atrophy occurs when rate of protein degradation exceeds that of protein synthesis. There are two major protein degradation pathways in skeletal muscle. One, the ubiquitin-proteasome pathway, plays a major role in selective protein degradation and serves as the primary degradation route for most short-lived proteins (Rock et al. 1994). The other, the autophagy-lysosome pathway, is an intracellular bulk degradation system that is responsible for the degradation of most long-lived proteins, as well as some organelles (Mortimore and Pösö 1987). Both proteolytic pathways become activated during fasting to maintain amino acid pools, leading to muscle atrophy (Mitch and Goldberg 1996, Bujak et al. 2015).

An alternative dietary weight-loss approach practiced by athletes is daily calorie restriction, which results in slower body weight loss compared with fasting. Many Japanese bodybuilders empirically believe that the slower body weight loss induced by daily calorie restriction has less atrophic effects on skeletal muscle than the fasting-induced rapid weight loss and therefore adopt the slower body weight-loss strategy before competitions. However, it remains unclear which type of body weight loss more strongly activates the autophagy-lysosome and ubiquitin-proteasome pathways and induces muscle atrophy.
when body weight is reduced to the same extent, because no study has directly compared
the effects of rapid vs. slow body weight reduction on the major protein degradation
pathways and on protein content in skeletal muscle. Thus, the purpose of this study was to
directly compare the effects of rapid or slow body weight loss on the autophagy-lysosome
and ubiquitin-proteasome pathways and on protein content in rat skeletal muscle during an
equivalent weight loss.

Methods

Animal treatment

Nineteen-week-old male Fischer-344 rats were obtained from Japan SLC
(Shizuoka, Japan) and individually housed under a 12:12-h light:dark cycle (light
09.00-21.00 h) in an air-conditioned room (23°C). Rats were given a standard laboratory
diet ad libitum (CE-2; CLEA Japan, Tokyo, Japan) and water and acclimated to the housing
facility for 1 wk. After the acclimation period, the rats were divided into three groups, matched for
body weight: one group continued to receive the standard diet ad libitum for the entire
14-day experimental period (Con; n = 5); a second group received the standard diet equal
to 70% of the average amount of food eaten by the Con group during the 14 days to
decrease their body weight slowly (Slow; n = 5); the third group was fed the standard diet
ad libitum for 11 days and fasted thereafter for the last 3 days of the study period to rapidly
decrease their body weight to a comparable extent as that of the Slow group (Rapid; n = 5).
All rats were allowed to drink water freely during the 14-day dietary intervention. Body
weight and food intake were recorded daily during the dietary intervention.

At the end of the dietary intervention, fast-twitch plantaris, extensor digitorum
longus (EDL), and slow-twitch soleus muscles were quickly and carefully dissected out under anesthesia with isoflurane immediately after the 12-h dark period during which rats eat most food. The muscle samples were weighed, quickly frozen in liquid N\textsubscript{2}, and stored at –80°C until analysis. After the blood samples were collected from the heart, intra-abdominal fat (sum of the epididymal, mesenteric, and retroperitoneal fat pads) was removed and weighed. The experimental protocols were approved by the Animal Experimental Committee of The University of Tokyo.

**Muscle homogenization**

Frozen plantaris and soleus muscles were homogenized in ice-cold Radio-Immuno Precipitation Assay (RIPA) lysis buffer (EMD Millipore, Temecula, CA, USA) containing 50 mM Tris-HCl, pH 7.4, 150 mM NaCl, 0.25% deoxycholic acid, 1% NP-40, 1 mM ethylenediaminetetraacetic acid (EDTA), protease inhibitor cocktail (SIGMA-Aldrich, St. Louis, MO, USA), and phosphatase inhibitors (PhosSTOP; Roche, Basel, Switzerland). The homogenates were frozen and thawed three times to disrupt intracellular organelles and rotated end-over-end at 4°C for 60 min to solubilize the protein. Total protein content per muscle was measured with a bicinchoninic acid (BCA) protein assay kit (Pierce, Rockford, IL, USA). Homogenized samples were then centrifuged at 700 × g for 5 min at 4°C and the supernatants were harvested.

