DISCUSSION

Handgrip strength is a measure of strength of several muscles in the hand and the forearm. Synergistic action of flexor and extensor muscles and their interplay plays a key role in the resulting grip (Richards et al., 1996). During such activities, the muscles of the flexor mechanism (for example, thenar and hypothenar muscles, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, flexor digitorum profundus) in the hand and forearm create grip strength while the extensors of the forearm (extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum) stabilize the wrist (Waldo, 1996). The hand does not function in isolation, and is dependent on the integrity of the shoulder and elbow complexes to allow the appropriate positioning of the hand in space to complete the desired task (Blair, 2002).

Grip strength has been used to assess general strength in order to determine work capacity, for extent of injury and disease processes and the potential for progress in rehabilitation (Dash and Telles, 2001). Measurement of handgrip strength is commonly performed to measure baseline deficiency in hand muscle power, to monitor progress during rehabilitation, and to document outcome after rehabilitation. Strength testing has been used to monitor the therapeutic response of patients to medical therapies, hand surgery and to orthotic interventions (Lee et al., 1974). It is widely used in adults as an indicator of muscle strength in fitness testing (Bookwalter, 1950; Cotton and Johnson, 1968) and as a representative of total body strength (Wessel and Nelson, 1961; Tinkle and Montoye, 1961; Heyward and McCleary, 1975). It is also a measure predictive of social behavior in older adolescent males (Gallup et al., 2010). Poor nutritional status has been associated with poor handgrip strength, independent of sex, age and height (Pieterse et al., 2002).

Grip strength data could also be used to monitor specific hand disabilities such as rheumatoid arthritis, which causes progressive hand weakness (Agnew and Maas, 1991). Hand strength has been identified as an important factor to predict disability in musculoskeletal diseases such as rheumatoid arthritis (Oken et al., 2008) and bone mineral density (Di Monaco et al., 2000). It even predicts complications and general morbidity after surgical interventions (Mahalakshmi et al., 2004), general disability and future outcome in older age (Rantanen et al., 1999), as well as cause specific and overall
mortality in elderly people (Rantanen et al., 2003). Handgrip strength is found to be a significant determinant of bone mineral content and bone area and has a positive correlation with lean body mass and physical activity. It determines the muscular strength of an individual (Foo, 2007).

5.1 Trends of Handgrip Strength and Selected Anthropometric Characteristics

In the present study, the trends of handgrip strength and selected anthropometric variables were studied in individuals of Amritsar, aged 6-25 years (Tables 4.1-4.20). There were continuous increments in the mean values of most of the parameters in male and female students, as the chronological age advanced from 6 to 25 years. The findings showed higher mean values in male students than their female counterparts in most of the parameters considered. This is similar to the findings of Oyewale et al. (2010) and Bailey and Hurd (1982). There was not much change in the various components as age advanced from 13-14 years. An increase was seen in most of the parameters from 6-13 years among the female students. This is referred to as embarkment in the growth spurt in girls. Girls generally reach puberty ahead of boys and they embark on the adolescent growth spurt at an average age of 10.5 years, as against 12.5 years for boys. Although the intensity and duration of this spurt vary widely from one youngster to another, it usually lasts for 2-2.5 years in both sexes (Tanner and Marshall, 1968).

