Physiol. Res. 43: 243–251, 1994

Histochemical and Functional Parameters in Nordic Combination Athletes

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Received January 28, 1994
Accepted April 19, 1994

Summary

Bioptic samples from the vastus lateralis muscle were analyzed in a group of Czechoslovak representatives in the Nordic combination (ski-jumping and 15 km cross-country skiing). The distribution of individual muscle fibre types (FG, FOG and SO) was detected and correlated with values obtained by motor and functional performance tests. Histochemical analysis of the bioptic samples revealed a considerably heterogeneous distribution of muscle fibre types in the group studied. No typical profilation for this sport discipline was found. Weak correlation between the proportion of fast muscle fibres and explosive strength parameters was ascertained. The correlation between the proportion of slow muscle fibres and the capacity of O_2 utilization (VO_2max) was statistically significant. Strong correlation between the proportion of fast twitch fibres and relative maximal strength of knee extensors (N/kg) was disclosed. A non-linear relation between the area of fast twitch fibres and vigour of take-off was found.

Key words

Nordic combination – Muscle fibre types – Structural-functional parameters

Introduction

The proportion of the individual types of muscle fibres determines the overall functional capacity of muscle (Romanul 1964), being one of the important determinants of athletic ability and consequently of success in disciplines or sports which require speed, strength or endurance (Flandrois 1980). It is generally assumed that speed or power are characterized by a higher proportion of fast muscle fibres (especially glycolytic ones), whereas endurance athletes have a preponderance of slow oxidative muscle fibres (Gollnick *et al.* 1972, Saltin 1973, Thorstenson 1976, Costill *et al.* 1976, Sharp 1982). The reciprocal ratio of fast and slow fibres in muscles is regarded as a considerably stable property. Thus, a prerequisite for the successful performance of speed-power and endurance sports is determined. Komi and Karlsson (1979) stated a very high heritability index for the occurrence of slow fibres in the vastus lateralis muscle. Colling-Saltin (1980) reported high-stability in individual types of muscle fibres in the course of ontogenesis. Our results of repeated bioptic examinations were also in accordance with these findings (Matolín at al. 1987). On the other hand, Bouchard *et al.* (1986) have not demonstrated such an expressive genetic effect on muscle fibre distribution.

For assessment of the actual form and prediction of the future performance, a great variety of parameters is being watched and many test sets have been assembled. While the proportion of fast twitch fibres may predict anaerobic performance (Esbjörnsson *et al.* 1993), slow twitch fibres are decisive for maximal oxygen uptake and endurance capacity (Bergh *et al.* 1978, Rusko *et al.* 1978, 1992, Foster *et al.* 1978).

The aim of the present work is to ascertain the correlation between muscle profilation and speed, power and endurance characteristics in Nordic combination, consisting of such different disciplines as ski-jumping and cross-country skiing. The results of bioptic examinations and complex functional assessment of members of the Czechoslovak representative team in the Nordic combination were studied.

Methods

Twelve members of the Czechoslovak team in the Nordic combination were investigated in the course of the preparatory training period for assessing the level of their trainability and capacity for high sport performance. Besides the bioptic examination our investigation included both laboratory and track tests of speed-power, endurance performance and functional examination.

The bioptic samples from vastus lateralis muscle were taken for histochemical analysis under local anaesthesia. They were embedded in the Tissue-Tek medium (Miles, Naperville, IL) and frozen in liquid nitrogen. The 8 μm thick cryocut sections were stained using the inhibition-reactivation myofibrillar ATPase technique (Horák and Matolín 1990). The incidence of individual muscle fibre types, i.e. FG (fast twitch glycolytic), FOG (fast twitch oxidative-glycolytic) and SO (slow twitch oxidative), their diameters and cross section areas of fast and slow muscle fibres (FTA and STA) were determined. About 250 fibres in each subject were counted.

