INTRODUCTION

The learning process of the human beings commences at a very early age that enables them to achieve an extremely wide range of functions and skills with the hand. For example, during the first six weeks of life, babies grasp a finger placed in the hand. With an increase in the voluntary movements, children learn by feeling objects and using all other sensory modalities such as watching and listening. At about three months, babies can roll on to prone position, learn to extend their fingers and support themselves on their forearms (Minett, 1985) acquiring stability of the head on trunk and trunk on hands. At 4-5 months, babies reach out independently for toys and to coordinate movements. Thus, long term evolution over generations has produced anatomical variations from the muscular hand of laborer to the long, tapering fingers of the dancers and artists. The hand represents the most sophisticated and differentiated musculoskeletal tool in the human being, demanding the largest capacity of the nervous system in relation to its size. The complex anatomical and functional structure of the hands converges mainly in gripping, which is observed constantly during the activities of daily living of any individual (Kapandji, 2000). The human hand is unique and devoted entirely to functions of manipulation. Its effectiveness in these activities is due to particular configuration of the bones and muscles which permits opposition of the pulp surface of the thumb to the corresponding surfaces of the other four finger tips in a firm grasp, together with a highly elaborated nervous control and sensitivity of the fingers (Markze, 1971).

High activity levels of the flexor musculature of the forearms and hands are required in many daily functions and sporting events. For example, in sports like wrestling, tennis, and baseball to daily activities such as carrying laundry and turning a doorknob, varying degree of handgrip strength is required. The muscles of the forearm and hand are involved in gripping activities. During such activities, the muscles of the flexor mechanism in the hand and forearm create grip strength while the extensors of the forearm 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).
1.1 Musculo-Skeletal Anatomy of the Hand

1.1.1 The hand complex

The hand is composed of four fingers and a thumb. Each digit has a carpometacarpal joint and a metacarpophalangeal joint. Each finger has two interphalangeal joints, the proximal and distal, and the thumb has only one.

Carpometacarpal joints

The carpometacarpal joints are formed by the articulations between the distal carpal row and the bases of the second through fifth metacarpal joints. The proximal portion of the four metacarpals of the fingers articulates with the distal carpals to form the second through fifth carpometacarpal joints. The second metacarpal articulates primarily with the trapezoid and secondarily with the trapezium and capitate. The third metacarpal articulates with the capitate, and the fourth metacarpal articulates with the capitate and hamate. The fifth metacarpal articulates with the hamate. Each of the metacarpals also articulates at its base with the contiguous metacarpal or metacarpals, with the exception of the second metacarpal, which articulates at its base with the third but not the first metacarpal. All finger carpometacarpal joints are supported by strong transverse and weaker longitudinal ligaments volarly and dorsally (Nakamura et al., 2001; Dzwierzynski et al., 1997). The ligamentous structure is primarily responsible for controlling the total range of motion available at each carpometacarpal joint.

Metacarpophalangeal joints

Each of the four metacarpophalangeal joints of the fingers is composed of the convex metacarpal head proximally and the concave base of the first phalanx distally. Two collateral ligaments at the volarly located transverse metacarpal ligament enhance joint stability. At the metacarpophalangeal joint, stability is provided by the volar plate. The radial and ulnar collateral ligaments of the metacarpophalangeal joint are composed of two parts: the collateral ligament proper, which is cordlike, and the accessory collateral ligament. They also serve to the stability of the joint.

Interphalangeal joints of the fingers

Each of the proximal interphalangeal and distal interphalangeal joint of the fingers is composed of the head of a phalanx and the base of the phalanx distal to it. Each
interphalangeal joint is a true synovial hinge joint with one degree of freedom (flexion/extension), a joint capsule, a volar plate, and two collateral ligaments. Volar plates reinforce each of the joint capsules and enhance stability, limiting hyperextension. Stability is provided by the collateral ligament complex because some portions remain taut and provide support throughout proximal interphalangeal and distal interphalangeal joint motion (Tubiana et al., 1996; Minamikwa et al., 1993; Rhee et al., 1992).

