

Skeletal Muscle Phenotype, Fat Content and Voluntary Running Activity in the Fast-Twitch Fibre Dominant and Control Rats

Suwa, Masataka

Institute of Health and Sport Sciences, University of Tsukuba

Kumagai, Shuzo

Institute of Health Science, Kyushu University

Higaki, Yasuki

Department of Community Health Science, Saga Medical School

Nakamura, Tomohiro

Department of General Education, Osaka Institute of Technology

他

<https://doi.org/10.15017/700>

出版情報：健康科学. 22, pp.59-64, 2000-02-10. Institute of Health Science, Kyushu University
バージョン：
権利関係：



Skeletal Muscle Phenotype, Fat Content and Voluntary Running Activity in the Fast-Twitch Fibre Dominant and Control Rats

Masataka SUWA, Shuzo KUMAGAI*, Yasuki HIGAKI**
Tomohiro NAKAMURA*** and Shigeru KATSUTA

Abstract

The purposes of the present study were to investigate various muscle characteristics including the fibre composition and capillary supply, abdominal fat accumulation, and the distance for voluntary wheel running. Fast-twitch fibre dominant rats (FFDR) obtained by selection breeding for higher percentage of type II fibres and control rats (CR) obtained by random breeding were used in this study. FFDR had lower percentage of type I (%type I) fibres in M. gastrocnemius and soleus than those of CR, and higher percentage of type IID/B (%type IID/B) fibres in M. gastrocnemius and percentage of type IIA (%type IIA) fibres in M. soleus than those of CR. In the fibre compositions of plantaris muscle, no significant differences were observed between FFDR and CR. The body weight, abdominal fat content, and capillary supply in FFDR were identical with CR. Another groups of animals aged 4wks were subjected to voluntary wheel running for 5 weeks. The running distance in FFDR during the last week and the total running distance were both significantly higher than those in CR. Based on these observations, it is suggested that the muscle fibre composition is not a single determinant of body fat accumulation and influences on physical activity level.

Key words: abdominal fat content, capillary supply, muscle fibre composition, voluntary wheel running
(Journal of Health Science, Kyushu University, 22 : 59–64, 2000)

Introduction

Skeletal muscle fibres are categorized as slow-twitch (type I) and fast-twitch (type II) fibres. It was pointed out that the muscle fibre composition was one of the risk factors of hypertension, insulin resistance, and obesity²⁾¹⁰⁾. Some studies have found that the percentage of type I (%type I) fibres is negatively correlated

with the percentage of body fat (%fat) in men¹¹⁾²⁰⁾, and corresponding findings have been reported in rats¹²⁾¹⁸⁾. In addition, a significantly positive correlation has also been observed between the percentage of type IIB (%type IIB) fibres and %fat in men¹¹⁾. In contrast to this, no such correlations have been observed in humans¹⁵⁾ and rats⁵⁾. From these studies, it is not clear whether or not the muscle fibre composition is related to

Institute of Health and Sport Sciences, University of Tsukuba, Tsukuba, Ibaraki 305–8574, Japan

* Institute of Health Science, Kyushu University 11, Kasuga, Fukuoka 816–8580, Japan

** Department of Community Health Science, Saga Medical School, Saga 849–0937, Japan

*** Department of General Education, Osaka Institute of Technology, Osaka 535–0002, Japan

fat accumulation. The physical activity level is also related to the fat accumulation⁷⁾, but there have been no reports of the influence of hereditary determined muscle fibre composition on the voluntary activity level.

Suwa et al.¹⁷⁾ developed fast-twitch fibre dominant rats (FFDR) by selection breeding and control rats (CR) by random breeding. The percentage of type II (%type II) fibres of FFDR in the gastrocnemius, soleus, vastus intermedius, and biceps brachii muscles were higher than those of CR¹⁶⁾. These rats are thus considered to be a good model to examine the relation between muscle fibre composition and either the fat accumulation level or the physical activity level. The main purpose of the present study was thus to compare the muscle fibre composition, abdominal fat content, and voluntary wheel running distance in FFDR with those in CR.