**Western blotting**

Protein concentrations of the supernatant harvested as described above were measured with the BCA protein assay kit. Samples were prepared in Laemmli sample buffer (Wako Pure Chemical, Osaka, Japan) and heated for 5 min in a heating block at
95°C. Equal amounts of sample protein were subjected to sodium dodecyl
sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) (7.5% or 15% resolving gels) and
then transferred to polyvinylidene difluoride (PVDF) membranes at 200 mA for 90 min. After
transfer, membranes were blocked for 1 h at room temperature in Tris-buffered saline
(TBS) with 0.1% Tween 20 (TBS-T; 20 mM Tris base, 137 mM NaCl, pH 7.6) supplemented
with 5% (w/v) nonfat powdered milk or 5% (w/v) bovine serum albumin. Membranes were
incubated overnight at 4°C with the primary antibody diluted 1:1000 in TBS-T containing
5% bovine serum albumin. The primary antibodies used were anti-microtubule-associated
protein light chain 3 (LC3) (Medical & Biological Laboratories, Nagoya, Japan),
anti–phospho-p70S6K (Cell Signaling Technology, Danvers, MA, USA), and
anti–phospho-Akt (Ser473) (Cell Signaling Technology). After the incubation with primary
antibody, membranes were incubated for 1 h at room temperature with secondary
antibodies (goat anti-rabbit IgG or goat anti-mouse IgG, Jackson ImmunoResearch
Laboratories, West Grove, PA, USA) diluted 1:5000 in TBS-T containing 1% nonfat
powdered milk. Bands were visualized by enhanced chemiluminescence (ECL) reagent
(GE Healthcare Life Sciences, Piscataway, NJ, USA) and quantified by Image Studio
(LI-COR, Lincoln, NE, USA). The membranes were stained with Ponceau (Sigma-Aldrich)
to verify equal loading of protein across lanes.

Polyubiquitinated protein concentration analysis

The supernatants of the plantaris and soleus muscle homogenates were also
used for the measurement of polyubiquitinated protein concentrations. Polyubiquitinated
protein concentrations were measured with an enzyme-linked immunospecific assay
(ELISA) kit according to the manufacturer's instructions (Cyclex Poly-Ubiquitinated Protein
ELISA Kit; Medical & Biological Laboratories).

Serum glucose and insulin concentrations
Serum glucose and insulin concentrations were determined with the Glucose C2 Test Wako kit (Wako Pure Chemical) and Rat Insulin ELISA Kit (Mercodia AB, Uppsala, Sweden), respectively.

Muscle glycogen concentration
For the measurement of the muscle glycogen concentration, EDL muscles were homogenized with 0.3 M perchloric acid. The glycogen concentration was determined by the enzymatic methods of Lowry and Passonneau after acid hydrolysis (Lowry and Passonneau 1972).

Statistical analysis
All data are presented as means ± SEM. Statistical analysis was performed by Welch’s ANOVA and Bonferroni correction for post-hoc analysis (Social Survey Research Information Co., Ltd., Tokyo, Japan). We performed least-squares regression analyses to examine relationships between variables. Statistical significance was defined as p<0.05.

Results
Body weight, total intra-abdominal fat weight, and total food intake
Changes in body weights during the 2-wk dietary intervention are shown in Fig.1. During the intervention period, daily calorie restriction in the Slow group for 2 wk and 3-day fasting in the Rapid group caused a substantial reduction in body weight. The body weight
in the Slow group became significantly different from the Con and Rapid groups at day 3 (p<0.05). In addition, significant body weight reduction in the Slow group from day 0 was observed at day 3. The body weight in the Rapid group became significantly different from the Con group at day 12 (1 day after the onset of fasting). The final body weights were about 15% lower in both the Slow and Rapid groups than in the Con group (p<0.001) (Table 1). Total intra-abdominal fat weights were also significantly lower in both the Slow and Rapid groups than in the Con group (p<0.001), with no significant differences between the Slow and Rapid groups (Table 1).

Total food intake during the 2-wk experimental period was significantly lower in the Slow and Rapid groups than in the Con group (p<0.001; Table 1). Furthermore, total food intake was significantly lower in the Slow group than in the Rapid group (p<0.05).

**Serum glucose and muscle glycogen concentration**

At the completion of the 14-day dietary intervention, there was no significant difference in serum glucose concentration among the three groups (Table 1). Although there was no significant difference in the glycogen concentration of EDL muscle between the Con and Slow groups, the muscle glycogen concentration was significantly lower in the Rapid group than in the Con and Slow groups (p<0.001; Table 1).

**Muscle wet weight and muscle total protein content**

There were no significant differences in muscle wet weight and total protein content of the soleus muscle among the three groups (Table 1). Although the wet weight and total protein content of the plantaris muscle did not differ between the Con and Slow groups, the muscle weight and total protein content in the plantaris muscle were
significantly lower in the Rapid group than in the Con group (p<0.05; Table 1).