In the present study, male and female students showed an increase in handgrip strength with age. The increase in dominant and non-dominant handgrip strength with age was approximately parallel for male and female students until 13 years of age, after which male students were significantly stronger than female students similar to the earlier reports (Bohannon et al., 2006; Bassey and Harries, 1993). Statistically significant differences (p<0.05-0.001) for dominant handgrip strength were found in 8, 9 and 14-25 years. For non-dominant handgrip strength also, statistically significant differences (p<0.05-0.001) were found in 9, 10 and 14-25 years. A general rule often used suggests that the dominant hand is approximately 10 percent stronger than the non-dominant hand (Petersen et al., 1989, Amstrong and Oldham, 1999). Sartorio et al. (2002) reported that age dependent increase of handgrip strength in males and females were strongly associated with changes of muscle mass during their childhood. The stronger grip and taller figure of girls might be the effect of growth hormone after entering puberty.
Generally, the girls enter the pubertal period earlier than boys (Sinclair and Dangerfield, 1998; Tanner, 1989; Deurenberg et al., 1990). Moreover, Rogol et al. (2002) has also demonstrated that pubertal girls are stronger than pre-pubertal boys at the same chronological age. Previous studies have also supported the relationship between age and handgrip strength (Kellor, 1971; Schmidt and Toews, 1970; Shephard, 1987; Chatterjee and Chowdhuri, 1991; Oberg et al., 1994). Shephard (1991) found a linear decrease in muscle strength of 68 percent per decade over the span examined (45-75 years), but in the males the loss was most marked in terms of handgrip. It indicates an increase in the strength of the boys as they grow in age as compared to girls. During adolescence, acceleration in strength gain in males is reported to be more marked than in females. The peak of the strength spurt occurs after the peak of weight and height spurts (Norgan, 1994). Tables 4.73-4.78 showed the normative values of handgrip strength in males and females of different age groups in various populations of the world. On comparing the mean value of handgrip strength of present study with the children of Italy (Table 4.74), it was found that Indian children of age 6-9 years had lower mean values for handgrip. In the present study, the difference in handgrip strength between male and female students widened after 13 years of age, similar to the results of Kellor et al. (1971), who found that by age 20 years, men had about twice the grip strength of women.

Female students too, in the present study, displayed similar trends of gradual increments both in dominant and non-dominant handgrip strength, but they showed lower mean values than their male counterparts. It is a common knowledge that females generally have lesser muscle strength than males and that muscle strength decreases with age. This loss of muscle strength seems to be closely related to a reduced muscle mass, brought about by ageing, inactivity or both (McArdle et al., 1986; Shephard, 1987; Astrand and Rodahl, 1986). Genetic factors are also known to contribute to the interindividual differences in handgrip strength (Fredericksen et al., 2002; Carmelli and Reed, 2000; Tiainen et al., 2004). The sex differences in handgrip strength are also likely due to higher levels of androgenic hormones (Page et al., 2005), greater muscle mass (Kallman et al., 1990), and greater height and weight in males (Kamarul et al., 2006; Kuh et al., 2006). Growth hormone and testosterone have more effects on physical body and performance of boys than girls even though the boys enter pubertal stage later than girls.
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(Sinclair and Dangerfield, 1998; Tanner, 1989). Testosterone levels are one of the leading factors playing a major role in the variation of handgrip strength among males. It has been reported that when testosterone level is increased in men with low serum testosterone, an increase in handgrip strength is found (Page et al., 2005; Sih et al., 1997; Wang et al., 2000).

In male and female students, there was an increase in the mean values of almost all the anthropometric characteristics with the progression of age. Male students showed higher mean values for height than female students in all age groups except 6, 7 and 10-13 years. A continuous increase in height was observed in male students up to 20 years. Similar trends were observed in female students too showing continuous increments of height up to the age of 18 years. After entering puberty, the growth rate of boys becomes higher than girls and it continues up to the age of 18 years, resulting in the boys becoming taller (Gokhale and Kirschner, 2003). The differences in the size between males and females are to a large degree due to the differences in timing and intensity of adolescent spurt. The difference partly comes about because of the later occurrence of male spurt allowing an extra period for growth, even at the slow pre-pubertal velocity and partly due to the greater intensity of the spurt itself (Harrison et al., 1988). Greater body height means greater bone length, which is an important determinant of muscle mass and force (Schoenau et al., 2000; Neu et al., 2002).

The linear growth in the body weight was found to be proportionate to the height of the students. For weight, the mean values continued to rise up to 21 years for male students and up to 18 years for female students. However, female students showed a slight increase in the mean values than male students in the age group of 7, 10-13 years. Most of the body components such as height, weight also increased significantly as reported earlier by Tanner and Marshall (1968). Amongst male students, the mean value for BMI showed an irregular trend from 6-12 years, followed by a steady increase till 18 years. In case of female students, the mean values for BMI showed a steady trend of increment from 6-25 years of age group (except in 16, 19, 21 and 23 years). These values were lower than the values reported for American Indian children of age 5-17 years (Jackson, 1993) and African children (Oyewale et al., 2010). Similar to earlier findings (Chinn et
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al., 1992), present study also showed that BMI was strongly associated with height in children and adults (Table 4.48).

