EVOLUTIONARY AND BIOLOGICAL ASPECTS OF WOMAN'S FUNCTIONAL CAPACITY

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The differing body composition of man and woman can be traced back to an evolutionary, biological process of development in which the female anatomy is determined by the demands of reproduction. Top competitive sport, however, makes demands that at first glance appear to be of a quite different order: namely, the optimalisation of endurance, strength, speed, flexibility and coordination. In women, the consequence of this is an approximation of her physical build to that typical of the male, and in young girls the retardation of development. The Author examines the various aspects of this problem; a much debated issue in women’s athletics.

In 1905 the Senior Medical Officer and Anatomist, Prof. Gustav Fritsch (1), described the characteristic features of the female anatomy as follows: “The habitus of the female body differs fundamentally from that of the male, in so far as it displays a form that is altogether more simple and more rounded. The difference lies largely in the greater delicacy of bone structure, the less marked development of the muscles, and in the generous layer of fat that is distributed evenly over the deeper structures and is the main factor responsible for producing the attractive rounding of the limbs. It is for this reason that those members of the gentle sex whom we see performing in competition with men on the trapeze, or on other gymnastic equipment in the circus, rarely exhibit the unsightly accumulations of muscles on trunk and limb that can be seen in men engaged in similar activity; in this respect, the sex undoubtedly deserves to be described as beautiful. Anyone preferring the more richly modelled form, a line more expressive of strength, will of course feel unable to subscribe to this statement, and indeed, this trend in taste is by no means a rare one” (1).

Translation from the original German by Sylvia Furness
This charming description by Dr. Fritsch is certainly based on the classical ideal of female beauty, which for centuries has informed aesthetic thinking, and especially that of the male observer. On the other hand, indications of functional and anatomical descriptions already make themselves heard, suggesting phrases like: specialized anatomy, fatty deposits, hypertrophy of the muscular system and strength-development. There is also a cautious indication that the accepted classical concepts are subject to change and that, even at that time, they no longer represented everyone's taste. The extent to which the “rounded, simple forms” can be transposed into “richness of modelling and strength of line” would certainly cause much astonishment to the good doctor if he had to deal with the constitution and biology of the female competitive athlete of today.

The classical ideal of beauty is based on woman’s genetically determined, “typically feminine” anatomy, made manifest in its secondary sexual characteristics. But in comparison with the criteria determining the physique of the modern woman athlete, it is clear that, for women, a high degree of anatomical adaptability is a necessary prerequisite. It is a fundamental tenet of biology that structure is the vehicle of function. If the structure is improved or augmented, it can be expected that the function will also improve. If, however, the entire structural framework is changed, it can be assumed that physiological functions will also alter. This can affect the entire organism positively or negatively, depending upon the demands made upon it. Training for top competitive sport, in whichever branch of sport it is carried out, makes stipulations which effect changes to particular physical structures and, consequently, also to physiological functions in the organism of the woman athlete, and it was these changes which initially led to various moral judgements being made.

For a long time, women’s athletics has had to struggle against these judgements, which range between two extremes: on the one hand, the natural woman, adjusted for procreation and shown to be so by her secondary sexual characteristics; on the other, the unfeminine, functionally more efficient man-woman figure considered as a kind of “violation of nature”. For a long time, these opposing aspects seemed to be mutually exclusive, the question of the naturalness of both varieties was never posed, much less the question of their biological significance. Clearly, the appearance of a woman depends to a high degree upon the demands made upon her; that is, she is adaptable. The natural demand made on the female organism is – in the briefest possible terms – to ensure the preservation of the species. If the woman with her “typically feminine” anatomy had not been optimally equipped for this task, she would certainly not have been able to achieve it throughout the course of evolution. Top competitive sport, however, makes demands that at first glance appear to be of a quite different order: namely, the optimalisation of endurance, strength, speed, flexibility and coordination.

