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The Evolution of Physical Performance in Past and in Future Functional-Anatomical and Sports-Medical Points of View

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1. Introduction

During the last 25 years the Olympic challenge "citius" -"altius" - "fortius" has stimulated several research groups to investigate the tendencies and possible limits of human efficiency from functional anatomical, physiological and sportsmedical points of view. In these investigations our attention was directed to the specific individual factional and structural adaptability of the active and passive motor apparatus. The question was at what rates of adaptational speed and with which mechanisms the "functional system" skeletal muscle - tendon (or ligament) - cartilage - bone is reaction upon physical exercises of varying duration and intensity, a relation, that has been underrated for many years in its complexity. This comes true particularly to sports with early starting training loads (as e.g. in gymnastics, swimming, figure skating, and table tennis): the latter has taken in the past a special development by reason of its attractiveness and of its biological advantages (training of action speed and striking power, of skill, reaction and coordinative capacities and of endurance). We tried to study how far the adaptational characteristics, being an expression of epigenetic regulations, are valid for adaptation processes of the "functional system" upon athletic lads not only with children and adolescents but also with adults. This procedure has been chosen since the neurohumorally and metabolically controlled effects of differentiation, growth, and maturation are combining with the effects of functional and structural adaption upon external conditions, often overlapping them, thus making it not easy to assess exactly the original 2adaptational effect". Nevertheless, it should be attempted to demonstrate those adaptational reactions so far traceable caused by regular physical exercises, point to delayed temporal processes of adaptability (particularly in the areas of connective tissues), to show reasons for disorders or possible limits in the adaptation and to give some prophylactic recommendations for training programs sparing the "functional system".

2. Results and Discussion

2.1 Muscle fibre spectrum

The gradual preparation of human efficiency in sports is dependent among other things on the adaptability of skeletal muscular fibre types upon physical loads. According to our findings (19,25,28) an intensive strength exercise induced cross-sectional area increases of FT-fibres by 15.5 p.c., as compared by 10.6 p.c. with ST-fibres only. Following endurance exercises ST-fibres showed areal increases by 21.3 p.c., FT-fibres only by 16.3 p.c. It seems remarkable that the oxidative and glycolytical metabolism has been functionally consolidated at the 13th year of age. Fournier et al. (6) gained similar results after specific sprint and endurance training programs with children and adolescents including de-adaptations after a 6-month-non-training-interval and related activities of succinate dehydrogenase (SDH) and phosphofructokinase (PFK) in his investigations. While the endurance-trained subjects showed an increased SDH-activity (with no change in PFK-activity) by 42 p.c., the sprinters had an increase in SDH-activity). After de-training these activities returned to significantly lower values.

It should be mentioned that contrary to these positive reactions an immobilization of the leg leads in a very short time (4–6 days) to a considerable decrease of muscle fibre areals (in particular in the ST-fibres) by more than 20 p.c. and in connection with this to a diminished oxidative enzymatic activity (SDH). For example: After 4 weeks immobilization post operationem of a ruptured lig. cruciatum anterius the cross-sectional areas of ST-fibres were reduced from 44.0 mm^2 to 32.2 mm^2 demonstrating an unambigous muscle atrophy[1]. We should avoid, therefore, longer immobilizations in sportstraumatology; instead, we recommend movable cast braces enabling an early dynamical muscle training post operationem.

Recently the question was often raised as to whether and to what extent differences in the human skeletal muscular fibre type composition (governed mainly by hereditary factors) could be caused under physiological conditions, such as physical exercise. It is well-known that under experimental situations a fiebre type transformation from an ultrastructural appearance typical of ST-fibres to a normal FT-fibre ultrastructure is possible by cross-innervation and by specific electrical stimulation; but these artificial conditions are not in conformity with the aims of physical exercises, they are of minor importance in sports. We can, therefore, state that at the 10th to 12th years of age at the latest, the distribution on ST- and FT-fibres stays mostly constant with healthy individuals thus providing for a relatively stable pre-conditioning performance factor.

2.2 Mitochondria of skeletal muscle

We know that more than 95 p.c. of the consumed oxygen disappear in the mitochondria of skeletal muscle during maximal aerobic efforts. It seems, therefore, reasonable to register adaptational reactions of this enzymatic machinery (necessary for the oxidative replenishment of the energy stores of muscle cells) from training stimuli by determining the number of mitochondria (form and size may vary widely) and the density of their volumes. In our experiments (19,28) we could register increased surfaces of mitochondria by 37 p.c. and numbers by 18 p.c. after 4 weeks of endurances loads causing an increased oxidative cellular capacity from an enlarged total surface (by 69 p.c.) of the cristae mitochondriales, and leading to supercompensations during the period of recovery. Other authors like Hoppeler (9) and Schon et al. (21) found significant increases of the mitochondrial volume density by 38–43 p.c. (particularly in the ST-fibres) in endurance-trained people as compared with controls, demonstrating that oxidative enzyme activities and volume density of mitochondria describe the total oxidative potential of skeletal muscle cells equally well.