Materials and Methods

Animal

All experiments and procedures were approved by the Saga Medical School Animal Experiment Committee. To obtain the FFDR and CR, we used both selective and random mating. The methods of breeding have been previously described by Suwa et al.¹⁷⁾. The FFDR were bred by selective mating while the CR were bred randomly. Two sets of animals were used for these studies. The first was composed of CR (n=8) and FFDR (n=6) aged 8-9 weeks to compare muscle fibre composition, capillary network, and abdominal fat content. The other was composed of 4-week-old CR (n=7) and FFDR (n=7) to compare the wheel running activity. All animals were housed in a temperature ($22 \pm 2^\circ\text{C}$) and humidity-controlled ($60 \pm 5^\circ\text{C}$) room with a 12-hour light (8.30 a.m. to 8.30 p.m.), 12-hour dark (8.30 p.m. to 8.30 a.m.) cycle. Food and water were provided ad libitum.

Wheel running

The experiment was started at 4 weeks of age and continued until 9 weeks of age. The distance covered by wheel running was recorded in both

groups. A wheel was attached to one side of a standard rat cage and the animal had free access to the wheel. The animals were allowed to run voluntarily in the wheel. All animals were housed one per cage. The distance the animals ran was measured each day by a counter attached to the wheel. The body mass of each animal was recorded each week.

Muscle preparation and histochemical analysis
The rats were anaesthetized with pentobarbital sodium (50 mg/kg body weight i.p.). The muscles were rapidly dissected and about 2-3 mm cross-sectional segments were cut at the muscle belly. Each muscle piece was mounted on a specimen holder in an OCT embedding medium (Miles Tissue-Tek L) and frozen in isopentane previously cooled to a viscous fluid with liquid nitrogen. Transverse sections ($10 \mu\text{m}$) were then cut from each muscle in a cryostat maintained at -20°C and mounted on cover glasses. Each cryosection was processed to determine the myosin adenosine triphosphatase activity after preincubation at pH 4.3, 4.6 and 10.3 using the procedures described by Gollnick et al.⁶⁾. A composite photomontage of each preparation was made using micrographs, and then each fibre was identified as type I, type IIA, type IID/B and type IIC based on the nomenclature system of Brooke and Kaiser⁴⁾. The muscle fibre composition was determined by evaluating more than 600 M. gastrocnemius fibres, 500 M. soleus fibres, and 3500 M. plantaris fibres in each section. Deep portions were used for the M. gastrocnemius analysis. In order to visualize the capillaries, transverse sections ($16 \mu\text{m}$) were cut and then subjected to a two-step histochemical method³⁾. The stained sections were photographed (magnification, 200). In these photographs, artifact-free 0.35 mm^2 areas were analyzed and the capillary density (capillaries/ mm^2), capillary to fibre ratio (capillaries/muscle fibre), and mean number of capillaries around the fibre were determined. Deep portions were used in the M. gastrocnemius, the muscle core was used in the M. soleus, and deep and superficial portions

were used in the M. plantaris for the capillary analyses. All procedures were performed by one researcher blinded to the group.

Statistical analysis

All data are presented as the mean \pm SD. To determine any differences between the 2 means in all parameters, except for the running distance per week, the data were analyzed by Student's t test. To determine any differences in the running distance per week, we used the two-way ANOVA (week and group). Scheffé's post hoc test was conducted if the ANOVA indicated a significant difference. $P < 0.05$ was considered to indicate significance.

Results

In the rats subjected to the non-running experiments, the body weight, fat contents, and individual muscle weight of the FFDR were not observed to be significantly different from the CR, except for a higher weight of the M. soleus in the FFDR (Table 1). The percentage of type I fibres of M. gastrocnemius and soleus were lower than CR, and percentage of type IID/B (%type IID/B) fibres in M. gastrocnemius and percentage of type IIA (%type IIA) fibres in M. soleus were higher than CR. On the other hand, no significant differences were observed between the two groups regarding the percentage of fibre types of M. plantaris (Fig.2). These results regarding the body and muscle fibre composition corresponded to the rats subjected to voluntary running (data not shown). Table 2 showed the