The dynamometric observations included two modifications of vertical jump measurements, the level of the take-off vigour measured during ski-jumping (score shows the speed of the skier-ski system centre of gravity in the vertical direction against the base) and the measurement of maximal strength of isometric contraction of the knee extensors. The height of the modified vertical jump (cm) was tested by means of a dynamographic force plate (MI-Kistler, Switzerland) and on the basis of take-off-fall (I-JUMPS-AA device). The final score represents a vertical rise of the body's centre of gravity reached at the take-off from the in-run position. Vigour of the jumper's take-off activity v ($m.s^{-1}$) was observed under natural conditions on a ski-jump with an artificial surface in Frenštát pod Radhoštěm (Salinger 1979, 1980, Vaverka *et al.* 1986, Vaverka 1987). It expresses the increase of speed in the vertical direction against the base gained by the jumper in the final phase of take-off in the last 6 m from the take-off edge.

The isometric contraction value (N) and the value related per kilogram of body weight (N/kg) were measured with a dynamometric fixative device (Vaverka 1979). Maximal isometric strength (FI and FI/kg) was measured at a knee joint angle of 120 deg.

The values of maximal oxygen uptake (VO_2max) were tested by means of a treadmill automatic analyzer Eos-Sprint Jaeger (Germany). Performance in athletic track disciplines (15 m sprint and 3 000 m run) were tested on a sports stadium.

Usual statistical methods including the means and the standard deviation were calculated for each parameter. The relations between muscle profilation and the parameters given were ascertained by rank-order correlation.

All subjects gave their informed written consent prior to the experiment. No post-biopsy complication was noted. The ethical committee of the First Faculty of Medicine, Charles University, Prague approved this study.

Results

A wide range of individual fibre type frequencies was ascertained in the Nordic combination athlete team. The FG, FOG and SO fibre proportions varied in the range 0–32 % (no FG fibres were found in one case), 15–30 % and 46–72 %, respectively. In most members of the team slow fibres prevailed over fast ones. The average value of the slow fibres was 57.7 % and of the fast fibres (i.e. FG+FOG) was 42.3 % (Fig. 1). Large differences were ascertained in diameters of different fibre types in individual probands. The highest values of diameters were most often noticed in the FOG type, less often in the FG type. In several subjects, however, the highest values were found in the SO type. The average STA and FTA (FGA+FOGA) values were 51.2 % and 48.8 %, respectively (Table 1).

The functional parameters observed in individual probands are summarized in Table 2. Capacity of oxygen utilization (VO_2max values) was kept within limits of 4.24–5.35 l/min. The highest value of VO_2max was revealed in the athlete with the highest number of slow fibres (no fibres of the FG type were detected in this proband).

Fig. 1
Heterogeneous distribution of individual muscle fibre types in four Nordic combination athletes (the inhibition reactivation myofibrillar ATPase technique, bar=150 μm). A – preponderance of fast twitch fibres (subject No. 2) B – equal distribution of individual muscle fibre types (subject No. 5), C – preponderance of slow twitch fibres (subject No. 1), D – no FG fibres were found in the sample (subject No. 8).