In women, the consequence of this is an approximation of her physical build to that typical of the male, and in young
girls, a retardation of development. A woman successful in competitive sport today must, in terms of the standards by which her physique is judged, either become very masculine or remain very childish. There are outstanding examples of both postulates. In the final analysis, the physiological consequences in both cases affect her fertility. Whereas, in girls, the result may be to delay the onset of menstruation, the consequence in women undergoing endurance training in particular, is often secondary amenorrhoea; that is, absence of menstruation and therefore, temporary sterility. At first glance then, the constant repetition of physical stress appears to limit the reproductive capacity of the woman, in favour of increased physical efficiency. This is in no way a biological absurdity, for in the course of evolution, this capacity for adaptation undoubtedly had considerable value as a factor in natural selection, and precisely the temporary suspension of fertility during periods of physical stress may well have contributed substantially to the preservation of the species.

From an evolutionary-biological point of view, preservation of the species means not only success in reproduction, but also survival, and in particular, survival under the most unfavourable conditions imaginable, survival of the individual and in the long-term view, of whole generations in periods of excessive heat and cold or hunger and thirst. From a physiological point of view, it was necessary to counter temperature-stress and food deprivation, coupled with physical exertion, by making available appropriate energy supplies. So the human organism – and this applies equally to man and woman – developed into one of the most adipose of mammals. Up to 35% of his body weight can occur in the form of fatty tissue, at any rate in the industrial nations of today. The average for a pig is 27%, for a woman 25%; at 15% the figure for men is considerably lower. The so-called LBM, the fat-free body mass, is therefore much smaller for the female than for the male.

Basically, energy provision in extreme conditions, for instance the state of temperature stress, namely when the body sweats, shivers with cold or is in a state of hunger, occurs by the cleavage of triglycerides into glycerine and free fatty acids. With the decomposition of fatty acids and the cleavage of carbon compounds, there is an energy gain which is taken up into the citric acid cycle and so becomes an available source of energy for the organism. Human energy requirements are proportional to body size. An exception here is the brain. Although its volume makes up only two to three percent of the body mass, its functioning requires up to a third of the total energy requirements of glucose and oxygen. The intolerance of the brain to any interruption in supply or to an interruption in the mechanisms by which energy reserves are made available, is the real factor regulating physiological adaptation.

Energy consumption, or the basic metabolic rate, increases with body weight, as mentioned above. At 60 kg, it is about 1700 kcal (7140 kJ), at 80 kg 1900 kcal (7980 kJ). But for an individual weighing 70 kg, who is also very thin, it is considerably higher than for a fat individual of the same weight. In other words, the smaller the LBM, the
lower the energy consumption, because fatty tissue is much less active metabolically than is muscle tissue. This means that a fat person not only carries greater energy reserves about with him, but for the same activity, uses up this reserve more slowly.

But the human organism does not depend on fat alone. In addition to a supply of energy, it also requires proteins. Proteins consist of amino acids, and the essential amino acids in particular are of vital importance in processes of wound healing, the immune response and tissue replacement. In respect of its amino acid content, the body maintains a dynamic balance, in which the daily protein conversion is usually greater than that taken in as food. Amino acids that are freed by structural changes or breakdown, undergo a recycling process and are incorporated into newly synthesised proteins. Nitrogen is lost in the process. Maintenance of the nitrogen level determines the minimum supply of proteins that a human can tolerate. Proteins cannot be produced from the decomposition of fatty acids or from carbohydrates, but their amino acids can be used as sources of energy. Muscle tissue, as a protein store, usually exchanges amino acids with the body fluids. Although this exchange normally proceeds in a balanced way, when there is extremely high loading, amino acids that are given off by the muscles cannot be replaced. They are diverted to functions which at that moment are more vitally essential to the body, such as antibody synthesis, protection of the liver functions, or, as a result of cleavage, they are utilized as a source of energy. But mostly they act to maintain the body's immune respon-

se, even when synthesis of the antibodies means depletion of the available amino acids. Fat, as an energy reserve, and the muscles, as a storehouse for amino acids, have a very close functional correlation and their differing quantitative relationship determines the characteristics of male and female form.