Structure of the Thumb

Carpometacarpal joint of the thumb

The carpometacarpal joint of the thumb is the articulation between the trapezium and the base of the first metacarpal. The first carpometacarpal joint is a saddle joint with two degrees of freedom: flexion/extension and abduction/adduction.

Metacarpophalangeal and Interphalangeal joints of the thumb

The metacarpophalangeal joint of the thumb is formed by the articulation between the head of the first metacarpal and the base of its proximal phalanx. It is considered to be a condyloid joint with two degrees of freedom: flexion/extension and abduction/adduction (Ranney, 1995). The joint capsule, the reinforcing volar plate, and the collateral ligaments are similar to those of the other metacarpophalangeal joints. The first metacarpophalangeal joint provides additional flexion range to the thumb in opposition and allows the thumb to grasp and contour to objects. The interphalangeal joint of the thumb is the articulation between the head of the proximal phalanx and the base of the distal phalanx. It is structurally and functionally identical to the interphalangeal joints of the fingers.

1.2 Musculature of Forearm and Hand

Anterior compartment of forearm

The anterior compartment of the forearm consists of pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, and pronator quadratus.

Posterior compartment of forearm

The posterior compartment consists of the brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi,
extensor carpi ulnaris, supinator, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, and extensor indicis.

**Muscles of the hand**

The muscles of the hand can be divided into three groups i.e. thenar muscles, hypothenar muscles, and short muscles. The thenar muscles include abductor pollicis brevis, flexor pollicis brevis, opponens pollicis, and adductor pollicis. The hypothenar muscles are abductor digiti minimi, flexor digiti minimi brevis, palmaris brevis and opponens digiti minimi. The small muscles include four lumbricals, four dorsal interossei, and four palmar interossei.

**1.3 Arches of the hand**

The arches play an important role during activity. Their adaptability enables the hand to adjust accordingly. Actively they can be flattened by extension movements and passively by pressure or weight bearing on to the hand. Thus, palmar arches allow the palm and the digits to conform optimally to the shape of the object being held. This maximizes the amount of surface contact, enhancing stability as well as increasing sensory feedback. Three types of arches are present:

1. **Longitudinal.**
2. **Transverse.**
3. **Oblique.**

**Longitudinal**

It extends from the proximal row of carpals to the tips of fingers and thumb. Tension between the long flexors and extensors of fingers and thumb together with the interaction of the intrinsic muscles maintain this arch.

**Transverse arches**

These are found proximally through the carpal bones and distally through the heads of the metacarpals. Transverse arches are maintained by the action of all small muscles of the hand.

**Oblique arches**

These arise from the thumb when it is positioned in some degree of abduction and opposition and extend into either the index or little fingers. These are maintained largely
by the activity of thenar and hypothenar muscles in conjunction with the extrinsic and intrinsic muscles of the fingers.

1.4 Prehension

Prehension activities of the hand involve the grasping or taking hold of an object between any two surfaces in the hand. Various types of grips are present depending upon the size, shape, weight and solidity of the object to be held. Prehension can be categorized as either power grip (full hand prehension) or precision handling (finger-thumb prehension) (Melvin, 1989). Landsmeer (1962) suggested that power grip and precision handling can be differentiated on the basis of the dynamic and static phases. Power grip occurs as the result of a sequence of opening the hand, positioning the fingers, bringing the fingers to the object and maintaining a static phase constituting the grip. In contrast, precision handling follows the first three steps of the sequence but does not contain a static phase at all. In power grip, the object is grasped so that the object can be moved through space by the more proximal joints, while in precision handling, the fingers and thumb grasp the object for the purpose of manipulating it within the hand. Precision handling involves skillful placement of an object between fingers or between finger and thumb (Chao et al., 1976).