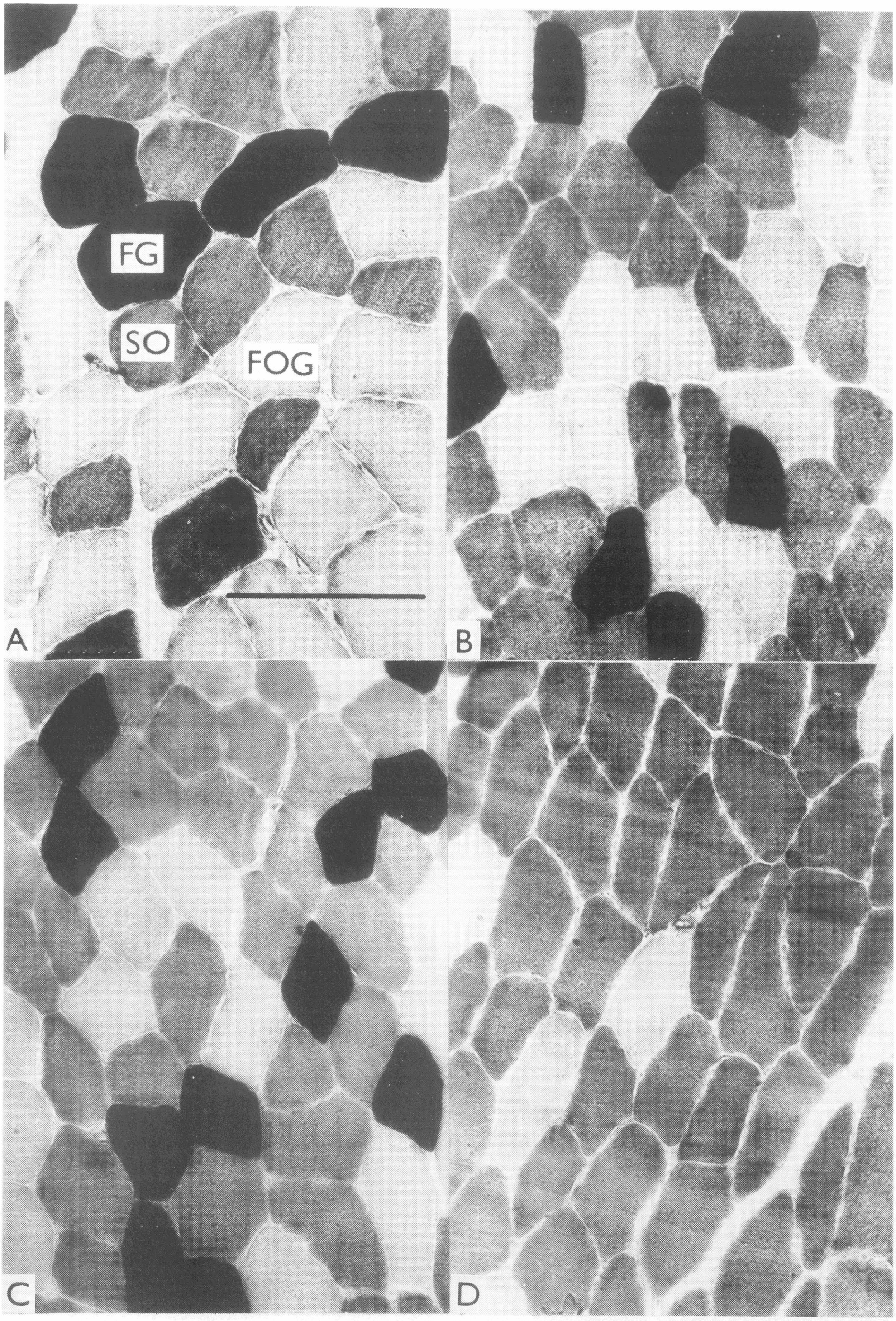
FG
SO
FOG
A
B
C
D

Table 1

Distribution of muscle fibre types in Nordic combination athletes

SUBJECT	FG %	FGD μm	FGA %	FOG %	FOGD μm	FOGA %	FT %	FTA %	SO %	SOD μm	STA %
1.	7.53	81.00	8.01	29.03	78.50	29.01	36.56	37.02	63.44	78.25	62.98
2.	31.82	113.50	37.02	21.97	112.50	25.08	53.79	62.10	46.21	95.25	37.90
3.	19.74	99.25	21.22	27.63	104.25	32.78	47.37	54.00	52.63	89.50	46.00
4.	23.58	68.75	19.66	25.20	81.50	29.54	48.78	49.20	51.22	75.00	50.80
5.	23.66	107.50	28.52	22.90	114.75	31.41	46.56	59.93	53.44	84.75	40.07
6.	21.05	90.25	24.77	27.63	92.00	33.83	48.68	58.60	51.32	74.75	41.40
7.	7.39	71.25	4.45	30.05	80.75	39.05	37.44	43.50	62.56	67.25	56.50
8.	0.00	–	–	27.61	107.50	33.40	27.61	33.40	72.39	93.75	66.50
9.	21.39	124.75	21.48	21.89	125.00	22.08	43.28	43.56	56.72	124.16	56.44
10.	17.47	111.25	20.12	14.55	129.50	22.58	32.12	42.70	67.88	95.50	57.30
11.	23.94	9 3.50	26.39	26.76	95.50	30.81	50.70	57.20	49.30	83.00	42.80
12.	18.24	107.00	19.63	15.72	130.00	24.97	33.96	44.60	66.04	94.50	55.40
MEAN	17.88	97.07	21.02	24.25	104.30	29.54	42.24	48.82	57.76	87.97	51.18
SD	8.84	17.98	8.96	5.02	18.78	5.08	8.39	9.44	8.39	14.77	9.44