**Autophagy-lysosome activity**

The microtubule-associated protein LC3 is now widely used to monitor the autophagy-lysosome system. The cytosolic form of LC3 (LC3-I) conjugates with phosphatidylethanolamine to form the LC3-phosphatidylethanolamine conjugate (LC3-II), which is recruited to autophagosomal membranes (Mizushima and Yoshimori 2007). Because the amount of LC3-II is correlated with the extent of autophagosome formation and an increased LC3-II/LC3-I ratio is representative of accelerated autophagy-lysosome activity (Lee et al. 2014), we determined the expression levels of LC3-I and LC3-II and used the LC3-II/LC3-I ratio as a marker of autophagy-lysosome activity.

In both plantaris and soleus muscles, LC3-II/LC3-I ratios were significantly higher in the Slow group than in the Con group (p<0.01; Fig. 2-A and -B). Further increases in LC3-II/LC3-I ratios were observed in the plantaris and soleus muscles of the Rapid group (p<0.001 vs. the Con and Slow groups; Fig. 2-A and -B). In the plantaris muscle but not the soleus muscle, the LC3-II/LC3-I ratio was significantly and negatively associated with the muscle wet weight (p<0.01) and muscle protein content (p<0.05; Fig. 3-A and -C).

**Polyubiquitinated protein concentration**

Intracellular proteins are marked with a polyubiquitin chain, after which they are degraded to peptides and free ubiquitin by the 26S proteasome (Goldberg 2003). In the present study, we used the polyubiquitinated protein concentration as a marker of ubiquitin-proteasome pathway activity. The polyubiquitinated protein concentrations of the soleus muscle did not significantly differ among the three groups (Fig. 2-D). In contrast, in
the plantaris muscle, they were significantly higher in the Slow and Rapid groups than in the Con group (Con vs. Slow: p<0.01; Con vs. Rapid: p<0.001; Fig.2-C). Moreover, the polyubiquitinated protein concentration was higher in the Rapid group than in the Slow group (p<0.05; Fig. 2-C). The polyubiquitinated protein concentrations were significantly and negatively associated with the muscle wet weight (p<0.01) and muscle protein content (p<0.05) of the plantaris muscle (Fig. 3-B and -D).

**Protein synthesis pathway**

Although mechanistic target of rapamycin (mTOR) is a master regulator of muscle protein synthesis (Wullschleger et al. 2006), the phosphorylation status of mTOR (phospho-mTOR) does not necessarily reflect mTOR activity (Eliasson et al. 2006, Fujita et al. 2007, Miyazaki et al. 2011). Many recent studies have instead evaluated the phosphorylation of p70S6K (phospho-p70S6K), a downstream target of mTORC1, as a biomarker of mTOR activity (Jacinto and Hall 2003, Tamura et al. 2014). Although both the Slow and Rapid groups tended to have lower phospho-p70S6K content in the plantaris and soleus muscles than the Con group, the difference was not statistically significant due to a considerable variability in phospho-p70S6K levels (Fig. 2-E and -F).

**Serum insulin concentration and phosphorylated-Akt content in skeletal muscle**

The insulin–Akt axis has strong inhibitory effects on both autophagy-lysosome and ubiquitin-proteasome pathways in skeletal muscle (Price et al. 1996, Mitch et al.1999, Lee et al. 2004, Sacheck et al. 2004, Stitt et al. 2004, Wang et al.2006). Here, the serum insulin concentration was significantly lower in both the Slow and Rapid groups than in the Con group (p<0.001; Table 1). In addition, the serum insulin concentration was significantly
lower in the Rapid group than in the Slow group (p<0.01; Table 1). The levels of phosho-Akt, which is the active form of Akt, in the plantaris and soleus muscles were significantly lower in the Rapid group than in the Con and Slow groups, with no significant differences between the Con and Slow groups (Con vs. Rapid: p<0.01; Slow vs. Rapid in plantaris muscle: p<0.01; Slow vs. Rapid in soleus muscle: p<0.05; Fig. 2-G and -H). The serum insulin concentration significantly and negatively correlated with the LC3-II/LC3-I ratio and polyubiquitinated protein concentration in the plantaris muscle (p<0.01; Fig. 4-A and -B). In addition, the phospho-Akt content was significantly and negatively correlated with the LC3-II/LC3-I ratio and polyubiquitinated protein concentration in the plantaris muscle (p<0.05; Fig. 4-C and -D).

