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Impact of Pubertal Growth on Physical Fitness

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Abstract Puberty is a combination of physical, physiological and psychological changes with detectable alterations in physical growth, which is a determining factor for assessment of physical fitness. Several studies have documented the functionality of physical activity for pubertal growth. But the present review has aimed to investigate whether normal pubertal growth, along with its endocrinological variations affect the level of physical fitness and what are the major fitness variables mostly regulated by the hormonal changes during puberty. Different sex hormones in boys and girls have been found to play the key role for regulation of various fitness determinants like body composition, muscle strength, bone development, erythropoiesis, cardiac function, substrate utilization etc. The major fitness components- strength, aerobic and anaerobic fitness, all have been found to be largely associated and influenced by the growth related endocrinological alterations during puberty.

Keywords: *puberty, hormonal alteration, physical fitness, body composition and muscle strength*

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1. Introduction

Pubertal age is the transitional period of life from childhood to adulthood, with significant physical, physiological and psychological changes. The most prominent and visible feature of this period is physical growth or biological maturity which is very much distinct among boys and girls. In the present context we are concerned about the physical fitness during puberty and it is evident that fitness is enormously influenced by the physical growth [1] that is achieved by several physiological rather endocrinological alterations during this stage. For assessment and understanding of the functionality of physical activity on the growth and development, the knowledge of natural processes of growth and development is essential [2,3]. According to Elham et al., [2] for measuring the physical fitness talents and capabilities, consideration of the components of growth and biological age is important, because any negligence in this regard can lead to the imbalance between capabilities and physiological abilities relating to their growth while doing physical activity [3]. Many studies have already documented the differential effect of pubertal hormones on growth and different variables of physical fitness; including strength, aerobic fitness and anaerobic fitness [3,4,5].

There are many studies available which have well-established the effect of physical exercise and fitness on pubertal growth involving the endocrinological alterations [6,7]. There is a common phrase, frequently heard- "Do some sport to grow more". But the aim of the present review is to explore whether pubertal changes regarding growth affects the physical fitness and what are the prime physical fitness variables that are mostly influenced by the endocrinological alterations during puberty in both the genders.

2. Puberty and Growth – Physiological Basis

Puberty is the successive changes of anatomical and physiological characteristics in the early adolescence which mark the transition period from the sexually immature to the fully fertile state. It is also explained as a dynamic period of development expressed by rapid changes in body size, shape and composition with sexual dimorphism. At the skeletal (biological) age of 13 years there is onset of puberty among boys, but the girls experience it 2 years earlier, i.e. at 11 years [8]. Physical growth is defined by the interactive phenomena of cellular, biological, biochemical and morphological changes via a pre established genetic pathway, which is also influenced by the environment [9,10].

Here we are concerned about the pubertal growth or biological maturity, in the context of physical fitness, because biological maturity is a determining and prominent factor of physiological responses to physical activity and exercises. Evidence suggests that, strength, muscular endurance, aerobic capacity and anaerobic power are affected by growth [1]. So, the causative agents for pubertal growth seek greater attention.

2.1. Hormonal Basis

The base for physical growth during childhood is the growth hormone (GH) / Insulin like growth factor I (IGFI)

axis. The principal component of this axis is the single chain, 191 amino acid protein, Growth hormone (GH), also known as somatotropin, produced in high amounts by the anterior hypophysis, in a pulsatile manner and most prominently during sleep at night [11,12]. It's secretion is controlled by a complex mechanism involving stimulatory Growth hormone-releasing hormone (GHRH) and inhibitory Somatostatin. Although GH is produced during lifetime, its peak of highest secretion has been observed during puberty [7,13,15]. It plays an important role in the growth of bones and soft tissues [15,16].