FG - fast twitch glycolytic fibres, FGD - diameter of FG fibres, FGA - area of FG fibres, FOG - fast twitch oxidative-glycolytic fibres, FOGD . diameter of FOG fibres, FOGA - area of FOG fibres, FT - fast twitch fibres (FG + FOG), FTA - area of FT fibres, SO - slow twitch oxidative fibres, SOD - diameter of SO fibres, STA - area of SO fibres

Table 2

Histochemical, performance and functional parameters in Nordic combination athletes

Subject	FG %	FT %	FTA %	v m/s	J cm	MJ cm	FI N	FI/kg N/kg	15 m s	SO %	STA %	VO_2max l/min	3000 m s
1.	7.63	36.56	37.02	2.09	45.70	47.93	756.00	11.38	2.89	63.44	62.98	4.60	574.00
2.	31.82	53.79	62.10	2.27	48.60	49.06	827.00	13.34	2.87	46.21	37.90	4.24	565.00
3.	19.74	47.37	54.00	2.39	45.00	43.48	838.00	12.64	2.85	52.63	46.00	4.91	610.00
4.	23.58	48.78	49.20	2.62	51.30	56.98	964.00	13.65	2.82	51.22	50.80	4.93	570.00
5.	23.66	46.56	59.93	2.20	47.70	52.36	820.00	11.69	2.83	53.44	40.07	4.88	576.00
6.	21.05	48.68	58.60	2.23	46.70	42.58	987.00	12.94	–	51.32	41.40	5.17	654.00
7.	7.39	37.44	43.50	–	40.30	40.24	–	10.05	3.09	62.56	56.50	–	627.00
8.	0.00	27.61	33.40	2.14	41.30	41.53	769.00	9.37	2.84	72.39	66.60	5.63	612.00
9.	21.39	43.28	43.56	2.44	46.30	51.17	904.00	12.25	2.83	56.72	56.44	4.95	595.00
10.	17.57	32.12	42.70	2.28	53.00	53.44	870.00	11.60	2.88	67.88	57.30	5.23	567.00
11.	23.94	50.70	57.20	2.30	48.60	45.48	839.00	12.49	2.90	49.30	42.80	4.88	625.00
12.	18.24	33.96	44.60	–	47.00	45.63	693.00	9.46	2.93	66.04	55.40	–	–
MEAN	17.99	42.24	48.82	2.29	46.79	47.49	843.20	11.73	2.88	57.76	51.18	4.94	598.60
SD	8.84	8.39	9.44	0.15	3.60	5.23	86.43	1.44	0.07	8.39	9.44	0.36	31.02

FG - fast twitch glycolytic fibres, FT - fast twitch fibres (FG + FOG), FTA - area of FT fibres, v - vigour of the take-off under jumping hill conditions, J - height of vertical jump, MJ - height of the modified vertical jump, FI - maximal isometric strength, VO_2max - capacity of O_2 utilization, SO - slow twitch oxidative fibres, STA - area of SO fibres, 15 m - 15 m sprint, 3000 m - 3000 m run

