

## Estimation of hand index for male industrial workers of Haryana State (India)

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### Abstract

This work analyses the right hand anthropometric dimensions of 1540 male industrial workers of the age ranging from 18 to 62 years belonging to four different divisions of Haryana state of India. Hand index derived from measured hand dimensions can be used to estimate differences related to sex, age and race in forensic and legal sciences. It has been calculated as percentage of hand breadth over the hand length; which suggests that the male industrial workers population of state belong to mesocheir group of hands. The hand length, breadth and derived index of the subjects have been compared with population of the twelve other states of the country. Comparison of hand length, hand breadth and hand index of the subjects of the state has also been made with the male population of twenty-five other countries. There exist significant differences in hand anthropometric – amongst male population of different countries and also within country - which must be taken into consideration while designing the hand tools or equipment to be controlled by users' hands of different populations.

*Keywords:* Hand length, hand breadth, hand index, population identification.

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### 1. Introduction

The hand acts as a chief tactile apparatus and is endowed with gripping and precision movements for skilled works (Chaurasia, 1995). Most of human mechanical interactions with the surrounding world are performed by hands. They allow us to perform very different tasks; from exerting high forces (e.g. using a hammer) to executing very precise movements (e.g. cutting with a surgical tool). This versatility is possible because of a very complex constitution: a great number of bones connected through different joints, a complicated musculature and a dense nervous system. This complexity is already evident from the kinematics point of view, with more than 20 degrees of freedom (DOF) controlled by muscles, tendons and ligaments. However, the hand bones have been documented as good anthropometric parameters and had proven to exhibit great ethnic variations (Sancho-Bru et al., 2011). There is a long record of discussions on human variation in anthropometric research. Anthropologists observed and compared the relationship between body segments to highlight variations between ethnic origins (Lucia et al., 2002). Anthropometric data finds valuable applications in many professions, particularly in ergonomics, medicine and different areas of design. The need for determination of people from skeletal remains in living and non-living population for genetic, anthropological, odontologic and forensic purposes has been documented by several researchers. Anthropological measurements of the skeleton and the comparison with existing standard data must then be applied and may help to differentiate between male and female (Vandanaet al., 2008). These have become useful in recent times due to mass disasters like plane crash, mass suicide, forest fires, terrorists attacks and earth quakes. In the past, determination of anthropological variables such as sex, age and stature had been done from osteological analysis of the hand and foot bones (Dayal et al., 2008).

The human hand which is the most used and versatile part of the body; is of great scientific importance to investigators, particularly in the field of anthropometry, forensic pathology, orthopaedic surgery and ergonomics. Besides that every ethnic

group and person need to feel that their unique requirements are understood and addressed when it comes to design. Imrhan et al. (1993) stated that hand anthropometry is useful for determining various aspects of industrial machineries so as to design the equipment and machines for better efficiency and more human comfort. It has been well-established fact that for the scientific design of hand tools and hand equipment, hand anthropometric database is a prerequisite. Hence, to achieve better efficiency, performance, safety and more human comfort, it is necessary to design the equipment keeping in consideration the workers capabilities and limitations.

There has been a growing demand of the professional hand tool users to have ergonomically designed products (Schmidtke, 1984; Snow and Newby, 1984). Some reported occupational risk factors accounting for upper limb cumulative trauma disorders (CTD) are: hands held in fixed position over long periods, repetitive exertions and motion with flexed or hyper extended hand or wrist, pressure at the base of the palm, persistent strain, gripping, jolting, vibration, forearm pronation or supination & extreme hand and wrist postures among others (Armstrong and Silverstein, 1987). These risk factors can produce internal reactions within the workers' upper limb such as compression of nerves, deformation of tissues or decreased circulation (Martin et al., 1996).

Ducharme (1977) observed that soldering tools, pliers and wire strippers caused frequent complaints in women workers, due to dimensional incompatibility and improper usage of tools. In adults, sexual differences are evident in hand length measurements and in hand width to length ratios (Mcfadden and Shubel, 2002). Although this has been reported by several researchers but the obvious truth remains that standards of morphological and morphometric sex differences in the skeleton may differ with the population sample involved especially with reference to dimensions and indices and thus cannot be applied universally (Krogman and Iscan, 1986).

In recent decades, as many countries have been enjoying the rapid economic growth brought upon by globalization, people begin to ask for products and environments that better suit their own requirements. This trend has led to the emergence of mass customization, in which anthropometric data becomes a basic design requirement (Wang and Chao, 2010). Mandahawi et al., (2008) stated mismatch between hand anthropometric dimensions and equipment's are known to be contributing factor in decreased productivity, discomfort, accidents, biomechanical stresses, fatigue, injuries and cumulative occupational trauma disorders associated with the improper use and cumulative exertion of the wrist and hand, include osteoarthritis, dislocations or subluxations, synovitis, ligament strains, ganglia, tenosynovitis, trigger finger, intrinsic muscle strains and carpal tunnel syndrome they occur in people performing repetitive handwork (Nag et al., 2003).

Anthropometry is the scientific measurement and collection of data about human physical characteristics and the application (engineering anthropometry) of these data in the design and evaluation of systems, equipment, manufactured products, human made environments, and facilities (Park et al., 2009). Mokdad and Al-Ansari (2009) has seen a lot of interest in children, especially school children as it is well known that many postural problems, such as back pain and repetitive strain injuries, start at an early age. Therefore, ergonomics design for children is as important as designing for adults. Anthropometric data are essential for this design. The assessment of the physical dimensions of the human hand provides a metric description to ascertain human-machine compatibility in the design of manual systems for the bare and gloved hand e.g. design of hand tools, workplace, clothes, knobs and controls, personal equipment, consumer appliances in the home, industry and many products for human use (Chandra et al., 2011).