GH/IGF-1 axis directed growth singly operates up to the age of 12 years. But after that these anabolic effects are supplemented by the influences of the sex hormones (testosterone in male, estrogen in female) during the process of puberty. These two sex steroids play the key role for variances in physical fitness, depending on growth during pubertal age. But clinical observations have shown that both GH and sex steroid hormones are the musts for normal pubertal growth [17]. Any selective deficiency of either of these two hormones (e.g., hypogonadotropic hypogonadism or isolated GH deficiency) leads to reduced growth spurt [18,19]. According to Rogol study, the gonadal steroids and the GH/IGF-I axis need to operate in a combined fashion, despite of their independent activity, as their interaction is crucial for body composition and alteration in linear growth during puberty [20]. However, along with the gonadal steroids, the other major influential factors for growth are adequate levels of thyroid and cortisol hormones. Another component which in the recent years is being considered to be the prerequisite for the process of puberty is Leptin, a protein product of the obesity (ob) gene, secreted by the fat cells. It is being implicated with the energy expenditure, nutrition and pubertal changes [21,22]. The role of leptin in this context becomes more clear following Horlick et al. study who reported that in both males and females, plasma leptin levels were found to be positively correlated with the fat mass at all levels of sexual maturation, after examining the relationship among level of sexual maturation, gonadal hormones, fat mass and circulating leptin during the course of puberty in 6 to 19 years old subjects [23].

3. Effects of Different Sex Hormones on Physical Fitness Variables

The physical fitness is regulated by several components, among which body composition, muscle strength, bone development, erythropoiesis, cardiac size, substrate utilization etc. are the principal determinant variables, which are affected by the altered secretion of sex hormones at the pubertal age.

3.1. Body Composition

The most obvious and most prominent differential effect of sex hormones at puberty is the stimulation of linear growth and development of muscle bulk in males and fat accumulation and bone maturation in females [24]. Boys show significant rise in growth of bone, stature and muscle mass and simultaneous loss of fat in limbs under the influence of testosterone [25]. A 11 year old boy possess 15 kg of muscle mass, which increases to 35 kg., due to puberty induced growth, by the time he is 17 [26], [17]. Females experience lesser increment in stature and muscle mass, but a significant accumulation of body fat. Fat accumulation resumes in both sexes, but it is twice as rapid in girls. Reaching adulthood males obtain 150% of the lean body mass of the average female and twice No. of muscle cells [27]. This increment and skeletal size and muscle mass correspond to increased strength in males. Whereas, the fat accumulation in females is detrimental for the performance in weight bearing activities (e.g. running, chin-ups). Because, the added adipose tissue creates a additional inert load which has to be beared. Rowland et al. 1999 stated that by variation in body fat content, upto 1/3rd of the variance in performance of the 1 mile run by a group of average six graders can be obtained. However, another study by Rowland et al. [28] documented that during cycle resting body fat does not have any detrimental effect on cardiac functional reserve, but upto a moderable levels of obesity [29].

3.2. Muscle Strength

There are numerous evidences supporting the hypothesis that, testosterone increases skeletal muscle bulk and strength.

A rise in testosterone level is closely associated with the alteration in muscle strength at puberty. As men ages, parallel decline in testosterone level and muscle strength are observed [30]. It is still under investigation that how testosterone augments muscle protein synthesis and increases the muscle size and strength. Probably testosterone stimulates the anabolic effects of IGF-1 in the muscle cell. [31]. IGF-1 is also associated with the cell differentiation process and synthesis of type- 1 collagen via the action of GH [13,15,16,32,33]. Some studies reported that Estrogen may have an Inotropic effect on muscle strength, because muscle strength decreases with the onset of menopause [34,35]. Estrogen promotes the secretion major anabolic hormone GH. If sufficient level of Estrogen is present, individuals with complete Androgen insensitivity, do not require androgens for normal adolescent growth or to achieve pubertal levels of GH and IGF-1 [36]. Some early researches suggested that estrogen up regulates the ability of muscles to contract by about 10%, with a peak in strength just before ovulation [37,38].