Weak correlation was found between the parameters of explosive strength and the proportion of fast twitch fibres (r=0.33−0.5) (Table 3). Nevertheless, the lowest values of these coefficients were ascertained in athletes with the lowest percentage of fast twitch fibres. The relationship of non-linear dependence between the area of fast twitch fibres and vigour of take-off was ascertained: $v=-1.33+0.15\ FTA-0.001\ FTA^2$. The highest correlation was found between the percentage of fast twitch fibres and relative strength of maximal isometric contraction (N/kg) of knee extensors (r=0.85). The correlation between the number of fast twitch fibres and values of absolute strength was low again. The average value of maximum strength of isometric contraction of knee extensors was 842 N. Correlation between the slow muscle fibre proportion and VO_2max was statistically significant (r=0.65). Low correlations were ascertained between the number of fast twitch fibres and the performance at 15 m sprint as well as between the number of slow muscle fibres and the performance at 3 000 m (r=−0.33 and −0.31, respectively). More detailed data are given in Table 3.

Table 3
Correlation coefficients among the selected histochemical, performance and functional parameters (n=12)

Variable	v	J	MJ	15 m	FI	FI/kg	VO_2max	3000 m
FG %	0.34		0.50			0.76*		
FT %	0.42	0.33	0.00			0.85*		
FTA %	Q			−0.33	0.34	0.67*		
ST %							0.65*	−0.31
ST area %					0.38		0.49	

Absolute values of correlation coefficients lower than 0.3 are not mentioned. FG – fast twitch glycolytic fibres, FT – fast twitch fibres (FG + FOG), ST – slow twitch fibres, v – vigour of the take-off under jumping hill conditions, J – vertical jump, MJ – height of modified vertical jump, 15 m – 15 m sprint, FI – maximal isometric strength, FI/kg – maximal isometric strength/kg, VO_2max – capacity of O_2 utilization, 3000 m – 3000 m run (p=0.05 when r=0.53 or greater)
** – statistically significant Q – non-linear relation between FTA and v was found*

Discussion

The method of histochemical analysis of muscle biopsies is useful for determination of the aptitude for particular sport disciplines. Esbjörnsson *et al.* (1993) stated that anaerobic performance is directly related to fast contraction and/or to anaerobic metabolic properties of skeletal muscles as indicated by the proportion of fast twitch fibres. Bergh *et al.* (1978) and Ivy *et al.* (1980) reported the highest VO_2max and slow twitch fibre frequency in endurance athletes. These fibres show the highest activities of oxidative enzymes and great mitochondrial density (Hoppeler *et al.* 1973).

The Nordic combination includes both speed-strength and endurance disciplines. Our results revealed a considerably heterogeneous distribution of muscle fibre types in the investigated group. This corresponds to the fact that among our athletes were those with well-balanced efficiency in both disciplines as well as those with considerably higher efficiency in one discipline. The mean value of slow twitch fibres in our group was lower than in the group of Nordic combination athletes investigated by Rusko *et al.* (1978). We did not detect any FG fibres in one athlete. This unusual muscle composition could be caused genetically or connected with a difference in depth of the muscle biopsy.

The highest values of maximal oxygen uptake were found in elite cross-country skiers in comparison with athletes of other sports disciplines (Saltin and Astrand 1967, Rusko *et al.* 1978, Bergh *et al.* 1978, 1992). They demonstrated 75 % of slow twitch fibres and 82 ml/min/kg VO_2max. Their maximal oxygen uptake may be up to 12 % higher than in endurance runners (Strömme *et al.* 1977). The measured values of VO_2max in our group were considerably above the average of non-trained subjects (Melichna 1990). Changes in maximal aerobic capacity during the annual training cycle were stated by Šprynarová *et al.* (1980). Rusko (1992) studied the effect of different training regimes on the development of oxidative capacity.

Intensive training at the "anaerobic threshold" or higher intensity seems to be most effective for improving in maximal oxygen uptake. Skiers with a higher percentage of slow twitch fibres were able to increase their VO_2max more than those with a lower incidence of slow fibres. After 8 years of intensive endurance training an increase of slow twitch fibres by 11 % was found.

