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Modelling the Car Seated Human Body using Composite Ellipsoidal Bodies and Evaluation of Size and Shape Specific Stiffness Data for Various Human Segments

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Abstract

The automobile is one of the primary modes of the worldwide transport system, which must offer the highest level of health, safety, and comfort levels for the occupants inside. The health, safety, and comfort of any moving vehicle and its human occupants are mainly characterized by the vibration generated inside the human body. With the development of modern computer-based technologies, computerized simulations have gained huge importance to anticipate the level of vibration generated inside the automotive seated human body over the last few decades. Many simulation-based research works had been conducted in the past to predict the effect of vibration inside the automotive-human assembly, though one of the key parameters to define the Simulation set up, namely stiffness values of different human segments; had been collected from past relevant research studies or available testing data resources, which overlooked the real shapes and sizes of the human portions, hence, lacking the practical feasibility.

In this research paper, a simplified car seated human-made of ellipsoidal segments have been proposed. The segmental dimensions and masses have been extracted from the anthropometric database, and later, the formulations for a composite fiber-matrix configuration have been implemented. A systematic approach has been outlined to evaluate the three-dimensional stiffness values for all the human portions. The obtained stiffness values have been validated by comparing the data obtained from similar investigations and test results.

Keywords — *Ellipsoidal human segment, car seated human driver, three-dimensional stiffness, computerized Simulation, human size-specific stiffness.*

I. INTRODUCTION

As modern technologies evolved, computer-based simulation methods for monitoring, assessing, and measuring the effects of vibration inside automotive seated human portions became popular in the last few decades. Depending on the study's nature, either lumped mass parameter, multi-body or finite element method is used to judge the level of vibration in terms of frequency, acceleration, or displacement. Each of the methods got its pros and cons. Numerous combinations of input factors, portions of interest, and output results can be considered while carrying out an effective simulation methodology. However, one of the inevitable and common input parameters for the past explorations have been identified as stiffness values of human segments.

The automotive rear impact was analyzed using a bio-dynamic human model in the MSC Visual Nastran 4D-2001 environment [1]. The seating postures were assigned based on a real-life photograph of a car seated human body. The same study further explored the structure by assigning the contact mechanism between the automotive seat and the human body by splitting the mating areas into rectangular or trapezoidal shapes. However, it was restricted to allow only a single frictional co-efficient value for all the portions. To model the entire Simulation with more reasonable frictional coefficients, the structure was taken to the MATLAB environment, simulating the human body's torso, back, and buttocks. The investigation recorded the simulation outputs at 50th ms, 89th ms, 100th ms, 150th ms, 200th ms, 250th ms, and 300th ms. The entire analysis work used the stiffness values of human torso joints from the BMH model and Bourdet-Willinger model. Bio-dynamic numerical algorithms were generated for the seated human body [2] under the effect of vertical vibration by considering four and seven degrees of freedom models and assuming hypothetical stiffness parameters from the standard database. Research work on vertical vibration [3] used the spring-dashpot system for vibration transmission. The automotive seat cushion's damping and stiffness values would be the major defining parameters for the vibration transmission from the automotive to the human occupant.

Human muscle and seat foam properties were primary accounted for during studies of experimental, numerical interaction of human body and seat [4], stress generation inside muscles of the seated human body [5], the interaction of human tissues and automotive seat [6], three-dimensional computerized programming of human buttocks ([7] and design of comfort parameters of automotive seat [8]. Modal analysis of the human portions in touch with automotive seat cushion using estimated stiffness values was carried out [9] to extract the first seven mode shapes under the frequency limit of 10 Hz. Human spine segments were made of rigid bodies, while the intervertebral discs were constructed by deformable. An improved methodology was followed to design the articulated automotive seat by constructing several human bodies of different sizes [10]. The spine was modeled as a deformable-body, while ribs, skull, and pelvis were considered rigid bodies. Muscles and skins were incorporated into the entire assembly by assigning suitable tissue properties. The assemblies were taken to a new research facility [11] and configured to various postures to analyze the seated human occupant's ergonomics inside an automotive. Similar kinds of investigations were carried out using finite element [12], [13], [13], [15], [16], [3] to assess the human comfort inside automotive by taking into account the contact interactions between the automotive and human occupant. While exploring the effect of automotive seat orientation on the human body ergonomics [17], a comprehensive anthropometric data table was estimated for comfortable seating positions based on different genders and body sizes.