Discussion

A severe energy deficit during body weight loss causes significant reductions in skeletal muscle and body fat masses. To our knowledge, this is the first study to directly compare the effects of rapid and slow weight reductions, which result in acute and gradual energy deficits, respectively, on protein degradation pathways and protein content in skeletal muscle during an equivalent weight loss in rats. We found that the rapid weight loss induced by the 3-day fast potently activated both autophagy-lysosome and ubiquitin-proteasome pathways (Fig. 2). This fast resulted in significant reductions in the total protein content and wet weight of the fast-twitch plantaris muscle (Table 1), although both weight-loss methods decreased rat body weight and total intra-abdominal fat mass to a similar extent (Table 1 and Fig. 1).

Muscle atrophy occurs when protein degradation rates exceed protein synthesis rates. Although the phospho-p70S6K contents of the plantaris and soleus muscles
appeared to be lower in both the Slow and Rapid groups than in the Con group, the
difference was not statistically significant (Fig. 2-E and -F). In addition, the
phospho-p70S6K contents of the plantaris muscle were almost identical in both weight-loss
groups. It is therefore unlikely that fasting-induced atrophy in the plantaris muscle of the
Rapid group was due to a diminished protein synthesis rate, although we did not directly
evaluate the muscle protein synthesis rate.

Even though the total food intake during the 14-day dietary intervention was
significantly higher in the Rapid group than in the Slow group, the muscle glycogen
concentration was substantially lower in the Rapid group, suggesting that only the 3-day
fast resulted in a severe energy deficit in muscle cells. A severe energy deficit induced by
fasting and starvation activates autophagy-mediated protein degradation (Mizushima et al.
2004). In this study, we found that the LC3-II/LC3-I ratio, frequently used as a biomarker of
autophagy-lysosome activity (Lee et al. 2014), was significantly higher in the plantaris
muscle of the Rapid group than in that of both the Slow and Con groups (Fig. 2). This
finding indicates that the autophagy-lysosome pathway was more potently activated in the
Rapid group than in the Slow group, despite the equivalent weight loss. In addition, the
LC3-II/LC3-I ratio was significantly and negatively correlated with the total protein content
and muscle wet weight in the plantaris muscle (Fig. 3-A and -C). Based on these results, it
is plausible that the higher autophagy-lysosome activity was responsible for the rapid
weight loss-induced atrophy in the plantaris muscle.

Our results also indicate that another protein degradation pathway, the
ubiquitin-proteasome system, might be involved in the muscular atrophy in the Rapid group.
In the ubiquitin-proteasome system, proteins are targeted for degradation by the 26S
proteasome through covalent attachment of a chain of ubiquitin molecules (Goldberg 2003).
We determined the polyubiquitinated protein concentration in skeletal muscle and found that the plantaris muscle in the Rapid group had a significantly higher polyubiquitinated protein concentration (Fig. 2-C), as well as LC3-II/LC3-I ratio, than the Con and Slow groups. Similar to the LC3-II/LC3-I ratio, the polyubiquitinated protein concentration was significantly and negatively associated with total protein content and muscle wet weight in the plantaris muscle (Fig. 3-B and -D). These results provide strong evidence that the two major proteolytic pathways are more strongly activated during rapid body weight loss than during slow body weight reduction, resulting in a significant loss of total protein content and wet weight of fast-twitch muscle.

Insulin and its downstream effector Akt strongly inhibit both autophagy-lysosome and ubiquitin-proteasome pathways in skeletal muscle (Price et al. 1996, Mitch et al. 1999, Lee et al. 2004, Sacheck et al. 2004, Stitt et al. 2004, Wang et al. 2006). Whereas the serum insulin concentration and phospho-Akt content of the plantaris muscle were almost negligible in the Rapid group, the Slow group rats maintained a serum insulin concentration and phospho-Akt content similar to that of the ad libitum-fed Con group rats (Table 1 and Fig. 2-G). In addition, the serum insulin concentration and phospho-Akt content were negatively correlated with the LC3-II/LC3-I ratio and polyubiquitinated protein concentration in the plantaris muscle (Fig. 4). Taken together, it is likely that the slow body weight reduction induced by daily calorie restriction can partially prevent muscular atrophy during weight loss, at least in part by maintaining the serum insulin level and its signaling pathway in skeletal muscle. Because it has been well documented that blood insulin level substantially decreases even after overnight fasting, we could not rule out the possibility that the higher proteolytic activities observed in the muscles of the Rapid group might be reflecting an acute effect of fasting (acute insulin deficiency) rather than chronic effects.
However, Ogata et al. (2010) reported that LC3-II content in rat skeletal muscle did not increase in response to 1-day fasting, whereas 3-day fasting induced significant and large increase in muscle LC3-II content. It is therefore plausible that higher proteolytic activities in the Rapid group resulted from chronic and accumulated effects of 3-day fasting, but not acute effect. Future studies are required to measure the proteolytic activities in the Con and Slow group in the fasting condition, or in the Rapid group after a few hours feeding in order to assess the chronic adaptations and differentiate them from potential acute effects.