1.4.1 Power grip

It is achieved by the flexion of the fingers around the object with the wrist stabilized in extension. The object lies diagonally across the palm. The power grip is of four types, cylindrical grip, spherical grip, hook grip, and lateral prehension (Long et al., 1970).

Cylindrical Grip

Cylindrical grip almost exclusively involves use of the flexors to carry the fingers around and maintain grasp on an object. The function in the fingers is performed largely by the flexor digitorum profundus muscle, especially in the dynamic closing action of the fingers. The thumb usually comes around the object, then flexes and adducts.

Spherical Grip

Spherical grip is almost similar to cylindrical grip but the main distinction can be made by the greater spread of the fingers to encompass the object.
**Hook Grip**

Hook grip is a specialized form of prehension. It is a function primarily of the fingers. It may include the palm but never includes the thumb. It can be sustained for prolonged periods of time, as anyone who has carried a briefcase at his side. The major muscular activity is provided by the flexor digitorum profundus and flexor digitorum superficialis muscles.

**Lateral Prehension**

Lateral prehension is a unique form of grasp in which contact occurs between two adjacent fingers. The metacarpophalangeal and interphalangeal joints are usually maintained in extension as the contiguous metacarpophalangeal joints simultaneously abduct and adduct.

**1.4.2 Precision grip**

It is most frequently used form of grasp. Precise and accurate movements can be achieved by the application of the tips of fingers and thumb, utilizing the skin areas with maximum sensory supply. Precision grips can be categorized as pad-to-pad prehension, tip-to-tip prehension, and pad-to-side prehension. Each tends to be a dynamic function with relatively little static holding.

**Pad-to-Pad Prehension**

Pad-to-pad prehension involves opposition of the pad, or pulp, of the thumb to the pad, or pulp, of the finger.

**Tip-to-Tip Prehension**

In tip-to-tip prehension, the interphalangeal joints of the finger and thumb have the range and available muscle force to create nearly full joint flexion. The metacarpophalangeal joint of the opposing finger must also be ulnarily deviated (with fingertip pointed radially) to present the tip of the finger to the thumb. In the first finger, the ulnar deviation occurs as metacarpophalangeal joint adduction. In the remaining fingers, metacarpophalangeal abduction produces ulnar deviation.

**Pad-to-Side Prehension**

Pad-to-side prehension is also known as key grip (or lateral pinch) because a key is held between the pad of the thumb and side of the index finger. Pad-to-side prehension
differs from the other forms of precision handling only in that the thumb is more adducted and less rotated.

1.5 Handgrip Strength

Handgrip strength is a measure of strength of several muscles in the hand and the forearm. Handgrip strength can be quantified by measuring the amount of static force that the hand can squeeze around an instrument called as handgrip strength dynamometer. The force is most commonly measured in kilograms and pounds, but also in millimeter of mercury and in Newtons. It is a reliable measurement when standardized methods and calibrated equipment are used, even though different brands of dynamometers are available (Schmidt et al., 2002). The estimation of handgrip strength and type of grip is of immense importance in determining the efficacy of different treatment strategies of hand and also in hand rehabilitation. Measurement of handgrip strength is commonly performed by physiotherapists to measure baseline deficiency in hand muscle power, to monitor progress during rehabilitation, and to document outcome after rehabilitation. There are several studies that have examined the reliability of the handgrip strength test in untrained children (Clerke et al., 2005; España - Romero et al., 2010; Ortega et al., 2008; Ruiz et al., 2006) and adults (Lagerstrom et al., 1998; Peolsson et al., 2001). Peolsson et al. (2001) and Ruiz-Ruiz et al. (2002) found high reliability of the handgrip strength test in healthy adults using the Jamar and Takey dynamometers, respectively. Gerodimos (2012) found highest reliability of handgrip strength, using the Jamar dynamometer, in pre-pubertal, adolescent and adult male basketball players. Handgrip strength in English children was found to be broadly similar to existing European data (Cohen et al., 2010). Measurement of handgrip strength may be useful for detecting neurotoxic exposure (Charles et al., 2006). In certain occupations like farm work, workers are exposed to some hazardous neurotoxic substances which may adversely affect their muscle strength and nervous system. Ho et al. (2000) found that the mean grip and key pinch strength of the left hand was about 90 percent that of the right hand and the mean grip and key pinch strength of the women was about 60 percent that of men in a study on 15 to 22 year old Chinese students.