5.1.1 Hand anthropometry

As the age advanced, the trends of the hand anthropometric variables were almost similar for both male and female students up to 13 years. In male students, mean values of hand length increased sharply as compared to female students from 14 to 25 years. In female students, steady trends of increment were observed for hand length up to the age of 15 years. For hand breadth, male students recorded higher mean values than their female counterparts in all age groups (with some exceptions). For 2nd digit length, increasing trends were observed in male students up to 17 years. In female students, a continuous increase in mean values was seen from 6 to 18 years. The mean values for 4th digit length increased in male students up to 17 years, whereas in female students, mean values of this trait followed an increasing trend up to 13 years after which a slight fall was followed by a continual increase till 18 years. Hence, it was observed that both the length parameters and weight parameters increased significantly but proportional to each other as reported by Tanner (1964). In case of 2D/4D ratio, an irregular trend was observed in both the sexes. Female students showed highest mean value for 2D/4D ratio of 0.99 at the age of 21 years, while male students showed minimum value of 0.95 in the age of 20 years.

5.1.2 Circumferential measurements

Male and female students showed almost similar gradually increasing trends for upper arm circumference up to 15 years. Male students exhibited higher mean values of upper arm circumference than female students from 16 years onwards. Upper arm circumference was lower in the younger girls than in the older counterparts, whereas in male students, mean value of this trait spurted in the later age (17-20 years). Upper arm circumference is reported to rise progressively throughout adolescence at a rate greater than that in early childhood (Frisancho, 1981). Similarly, it is also reported to change with onset of puberty (Gasser et al., 1993). The mean values of upper arm circumference in the present study were lesser than those of Portugese children (Sardinha et al., 2012). Hip circumference among male students continued to increase from 6-20 years after which a slight decline was observed. Female students too displayed a gradual increment in mean values from 6 to 25 years (except in 19 and 22 years). However, female students
showed higher mean values for hip circumference than male students in 7, 8, 10-16 and 24-25 years. The greater relative hip circumference in female students than male students is largely due to the specific stimulation of cartilage cells by oestrogens in females (Harrison et al., 1988).

5.1.3 Skinfold measurements

An irregular pattern of variation of skinfolds with age was observed both in male and female students. Female students showed almost higher mean values of skinfolds than male students in almost all the age groups which was similar to the earlier studies (Raizada et al., 1990; Oyewale et al., 2010), indicating more fat deposition in puberty. In the present study, the mean calf skinfold thickness was the highest and biceps skinfold thickness was the lowest in both the sexes from 6 to 25 years. Female students showed a sharp rise in the mean values between the age group of 10-15 years for the biceps skinfold (maximum value at 15 years), 14-17 years for the triceps skinfold (maximum value at 17 years), 11-15 years for the subscapular skinfold (maximum value at 15 years), 11-17 years for the suprailiac skinfold (maximum value at 25 years) and 11-17 years for the calf skinfold (maximum value at 21 years). Male students in the age of 15 years recorded a sharp decline in the mean values for all skinfold parameters. This may be attributed to greater lean body mass in males at puberty with the influence of testosterone and fatty deposits in females with oestrogen and progesterone. In male students, the maximum mean value was found in age group 22 years for biceps skinfold, for triceps, suprailiac and calf skinfolds at 17 years and subscapular skinfold at 23 years. Triceps skinfold thickness has been reported to give the best results for obesity screening in boys and girls aged 10–15 years (Sardinha et al., 2012). With the onset of puberty, the rate of subcutaneous fat deposition and fat distribution are changed, as measured by skinfold thickness (Martinez et al., 1993; Gasser et al., 1993).

5.1.4 Arm anthropometry

In male and female students, a continuous increase was observed in the mean values of upper arm length (upto 19 years in males and 15 years in females), forearm length (upto 19 years in males and 13 years in females) and total arm length (upto 19 years in males and 18 years in females). However, male students showed a steady increase in the mean values between 16-19 years for upper arm length, forearm length
and total arm length. Male students recorded higher mean values for forearm length than females from 14 years onwards and it is probably due to laying down in early foetal life of slightly more active tissue in this area in males (Harrison et al., 1988).

Male students showed higher mean values for humerus and femur biepicondylar diameters and arm muscle area than female students in all the age groups as reported in earlier studies (Toselli et al., 2006). The anthropometric assessment of upper arm muscle area has been repeatedly shown to provide useful information on the nutritional status of children, adolescents, and adults (Frisancho, 1981; Katch and Hortobagyi, 1990).