The question now arises of why the human phenotype has, in the course of evolution, developed along two parallel but different lines. Why are women as a rule smaller, lighter, weaker, but at the same time fatter? From a biological and evolutionary point of view, the woman's task in the preservation of the species is to ensure both her own survival and to reproduce successfully; in complete contrast to the man. Fundamentally, males are males because their rôle in the process of reproduction consists of fertilizing women, whereas the true "femininity" of women lies in making possible in cycles of short duration the fertilization of her ova. Up to this point, the rôle of the sexes is entirely similar. But once fertilization has been achieved, this similarity quickly breaks down. The rôle of the male is now only of a psychological or behavioural-technical nature, while that of the female entails far-reaching physiological changes. Certainly the child receives its genetic information equally from each of its parents, but everything that allows this information to be brought to realization, including its immune competence, it receives from its mother in the course of pregnancy and during lactation. Altogether this period lasts 15 to 18 months, and indelibly marks the physiology of the woman as the provider of nourishment for the child.
If we now assume that evolutionary strategy was based on a virtually continual sequence of pregnancies and lactation periods in order to ensure a growth of population, in spite of a low rate of reproduction – we are dealing after all with single births – then the physical structure of the woman can be interpreted as an adaptation to this provision of nourishment on the one hand, but also as a means of ensuring her own survival. In this, the survival of the woman is of paramount importance. Reproduction, in terms of evolutionary biology, becomes entirely pointless if the progeny is non-viable or if the mother dies. The temporary suspension of fertility in periods of physical stress now appears in a different light.

In the woman, the total extent of stored energy at the time of sexual matu-
rity has been calculated by Frisch (2) to be between 75,000 and 90,000 kcal. This is sufficient to carry her through an entire pregnancy and into the beginning of the lactation period. From a technical-evolutionary point of view, fat stores and the LBM, and their relationship to one another, determine reproductive success. In addition, the fatty tissue is of primary significance as a regulatory factor. If the proportion of body fat decreases beyond a particular limit, there is a temporary suspension of fertility in the form of secondary amenorrhoea. If, in the case of a girl, it does not reach this limit, the menarche is delayed. As a clinical example, cases of anorexia nervosa are characterized by a similar feature. In addition, if in the case of obese women, a certain tolerance level is exceeded, symptoms of oligomenorrhoea can result, also leading to fertility disorders - a condition that could not have been foreseen in the evolutionary process.

A woman's fertility is known to be subject to hormonal regulation. Under the stimulus of the hypothalamus, the gonadotrophins FSH (follicle-stimulating hormone) and LH (luteinizing hormone) are released from the hypophysis; these control the production of the sex hormones oestrogen and progesterone, so that in regular and constantly repeating cycles, a ripe ovum can be discharged, and if fertilization has occurred, the mucous lining of the uterus permits the embedding of the ovum. In this, a key rôle is played by oestrogen as the female sex hormone. If this hormone is not produced in adequate quantities, maturation of the ovum does not occur, there is no ovulation, no production of progesterone and so no effect on the uterine lining. The result is amenorrhoea, accompanied by increased gonadotrophin levels.