3.3. Bone Development

Experimental evidences indicate that irrespective of gender, estrogen is the prime determinant of normal maturation. There is significant delay in bone development in the individuals who have hypoestrogenemia (e.g. those with turner's syndrome) or in the rare males who lack estrogen but possess normal levels of androgens [39]. Some others studies states that Estrogen and Androgen both lead to bone mineral deposition [40,41]. More than 90% of peak skeletal mass is present at the age of 18 years, who have gun through normal pubertal development. Skeletal mass at this age accounts for most of the variability in bone mass and osteoporosis at older ages [39]. Although both osteoclasts and osteoblasts possess estrogen receptors, but estrogen mainly operates via bone changes by initiation of resorptive process rather than stimulation of osteoblasts so

there is excessive osteoclastic activity, with remodeling and resorption of bone tissue with the deficiency of estrogen performed a study on 318 healthy youths aging 6 to 22 years. For assuming bone and muscle strength they measured cortical area of radius (CA)and muscle cross sectional area (MA) respectively using computed tomography and reported that muscle mass is the strongest predictor of CA, pubertal stage and sex both have significant influence on it and estrogen promotes excessive bone growth during pubertal age [42,43].

3.4. Erythropoiesis

We all know that greater number of red blood cells, i.e. higher haemoglobin concentration is essential for efficient aerobic performance, as it leads to higher oxygen carrying capacity. So, erythropoiesis is an important variable for determination of physical fitness. In the context of erythropoiesis testosterone is the principal hormone. It stimulates the process of erythropoiesis, increases the haemoglobin concentration, haematocrit and red blood cell volume [44]. It is proved by castration of adult male animals, which then becomes anemic and then it can be reversed by the external administration of androgens. Several invivo studies demonstrated that androgens can directly stimulate erythropoietic stem cells [45]. But few other studies stated that, effects of androgen on haemoglobin and red cell production are eliminated in nephrectomized rodents, therefore testosterone might act indirectly on the production of red cell by enhancement of erythropoietin production by the kidney [46]. Boys and girls possess almost same haemoglobin concentration before the onset of puberty, with a slow rise from about 12.6 $g.dl^{-1}$ at age of 2 years to 13.7 $g.dl^{-1}$ at age of 12 years, which remains stable for pubertal girls but in boys it continues to rise with the onset of puberty and reaches 15.2 $g.dl^{-1}$ in 16 year old boy, due to the effect of increasing level of testosterone [47]. Post pubertal male and female have the haematocrit value of average 47% and 42% respectively which prominently depicts the lower aerobic capacity and physical fitness among female [48,49].

3.5. Cardiac Size and Function

Another major physical fitness variable, influenced by pubertal hormones is cardiac size and its function. According to Koenig et al after administration of testosterone, there is myocardial hypertrophy increased cell RNA and protein and more cytochrome oxidase in animal heat muscle [50]. A decrease ventricular contractility is observed in both pre and post pubertal male and female rates after gonadectomy and was prevented by testosterone replacement in males and both estrogen and testosterone in females [51]. A study by Broulik et al. in 1973 revealed that after castration cardiac output fell by an average of 13% [52].

In humans, during puberty left ventricular size increases faster than in females, which clearly indicates the strong anabolic effect testosterone on the myocardium [53].

3.6. Substrate Utilization

It is well established that for improvement of exercise capacity, proper substrate utilization is essential.

Several evidences suggest that's estrogen might have an influence on substrate utilization during exercise [54]. Essential might enhance the hypolysis, which utilizes the fats and spare the glycogen utilization, ultimately resulting in improved exercise capacity. Kendrick et al. (1987) showed the fact by administration of estradiol in rats and found that estradiol receiving rats had greater runtimes to exhaust in comparison to the control group [55].

In case of humans most of the studies have been conducted to compare the physiologic variables in respect to varying levels of circulating estrogen. Some of them deal with the changes in respiratory exchange ratio (RER), indicating alterations in lipid utilization, which correspond to different phases of menstrual cycle, while the others have not [54]. Weise et al., documented that concentration of epinephrine fell with the progressive stages of puberty, this declination of epinephrine level was inversely related to increases in estrodiol, testosterone and insulin, which might have an impact on substrate utilization [55].

4. Pubertal Effects on Physical Fitness

4.1. Maximal Aerobic Power

Maximal aerobic power or aerobic fitness is strongly affected by puberty, especially in boys. According to Armstrong et al. 1997 an 11 years boys has the same muscle mass with his female counterparts, but at the age of 17 muscle mass increases to 35 kg in case of boys and 22 kg in case of girls. The differences occur due to an influence of sex on muscle fiber size rather than the cell number. During puberty gains in fat mass in females are double than males [17,26,47].