Male students showed increasing trends for arm area in almost all ages except 7, 10, 14, 21, 24 and 25 years. Female students showed increasing higher mean values of arm area till 15 years after which it showed an irregular pattern with a maximum mean value in the age of 25 years. Increasing trends were also observed for arm fat area in male and female students from 6-12 years followed by some irregular trends. Irregular trends for arm fat index in female students were also observed. This may be due to increase in fat deposition as a secondary sexual characteristic. Higher mean values were observed for percent body fat and lower values for percent lean body mass in female students than male students in all age groups. The values for percent body fat in the age group of 6-11 years were lower than reported for American Indian children (Lohman et al., 1999).

Under the influence of the gonadal steroid hormones and growth hormone, an increase in bone mineral content and muscle mass occurs and the deposition of fat is maximally sexually dimorphic. The typical android and gynoid patterns of fat distribution of the older adolescent and adult is reported to be due to the changes in the distribution of body fat (central compared with peripheral, subcutaneous compared with visceral, and upper compared with lower body) (Johnston, 1992). In boys, the significant increase in lean body mass exceeds the total gain in weight because of the concomitant loss of adipose tissue. As height velocity declines, fat accumulation resumes in both sexes but is twice as rapid in girls. In adults, males have 150 percent of the lean body mass of the average female and twice the number of muscle cells (Bonjour et al., 1991). Different anthropometric variables like BMI, triceps skinfold thickness, body fat and upper arm circumference have been used with reasonable success to detect childhood and adolescent obesity (Sardinha et al., 2012; Lohman, 1981; Roche et al., 1981).
5.2 Age-Group Wise Trends of Handgrip Strength

Amongst boys and girls of age group 6-10 years, boys recorded higher mean values for both dominant and non-dominant handgrip strength as compared to their girl counterparts. Also, statistically significant differences (p<0.001) were observed for the same (Table 4.21). For the remaining variables, statistically significant differences (p<0.05-0.001) were observed in all skinfold measurements, humerus biepicondylar diameter, femur biepicondylar diameter, arm muscle area, arm fat area, arm fat index, percent body fat and percent lean body mass. Similar trends were observed in the age group of 11-15 years also where boys recorded higher mean values for handgrip strength than girls. Statistically significant differences (p<0.05-0.001) were observed for all the variables except height, body weight, 2nd digit length, 4th digit length, 2D/4D ratio, upper arm circumference, upper arm length, forearm length and total arm length (Table 4.22).

In the age group of 16-20 years, male students continued to record higher mean values for both dominant and non-dominant handgrip strength as compared to female students. Statistically significant differences (p<0.05-0.001) were found for all the variables except 2D/4D ratio and biceps skinfold (Table 4.23). Similar trends were observed for the age group of 21-25 years also. However, statistically significant differences (p<0.05-0.001) were observed for all the variables except 2D/4D ratio, hip circumference, biceps skinfold, subscapular skinfold and arm fat area (Table 4.24).