Handgrip strength is widely used in adults as an indication of muscle strength in fitness testing, (Bookwalter, 1950; Cotton and Johnson, 1968) and is seen as the single
Grip strength has been used as an indicator of overall muscle strength (Bassey and Harries, 1993; Kallman et al., 1990; Wind et al., 2010; Koley et al., 2008). Handgrip strength is also frequently used as a single or as part of indicators of frailty (Fried et al., 2001; Syddall et al., 2003). Tietjen-Smith et al. (2006) found a direct correlation in grip strength and overall body strength in very old and oldest females. Many of the research studies correlated grip strength to various other physical variables including nutritional status, rotator cuff weakness, fatigue, and overall physical function. Heavier men are shown to have better handgrip strength than lighter men, which is likely to be due to the contribution of lean mass, while women showed reverse trend which may be attributed to their greater proportion of body fat (Kuh, 2002 and 2005; Sternfield, 2002). Handgrip strength is a measure predictive of social behavior in older adolescent males (Gallup et al., 2010). Adolescents who had continuous growth hormone deficiency, showed a decrease in lean body mass as compared with the patients defined as having sufficient endogenous growth hormone. (Hulthe´n et al., 2001).

Occupational therapists have also investigated grip strength measures as an index of strength and dexterity in university students and have used the test in the assessment of clinical progress after treatment (Kellor et al., 1971; Agnew and Maas, 1982). Assessment of hand strength assumes importance in a number of situations and it has been used as an objective clinical measure in a variety of situations. 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). A reliable handgrip assessment is important when assessing the results of various surgical treatments. Few clinical studies confined to a surgical setting have shown the association of lower grip strength with increased post-operative complications (Guo et al., 1996; Klidjian et al., 1980). Le Cornu et al. (2000); Webb et al. (1989) also showed a relationship between pre-operative grip strength and post-operative length of stay.

Grip strength is a marker for overall fragility and general health and for the adequacy of skeletal loading exercise (Kritz-Silverstein et al., 1994). Handgrip strength
appears to be a convenient and suitable phenotype for identifying environmental and genetic factors influencing mid- to late-life physical functioning (Frederiksen, 2002; Karasik, 2005). Genetic factors also contribute to inter-individual differences in handgrip. Cournil et al. (2010) investigated the pattern of inheritance of handgrip strength by analyzing correlations between individuals aged 90 years and older and one of their offspring in three different European regions in Denmark, France, and Italy. They found that handgrip trends in women may be mediated more through the paternal than the maternal line.