The proper matching of machine requirements with the human capabilities is basically necessary for optimum performance of man-machine system. For efficient design/design refinement of machinery/equipment, it is necessary to follow the guidelines and principles of ergonomics, which provide an orientation towards physiological and psychological needs of operators. The design of equipment is always a compromise between the operator's biological needs, which are determined by the ergonomics guidelines, and physical requirements of the machinery/equipment (Das and Grady, 1983; Das and Sengupta, 1996). In this regard, the basic information required is the anthropometric body dimensions of the users of tools and equipment (Dewangan et al., 2008). A high level of safety and worker efficiency can be achieved. This means of user-centered design involves the product, the user, and the task. However, variation in body dimension among people, between the sexes, and among different races, can make product design problematic. While it is impossible to design systems to suit all body types and sizes, it is prudent to deal at least with the important dimensions (Chuan et al., 2010).

Risley (1915) classified the Indian population into seven racial types namely, Turko-Iranian, Indo-Aryan, Scytho-Dravidian, Aryo-Dravidian, Mongolo-Dravidian, Mongoloid and Dravidian. The population of Northern region of India basically belongs to Indo-Aryans, though there is a lot of intermingling of other racial population as well. Designs without due consideration to the body dimension of intended users do not serve their purpose and have less user acceptance value and also results into numerous medical problems. Wrongly-designed systems induce improper postures, leading to operational uneasiness and musculo-skeletal and some physiological disorders. Hence, the human and the product geometry must be suitably fitted together to make the product safe and satisfying for the users (Chandna et al., 2010).

Population differences in anthropological studies have been noted and it is well realized that they need to be studied separately (Telkka, 1950). Earlier studies have observed that various hand measurements tend to differ in various ethnic groups (Okunribido, 2000; Davies et al., 1980). It has also been emphasized that differences in body dimensions among population and ethnic origins are as a result of differences in nutrition and levels of physical activity (Malina, 1994).

The present investigation is an attempt to find the hand index from selected hand dimensions of the male industrial workers of Haryana state using statistical considerations (extreme giant and dwarf are rejected). Further in this study anthropometric

measurement of the length and breadth of hand dimensions of 1540 industrial workers of Haryana state is compared with existing standard hand anthropometric data of other states of India and male populations of other countries of the world in terms of with the characterization of hand index, which may help to differentiate between populations. The study will, have lot of significance including plastic and reconstructive surgery of hands where the available dimensions of the extremities may be used in post-traumatic reconstruction of the other.

## 2. Methodology

Haryana is a landlocked state of Northern region of India. It is located between  $27^{\circ}37'$  to  $30^{\circ}55'$  N latitude and between  $74^{\circ}28'$  and  $77^{\circ}28'$  E longitude. Haryana state of country has total geographical area of 44212 sq. meters. Twelve major districts shown in Figure 1 were chosen as sampling location to represent a wide diversity of male industrial populations from vast geographical areas across Haryana. The numbers of subjects selected for measurement, from 12 districts of four divisions in Haryana are presented below in Table 1. The range of industries considered for data collection are: automobile, railway workshops, agricultural sectors, metal sectors, tools and instruments among others, mainly located in the four different divisions of the state.



Figure 1. Geographical locations of Haryana

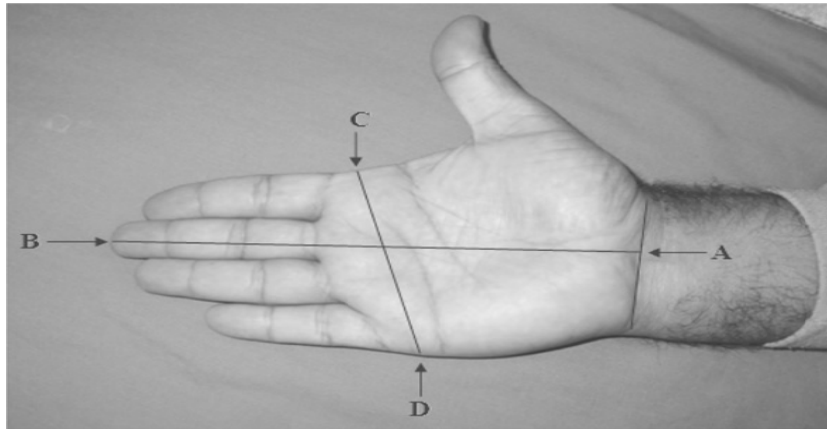
Table 1. Subjects distributions

S.No.	Location	Districts Considered	Number of Subjects
1	Ambala division	Ambala, Kurukshetra and Yamuna Nagar	305
2	Rohtak division	Karnal, Panipat and Sonipat	326
3	Gurgaon division	Gurgaon, Faridabad and Mahendragarh	586
4	Hissar division	Hissar, Bhiwani and Jind	323

An important planning goal of the present study was to include maximum categories of industrial workers thus no restrictions were placed on the height, weight, social status or ethnic group of the workers. Age of the inclusive subjects varies from 18 to 62 years with an average age of 36.49 years. Mean stature height and body weight of the subjects are found as 1641 mm and 63.13 kg with standard deviation of 73.12 mm and 10.39 kg respectively.