Table 1. Morphometric measurements in the CR and FFDR.

| | CR (n=8) | FFDR (n=6) |
|-------------------------|-----------------|-----------------|
| Body mass (g) | 247 \pm 17 | 257 \pm 13 |
| Abdominal fat mass (g) | 9.16 \pm 1.51 | 7.67 \pm 2.19 |
| Gastrocnemius mass (mg) | 1258 \pm 87 | 1293 \pm 76 |
| Soleus mass (mg) | 110 \pm 11 | 123 \pm 10* |
| Plantaris mass (mg) | 263 \pm 19 | 238 \pm 23 |

Data are expressed as mean \pm SD.

* $P < 0.05$ vs. CR.

capillary network in CR and FFDR. No significant differences were observed in any muscles between two groups.

Fig. 2 showed the voluntary wheel running distances in the CR and FFDR. The distance per week in FFDR from 1 to 4 weeks did not significantly differ from that in CR. On the

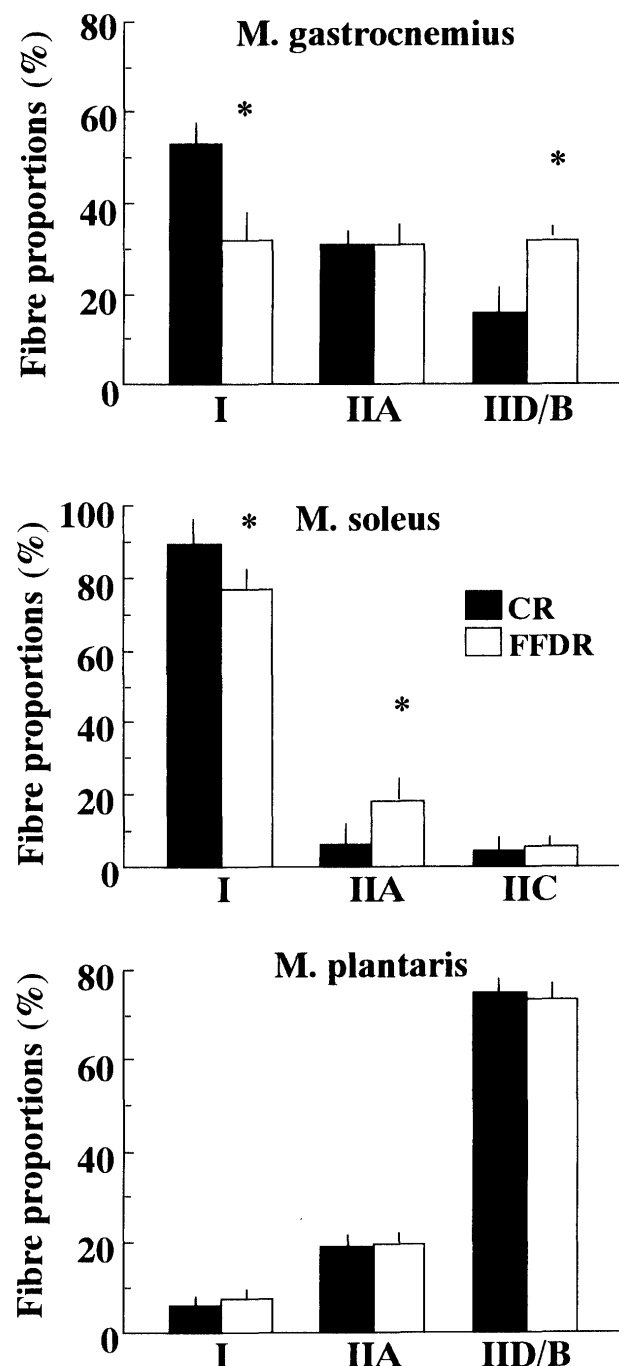


Fig. 1. Muscle fibre compositions in CR and FFDR. A: M. gastrocnemius. B: M. soleus. C: M plantaris. Value are the means \pm SD. *:Significantly different from CR ($p < 0.05$).