5.3 Correlations of Handgrip Strength with Selected Anthropometric Characteristics

5.3.1 Bivariate correlation

In the context of simple Karl Pearson’s product moment correlations, significant correlations (p<0.05-0.001) of dominant and non-dominant handgrip strength were found with almost all the anthropometric characteristics studied (Tables 4.34 and 4.41). Both dominant and non-dominant handgrip strength showed statistically significant (p<0.05-0.01) positive correlations with height, body weight, BMI, hand length, hand breadth, 2nd digit length, 4th digit length, upper arm circumference, hip circumference, humerus and femur biepicondylar diameters, upper arm length, forearm length, total arm length, arm muscle area and arm area in all the age groups, with arm fat area (in all age groups except 16-20 and 21-25 years in dominant handgrip strength and only in 6-10, 6-25 years with
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non-dominant handgrip strength), percent lean body mass (only in 16-20 and 21-25 years), biceps skinfold (in all age groups except 16-20 years), triceps, subscapular, suprailiac and calf skinfolds (only in 6-10, 11-15 and 6-25 years) (Table 4.34). Significant negative correlations (p<0.05-0.01) of dominant and non-dominant handgrip strength were found with triceps and calf skinfolds, percent body fat (in 16-20 and 21-25 years), arm fat index (in all age groups except 6-10 years). Non-dominant handgrip strength showed significant negative correlations (p<0.05-0.01) with subscapular skinfold in the age group of 16-20 years and 2D/4D ratio in 21-25 years. BMI has been considered as an indicator of obesity in children and adults (Martorell et al., 2000). It has also been associated with height, weight and skinfolds, other factors such as parent’s BMI, level of education and native place etc (Freeman et al., 1995; Chinn and Rona, 2001; Gulliford et al., 2001). It has been reported that the highest rate of weight gain is followed by the highest rate of height gain during the adolescent growth spurt. This leads to acceleration in BMI shortly after reaching the peak height velocity. This rise is more associated with the pubertal development than chronologic age (Riley et al., 1989; Riley, 1990). The present study showed significantly positive correlations of dominant and non-dominant handgrip strength with BMI in both genders in contrast to the earlier reports showing no such relationship (Apovian et al., 2002; Koley et al., 2009; Chilima and Ismail, 2001; Vaz et al., 2002). Chatterjee and Chowdhuri (1991) reported that handgrip strength when measured by Jamar hand dynamometer was positively correlated with weight, height and body surface area. In the present study, no significant correlation of handgrip strength with 2D/4D ratio was found, which followed the earlier reports (Bailey and Hurd, 2005; Millet and Dewitte, 2006). An association between the increase in lean body mass and bone mass in children has been reported (Nelson et al., 1997). In a longitudinal study, Hulthe´n et al. (2001) reported a continuous increase of lean body mass in both healthy males and females between 19 and 21 years of age. It was in contrast with a cross-sectional study of children and young adults aged 4–26 years, conducted by Ogle et al. (1995) where they reported that lean body mass increased until the age of 16.6 and 13.4 years in males and females respectively. They found a close correlation between the increase in lean body mass and the increase in muscle strength.
5.3.2 Linear regression

Linear regression ($R^2$) of dominant and non-dominant handgrip strength with selected anthropometric variables in male and female students of age 6-25 years in different age groups (tables 4.35 and 4.42) showed statistically significant correlations ($p<0.05-0.001$) with all the variables in all age groups except biceps skinfold in 16-20 years, arm fat index in 6-10 years, percent body fat and percent lean body mass in 6-10 and 11-15 year age groups, subscapular skinfold (16-20 years in DHG and 21-25 years in DHG and NDHG), suprailliac skinfold in 16-20 and 21-25 years and 2D/4D ratio in all age groups (except 21-25 years in NDHG). Sartorio et al. (2002) found that fat free mass is a major contributing factor to handgrip strength which is negatively correlated with percent body fat. With the maturity of both the sexes, male students tend to have higher measures of fat-free mass than their female counterparts. This trend of body composition continued up to adulthood (Kyle et al., 2005).

5.3.3 Multiple regression

Multiple regression of dominant handgrip strength with anthropometric characteristics in male and female students of 6-10 years (Table 4.37) showed that hand length ($t = 1.93$), hand breadth ($t = 2.389$), non-dominant handgrip strength ($t = 16.466$) and arm muscle area ($t = 1.985$) correlated significantly ($p<0.05-0.001$) ($R^2 = 0.813$). In the age group of 11-15 years also (Table 4.38), only hand breadth ($t= 2.873$), non-dominant handgrip strength ($t=20.555$) and triceps skinfold ($t= 1.976$) showed significant correlations ($p<0.05-0.001$) with dominant handgrip strength ($R^2 = 0.872$). In the age group of 16-20 years (Table 4.39), significant correlations ($p<0.05-0.001$) of dominant handgrip strength were observed with hand length ($t = 2.088$), hand breadth ($t = 4.322$), hip circumference ($t = 2.066$), suprailliac skinfold ($t = 2.664$), upper arm length ($t = 1.975$), forearm length ($t = 2.004$) and total arm length ($t=2.002$) and percent body fat ($t = 4.410$) ($R^2 = 0.758$). In the age group of 21-25 years (Table 4.40), significant correlations ($p<0.05-0.001$) of dominant handgrip strength were observed with non-dominant handgrip strength ($t = 11.858$), suprailliac skinfold ($t=2.274$) and calf skinfold ($t = 3.054$) ($R^2 = 0.901$). Multiple regression of non-dominant handgrip strength with anthropometric variables in male and female students of 6-10 years (Table 4.44) showed that only dominant handgrip strength ($t=16.570$) correlated significantly ($p<0.05-0.001$) ($R^2 =
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In the age group of 11-15 years also (Table 4.45), only dominant handgrip strength ($t = 20.555$) and arm fat area ($t = 2.038$) showed significant correlation ($p<0.05-0.001$) with non-dominant handgrip strength ($R^2 = 0.865$). In the age group of 16-20 years (Table 4.46), significant correlations ($p<0.05-0.001$) were observed only with dominant handgrip strength ($t = 24.816$) ($R^2 = 0.917$). In the age group of 21-25 years (Table 4.47), significant correlations ($p<0.05-0.001$) were observed only with upper arm circumference ($t = 11.858$) and percent body fat ($t = 2.045$) ($R^2 = 0.889$).