Which mechanisms induce and control these complex structural and functional adaptations? Decisive effects on muscular growth results from hormones of the peripheric endocrinal organs (in particular by thyroxine, by somatotropical hormone as well as by testosterone) controlled by hypothalamic nucclei fields (25,28). These hormones become highly active during puberty after changing secretional processes (e.g. reduction of suprarenal activity and increasing thyroidal function) in form of secretional peaks very sensitively reacting upon training loads. We know on the other hand, that essential improvements of strength capacities can only be achieved after increased testosterone production and -release and peripheric sensibilization towards that hormone. Strength training should, therefore, at first be concentrated on the consolidation of motor processes and control of movements during pre-pubertal stages.

2.3 Capillary density and capillarization of skeletal muscle

The oxidative capacity of skeletal muscle is, as demonstrated, related to clear training–specific adaptions. We may,therefore, conclude that the capillary density and the capillarization are also adapting to loads in a similar manner. Our investigations (25,28) with endurance–trained individuals showed functionally enlarged capillary beds by 45 p.c. (as compared with controls) caused by an increased metabolism and a higher osmotic pressure and initiated by a hyper–polarization of the smooth vascular wall muscles of the arterioles and pre–capillaries thus safeguarding an increase of the skeletal muscle's oxygen consumption up to the 50 fold. According to Ogawa's findings (17) the microcirculation in FTG–fibres is significantly weaker at untrained and trained conditions than in untrained and trained ST–fibres.

From these informations we may conclude that muscular structures with their extraordinary plasticity and functional dispositions are already available in children's organism vastly coinciding with the value of adolescents and adults. The physical range of performance and the trainability of this are well developed and their limitations will only seldom be reached from the point of skeletal muscular pre–suppositions, when systematic training programs take individual biological adaptability of musculature into consideration and sufficient periods for active recovery are established.

3. Connective tissues

We know today that the connective tissues also possess fine–structural adaptational capacities upon physical exercises which show – as compared with skeletal musculature – temporary delays. They react particularly with adolescents very sensitively upon "load jumps" leading to mis–relations between load and loadability; this should be illustrated by some examples.

3.1 Collagenous tight connective tissue

Studying the Achilles'– tendon (26) we could point out after an 8 week dynamic endurance training that tendinous fibrils (particularly their sclero–proteins having mechanical tasks) possess a clear hypertrophy, an increased tensile strength (by 6.2 kg/mm^2) but also small decrease of stretchability (by 6 p.c.). Comparing the two sexes no principal difference could be found concerning the adaptability if one neglects the somewhat lower tensile strength of female tendon tissue. The specific adaptations to endurance–, speed– and interval–training point clearly to considerable possibilities of differentiation and trainability of tendon tissue; this was also confirmed by other authors (24,32).

Submicroscopically interesting is the behaviour of the tendinous fibrils' double refraction: after 2 days of exercise it decreases at first, quickly increases after 3 weeks of training. This means that the tendon reacts at first on a short–time load by relaxing its fine structure; the tendon is in a rupture–liable reconstructuring phase, its tensile strength is reduced by 10 p.c. Training programs for children and adolescents should, therefore, always be arranged in a "connective–tissue–sparing–manner". "Load jumps" or abrupt load changes should absolutely be avoided, as they lead among other things to achillodynies in more than 90 p.c. These impressions explain the importance of regular physical exercises from early up to old age, because the loss of normal motion leads certainly to biochemical change in the cell metabolism, to depletions of glycosaminoglycans and finally to a decrease in tendon or ligament strength (7,31,33).

3.2 Articular cartilage

The hyaline articular cartilage whose nutrition and complete function is dependent above all on the intact metabolic transit–distance (because it is without own blood vessels) shows also clear adaptational reactions upon physical exercises, demonstrated by several authors (4,8,11,12,14,20). They point out:

– running exercises increase uncalcified cartilage thickness by 18–23 p.c. and proteoglycans concentration, mostly at regions subjected to high pressure;

– the intermediate, deep and calcified zones show an increased glycosaminoglycans content, mainly chondroit insulphate; this is considered to improve the biomechanical properties, the stability and elastic stiffness of the cartilage;

– daily running exercises increase the cell size and cell number within the uncalcified cartilage.