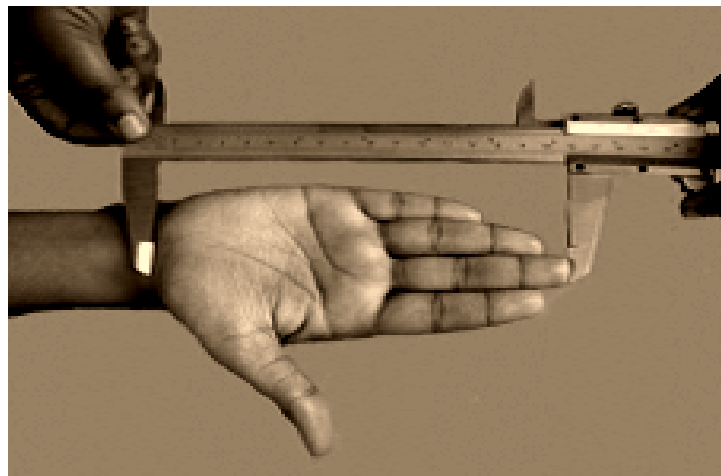
Under the supervision of trainer and faculty members, survey teams consisting of eight members were trained during training they were familiarized with the measuring techniques, location of landmarks, etc. and by allowing them to take the measurements of hostel residents as subjects. Only after their measurements were considered to be accurate, reliable and consistent they were being sent to industries for data collection team spent around fifteen months to collect data from thirty eight different industries of Haryana. During the measurement of hand dimension, proper care has been taken to avoid any excessive compression of underlying tissues and to record the measurement precisely. Measurements were, wherever possible, conducted in an enclosed area or room to ensure the privacy of subjects. All measurements were taken on level, non-carpeted floor well lit for maximum accuracy. The measurements were taken in proper order and in the same sequence for all subjects between 9:30 am to 5:00 pm. Industrial workers with any disease, deformity, injury, fracture, amputation or history of any surgical procedures of either hand

were excluded from the study. Subjects were selected according to their availability and willingness to participate without any payment or incentives, based on their origin and racial strain criteria for ensuring that the samples were true representatives of their respective target population. The effect of hand dominance on measurements has been suggested (Means and Walters, 1982); hence, left-handed industrial workers were excluded. The measurements were taken by only one observer in order to avoid inter-observer error. The land marking of hand length and hand breadth are done as shown in Figure 2. Measurements were recorded for right hand to the nearest millimeter using standard anthropometrical instruments (vernier caliper) according to the techniques described by Vallois (1965).



**Figure 2.** Human hand illustrating the landmarks; hand length (A-B) and hand breadth (C-D)

**2.1 Hand length:** Hand length (HL) is the projected distances between the point's interstylium and the tip of the third finger. Interstylium is the middle point of the line connecting the point styliumradiale (the most distal point on the styloid process of radius) and styliumulnare (the most distal point on the styloid process of ulna) Figure 3. The subject is asked to stand erect. The hand, being pendent along the body, is held with the left hand, which presses on the fingers to keep them fully extended. The measuring apparatus, held in the right hand is placed along the radial border at the hand, its stem being strictly parallel to the axis of the hand (the axis of the medius extending the axis of the forearm). The end of the upper branch is applied to the inter stylium point and the end of the lower branch to the tip of the third finger and the reading is recorded as explained by Kanchan et al., (2010).



**Figure 3.** Measurement of the hand length

**2.2 Hand breadth:** Hand breadth (HB) is the distance between the most prominent points outside of the lower epiphyses of the 2nd metacarpal (metacarpal radiale) to the most prominent inside point of the lower epiphyses (metacarpal ulnar) of the 5th metacarpal. Metacarpal radial is the point most medially projected on the head of the 2nd metacarpal when the hand is stretched and metacarpal ulnar is the point projecting most laterally from the head of the 5th metacarpal as shown in Figure 4. The measurement is taken over the dorsum of the hand in full extension as explained by Kanchan et al. (2010). It is easy to locate the points by palpation of the landmarks corresponding to the heads of the metacarpal. Breadth is somewhat oblique with regard to the axis of the hand.



**Figure 4.** Measurement of the hand breadth

**2.3 Hand Index:** Hand index is defined as the percentage variation of hand breadth to hand length. Table 2 introduced five classes of hand indices based upon measurement of length and breadth of hands for classification of population (Krogman and Iscan, 1986).

$$\text{Hand index} = \left( \frac{\text{hand breadth}}{\text{hand length}} \right) \times 100$$

**Table 2.** Classification of Hand based upon the value of Hand Index

S.No.	Hand Index	Classification
1	$\leq 40.9$	Hyperdolichocheiri (hdch)
2	41.0-43.9	Dolichocheiri (dch)
3	44.0-46.9	Mesocheiri (mch)
4	47.0-49.9	Brachycheiri (bch)
5	$\geq 50.0$	Hyperbrachycheir (hbch)

A good measure to describe the shape of the hand is the so-called 'hand index', which is defined as the ratio between the 'hand breadth' (palm width measured at the metacarpals) vs. the 'hand length' (the distance between the tip of the middle finger and the distal wrist crease). Characteristics of various hands are - Hyperdolichocheiri (hdch) hands have very long fingers with narrow smaller palm, dolichocheiri (dch) hands shape indicates long fingers and narrow small palm, mesocheiri (mch) hands are with long fingers and short small palm, brachycheiri (bch) hands have short fingers with long large palm whereas hyperbrachycheir (hbch) hands have short fingers with broader large palm respectively.