5.4 Evaluation of Handgrip Strength in Sport Persons

Ball games require comprehensive ability including physical, technical, mental, and tactical abilities. The interest in anthropometric characteristics and body composition of athletes from different competitive sports has increased tremendously over the last decades. The present study evaluated the handgrip strength and selected anthropometric characteristics of male and female volleyball and softball players of inter-university level. The findings were compared with their control counterparts and resulted in certain trends.

5.4.1 Volleyball

Volleyball is a team sport in which two teams of six players are separated by a net. Each team tries to score points by grounding a ball on the other team's court under organized rules. Volleyball is a specialized sport, with specific anthropometric, physical and performance traits (Duncan et al., 2006). Many studies have shown that volleyball players possess muscular power, jumping prowess, strength and height in blocking, strength and speed for spiking, endurance, speed and agility, among other anthropometric characteristics (Gualdi- Russo and Zaccagni, 2001; Miltner et al., 2010). Anthropometric attributes of volleyball players correlate with the sport’s technical-tactical demands, (Gualdi- Russo and Zaccagni, 2001; Bayios et al., 2006) as in other team sports such as basketball (Ivanović, 2009), handball (Bayios et al., 2006) and baseball (Hoffman et al., 2009).

In the present study, male volleyball players showed higher mean values than female players for all the variables except BMI, 2D/4D ratio, hip circumference, all five skinfold measurements (i.e. biceps, triceps, subscapular, suprailiac and calf), upper arm length, arm fat area, arm fat index and percent body fat. Highly significant differences ($p<0.001$) were noted between male and female volleyball players in all the variables.
except BMI, 2D/4D ratio, subscapular skinfold, arm area and arm fat area (Table 4.81).

In the present study, the mean height of the male volleyball players (181.80 cm) was greater than the male volleyball players of West Bengal, India (173.10 cm ± 4.19) as reported by Bandyopadhyay (2007), but lesser than the English (191.00 cm ± 5.0) (Duncan *et al.*, 2006), while in female players, the mean height (164.97 cm) was lesser than the American (176.70 cm, ± 4.60) (Ferris *et al.*, 1995) and Japanese (168.70 cm, ± 5.89) (Tsunawake *et al.*, 2003) female volleyball players. In the present study, significantly greater body weight among volleyball players might be disadvantageous for them in attaining a good jumping height as they have to lift a greater weight. On comparing the data for height, weight and skinfolds with the Bahraini ball game players, Indian male volleyball players of the present study showed higher mean values for height as compared to the volleyball, football, handball and basketball players of Bahrain. Also, Indian players were heavier in weight than the Bahraini volleyball players. The subscapular and suprailiac skinfolds of Indian players were greater than the volleyball players but less than the basketball and handball players of Bahrain. Mid upper arm circumference and arm muscle area of Indian players was less while that of mid calf skinfold was more than those of volleyball, basketball and handball players of Bahrain (Abdulrahman *et al.*, 1994).

In the present study, the male volleyball players showed higher mean values for all the variables except BMI, upper arm circumference, hip circumference, all skinfolds (namely biceps, triceps, subscapular, suprailiac, calf skinfolds), arm fat area, arm fat index and percent body fat than their control counterparts (Table 4.79). Highly significant differences (*p* ≤ 0.001) were observed in height, BMI, hand length, 2nd digit length, 4th digit length, non-dominant handgrip strength, biceps, triceps, subscapular, suprailic and calf skinfolds, forearm length, total arm length, arm fat area, arm fat index, percent body fat and percent lean body mass between them. Greater value of height in male players as compared to control group may be attributed to the fact that volleyball elite athletes prerequisite to have greater height and strength in wrist and fingers, due to the nature and the type of the sport. In the present study, the estimated percent body fat of the volleyball players was lesser and percent lean body mass of both the sexes was higher than controls in both sexes, similar to the findings of Koley and Singh (2012). In the present study,
male volleyball players showed higher mean values for triceps, subscapular and suprailiac skinfolds as well as height and percent body fat as compared to Indian sprinters and jumpers. They also showed lower mean values for percent lean body mass and femur biepicondylar diameter (Abraham, 2010). Lower values of skinfolds and percent body fat in sprinters may be due to the fact that sprinters are highly mesomorphic in physique (Tanner, 1964; Sodhi, 1986).