Acceleration transmission and sitting comfort of automobile seats were showed [18] using the contact between foam seat and human. In contrast, the pressure distribution inside the seat foam cushion was monitored [19] considering physical properties. Assessment of human safety during automotive collision [20] concluded that the automotive seat material properties and shape would be crucial factors for characterizing the human body dynamics in the side and rear directions.

The previous research works on the automotive-human system; it is clear that the investigations for vibration-related assessments were made in different fields. However, the assignment of stiffness parameters for the human segments was based on hypothetical or standard databases. Many past automotive-human studies focused on the hyper-elastic or viscoelastic material properties of the human tissue and ignored the size-specific stiffness parameters.

A non-robust car seated 50th percentile male human driver constructed by ellipsoidal solid bodies has been represented during this research work. The dimensions and masses of the ellipsoids have been gathered after careful consultation with a worldwide anthropometric database. It has been assumed that the human bone-muscle structure is made of composite fiber-matrix material, and the applicable formulations have been applied.

A step by step methodology has been drawn to calculate precise three-dimensional stiffness values for the human head, chest, upper arm, lower arm, wrist, thigh, and leg. The acquired stiffness values have been authenticated by comparing data used or found in the similar relevant literature.

II. METHODOLOGY

A. *Masses of Human Portions*

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A 50th percentile male body of 77.3 kg mass has been taken into account for carrying out this methodology. The human segmental masses have been calculated as percentages of entire human body mass, and for this purpose, the databases and guidelines of the human portion [21], [22] have been consulted. Table I is showing the fractional figures of social segments concerning the entire human body.

TABLE I
Masses considered for male human segments in terms of percentages of total human body mass

Human portion	**Mass of the portion (%)**	**Relevant database**
Head	8.26	Plagenhoef et al., 1983
Whole trunk	55.1	
Thorax	20.1	
Abdomen	13.06	
Pelvis	13.66	
Total arm	5.7	
Upper arm	3.25	
Forearm	1.87	
Hand	0.65	
Forearm and hand	2.52	
Total leg	16.68	
Thigh	10.5	
Leg	4.75	
Foot	1.43	
Leg and foot	6.18	
Head and neck	6.94	Leva, 1996
Trunk	43.46	
Upper arm	2.71	
Forearm	1.62	

Human portion	Mass of the portion (%)	Relevant database
Hand	0.61	
Thigh	14.16	
Shank	4.33	
Foot	1.37	

B. *Dimensions of Human Portions*

Human dimensions measurement guidelines have been provided in the international standards PD ISO/TR 7250-2:2010 and BS EN ISO 7250:1998. Anthropometric dimensions of human bodies have been outlined [23] based on analysis, and factors for human comfort have been shown in the handbook on human ergonomics [24]. Biodynamic anthropometric data for different countries have been published in industrial personnel in Asia [25], elderly Chinese people [26], Turkish females [26], Mexian adult people [28], rugby athletics [29], and Italian gymnasts [30].

After a thorough consultation with all the relevant guidelines, standards, literature, and handbooks, the dimensions of all the segments of a 50th percentile 77.3 kg male human have been collected and presented in Table II.