Hand shape varies between the sexes: males typically have larger and relatively broader hands. Hand shape also varies among the races: in Asia the average hand shape is relatively narrower than in European and North American countries. But in order to understand these patterns properly, one first has to understand the relationship between hand shape and body length. Because in general, all longer populations in the world (males, Europeans and North Americans) typically display a relatively broad hand shape, while all small populations (females, Asians) typically display a relatively slender and narrow hand shape.

In males the 'hand index' is typically higher than 44, and measures above 45 are often seen. While in females the 'hand index' is typically lower than 44, and measures below 43 are not rare at all. These sex differences are for a large part the result of the body height differences between males and females.

The value of hand index classifies the type of hand as country like India is well known for human diversity in anthropometry i.e. differences in the morphological characters amongst inter and intra population exists. Variations in the hand dimensions are influenced by various factors like nutritional status, socio-economic status and climate. Hand index which is derived from hand dimensions can be used to estimate differences related to sex, age and race in forensic and legal sciences. Hence the human population tends to have certain specific characters which stamp them as residents of a particular place in the world. The hand length and hand breadth have been found to show high accuracy in sex/nation determination when compared to indices. When a dismembered upper limb is encountered, the dimensions of hand can help to determine the resident place of the individual. The dimensions of hand may also provide guidance in planning for the selection of free skin graft in plastic surgeries. Male population of different countries of the world have different hand index based upon their hand anthropometric dimensions. Based on the nation/state using the value of hand index for the population best possible fit could be obtained.

### 3. Results and discussions

The data obtained from measurement were computed and analysed using SPSS (Statistical Package for Social Sciences, version 16.0) computer software. Table 3 represents the values for- mean, maximum, minimum, standard deviation and coefficient of variance of hand length and hand breadth for male industrial workers population of Haryana state.

**Table 3.** Summary of measured hand dimensions

Hand dimension	Mean (mm)	Maximum (mm)	Minimum (mm)	Standard deviation	Coefficient of variation
Hand length	186.52	208.00	166.00	8.13	4.36
Hand breadth	84.29	95.00	73.40	4.04	4.79

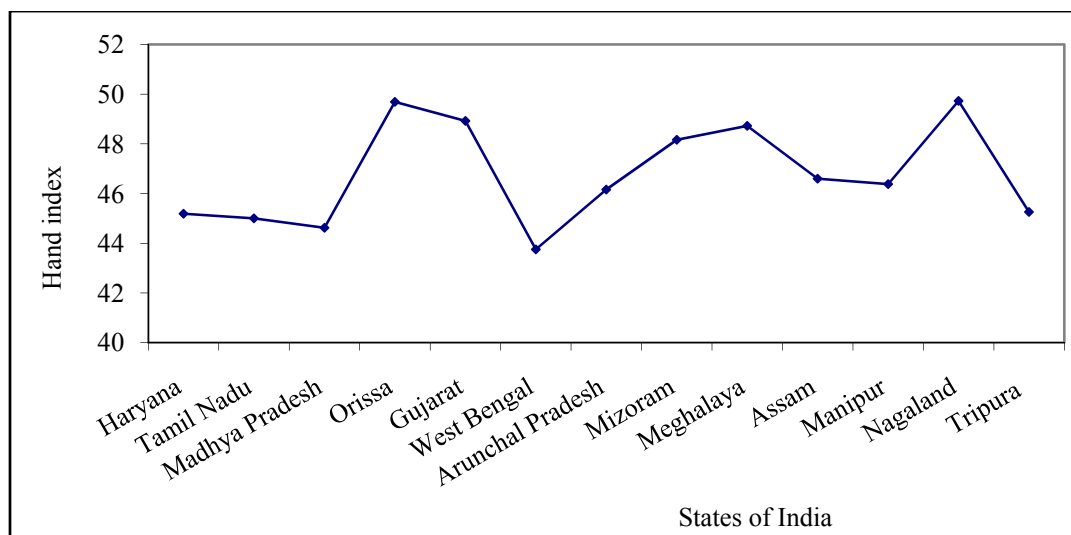
The average hand length for population was  $186.52 \pm 8.13$  and average hand breadth was  $84.29 \pm 4.04$  for male industrial workers of Haryana state, while the average hand index of right hand for male workers were 45.19. The hand index of the workers indicates that the male industrial workers population of Haryana state belongs to Mesocheri (mch) group. Table 4 provides the comparison among hand length, hand breadth and hand index of male industrial of Haryana state to male population of 12 other states of India.

**Table 4.** Comparison of mean values of hand length, hand breadth and hand index of male population of different states of India

S.No.	States	Hand breadth (mm)	Hand length (mm)	Hand index
1	Haryana (Present study)	84.29	186.52	45.19
2	Tamil Nadu (Agarwal et al., 2010)	81.00	180.00	45.00
3	Madhya Pradesh (Agarwal et al., 2010)	83.00	186.00	44.62
4	Orissa (Agarwal et al., 2010)	81.00	163.00	49.69
5	Gujarat (Agarwal et al., 2010)	91.00	186.00	48.92
6	West Bengal (Tewari et al., 2007)	77.00	176.00	43.75
7	Arunachal Pradesh (Dewangan et al., 2005)	84.10	182.20	46.16
8	Mizoram (Dewangan et al., 2005)	85.00	176.50	48.16
9	Meghalaya (Dewangan et al., 2005)	87.70	180.00	48.72
10	Assam (Dewangan et al., 2005)	82.30	176.60	46.60
11	Manipur (Dewangan et al., 2005)	83.40	179.80	46.38
12	Nagaland (Dewangan et al., 2005)	90.50	182.00	49.73
13	Tripura (Dewangan et al., 2005)	81.20	179.40	45.26