Handgrip strength is influenced by a number of factors including age, gender, handedness, motivation, and position of extremity during test (Thorngren and Werner, 1979; Hantén et al., 1999; Gilles and Wing, 2003; Tredgett and Davis, 2000; Oxford, 2000; Kuh, 2005; Vianna et al. 2007). Several studies have shown that handgrip strength decreases with age from mid-adulthood onward, reflecting biological decline in muscular strength (Frederiksen et al., 2006; Rantanen et al., 1998; Van Lier and Payette, 2003). Significant association of handgrip strength is found with gender and a decreasing trend of handgrip is observed with age (Budziareck et al., 2008). Handgrip strength decreases with increasing age for both dominant and non-dominant hands (Adedoyin et al., 2009). A study by Incel et al., (2002) concluded that the dominant hand is significantly stronger in right handed subjects but no such significant difference between sides could be documented for left handed people. In certain studies, grip strength is found to diminish curvilinearly with age, and men are consistently stronger than women. Analysis of grip strength by gender shows higher grip by males at all ages, and analysis by age group demonstrates a peak of grip strength in the fourth decade and then a gradual decline in grip strength for both genders (Angst et al., 2010; Bohannon et al., 2006; Bassey and Harries, 1993; Mathiowetz et al., 1985). This trend is always present even though some studies divide participants by age, gender, and then by right and left hand, while a small number of studies divide participants by age gender and then dominant and non-dominant hand (Bohannon et al., 2006). Wide variation in grip strength exists between individuals of the same age, and well documented influences include gender, size and physical activity (Bassey and Harris, 1993).
Another important factor affecting handgrip strength is hand span (Härkönen et al., 1993; Ruiz-Ruiz et al., 2002). Strong predictors for handgrip strength are sex, age, body height and mid-forearm circumference (Chong et al., 1994 and MacDermid et al., 2002) whereas weaker predictors are body weight and hand size measures (MacDermid et al., 2002). Ranganathan et al., (2001) observed more pronounced decrease in the ability to maintain steady submaximal pinch force in women than men. Aging thus has a degenerative effect on hand function. Other factors like midlife physically strenuous work, excess body weight, smoking, cardiovascular disease, hypertension, diabetes mellitus, and asthma results in decline in muscle strength with increase in age. In addition, pronounced weight loss, becoming physically sedentary, persistent smoking, coronary heart disease, other cardiovascular disease, diabetes mellitus, chronic bronchitis, chronic back syndrome, long-lasting cardiovascular disease, hypertension, and asthma are also associated with acceleration of decline in handgrip strength. Lifestyle and physical health earlier in life determine rate of muscle strength decline in old age. (Stenholm et al., 2012). Carmelli and Reed (2000) investigated aging-related changes in the contribution of genetic and environmental influences to handgrip strength in late adulthood and concluded that the stability in handgrip strength in late adulthood is primarily due to the continuity of genetic and familial influences. Grip strength is related to total muscle strength.

One’s grip strength plays a key role in injury prevention and overall strength development (Budoff, 2004; Fry et al., 2006; Tietjen-Smith et al., 2006; Yasuo et al., 2005). It has widely been studied as an important factor in sports, especially in ball games like basketball, volleyball, judo, tennis etc. Ball games require comprehensive ability including physical, technical, mental and tactical abilities. Among them, physical abilities of players exert marked effects on the skills of the players themselves and the tactics of the team. Both morphology and functional properties of hand are therefore important for the performance in the ball games.