TABLE II
Collected human segmental dimensions

Dimension for various human portion	Dimension (cm)
Standing Height	175.49
Shoulder Height	59.80
Head Length (Including Neck)	31.31
Head Breadth (Including Neck)	15.50
Shoulder to Elbow Length	36.88
Forearm Hand Length	26.92
Biceps Circumference	24.40
Elbow Circumference	27.30
Forearm Circumference	22.80
Wrist Circumference	15.60
Thigh Circumference	46.70
Upper Leg Circumference	42.40
Knee Circumference	35.10
Calf Circumference	31.90
Ankle Circumference	23.90
Foot Breadth	10.00
Foot Length	26.50
Upper Leg Length	60.50
Thigh Thickness	15.50
Lower Leg Length	45.00
Chest Depth	24.50
Abdominal Depth	27.50
Average Torso Depth	26.00
Torso Height	59.80
Torso Top	48.50
Torso Bottom	39.00
Average Torso Width	43.75
Hand Length (Fist)	6.94
Hand Width	9.03
Hand Depth	2.41
Upper Leg Length	61.54
Lower Leg Length	50.39

C. *Human portions Represented by Ellipsoidal Bodies*

Simplified ellipsoidal bodies can represent robust human portions. This method is advantageous to define the three-dimensional stiffness values of human portions along the principal axes of ellipsoids as functions of directional lengths and valid for various ranges of human shapes and sizes.

Study in an academic environment on the eigenvectors of human segments modeled the human bodies with truncated ellipsoids [31] and dimensions of each segment had been taken from the anthropometric database. Investigation on human arm and leg [32] outlined the idea of presenting human segments through ellipsoidal cross-sectional areas.

The displacement magnitude of a particular point on an ellipsoidal cross-section has been displayed in Fig 1, and the hypothetical formulation for calculating the displacement is shown in Equation (1).

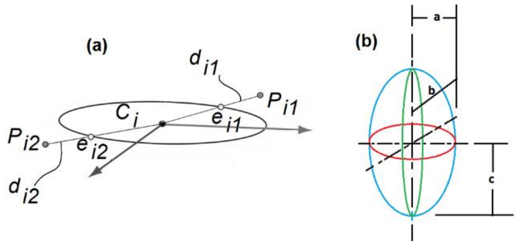

Fig 1: (a) Displacement of a point on ellipsoidal cross-section and (b) axial directions considered

$$D(u_{ij},v_i)=d_{ij}=\|P_{ij}-e_{ij}\| \tag{1}$$

$i=1,.....M,$

$j=1,.....N_i$

$(u_{ij},v_i)=$ Surface parameters of the point e_{ij} on the ellipsoid surface C_i.

In this paper's methodology, the human body has been assumed to be made of head, neck, legs, thighs, feet, upper arms, lower arms, hands, and torso. From the comprehensive anthropometric data in Section II.B, the dimensions of ellipsoidal portions have been derived, as shown in Table III.

TABLE III
Dimensions of ellipsoidal segments

Body Segment	Ellipsoid Parameter (cm)		
	a	b (depth)	c
Head including Neck	7.75	7.75	15.66
Torso	21.88	13.00	29.90
Upper Arm	3.88	3.88	18.44
Lower Arm	3.63	3.63	13.46
Hand	4.52	1.21	3.47
Thigh	6.75	7.75	30.25
Leg	5.08	5.08	22.50
Foot	5.00	3.05	13.25

D. The posture of Car Seated Male Human Body

The comfortable sitting posture of car seat humans can be configured based on the international standards ISO/TC 159/SC 1, ISO/TC 159/SC 3, and ISO/TC 159/SC 4 for principles of ergonomic, anthropometric data and biomechanical interaction between the system and human, respectively. To make this approach more practical, all the angular dimensions of a car seated human body have been measured from a photograph of a 77 kg mass car driver.

The photograph was imported into Solidworks 2016 drafting environment to measure all the angular orientations in three-dimensional spaces. From those measured values, a parametric seated human driver model was established in Solidworks 2016. The imported photograph and developed 3D model are shown in Fig 2.