Female volleyball players showed higher values for all variables except hand breadth, upper arm circumference, biceps, triceps, subscapular, suprailiac and calf skinfolds, femur biepicondylar diameter, arm muscle area, arm area, arm fat area and percent body fat as compared to control counterparts (Table 4.80). Highly significant differences \((p<0.05-0.001)\) were observed for height, weight, hand length, 2\(^{nd}\) digit length, 4\(^{th}\) digit length, dominant and non-dominant handgrip strengths, biceps skinfold, humerus and femur biepicondylar diameter, upper arm length, forearm length and total arm length, between female volleyball players and controls. Female players showed higher mean values for height, weight and percent body fat, and lower mean values for percent lean body mass as compared to the literature reported earlier by Koley and Singh (2012). On comparing the results of present study with the female volleyball players of Japan, it was found that Japanese female players have higher mean values for height, body weight but lower mean values for percent body fat (Tsunawake \textit{et al.}, 2003). Literature showed body fat values of sporting women between 12-16 percent depending upon the type of sport (Lohman, 1992). Malá \textit{et al.} (2010) reported a value of 13.72 percent ± 2.4 of fat mass by means of bioimpedance analysis in the Slovak national volleyball players who participated in the European Championship of 2009. According to the study of Bandyopadhyay (2007), volleyball players showed significantly higher lean body mass values than the non-sporting population. This parameter, including all body tissues except for fat deposits, is considered a major precondition for a good performance in volleyball. Studies have shown that various anthropometric and physical characteristics like height, body weight, percent body fat and physical-performance parameters positively correlate with higher performance of the volleyball players (Koley \textit{et al.}, 2010).
An excessive amount of adipose tissue is considered an unused mass, because the athlete’s body has to repeatedly cope with gravitation during locomotion and jumps (Reilly, 1996) which results in a lowering of performance and an increase of demands on energy during the performance of a particular action. In the present study, when the data of Indian female volleyball players aged 18-25 years was compared with female adolescent volleyball players of Rio de Janeiro aged 15-20 years, it was found that the Indian players had lower mean values for three skinfold measurements (biceps, triceps, subscapular) and in arm and hip circumferences. Higher mean value was observed only for suprailiac skinfold in Indian players (Almeida and Soares, 2003). It was reported that the body fat percent of female volleyball players falls in the range of 11.7–27.1 percent (Malousaris et al., 2008; Viviani and Baldin, 1993) and BMI values for female volleyball players of different ages, different nationalities and different competitive levels range between 20.5–22.5 kg/m² (Malousaris et al., 2008; Gualdi- Russo and Zaccagni, 2001). In the present study, female volleyball players showed higher mean values of body fat (26.53 percent) as compared to the findings of Malousaris et al. (2008). The results obtained for female volleyball players in our study showed BMI value of 21.45 kg/m² which was less than the Cuban female volleyball players (22.8 kg/m²) as reported by Carvajal et al. (2012). Some of the physical variations between different athletes represent an interaction between individual characteristics, and selective impacts of different elements of different sports (Power and Howley, 2001; Kraemer et al., 2005).

5.4.2 Softball

Softball is a direct descendant of baseball. It requires speed, strength and endurance (Terbizan et al., 1996). The game of softball is played on a softball field or pitch that includes three bases and a home plate arranged in the shape of a diamond. Softballs are larger than baseballs, and pitches are thrown underhand rather than overhand. Softball is played on a smaller diamond with a softer ball and handgrip plays a crucial role in swing velocity and pitch speed of softball. Softball players require a significant amount of upper body muscle balance due to the specificity of the underarm activity.