There is a strong correlation between grip strength and the anthropometric measures like weight, height and, in particular, hand length in normal subjects (Chandrasekaran et al., 2010), as well as sports persons (Mitchell et al., 2011; Watts et al., 2003; Mermier et al., 2000; Koley et al., 2010). Häger-Ross and Rösblad (2002)
conducted a study on 530 Swedish 4-16 year olds and found an increase in grip strength with age in both boys and girls approximately parallel until 10 years of age, after which boys were significantly stronger than girls. Right-handed children were significantly stronger in their dominant hand, while left-handers did not show any strength difference between the hands. Jakobsen et al. (2010) reported a relation between handgrip strength and physical activity in healthy female subjects and male patients. Some researchers reported a positive relationship between grip strength and BMI in both genders and all ages, while others found no relationship (Apovian et al., 2002; Koley et al., 2009; Vaz et al., 2002; Chilima and Ismail, 2001; Pieterse et al., 2002). It is widely accepted that, grip and pinch strength measurements provide an objective index of the functional integrity of the upper extremity (Balogun et al., 1991). The major external factors known to be associated with muscular strength are physical activity, health, and nutritional status (Rantanen et al., 2003). Nutritional status has also been primarily correlated to handgrip strength. Guo et al., (1996); Kenjle et al., (2005) found grip strength to be a strong predictor of an individual’s nutritional status. One’s nutritional status leads to specific levels of body mass, which in turn has been found to correlate directly to grip strength. Lower handgrip strength along with low body composition was observed in malnourished patients in a study by Kruizenga et al. (2006). Grip strength in various clinical and epidemiologic settings has shown its suitability as marker of nutritional status in cross-sectional as well as intervention studies (Norman et al., 2011). Handgrip strength also predicts changes in functional, psychological and social health among oldest old (Taekema et al., 2010). Poor nutritional status has been associated with poor handgrip strength, independent of sex, age and height (Pieterse et al., 2002). Humphreys et al. (2002) showed that the hospitalized patients in whom functional status declined during hospital stay, on admission, had lower left handgrip strength. 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). A highly sectional relationship between mid-forearm cross-sectional area and grip in normal subjects and rheumatoid arthritis patients has been shown (Helliwell and Jackson, 1994). Loss of handgrip and function is a major cause of disability in patients with rheumatoid arthritis. Such dysfunction results from pain or fear of pain, reflex inhibition, disuse atrophy and
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eventually mechanical disruption. Handgrip measurement is a simple non-invasive method of measurement, which may provide nutritionists and medical professionals with valuable screening data, prior to further more invasive testing.

Bragagnolo et al. (2011) found handgrip strength and adductor pollicis muscle thickness as reliable indicators of post-operative outcome in patients undergoing major abdominal operations. Handgrip strength has also shown correlation with the presence and absence of fibromyalgia and its severity in women (Aparicio et al., 2011). Low grip strength in healthy adults predicts increased risk of functional limitations and disability in higher age as well as all-cause mortality.

Epidemiological studies have shown that grip strength measured in middle-aged and older people is a powerful predictor of functional decline, disability and mortality (Rantanen et al., 1999, 2000; Laukkanen et al., 1995). Goh et al. (2001) performed a study on the effects of one night of sleep deprivation and its effects on hormonal profile and performance. They performed grip strength and hormonal profile testing at different times throughout the day and found that changes in grip strength occurred as a function of time of day. Grip performance increased progressively during the day, but declined during the night. Cappaert, (1999) had similar findings, concluding grip strength also showed time of day differences with the peak in the afternoon. He also concluded that time of day differences in endocrine function, as measured by plasma cortisol and β endorphin as well as levels of catecholamines in the urine mirrored the differences in muscular strength. Handgrip strength was found to be significantly lower in the very low birth weight children for left and right hands tested individually and for both hands used concurrently (Ford et al., 2008).

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). Longitudinal studies suggest that poor grip strength is predictive of increased mortality from cardiovascular disease and from cancer in men, even when factors of muscle mass and body mass index are adjusted for (Gale et al., 2007; Rantanen et al., 2003).

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).

1.6 Aims and Objectives

Normative data on grip strength in children is very limited, thereby making it difficult for the therapist to distinguish between the grip strength of children with and without disabilities (Robertson and Deitz, 1988). From the best of our knowledge, the normative values of handgrip strength in different Indian populations are still unreported. Though some sporadic literature is available, but comprehensive database collected in organized way is essential. So, the present study was planned with the following objectives:

- To estimate the trends of handgrip strength in children, adolescents and adults of Amritsar covering a wide age range from 6-25 years.
- To study the gender differences on the basis of handgrip strength in various age groups.
- To search any association of handgrip strength with different anthropometric traits of the population studied.
- To estimate the handgrip strength of volleyball and softball players aged 18-25 years for performance enhancement and talent identification.

1.7 Hypothesis

Normative values of handgrip strength of Indian population would differ between the two sexes and also from other populations. There would be some associations between handgrip strength and selected anthropometric characteristics in the studied population. There would be considerable differences in handgrip strength in sports persons of various sports events.