These change appear soon after the beginning of the loading; they are reversible, since the enhanced glycosaminoglycan synthesis returns to control levels 18 hours after discontinuation of the cyclic stress. The cyclic nature of joint loading is, therefore, very important in the modulation of cartilage matrix. Contrary to these positive dynamical reactions of the articular cartilage upon intermittent leads, static ones cause (e.g. in the epiphysal cartilage of tubular bones) a significant narrowing of the cartilage 's diameter and overload–conditioned irritations of the chondrocyte's metabolism in form of a plain reduction of number and size of cells and a lowering of the alcalic phosphatase activity, findings that can be assessed as a reversible catabolic direction on the chondrocytes' metabolism(28).

A more serious influence upon articular cartilage and its loadability in sports have muscular disbalances, essentially a consequence of imbalanced training programs (27). What can be the reasons for those disbalances? Experimental investigations have brought to our attention that muscles doing predominantlysupportive work ("tonic" or "postural" muscles) tend to shorten their length, whilst those of mainly dynamical tasks ("phasic" muscles) are characterized by a reduction in their strength.

We should diagnose muscular disbalances between agonies and antagonists early, in order to avoid sequals from faulty loads like an anteversion of the pelvic girdle caused by shortened iliopsoas, rectus femoris and erector spinae muscles and by weakened glutaeus maximums and rectus abdominis muscles, thereby enacting the load–mechanically unfavourable hyperlordosis with its small intervertebral joints. Further on it is necessary to avoid cases of chondropathia retropatellaris, permanent overloads of muscle–tendon transitions or muscle–traction–fractures caused by muscular disbalances.

Following recommendations are tabled for sport physicians, physiotherapists, trainers/coaches in the interest of a successful programming of training loads:

– prior to top–class training: registration of torsion and axis deviations in the area of lower extremity-because without correction of statics (e.g. by shoe supports) symptoms of overcharge in the knee joint or in the ankle can arise;

– test the contractility and stretchability of agonists and antagonists (which are mainly contributing to motor processes) among others by the Janda muscle function test (10);

– when muscular disbalances have been found: at first concentrated stretching programs for shortened muscles, because forced development of muscles depends on their stretching condition prior to contraction. Only then individually adapted stretching of weakend muscles (particularly considering the abdominal, gluteal and vastus medialis muscles) in order to compensate starting or lasting ligament instabilities. The effects from these measures should be controlled three to four times annually by repeated muscle function tests.

3.3 Bone tissue

The "lamellary" or "breccial" bone is characterized by high plasticity, changing density and form and possesses, therfore, manifold adaptional reactions because its intensive metabolism and blood supply. To the most important adaptions of bone tissue upon physical exercises belong among others:

- an increase in both the diameter and the number of Haversian canals in the diaphysis of long bones (2,5,18); the magnitude of changes is proportional to the intensity of exercise;
- an increase of vascularization of long bones by 50–75 p.c. of their resting values (30); this hyperemia can be maintained for up to an hour after exercise;
- an increase of bone density and mass (22,28) and an enlargement and ventralization of the lumber vertebral bodies (29);
- an increase of bone mineral content (16) compared to the non-loaded bone;
- an increase of osseous formation in the zones of attachment for mascles, tendons, and joint capsules by high tensile loading (29);
- slacking in the area of symphysis pubis particularly with younger female gymnasts (29), and last but not least
- changes in the internal structure of bones in the direction to an increasing sclerosis particularly in the area of the femoropatellar joint.

All these adaptations confirm once more the close interrelations of skeletal muscle – tendon (ligament) – cartilage – bone as well as their mutual dependencies in shaping capable structures. Let us come back to the question for tendencies and possible limits in the evolution of efficiency in sports. Starting from the experience that the duration of daily training sessions increased continuously it becomes comprehensible, that limits can come in sight for further extent of training. Possible limits may be traced in the extensive loadability of connective tissues as well as in genetical factors (93 p.c. of the maximal aerobic capacity and 81 p.c. of the maximal anaerobic capacity are determined by the muscle fibre spectrum and its enzymatical equipment). Further on it should be mentioned that the scale of energy availability can grow up to a performance–limiting factor. The future of additional high performances in sports is, therefore, located above all in a more intensive training shape including sufficient times for relaxation. If we succeed in improving the selection and advancement of young talents, if we study and take into consideration the correlations between loadability and relievability as well as the efficiency tests and the effective utilization of new results achieved by sports medicine, sports sciences and engineering then it will be possible to perforate so–called "sonic barriers" also in future adequate to the Olympic aim "altius" – "citius" – "fortius".

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