There are conflicting opinions on the possibility of transformation between individual muscle fibre types (Jansson *et al.* 1978, Komi and Karlsson 1979, Simoneau *et al.* 1985). Close (1972) drew attention to the dynamic properties of skeletal muscles in mammals. A high intensity physical load notably increased the activities of oxidative enzymes so that the FOG and FG fibres cannot be distinguished. This is obviously the nature of the change stated by some authors as the transformation which takes place within muscle fibres (Essén-Gustavsson and Henriksson 1984). Larsson and Ansved (1985) supposed that this fibre type conversion does not actually concern fast and slow twitch fibres but probably takes place in both fast twitch types (FOG and FG fibres).

Thorstenson (1976) discovered a close relationship between strength parameters and muscle morphology. Our observed values of the strength of the lower limbs were close to those of long-distance runners (Melichna 1990). Gerard *et al.* (1986) described the correlation between muscle composition, strength parameters and height of the vertical jump. It seems that correlation between muscle composition and mechanical parameters became significant only for its function above 23 % of maximum tension. The relation between fast twitch fibres and maximal velocity as well as muscle power appears with the greater physical load (Tihanyi *et al.* 1982). The amount of power output depends on the total number of fast twitch fibres (Tihanyi *et al.* 1980). Their high percentage is essential precondition for high intensity training (Dons *et al.* 1979). Melichna (1990) studied the relations between the composition of the vastus lateralis muscle, height of the vertical jump and other explosive strength parameters and aerobic working capacity (VO_2max). He observed a positive correlation between the height of the vertical jump and proportion of fast twitch and slow fibres and a negative correlation between the VO_2max and the fast/slow muscle fibre ratio.

We found a surprisingly low correlation between the amount of fast muscle fibres and explosive strength parameters in the group of Nordic combination athletes in spite of the fact that the lowest number of fast twitch fibres was found in the jumper with the weakest take-off ability. Low correlation was also found between athletic track performance and morphological parameters. An interesting non-linear relationship was ascertained between the area of fast twitch fibres and vigour of the take-off receiving the top values of vigour around intermediate values of FTA. The correlation between the proportion of slow muscle fibres and VO_2max was significant. The highest correlation was found between the frequency of fast twitch (FOG+FG) fibres and relative maximal strength of knee extensors. Similarly, values of the maximal isokinetic torque corresponded to the fast twitch fibre area in the study of Borges and Essén-Gustavsson (1989).

The evaluation of efficiency in individual motor and functional tests is speculative. Tesch *et al.* (1983) and Macková *et al.* (1987) noticed a number of correlations between structural and metabolic properties of a muscle and efficiency tested by laboratory functional tests. The values of vertical jump height can hardly be compared when they are measured under different conditions and using different devices. This also refers to the different results in repeated tests. The usefulness of laboratory testing remains a problem from the point of view of their evident validity to predict the success in a race and to ascertain actual performance of athletes. Our results seem to prove that physiological and efficiency parameters used are related rather to general than to special levels of training. Direct interrelations among the composition of muscle tissue, take-off abilities and the performance of ski jumping can hardly be expected. Virmavirta and Komi (1991) studied electromyographically muscular activation during ski jumping. The vastus lateralis and vastus medialis muscles were found to contribute mostly to the entire take-off phase. Viitasalo and Bosco (1982) stated that the subjects having a high percentage of slow twitch muscle fibres in their vastus lateralis muscle could utilize better the elastic energy during jumping. However, the length of the jump is also influenced by other jump phases and above all by the flying phase, where other factors are involved (e.g. rotation, aerodynamics – Vaverka and Salinger 1986, Vaverka 1987, Vaverka *et al.* 1988).

In spite of the fact that some of the observed athletes asserted themselves in the World Cup, none of them won through to the absolute top. It would be very useful to obtain data from the best competitors for comparison.

Acknowledgements

We are grateful to Dr. O. Kříž and to coaches V. Seidel and T. Kučera for supplying us with valuable data. We also thank Ing. E. Jarošová and Ing. O. Doležal for their help with the statistical evaluation and consultation.

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