Table 2. Capillary network in the CR and FFDR.

| | CR | FFDR |
|--|-------------|-------------|
| <i>Deep portion of M. gastrocnemius</i> | | |
| Capillaries/mm ² | 736.4±131.6 | 786.2±123.3 |
| Capillaries/muscle fibre | 1.77±0.31 | 1.63±0.18 |
| No. capillaries around fibre | 4.56±0.61 | 4.52±0.63 |
| <i>M. soleus</i> | | |
| Capillaries/mm ² | 486.3±49.4 | 523.8±49.9 |
| Capillaries/muscle fibre | 1.53±0.27 | 1.6±0.24 |
| No. capillaries around fibre | 4.26±0.63 | 4.31±0.68 |
| <i>Deep portion of M. plantaris</i> | | |
| Capillaries/mm ² | 654.2±106.3 | 607.8±94.8 |
| Capillaries/muscle fibre | 1.57±0.13 | 1.43±0.16 |
| No. capillaries around fibre | 4.75±0.42 | 4.32±0.30 |
| <i>Superficial portion of M. plantaris</i> | | |
| Capillaries/mm ² | 400.6±42.7 | 427.8±89.7 |
| Capillaries/muscle fibre | 1.27±0.12 | 1.19±0.13 |
| No. capillaries around fibre | 3.53±0.50 | 3.56±0.51 |

Data are expressed as mean±SD.

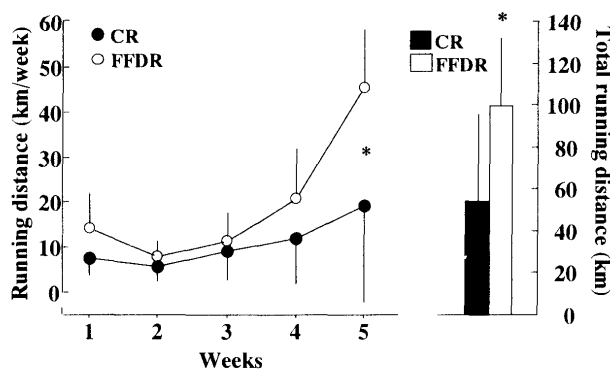


Fig. 2. Left: Weekly progression of voluntary running activity in the CR and FFDR. Values are the mean±SD. *:Significantly differences between CR and FFDR ($p < 0.05$).

Right: Total running distance for 5 weeks. Values are the mean±SD. *:Significantly different from CR ($p < 0.05$).

other hand, the running distance during last week and the total running distance for 5 weeks were significantly higher than that in CR.

Discussion

Interestingly, this study showed voluntary running to be related to the muscle fibre composition. Ishihara et al.⁹⁾ indicated that the

percentage of slow-twitch oxidative (%SO) fibres, which was corresponded to type I fibres, was negatively correlated with voluntary running distance and the percentage of fast-twitch oxidative glycolytic (%FOG) fibres, which roughly corresponded to type IIA or type IID fibres, was positively correlated with it. All type IIA and IID/B fibres in the deep portion of M. gastrocnemius and soleus of FFDR and CR were FOG fibres (Suwa et al., unpublished observation), therefore, it is suggested that the %FOG fibres of M. gastrocnemius and soleus in FFDR are higher than those of CR. It is thus considered that the results in this study are therefore consistent with those of Ishihara et al.⁹⁾. Although the intensity or speed of exercise were not recorded in this study, the voluntary wheel running might be a relatively high intensity exercise¹⁴⁾. From these data, it appears that the voluntary wheel running exercise requires the recruitment of FOG fibres and the distribution of FOG fibres affects the activity pattern. Further experiments concerning the relation between muscle fibre composition and the characteristics of spontaneous physical activity are thus still required.