Hand length of Haryana male industrial workers population is very near to the male population of Madhya Pradesh and Gujarat but higher than the values of the other states of India. The value of hand breadth of male industrial workers population of the Haryana state is lower than that of male population of Gujarat, Mizoram, Meghalaya and Nagaland but higher than the male population of Tamil Nadu, Madhya Pradesh, Orissa, West Bengal, Arunachal Pradesh, Assam, Manipur and Tripura.

The comparison of hand index of different male population indicates that the male population of India belongs to either of three groups that are- Dolichochei (dch), Mesocheri (mch) and Brachychei (bch). The male population of West Bengal have hand index as Dolichochei (dch), male population of Haryana (industrial workers) and male population of Tamil Nadu, Madhya Pradesh, Arunachal Pradesh, Tripura and Assam have same hand index - Mesocheri (mch) whereas male population of five other states - Orissa, Gujarat, Mizoram, Meghalaya and Nagaland have hand index as Brachychei (bch). Although there exists variation among hand length and hand breadth for the male population having same hand index. Study of the Figure 5 also shows that the male industrial population of Haryana differ in their anthropometric characteristics with the male population of other states of India.



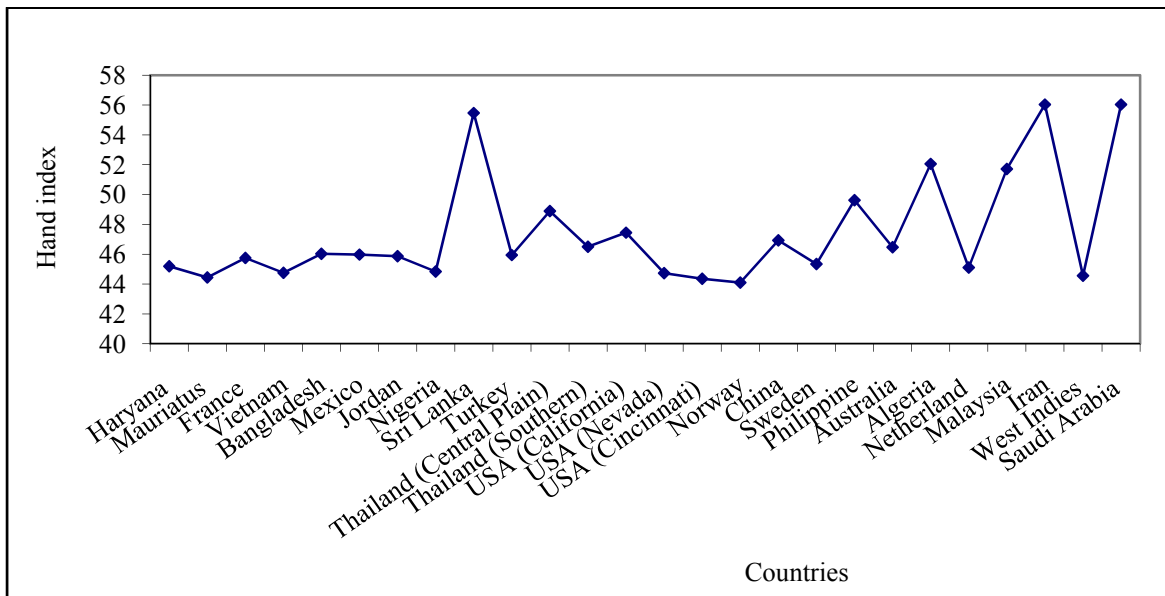
**Figure 5.** Variation of hand index among male population of various states

Further comparison of hand index and hand dimensions (hand length and hand breadth) of Haryana male industrial population was performed with male populations of 25 other countries of the world and is provided in Table 5.

**Table 5.** Comparison of mean values of hand length, hand breadth and hand index of male populations of different nationalities

S.No.	Countries	Hand breadth (mm)	Hand length (mm)	Hand index
1	Haryana (India) (Present study)	84.29	186.52	45.19
2	Mauriatus (Agnihotri et al., 2006)	84.00	189.00	44.44
3	France (Dean, 2006)	87.30	190.80	45.75
4	Vietnam (Imrhan et al., 1993)	79.20	177.00	44.75
5	Bangladesh (Imrhan et al., 2006)	80.10	174.00	46.03
6	Mexico (Imrhan and Contreras, 2005)	85.30	185.50	45.98
7	Jordan (Mandahawi et al., 2008)	87.70	191.20	45.87
8	Nigeria (Danborno and Elukpo, 2008)	89.00	198.50	44.84
9	Sri Lanka (Abeysekera and Shahnava, 1988)	99.50	179.38	55.47
10	Turkey (Iseri and Arslan, 2009)	87.11	189.59	45.95
11	Thailand (Central Plain) (Mamamsari and Salokhe, 1996)	90.20	184.50	48.89
12	Thailand (Southern) (Klamklay, 2008)	83.60	179.80	46.50
13	USA (California) (Rogers et al., 2008)	84.50	178.10	47.45
14	USA (Nevada) (Amayeh et al., 2008)	84.50	188.90	44.73
15	USA (Cincinnati) (Lee et al., 2009)	83.00	187.10	44.36
16	Norway (Bolstad et al., 2001)	86.00	195.00	44.10
17	China (Hu et al., 2007)	84.00	179.00	46.93
18	Sweden (Hanson et al., 2009)	87.50	193.00	45.34
19	Philippine (Del Prado-Lu, 2007)	98.00	197.50	49.62
20	Australia (Kothiyal and Tettey, 2000)	79.00	170.00	46.47
21	Algeria (Mokdad, 2002)	101.00	194.00	52.06
22	Netherland (Molenbroek, 1987)	83.00	184.00	45.11
23	Malaysia (Taha and Nazaruddin, 2005)	93.70	181.20	51.71
24	Iran (Motamedzade et al., 2007)	102.00	182.00	56.04
25	West Indies (Lewis and Narayan, 1993)	86.00	193.00	44.56
26	Saudi Arabia (Al-Haboubi, 1992)	102.00	182.00	56.04