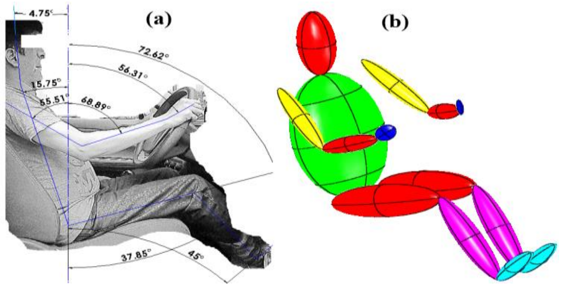

Fig 2: (a)Real human male driver of 77 kg mass and (b) CAD model of the driver

E. Young's Moduli of Human Body Segments

Young's Modulus (YM) Precise value for combined human bone and muscle structure is a tough challenge as the bone, muscle, and soft tissue are mechanically non-linear and exhibit hyper-elastic and viscoelastic material properties. Exploring human bone properties concerning variable age and gender [33] found the YM value of bone as 20.04 GPa... At the same time, a similar sort of finite element simulation [34] considered the YM of bone as 15 GPa. Indentation testing and measurement of the tensile strength of biological tissue concluded that the YM values for muscles and tissues would be in-between 3 kPa and 8 kPa. In this research methodology, YM values for human muscles and bones have been considered as 8 kPa and 20.04 GPa, respectively.

Depending on the nature of the bio-dynamic study, human bone-tissue structure can be modeled using the formulations of fiber, composite, or silicon material. Stiffness parameters for the composite materials can be calculated using fiber-matrix equations; hence, composite materials' usage is advantageous compared to other materials. The bone-muscle structure during this research procedure has been assumed to be made of composite material. For the ellipsoidal human segments, the fractions of muscles and bone have been taken as 85% and 15%, respectively, as per the guideline provided in the advanced nutrition database [35]. A simplified fiber-matrix composite assembly for the human segment is shown in Fig 3. Three directional YM values for human segments have been obtained using the co-relation in Equation (2) and Equation (3).

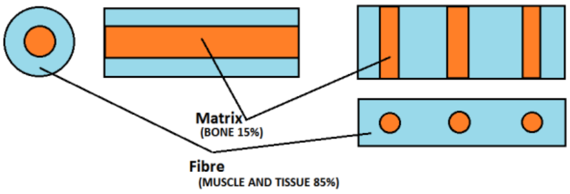

Fig 3: Matrix -fiber arrangement representing human bone, muscle, and tissue

$$E_{i-Axial}=E_{Muscle}\times f_{Muscle}+E_{Bone}\times(1-f_{Muscle})$$
(2)

$$E_{i-Transverse}=\frac{E_{Muscle}\times E_{Bone}}{E_{Muscle}\times(1-f_{Muscle})+E_{Bone}\times f_{Muscle}}$$
(3)

$E_{i-Axial}$ = Axial YM of the ith segment

$E_{i-Transverse}$ = Transverse YM of the ith segment

The evaluated for axial and transverse YM values are 3.006 GPa and 9.412 KPa, respectively.

III. RESULTS: THREE-DIMENSIONAL STIFFNESS VALUES FOR HUMAN PORTIONS

Combining the dimensions from Section C and YM values from E, three directional stiffness parameters for the human segments have been calculated using the theoretical relationship between stress, strain, force, and cross-sectional area, as shown in Equation (4).

$$K_{ij-Directiond} = \pi \frac{E_{ij-Directiond}\, a_{per-ij-Directiond}\, b_{per-ij-Directiond}}{C_{ij-Directiond}} \quad (4)$$

$K_{ij-Directiond}$= Stiffness of jth segment in ith direction

$E_{ij-Directiond}$= YM of the jth segment in ith direction

$a_{per-ij-Directiond}$= Half axis (Transverse axis-1) length of the of jth segment perpendicular to the ith direction

$b_{per-ij-Directiond}$= Half axis (Transverse axis-2) length of the of jth segment perpendicular to the ith direction

$C_{ij-Directiond}$= Half axis length of the jth segment in ith direction

The obtained stiffness values for the human portions are summarized in Table IV.