In the present study, male softball players recorded higher mean values than their female counterparts for all the variables except for biceps, triceps, suprailiac and calf
Discussion

Male softball players showed higher handgrip strength than female players. According to earlier reports, handgrip strength strongly correlated with various anthropometric characteristics (Benefice and Malina, 1996; Lohman et al., 1988), with males attaining stronger handgrip than their female counterparts (Benefice and Malina, 1996). Statistically significant differences (p < 0.05-0.001) were observed between male and female softball players for all the variables except 2D/4D ratio, biceps and subscapular skinfolds, and arm fat area. Male and female softball players showed lower mean values for hand length and comparable values of hand breadth, 2D/4D ratio as compared to the earlier reports of Koley and Kumamar (2011, 2012).

Both male and female softball players showed higher mean values for dominant and non-dominant handgrip strength than their control counterparts (tables 4.83 and 4.84). This trend was similar to the earlier reports (Koley and Kumamar, 2012). This could be due to regular physical exercise and practice of male and female players. Male softball players showed lower mean values than their female counterparts for all the skinfold measurements except subscapular skinfold (table 4.85). It may be due to sexual dimorphism and training effects. Female softball players showed lower mean values for dominant and non-dominant handgrip strength as compared to the findings of Giardina et al. (1997) but showed significant differences (p<0.05-0.001) in the dominant and non-dominant handgrip strength, similar to the reports of Koley and Kumamar (2011). Female softball players had lower mean values in height, weight and BMI, and higher value in percent body fat as compared to the earlier reports for the female handball players (Leyk et al., 2007). When compared with the study conducted by Koley and Kumamar (2011), almost similar results were obtained for hand breadth, hand length, 2nd digit length, 4th digit length and dominant handgrip strength in both male and female softball players. When the height, weight and BMI of the female softball players of the present study were compared with reported female softball players of India (Koley and Kumamar, 2011), almost similar mean values were observed. In earlier studies conducted on college level athletes, male subjects were reported significantly taller (182.34± 7.59) and heavier (74.95±12.02), while females had a significantly higher percent of body fat (Greene et al., 1998).
In the present study, male softball players had higher mean values in dominant handgrip strength, non-dominant handgrip strength, height, hand length, 2\textsuperscript{nd} digit length, 4\textsuperscript{th} digit length, humerus biepicondylar diameter, femur biepicondylar diameter, forearm length, arm fat index and percent body fat than their control counterparts (Table 4.83). Statistically significant differences (p<0.05-0.001) were found for non-dominant handgrip strength, upper arm circumference, femur biepicondylar diameter, upper arm length, arm muscle area, arm area, percent body fat and percent lean body mass. It may be due to genetic predisposition and growth affected by sports activity.

When female softball players were compared with their control counterparts, it was found that they had higher mean values in dominant and non-dominant handgrip strength, height, hip circumference, humerus and femur biepicondylar diameters, upper arm length, forearm length, total arm length and percent lean body mass than their control counterparts (Table 4.84). However, statistically significant differences (p<0.05-0.001) were found between female softball players and controls in dominant handgrip strength, non-dominant handgrip strength, upper arm circumference, biceps skinfold, femur biepicondylar diameter, arm muscle area and arm area.

5.5 Strength of the Study

1. To the best of our knowledge, the present study was the first of its kind reporting the normative values of handgrip strength in Indian populations covering large age groups from 6 to 25 years.

2. The large sample size comprising of 2167 samples was one of the unique criteria of the study along with 227 sports persons. No such study was reported earlier covering such a vast Indian population.

3. The findings of the study can be used as the age-wise representative reference values of handgrip strength especially of the north India.

4. The findings of the present study can be used to assess the nutritional status of the children as well as adults.

5. The normative values obtained can be used as a baseline to compare the progress during post surgery rehabilitation phase in both normal populations as well as in sports persons.
6. Correlations of both dominant and non-dominant handgrip strength with 26 anthropometric characteristics have been explored in this study. Such a vast number of anthropometric characteristics were not included in any earlier studies to search the correlations with the handgrip strength.

7. The data on the sports persons, collected from volleyball and softball players can be used for their performance enhancement, injury prevention as well as for talent identification in specific sports.

8. To support as well as criticize the present findings, a wide range of very recent references have been used.

5.6 Limitations of the Study

1. Only age groups from 6-25 years were taken.
2. Geriatric groups and people suffering from any kind of diseases were not considered for the study.
3. Samples were selected specifically from Amritsar.
4. Only two ball games were selected for the study.