There have been several reports concerning the relationship between muscle fibre composition and fat accumulation in humans^{11,20)}, and rats^{12,18)}. On the other hand, interestingly, our study did not show any difference in the abdominal fat content between CR and FFDR while FFDR had lower %type I fibres than CR. The data in this study conflict with the results of Mrad et al.¹²⁾, who recorded the weight gain in normal young rats having free access to food. The upper and lower quartile with respect to gain in body mass were classified as obesity-prone and obesity-resistant rats, respectively. The authors found that the obesity-prone rats had 16% fewer %type I fibres in the M. gastrocnemius than in the obesity-resistant rats. Significant genetic effects on the muscle fibre composition of rats were reported^{13,17)}. In addition, no change in the muscle fibre composition due to diet was

observed¹⁹⁾. Therefore, it was speculated that the genetic effects mainly induced the difference of muscle fibre composition between obesity-prone and obesity-resistant rats. However, in the study of Mrad et al.¹²⁾, the rats were given a high-fat diet (60% calories from fat) whereas the FFDR and CR were fed a normal diet (17% calories from fat). The muscle fibre composition therefore might not be a single determinant of fat accumulation and thus the muscle fibre composition plays a role in fat accumulation when combined with other factors, such as food intake. In this context, we recently demonstrated that FFDR with high-fat diet was more obesity-resistant as compared with CR with high-fat diet (Kumagai et. al, unpublished observation). Further studies focused on biochemical characteristics of skeletal muscle in FFDR.

In the present study, the running distance in the FFDR was significantly longer than in the CR. Obese animals and humans tend to be less active than lean individuals⁷⁾. It is possible that the effect of high %type II fibres in FFDR on fat accumulation is compensated by higher physical activity.

The oxidative enzyme activity of skeletal muscle was a important determinant of fat content¹⁵⁾. The oxidative capacity of skeletal muscle was associated with the supply of capillaries¹⁸⁾. Indeed, Capillary density was negatively correlated with %fat¹¹⁾. In this study, no significant differences between FFDR and CR were observed in capillary density, the capillary to fibre ratio, and the mean number of capillaries around the muscle fibre of all muscles. This finding may thus be one possible reason why the abdominal fat content in FFDR was identical to CR.

In conclusion, the muscle fibre composition is thus not considered to be a single determinant of body fat accumulation and it influences on physical activity level. Further studies focused on aging, a high-fat diet and the amount of physical activity regarding body fat accumulation and insulin sensitivity using this animal

model are thus called for.

Acknowledgements

This work was supported by research grants from The Japanese Ministry of Education, Science and Culture (No.10680037) to Dr. S., Kumagai.

References

- 1) Andersen, P., and Henriksson, J.: Capillary supply of the quadriceps femoris muscle of man: adaptive response to exercise. *J. Physiol.*, 270:677-690, 1977.
- 2) Bassett, D.R. Jr.: (Review) Skeletal muscle characteristics: relationships to cardiovascular risk factors. *Med. Sci. Sports Exerc.*, 26:957-966, 1994.
- 3) Batra, S., Kuo, C., and Rakusan, K.: Spatial distribution of coronary capillaries: A-V segment staggering. *Adv. Exp. Med. Biol.*, 248:241-247, 1989.
- 4) Brooke, M.H., and Kaiser, K.K.: Muscle fiber types: How many and what kind? *Arch. Neurol.*, 23:369-378, 1970.
- 5) Burbach, J.A., Schlenker, E.H., and Goldman, M.: Characterization of muscles from aspartic acid obese rats. *Am. J. Physiol.*, 249:R106-R110, 1985.
- 6) Gollnick, P.D., Parson, D., and Oakley, C.R.: Differentiation of fiber types in skeletal muscle from the sequential in activation of myofibrillar actomyosin ATPase during acid preincubation. *Histochemistry*, 77:543-555, 1983.
- 7) Holloszy, J. O.: Muscle metabolism during exercise. *Arch. Phys. Med. Rehab.*, 63:231-234, 1982.
- 8) Ingjer, F.: Effects of endurance training on muscle fibre ATPase activity, capillary supply and mitochondrial content of man. *J. Physiol.*, 294:419-432, 1979.
- 9) Ishihara, A., Inoue, N., and Katsuta, S.: The relationship of voluntary running to fibre type composition, fibre area and capillary supply in rat soleus and plantaris mus-