According to Armstrong et al. 1998 no differences were found in aerobic fitness between boys and girls but the developmental curves of VO_2max were diverge. In case of males a continual rise is observed but a plateau is observed in females. VO_2max is closely related to body mass. Between the age 6-16 yrs average VO_2max of boys is 52 ml/kg/min whereas in girls it is 40 ml/kg/min at the same age. These changes occur due to the alteration in body composition during puberty as well as low physical activity for females.

Improvements of VO_2max are closely related with the increase in maximal stroke volume, which is a reflection of left ventricular diastolic enlargement. Improvements of heart size with greater aerobic fitness should occur due to increase in lung size, skeletal muscle mass, muscle capilarization [57].

From the above we can conclude that puberty alters the aerobic fitness by increasing body size, dimension of the heart, lungs, muscles and circulatory system.

4.2. Sexual Maturation and Aerobic Fitness

Several literatures were available about influence of sexual maturation and heart development during puberty. Daniels et al. in 1995 explained variance in left ventricular mass by growth of lean body mass. According to them multiple regression analysis has no influence on sexual maturation [58].

A longitudinal relationship between VO_2max and maturation in boys and girls was studied by Malina et al. [4]. They conclude that the time pattern or tempo of the

development of aerobic fitness during puberty parallels that of sexual maturation.

Fahey et al. (1979) found no significant relationship between peak VO_2 (expressed relative to body mass) and testosterone levels when the effect of age was eliminated which was also reported by Welseman et al. 1994 [59], [60]. However no significant differences were found in average mass-relative VO_2max between pre and post pubertal boys by Williams et al. 1992 [61]. Armstrong et al. 1998 reported a significant influence of sexual maturation independent of body size on peak VO_2 in both boys and girls [49].

4.3. Strength

Puberty also affects the strength of an individual. Serial changes in grip strength both in boys and girls were explained by Neu et al. (2002) [3]. According to their findings the pattern of maximal isometric grip force reflected two components such as growth of muscle size and force of grip per cross sectional area (CSA) of the muscle. It is well established that increase in muscle size and strength is higher in males than females due to the hormonal influences during puberty but when normalized to fore arm length, grip strength per muscle CSA was not significantly different and was independent of the influence of sex steroids [3]. Another study reported body mass and stature were significant predictors of both knee extension and flexion but once these variables were accounted for in the analysis, age and sexual maturation did not contribute peak knee strength [62]. Increase in body size was occur for the improvement in muscle strength in girls whereas in boys a size independent contribution to strength improvements was observed by an sharp increase in blood testosterone levels. Besides the increase in muscle mass, some other action of testosterone possibly the bone growth were responsible for the changes in elbow flexor and knee extensor strength in boys [63]. In Oakland adolescent growth study boys and girls (age 11-18 yrs) were grouped according to tempo of sexual maturations as early, average, late matures [17]. In these study boys who were early matures performed better on tests of grip strength and shoulder pushing strength. No differences were found in the three groups of girls. Similar findings were found in Belgian boys [26,64].

4.4. Anaerobic Fitness

Anaerobic fitness is regulated by muscle mass as well as by size independent factors (glycolytic metabolism, muscle architecture, neurologic input). The amount to which size independent factors are inclined by the hormonal changes of puberty is unclear. Significant increase in mean and peak anaerobic power in prepubertal, mid and late pubertal boys were found by Falk and Bar-Or [5]. They studied the effects of sexual maturation on anaerobic fitness by Wingate tests. In prepubertal boys improvements in anaerobic fitness by an excess increase in body mass are seen. Falgairette et al. (1999) found correlation(r=.45, r=.47) between peak and mean anaerobic power and salivary testosterone levels. However Welsman et al. (1994) could not find any relationship between testosterone levels and submaximal blood lactate responses which are considered as a metabolic marker of anaerobic fitness [60,65].

5. Conclusion

From the present review it can be concluded that puberty has immense role on physical growth which influences the physical activity. The pubertal growth and hence the physical fitness is directly and indirectly affected by the hormonal changes during this period. These endocrinological alterations are essential for normal growth and development of physical activity. Among the several fitness variables body composition, muscle strength and bone development have been found to be mostly affected by the puberty.

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