TABLE IV
Axial and lateral stiffness values of human segments

Body Segment	Axial Stiffness (kN/m) - C Axis	Lateral Stiffness (kN/m) - B Axis Depth	Lateral Stiffness (kN/m) - A Axis
Head including Neck	362249.86	4.63	4.63
Torso	898003.69	14.87	5.25
Upper Arm	77246.85	5.45	5.45
Lower Arm	92403.13	3.98	3.98
Hand	148038.00	3.84	0.27
Thigh	163268.40	7.79	10.27
Leg	108208.38	6.65	6.65
Foot	108670.55	6.42	2.39

IV. VALIDATION AND DISCUSSION

The top and bottom limits of axial stiffness parameters are obtained as 898003.69 kN/m for the torso and 77246.85 kN/m for the upper arm. In comparison, the highest and lowest magnitudes in lateral directions are found as 14.87 kN/m at the torso and 0.27 kN/m at hand, respectively. To validate the stiffness values obtained, past references in relevant fields have been explored.

The seated posture's human body was modeled using truncated ellipsoids [31] and 15 degrees of freedom. Maximum and minimum axial stiffness limits were found to be 3119.12 kN/m at thigh and 75.61 kN/m at hand, respectively. In comparison, maximum and minimum lateral stiffness limits were found to be 2642.92 kN/m at the central torso and 129.24 kN/m at the foot, respectively. Investigation on the human leg [36] assumed the stiffness value as 28.5 kN/m. Research on the dynamic impact on human soft tissue [37] tried to estimate the stiffness constant for human tissue using 27 trials. The range of stiffness values were in-between 8.832 kN/m and 31.779 kN/m. The human body had been modeled using mass-spring-damper [38], and stiffness matrices had been generated in a multi-body environment. The results showed that the stiffness constants for various human segments appeared an in-the range of 0.05 kN/m and 100000 kN/m.

Human bone and muscle structure is a very complex assembly where numerous factors are associated. Any one of these factors can be responsible for altering the stiffness behavior of the structure. Distribution of tissues over the bone, homogeneousness of bone and soft tissue, expansion or contract condition at the time of stiffness measurement, age of the human taken into account, shape, and size of the human portion, variation in human structure depending on different geographical area, etc. all play major roles in defining the stiffness constant of human body segments. Hence, it is inevitable to have stiffness values for the same human components obtained from different sources.

The range of constant stiffness values from this research work results falls within the range described in past studies and literature. From the discussion in this Section, it can be concluded that this simplified methodology can successfully be implemented for predicting the stiffness values of car seated human portions.

V. CONCLUSIONS AND SCOPES OF FURTHER DEVELOPMENT

This research paper proposed a unique and simple technique to forecast the stiffness parameters inside car seated human body portions. From the results of this analysis work, the following conclusions can be drawn:

A. This methodology can be implemented efficiently to any portion of the human body to predict the three-dimensional stiffness constants. In this paper, this methodology has been executed on a human driver inside a car. Ideally, this stiffness measurement procedure can fruitfully be applied to any industrial or academic sector, demanding the anticipation of stiffness data for human parts.

B. Ellipsoidal bodies can model human portions in three special dimensional planes as per the dimensions provided in anthropometric guidelines. The bone-muscle arrangement can be represented through a composite-based matrix-fiber system to evaluate human shape-sized dependent stiffness data. This technique's stiffness values will have a higher degree of feasibility than those collected from the theoretical database or standards.

C. This procedure can estimate the stiffness data inside human segments in a moderately reasonable way. This method's results agree with defined or assigned stiffness values in other relevant kinds of literature.

Enormous scopes of further improvement are there to take this emerging methodology to an advanced level. Firstly, splitting the ellipsoidal human segments into more mini-ellipsoidal elements would be beneficial for more accurate results. This process will be time-consuming because of an anatomically correct human body requirement besides gathering data from anthropometric manuals. But, collecting dimensions for mini-ellipsoids will enhance the accuracy of the results to a great extent. Secondly, further research exploring ways to assign more input parameters will be advantageous, as explained in Section IV. With the increment of the number of key input parameters, obtaining more improved results will be increased. Thirdly, considering the operating environmental scenario and its impact on the human portions will be useful. Considerations of forces exerted to human parts from operating conditions, e.g., load from the steering wheel to hand, pressure from break or clutch on the leg, contact pressure from seat to pelvis, etc., will certainly add value to results.