Table 5 indicates that the male population of 26 countries of the world do not have hand index belonging to groups – hyperdolichocheiri (hdch) and dolichocheiri (dch). Male industrial population of Haryana and 17 other countries of the world have hand index in the range of mesocheiri (mch) group. The male population of three countries- Thailand, USA (California) and Philippine male population have hand index in the group of brachycheiri (bch). While five countries (Sri Lanka, Algeria, Malaysia, West Indies and Saudi Arabia) male population have hand index as hyperbrachycheiri (hbch).



**Figure 6.** Variation of hand index among male population of various countries

Study of the Figure 6 reveals that the India (Haryana) male industrial population differ in their hand index characteristics with the other countries of World. Although there exist variation in hand length and hand breadth among male populations' having same hand index. The difference in hand dimensions can be attributed to the population and ethnic differences between the populations. From the above view it may be suggested that variation is not only present in between races or ethnic groups but also present among individual races or ethnic groups. Chandra et al. (2011) have documented a positive correlation between hand length (HL) and hand breadth (HB).

Identification of human remains an essential element of any medico-legal investigation. DNA technology has simplified the issue of sex/nation determination to a great extent, but technology has its limitations with regard to skilled man power, time and financial issues involved, especially in developing countries and in cases when DNA analysis cannot be performed. Various techniques in forensic anthropology are still most commonly employed for identification of human remains. It is not uncommon to find the peripheral parts of the body such as hand and foot in mass disasters, and assault cases where the body is dismembered to conceal the identity of the victim. When an individual hand is recovered and brought for examination, dimensions of the hand, osteological and radiological examination can help in the determination of primary indicators of identification such as sex, age, stature, nation/state etc.

The variations in hand dimensions can be attributed to the population and ethnic differences between the study population and the other earlier studies. Population differences in anthropological studies have been noted and it is well realized that they need to be studied separately. Earlier studies have observed that various hand measurements tend to differ in various ethnic groups. However, owing to variability of dimensions according to the build of a person, individual parameters like hand length and breadth are not always reliable nation discriminators. The nation difference in the ratios of these parameters is independent of the body size, as the ratios are not significantly related to height and age.

#### 4. Conclusions

It can be concluded that hand dimensions and hand index ratio is useful to determine the nation of an isolated hand when it is subjected for medico-legal examination. In cases of mass disasters, utility of DNA analysis in forensic identification of population is limited. Although it provides the most reliable results, it is yet to be used frequently in forensic investigations in the developing countries owing to its cost-effectiveness, availability of laboratories and techniques, trained manpower and processing time. Hence, techniques in forensic anthropology continue to play a major role in identification of human remains using statistical considerations. This study has succeeded in establishing standard values of hand dimensions for male industrial workers population for Haryana state of India which will not only serve as a useful tool in forensic investigation and clinical practice, but also relevant to ergo-design applications of hand tools and devices for industries of the state. For further research, more hand dimensions should be taken and comparative dimensions with those from other nations could be conducted. The findings could be utilized by hand tools designers over countries to design fitted hand tools or equipment for workers from different nationalities.