As shown in Table 1, the soleus muscle, unlike the plantaris muscle, did not show any atrophic changes in response to either the rapid or slow body weight reduction. Our results support a previous finding that the degree of fasting-induced atrophy is greater in fast-twitch muscle than slow-twitch muscle (Li and Goldberg 1976, Frayn and Maycock 1979). Ogata et al. (2010) reported that a fasting-induced increase in LC3-II expression was notably greater in rat fast-twitch plantaris muscle than in slow-twitch soleus muscle. Consistent with these results, we observed that the magnitudes of the increase in the LC3-II/LC3-I ratio after rapid and slow body weight reductions appeared to be relatively lower in soleus than plantaris muscle (Fig. 2-A and -B), providing further evidence that the autophagy pathway is preferentially induced in fast-twitch muscle in an energy deficient state. Another major finding of the present study was that the polyubiquitinated protein concentration was markedly higher in the soleus muscle than in the plantaris muscle under basal conditions (the Con group) and that it did not increase in response to fasting and daily calorie restriction (Fig. 2-C and -D). The blunted responses in the ubiquitin-proteasome and autophagy-lysosome systems might be associated with the atrophy resistance of soleus muscle to a severe energy deficit.

This study has several limitations. First, muscle strength and exercise capacity
after the rapid or slow weight loss were not assessed in this study. Thus, we could not clarify which weight loss strategy is effective in improving exercise performance although slow weight loss induced by calorie restriction could maintain muscle mass. Second, we did not evaluate the effects of fasting or calorie restriction in combination with exercise on muscle protein content and muscle weight. The results obtained in this study cannot be directly extrapolated to athletic population, who engage in exercise training. Future extensive studies are required to examine the combined effects of exercise and dietary interventions on muscle functions as well as muscle mass in order to elucidate whether exercise training can prevent muscle atrophy induced by weight loss.

Conclusion

During an equivalent weight loss, the rapid weight loss induced by short-term fasting more strongly activates autophagy-lysosome and ubiquitin-proteasome pathways than a slow body weight reduction induced by daily calorie restriction, resulting in muscular atrophy in fast-twitch plantaris muscle but not in soleus muscle.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Numbers JP15K01615, JP25750330, and JP16J10555 (to S.T.).
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**Figure legends**
Figure 1. Changes in the body weights of rats during a 14-day dietary intervention. Con, ad libitum-fed control group; Slow, daily calorie restriction-induced slow body weight-loss group; Rapid, fasting-induced rapid weight-loss group. Values are means ± SEM. *p<0.05, **p<0.01 vs Con and Rapid, respectively; * p<0.001 vs Con; † p<0.05, †† p<0.01 vs day 0 in Slow group, respectively.

Figure 2. Effects of rapid or slow body weight loss on the LC3-II/-I ratio, polyubiquitinated protein concentration, phospho-p70S6K content, and phospho-Akt content in rat plantaris (A, C, E, and G) and soleus (B, D, F, and H) muscles. Con, ad libitum-fed control group; Slow, daily calorie restriction-induced slow body weight-loss group; Rapid, fasting-induced rapid weight-loss group; Values are means ± SEM. ** and *** indicate significant differences from the values obtained in the Con group at p<0.01 and p<0.001, respectively. §, §§, and §§§ indicate significant differences from the values obtained in the Slow group at p<0.05, p<0.01, and p<0.001, respectively.

Figure 3. Correlations between the LC3-II/-I ratio (A and C) and the polyubiquitinated protein concentration (B and D) and the total protein content and wet weight of rat plantaris.
muscle. Con, ad libitum-fed control group; Slow, daily calorie restriction-induced slow body weight-loss group; Rapid, fasting-induced rapid weight-loss group.