Physical stress, and training for top competitive sport can certainly be considered as such, can obviously lead to a lack of oestrogen by reducing the woman's fatty tissue. The question arises as to why this should be so, and permits us to consider briefly the biogenesis of oestrogen. Androgens, better known as the male sex hormones, represent the immediate preliminary stage in the production of oestrogens. Here we are dealing with testosterone and androstendion. Androstendion is the most important secreted androgen in the female system; both are produced in the ovary and in the suprarenal bodies known as the adrenal glands (3). On account of their chemical composition, both can be converted into oestrogen by aromatization. This process occurs in part directly within the ovary. Part of the androstendion and testosterone synthesised there passes into the blood and is aromatized into oestrogens only peripherally, i.e. primarily in the fatty tissue. Consequently, normal sexually mature women always have a plasma concentration of approximately 100-310 ng/100 ml androstendion, and approximately 15-60 ng/100 ml testosterone in the blood, with the maxima occurring at the time of ovulation. Thus, a woman's oestrogen production can derive from two principal sources: from direct synthesis in the ovary and in the suprarenal bodies, and also from the peripheral aromatization occurring predominantly in the fatty tissue. If there is a drastic reduction of the body fat, the result is not only the loss of this second source of oestrogen, but at the same time, an increase in the androgens in the blood can be expected. For example, Shan-
gold et al. (4) was able to establish a plasma concentration of about 34 ng/100 ml, which, however, could be attributed to a reduced hepatic clearance. Although these figures lie within the range of the normal, their maxima approach figures at which hirsutism has been found to occur. If one takes into consideration the anabolic potency of testosterone – provided always that it is transferred to the woman in its biologically active form, dehydrotestosterone – it is possible, at any rate theoretically, to establish a physiological basis for the adaptation of the female anatomy to masculine characteristics of build.

For a considerable time now, we have been familiar with the myotopic effect of testosterone, that is, its marked anabolic action in increasing the synthesis of the muscle proteins and maintaining the glycogen level in skeletal muscle, and indeed, with unwelcome examples of its misuse in the administration of its derivatives, the anabolics. From experiments with animals, it has been found that an additional effect when androgen levels are raised is an increase in aggressiveness, a fact that could play a not inconsiderable rôle in competition (5). As a result of alterations in the muscle-fat ratio, women in competitive training achieve a certain “self-drugging” effect, with a rise in their testosterone levels. But fertility disturbances arise only when the percentage of body fat falls below 20%. In girls, there is inhibition of sexual maturity as long as the 15% is not exceeded. In this context, the average figure for males of 15% achieves special significance.

In the light of these statements, the question can be posed as to whether it was legitimate to compare the suspension of fertility in a woman elicited for reasons of evolutionary strategy with that brought about by high level competitive training. The first, concerned with biological evolution, is based on physical stress occasioned by starvation, and is accompanied by a drastic reduction in the overall body weight. But in competitive sport, the athlete does not starve; and alterations in body weight are not dramatic. In a situation of hunger-stress, there is a relative increase in the LBM, since the fat tissue is mobilized and there is hypertrophy of the muscles. Because in either case, the basic mechanisms employed are similar, both processes lead, by way of a shift in the LBM/fat ratio, to the same result: the temporary suspension of fertility, and therefore they are comparable. So since the mechanism of adaptation that is evoked in competition training is, in evolutionary-biological terms, an old familiar one, the question of a possible health risk answers itself: something that makes good biological sense cannot imply a risk, nor is there any question of permanent infertility. As the training output decreases and the LBM decreases, reproductive capacity returns of its own accord.

To sum up, it can be stated that the differing body composition of man and woman can be traced back to an evolutionary, biological process of development, which began with particularly effective mechanisms of energy provision, was controlled by the brain’s unique provisioning requirement, and in which the female anatomy is determined by the demands of reproduction. In this, the physiological and anatomical adaptability of woman was a strategic factor of the utmost importance and is certainly also today the essential cause of her undisputed biological
superiority. Her higher life expectancy and reduced susceptibility to coronary heart disease and cardiac infarction are attributed to the protective oestrogen mantle that surrounds her. But it is precisely cardiac-circulatory disorders, as the diseases of civilization, and their prevention, that today drive large numbers of women into endurance training, in which astonishingly high demands in terms of energy and distances are often made. As long as the women are young, there are no objections to these loadings, because of the reversibility of the physiological changes involved. But in those women whose own production of oestrogen is in any case decreasing – those, that is, between the ages of 38 and 45 years – the questions should be put as to whether, along with their newly acquired functional efficiency, they are not also parting with their protective oestrogen mantle, and exchanging their biological superiority for particular risks that up to now have been largely reserved for men. It is time for some thought to be given to this matter.

REFERENCES