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## References

- Abeysekera, J.D., Shahnavaz, H., 1988. Body size variability between people in developed and developing countries and its impact on the use of imported goods. *International Journal of Industrial Ergonomics*, Vol. 4, pp. 139-149.
- Agnihotri, A., Purwar, B., Jeebun, N., 2006. Determination of sex by hand dimensions. *The Internet Journal of Forensic Science*, Vol. 1, No. 2, pp. 12-24.
- Agrawal, K.N., Singh, R.K.P., Satapathy, K.K., 2010. Anthropometric Considerations for Farm Tools/Machinery Design for Tribal Workers of North Eastern India. *Agricultural Engineering International: the CIGR Ejournal XII*, 1-11.
- Al-Haboubi, M., 1992. Anthropometry for a mix of different populations. *Applied Ergonomics*, Vol. 23, No. 3, pp. 191-196.
- Amayeh, G., Bebis, G., Nicolescu, M., 2008. Gender Classification from Hand Shape. *Computer Vision and Pattern Recognition Workshops IEEE Computer Society Conference* 1-7.
- Armstrong, T.J., Silverstein, B.A., 1987. Upper extremity pain in the workplace - role of usage in causality. In: *Handler, N. (Ed.), Clinical Concepts in Regional Musculoskeletal Illness*. Grune and Stratton, New York, 333-354.
- Bolstad, G., Benum, B., Rokne, A., 2001. Anthropometry of Norwegian light industry and office workers. *Applied Ergonomics*, Vol. 32, No. 3, pp. 239-246.
- Chandna, P., Deswal, S., Chandra, 2010. A. An anthropometric survey of industrial workers of the northern region of India, *International Journal of Industrial and Systems Engineering*, Vol. 6, No. 1, pp. 110-128.
- Chandra, A., Chandna, P., Deswal, S. 2011. Analysis of Hand Anthropometric Dimensions of Male Industrial Workers of Haryana State, *International Journal of Engineering*, Vol. 5, No. 3, pp. 242-256.
- Chandra, A., Chandna, P., Deswal, S. 2011. Hand Anthropometric Survey of Male Industrial Workers of Haryana State (India), *International Journal of Industrial and Systems Engineering*, Vol. 9, No. 1, pp. 98-120.
- Chaurasia, B.D. 1995. *The forearm and hand, 3rd ed., Human Anatomy, Vol. 1*, CBS Publishers and Distributors, New Delhi, India, pp. 106-124 (Reprint 2003).
- Chuan, T.K., Hartono, M., Kumar, N., 2010. Anthropometry of the Singaporean and Indonesian populations. *International Journal of Industrial Ergonomics*, Vol. 40, pp. 757-766.
- Danborn, B., Elukpo, A., 2008. Sexual dimorphism in hand and foot length, indices, stature-ratio and relationship to height in Nigerians. *The internet Journal of Forensic Science*, Vol. 3, No. 1.
- Das, B., Grady, R.M., 1983. Industrial workplace layout design: an application of engineering anthropometry. *Ergonomics*, Vol. 26, No. 5, pp. 433-447.
- Das, B., Sengupta, A.K., 1996. Industrial workstation design: a systematic ergonomics approach. *Applied Ergonomics*, Vol. 27, No. 3, pp. 157-163.
- Davies, B.T., Benson, A.K., Courtney, A., Minto, I. 1980. A comparison of hand anthropometry of females in the three ethnic groups, *Ergonomics*, Vol. 23, pp. 179-182.
- Dayal, M.R., Steyn, M., Kuykendal, K.L. 2008. Stature estimation from bones of South African whites. *South African Journal of Science*, Vol. 104, pp. 124-128.
- Dean, R.S. 2006. Sexual dimorphism in upper Paleolithic hand stencils. *Antiquity*, Vol. 80, pp. 390-404.
- Del Prado-Lu, J.L. 2007. Anthropometric measurement of Filipino manufacturing workers. *International Journal of Industrial Ergonomics*, Vol. 37, pp. 497-503.
- Dewangan, K.N., Prasanna Kumar, G.V., Suja, P.L., Choudhury, M.D., 2005. Anthropometric dimensions of farm youth of the north eastern region of India. *International Journal of Industrial Ergonomics*, Vol. 35, pp. 979-989.
- Dewangan, K.N., Owary, C., Datta, R.K., 2008. Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region. *International Journal of Industrial Ergonomics*, Vol. 38, pp. 90-100.
- Ducharme, R.F., 1977. Women workers rate male tools inadequate. *Hum. Factors Soc. Bull.*, 20: 1-2.
- Hanson, L., Sperling, L., Gard, G., Ipsen, S., Vergara, C.O., 2009. Swedish anthropometrics for product and workplace design. *Applied Ergonomics*, Vol. 40, pp. 797-806.
- Hu, H., Lia, Z., Yana, J., Wang, X., Xiaob, H., Duana, J., Zhenga, L., 2007. Anthropometric measurement of the Chinese elderly living in the Beijing area. *International Journal of Industrial Ergonomics*, Vol. 37, pp. 303-311.
- Imrhan, S.N., Contreras, M.G., 2005. Hand anthropometry in a sample Mexicans in the US Mexico border region. *Proceedings of the XIX Annual Occupational Ergonomics and Safety Conferences*, Las Vegas, NE, pp. 589-593.
- Imrhan, S.N., Nguyen, M., Nguyen, N., 1993. Hand anthropometry of Americans of Vietnamese origin. *International Journal of*