Figure 4. Correlations between the serum insulin concentration or phospho-Akt content and LC3-II/I ratio (A and C) or polyubiquitinated protein concentration (B and D) of rat plantaris muscle. Con, ad libitum-fed control group; Slow, daily calorie restriction-induced slow body weight-loss group; Rapid, fasting-induced rapid weight-loss group.
Table 1. Body weight, intra-abdominal fat weight, total food intake, muscle wet weight, total protein content, serum glucose, insulin and muscle glycogen concentrations in rats.

<table>
<thead>
<tr>
<th></th>
<th>Con</th>
<th>Slow</th>
<th>Rapid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial body weight (g)</td>
<td>303 ± 5</td>
<td>304 ± 5</td>
<td>304 ± 4***</td>
</tr>
<tr>
<td>Final body weight (g)</td>
<td>321 ± 6</td>
<td>270 ± 2***</td>
<td>265 ± 3***</td>
</tr>
<tr>
<td>Intra-abdominal fat weight (g)</td>
<td>13.7 ± 0.3</td>
<td>8.5 ± 0.5***</td>
<td>9.2 ± 0.9***</td>
</tr>
<tr>
<td>Food intake (g)</td>
<td>255 ± 7</td>
<td>170 ± 1***</td>
<td>193 ± 3***,§</td>
</tr>
<tr>
<td>Plantaris muscle wet weight (mg)</td>
<td>287 ± 9</td>
<td>267 ± 6</td>
<td>251 ± 6*</td>
</tr>
<tr>
<td>Plantaris muscle protein content (mg)</td>
<td>56 ± 3</td>
<td>54 ± 1</td>
<td>49 ± 1*</td>
</tr>
<tr>
<td>Soleus muscle wet weight (mg)</td>
<td>114 ± 3</td>
<td>103 ± 6</td>
<td>105 ± 2</td>
</tr>
<tr>
<td>Soleus muscle protein content (mg)</td>
<td>20 ± 1</td>
<td>18 ± 1</td>
<td>19 ± 1</td>
</tr>
<tr>
<td>Serum glucose (mmol/L)</td>
<td>12.4 ± 0.5</td>
<td>13.2 ± 0.3</td>
<td>11.1 ± 0.7</td>
</tr>
<tr>
<td>Serum insulin (µg/L)</td>
<td>7.6 ± 0.6</td>
<td>3.8 ± 0.4***</td>
<td>1.0 ± 0.4***,§§</td>
</tr>
<tr>
<td>Muscle glycogen concentration (µmol/g wet tissue)</td>
<td>47.1 ± 1.2</td>
<td>41.8 ± 1.6</td>
<td>27.7 ± 1.7***,§§§</td>
</tr>
</tbody>
</table>

Values are means ± SEM, n=5. * and *** indicate significant differences from the values obtained in the Con group at p<0.05 and p<0.001, respectively. §, §§ and §§§ indicate significant differences from the values obtained in the Slow group at p<0.05, p<0.01 and p<0.001, respectively.
Figure 1

![Graph showing body weight change over days for different groups.](image)

- **Con**
- **Slow**
- **Rapid**

**Y-axis:** Body weight (g)

**X-axis:** Days

Days: 0, 2, 4, 6, 8, 10, 12, 14
Figure 2

A. Plantaris

B. Soleus

C. Polyubiquitinated protein concentration (U/mg protein)

D. Polyubiquitinated protein concentration (U/mg protein)

E. phospho-p70S6K content (Arbitrary Unit)

F. phospho-p70S6K content (Arbitrary Unit)

G. phospho-Akt content (Arbitrary Unit)

H. phospho-Akt content (Arbitrary Unit)
Figure 3

A

$$r = -0.634, \ p < 0.05$$

Con
Slow
Rapid

Total protein content (mg)

LC3-II/LC3-I ratio (Arbitrary Unit)

B

$$r = -0.601, \ p < 0.05$$

Con
Slow
Rapid

Total protein content (mg)

Polyubiquitinated protein concentration (U/mg protein)

C

$$r = -0.690, \ p < 0.01$$

Con
Slow
Rapid

Muscle wet weight (mg)

LC3-II/LC3-I ratio (Arbitrary Unit)

D

$$r = -0.677, \ p < 0.01$$

Con
Slow
Rapid

Muscle wet weight (mg)

Polyubiquitinated protein concentration (U/mg protein)
Figure 4

A

B

C

D

r = -0.929
p < 0.001

r = -0.859
p < 0.001

r = -0.723
p < 0.01

r = -0.655
p < 0.05