- cles. *Eur. J. Appl. Physiol.*, 62: 211–215, 1991.
- 10) Kumagai, S., Higaki, Y., Nakamura, T., Suwa, M., and Katsuta, S.: (Review) Relationship between insulin resistance and skeletal muscle characteristics. *Adv. Exer. Sports Physiol.*, 6: 1–16, 1999. (Japanese with English abstract)
- 11) Lillioja, S., Young, A. A., Culter, C. L., Ivy, J. L., Abbott, W. G. H., Zawadzki, J. K., Yki-Järvinen, H., Christin, L., Secob, T. W., and Bogardus, C.: Skeletal muscle capillary density and fiber type are possible determinants of in vivo insulin resistance in man. *J. Clin. Invest.*, 80: 415–424, 1987.
- 12) Mrad, J. A., Yakubu, F., Lin, D., Petters, J. C., Atkinson, J. B., and Hill, J. O.: Skeletal muscle composition in dietary obesity-susceptible and dietary obesity-resistant rats. *Am. J. Physiol.*, 262: R684–R688, 1992.
- 13) Nakamura, T., Masui, S., Wada, M., Katoh, H., Mikami, H., and Katsuta, S.: Heredity of muscle fibre composition estimated from a selection experiment in rats. *Eur. J. Appl. Physiol.*, 66: 85–89, 1993.
- 14) Rodnick, K. J., Reaven, G. M., Haskell, W. L., Sims, C. R., and Mondon, C. E.: Variations in running activity and enzymatic adaptations in voluntary running rats. *J. Appl. Physiol.*, 66: 1250–1257, 1989.
- 15) Simoneau, J.-A., and Bouchard, C.: Skeletal muscle metabolism and body fat content in men and women. *Obes. Res.*, 3: 23–29, 1995.
- 16) Suwa, M., Miyazaki, T., Nakamura, T., Sasaki, S., Ohmori, H., and Katsuta, S.: Hereditary dominance of fast-twitch fibers in skeletal muscles and relation of thyroid hormone under physiological conditions in rats. *Acta Anat.*, 162: 40–45, 1998.
- 17) Suwa, M., Nakamura, T., and Katsuta, S.: Heredity of muscle fiber composition and correlated response of the synergistic muscle in rats. *Am. J. Physiol.*, 271: R432–R436, 1996.
- 18) Torgan, C. E., Brozinick, J. T., Castello, G. M., and Ivy, J. L.: Muscle morphological and biochemical adaptations to training in obese Zucker rats. *J. Appl. Physiol.*, 67: 1807–1813, 1989.
- 19) Yamaguchi, A., Horio, Y., Sakuma, K., and Katsuta, S.: The effect of nutrition on size and proportion of muscle fibre types during growth. *J. Anat.*, 182: 29–36, 1993.
- 20) Wade, A. J., Marbut, M. M., and Round, J. M.: Muscle fiber type and aetiology of obesity. *Lancet*, 335: 805–808, 1990.

要約

本研究の目的は、骨格筋線維組成、毛細血管供給などの骨格筋特性、腹腔内脂肪蓄積、および自発運動量を調査することであった。選択交配によって作成された速筋優位モデルラット (fast-twitch fibre dominant rats; FFDR) とランダム交配によって作成されたコントロールラット (CR) が本研究に用いられた。いずれも、被検動物は 8 週令の雄ラットである。FFDR の腓腹筋およびヒラメ筋の type I 線維の割合 (%type I) は CR に比べ有意に低値であり、一方腓腹筋の type IID/B 線維の割合 (%type IID/B) とヒラメ筋の %type IIA 線維の割合 (%type IIA) は、CR に比べ有意に高値を示した。足底筋の筋線維組成には、FFDR および CR 間に有意差を認めなかった。FFDR の体重、腹腔内脂肪量、および毛細血管供給は、CR との間に有意差を認めなかった。他のグループを用い、4 週令で自発運動量を開始し、5 週間継続する研究を行った。FFDR の 8 週令目の走行距離と全走行距離は、CR に比べ有意に高値であった。これらの観察から、骨格筋線維組成は腹腔内脂肪蓄積に関する単一の要因ではないが、身体活動水準には影響していることが示唆された。