- Industrial Ergonomics*, Vol. 12, pp. 281-287.
- Imrhan, S.N., Sarder, M.D., Mandahawi, N., 2006. Hand anthropometry in a sample of Bangladesh males. *Proceedings of the Eighth Annual Industrial Engineering Research Conference*, Clearwater, FL, pp. 15-18.
- Iseri, A., Arslan, N., 2009. Estimated anthropometric measurements of Turkish adults and effects of age and geographical regions. *International Journal of Industrial Ergonomics*, Vol. 39, pp. 860-865.
- Kanchan, T., Krishan, K., Sharma, A., Menezes, R.G., 2010. A study of correlation of hand and foot dimensions for personal identification in mass disasters. *Forensic Science International*, Vol. 199, 112.e1-112.e6.
- Klamklay, J., Sungkhapong, A., Yodpijit, N.E., Patterson, P., 2008. Anthropometry of the southern Thai population. *International Journal of Industrial Ergonomics*, Vol. 38, No. 1, pp. 111-118.
- Kothiyal, K., Tettey, S., 2000. Anthropometric data of elderly people in Australia. *Applied Ergonomics*, Vol. 31, pp. 329-332.
- Krogman, W.M. and M.Y. Iscan, 1986. Determination of Sex and Parturition. *The Human Skeleton in Forensic Medicine*. Charles C Thomas Publishers, Springfield, pp. 208-259.
- Lee, S-J, Kong, Y-K, Lowe, B.D., Song, S., 2009. Handle grip span for optimising finger-specific force capability as a function of hand size. *Ergonomics*, Vol. 52, No. 5, pp. 601-608.
- Lewis, W.G., Narayan, C.V., 1993. Design and sizing of ergonomic handles for hand tools. *Applied Ergonomics*, Vol. 24, pp. 351-356.
- Lucia E, Leema F, Tesfaye F, Demisse F, Ismail S, 2002. The use of arm spans measurement to assess the multinational status of adults in four Ethiopian ethnic groups. *European Journal of Clinical Nutrition*, 2002, Vol. 56.
- Malina, R.M., 1994. Physical activity and training: Effects on stature and adolescent growth spurt. *Medicine & Science in Sports&Exercise*, Vol. 26, No. 6, pp. 759-766.
- Mamansari, D.U., Salokhe, V.M., 1996. Static Strength and Physical Work Capacity of Agricultural Labourers in the Central Plain of Thailand. *Applied Ergonomics*, Vol. 27, No. 1, pp. 53-60.
- Mandahawi, N., Imrhan, S., Al-Shobaki, S., Sarder, B., 2008. Hand anthropometry survey for the Jordanian population. *International Journal of Industrial Ergonomics*, Vol. 38, pp. 966-976.
- Martin, B.T., Armstrong, S., Ulin, S.S., 1996. A Conceptual Model to Analyze Hand-Tool Selection and Design Processes. *Proceedings of the IESC*, Zurich, pp. 448-453.
- McFadden, D. and E. Shubel, 2002. Relative lengths of fingers and toes in human males and females. *Hormones Behavior*, 42: 492-500.
- Means, L.W., Walters, R.E. 1982. Sex handedness and asymmetry of hand and foot length, *Neuropsychologia*, Vol. 20, pp. 715-719.
- Mokdad, M., 2002. Anthropometric study of Algerian farmers. *International Journal of Industrial Ergonomics*, Vol. 29, pp. 331-341.
- Mokdad, M., Al-Ansari, M., 2009. Anthropometrics for the design of Bahraini school furniture. *International Journal of Industrial Ergonomics*, Vol. 39, No. 5, pp. 728-735.
- Molenbroek, J., 1987. Anthropometry of elderly people in the Netherlands: research and applications. *Applied Ergonomics*, Vol. 18, No. 3, pp. 187-194.
- Motamedzade, M., Choobineh, A., Mououdi, M.A., Arghami, S., 2007. Ergonomic design of carpet weaving hand tools. *International Journal of Industrial Ergonomics*, Vol. 37, pp. 581-587.
- Nag, A., Nag, P.K., Desia, H., 2003. Hand anthropometry of Indian woman. *Indian Journal of Medical Research*, Vol. 117, pp. 260-269.
- Okunribido, O.O. 2000. A survey of hand anthropometry of female rural farm workers in Ibadan, Western Nigeria. *Ergonomics*, Vol. 43, pp. 282-292.
- Park, J., Nam, Y., Lee, E., Park, S. 2009. Error detection in three-dimensional surface anthropometric data. *International Journal of Industrial Ergonomics*, Vol. 39, pp. 277-282.
- Risley, H.H. 1915. *The People of India*, Oriental Books, Reprint Corporation, New Delhi, India.
- Rogers, M.S., Barr, A.B., Kasemsontitum, B., Rempel, D.M., 2008. A three-dimensional anthropometric solid model of the hand based on landmark measurements. *Ergonomics*, Vol. 51, No. 4, pp. 511-526.
- Sancho-bru, J.L., Perez-Gonzalez, A., Mora, M.C., Leon, B.E., Vergara, M., Iserte, J. L., Rotriguez-Cervantes, P.J., Morales, A. 2011. Towards a Realistic and Self-Contained Biomechanical Model of the Hand, *Theoretical Biomechanics*, pp. 211-240.
- Schmidtke, H., 1984. Ergonomics and equipment design. NATO Conference series, Series III, Ergonomic data for equipment design. *Human Factor*, Vol. 25, pp. 19- 23.
- Snow, N.A., Newby, T.J., 1984. Ergonomically designed job aids. *Performance and Instruction Journal*, Vol. 28, pp. 26- 30.
- Taha, Z., Nazaruddin., 2005. Grip strength prediction for Malaysian industrial workers using artificial neural networks. *International Journal of Industrial Ergonomics*, Vol. 35, No. 9, pp. 807-816.
- Telkka, A. 1950. On the prediction of human stature from the long bones, *Acta Anat. (Basel)* 9, pp. 103-317.

- Tewari, V.K., Ailawadi, R., Sarangi, S., Dewangan, K.N., 2007. Rationalized Database of Indian Agricultural Workers for Equipment Design. *Agricultural Engineering International: the CIGR E-journal*, Vol. IX, Manuscript MES 05 004.
- Vallois, H.V. 1965. Anthropometric techniques, *Current Anthropology* 6, pp. 127-144.
- Vandana, M.R., S. Sushmita and B. Puja, 2008. Mandibular canine index as a sex determinant: A study on the population of western Uttar Pradesh. *Journal of Oral and Maxillofac Pathology*, 12, pp. 56-59.
- Wang, E.M., Chao, W., 2010. In searching for constant body ratio benchmarks. *International Journal of Industrial Ergonomics*, Vol. 40, pp. 59-67.

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