Based on the discussions on results, validation, conclusion, and scope of improvement, a statement can be made that this technique is providing realistic outputs on stiffness data, which can be effectively used in vibration-related bio-dynamic problems. Fine tunings and additions of input parameters can lead this methodology to anticipate stiffness data inside human portions in a more convincing way.

REFERENCES

[1] Himmetoglu, S., Acar, M., Bouazza-Marouf, K., and Taylor, A. A multi-body human model for rear-impact Simulation". Proceedings of the IMechE, Part D: Journal of Automobile Engineering. 223(5) (2009) 623-638.

[2] Abbas, W., Abouelatta, O.B., El-Azab, M., Elsaidy, M., and Megahed, A.A. Optimization of Biodynamic Seated Human Models Using Genetic Algorithms, Scientific Research. 2 (2010) 710-719.

[3] Verver, M.M. Numerical tools for comfort analyses of automotive seating, Eindhoven: Technische Universiteit Eindhoven. (2004) 7-70.

[4] Brosh, T., and Arcan, M. Modeling the body/chair interaction – an integrative experimental–numerical approach, Clinical Biomechanics. 15 (2000) 217-219.

[5] Chow, W.W., and Odell, E.I. Deformations and stresses in soft body tissues of a sitting person, Journal of Biomechanical Engineering. 100 (1978) 79-87.

[6] Setyabudhy, R. H., Ali, A., Hubbard, R. P., Beckett, C., and Averill, R. C. Measuring and Modeling of Human Soft Tissue and Seat Interaction, SAE International Congress and Exposition. (1997) 10.4271/970593.

[7] Todd, B. A., and Thacker, J.G. Three-dimensional computer model of the human buttocks, in vivo, The Journal of Rehabilitation Research and Development. 31(2) (1994) 111-119.

[8] Moens, CCM, and Horvath, I. Finite element model of the human body: geometry and non-linear material properties, Proceedings of the TMCE 2002 (2002)..

[9] Kitazaki, S., and Griffin, M.J. A modal analysis of whole-body vertical vibration, using a finite element model of the human body". Journal of Sound and Vibration, 200(1) (1997) 83-103.

[10] Hubbard, R.P., Haas, W.A., Boughner, R.L., Canole, R.A., and Bush, N.J. New biomechanical models for automotive seat design, SAE Conference 1993, SAE paper no 930110 (1993).

[11] Frost III, B.L., Hubbard, R.P., and Boughner, R.L. Development of back contours for automobile seat design, SAE Conference, SAE no 970590 (1997)..

[12] Grujicic, M., Bell, W. C., Arakere, G., and Haque, I., Finite element analysis of the effect of up-armoring on the off-road braking and sharp-turn performance of a high-mobility multipurpose wheeled vehicle, Proceedings of The Institution of Mechanical Engineers Part D-journal of Automobile Engineering - PROC INST MECH ENG D-J AUTO. 223. 1419-1434. 10.1243/09544070JAUTO1187 (2009).

[13] Konosu, A. Development of a Biofidelic Human Pelvic FE-Model with Several Modifications onto a Commercial Use Model for Lateral Loading Conditions, SAE Technical Paper Series 2003-01-0163 (2003).

[14] Murakami, D., Kitagawa, Y., Kobayashi, S., Kent, R., and Crandall. J, Development and Validation of a Finite Element Model of a Vehicle. SAE Technical Paper Series 2004-01-0325 (2004).

[15] Hartung, J., Mergl, C., Henneke, C., Madrid-Dusik, R and Bubb, H. Measuring Soft Tissue Compliance of the Human Thigh. SAE Technical Paper Series 2004-01-2158 (2004)..

[16] Mergl, C., Anton, T., Madrid-Dusik, R., Hartung, J., Librandi, A., and Bubb, H, Development of a 3D Finite Element Model of Thigh and Pelvis, SAE Technical Paper Series 2004-01-2132 (2004)..

[17] Kovacevc, S., Vucinic, J., Kirin, S., and Pejnovic, N. Impact of anthropometric measurements on ergonomic driver posture and safety. Periodicum Biologorum, 112(1) (2010) 51-54.

[18] Zhao, L.Q., Xia, Q.S., and Wu, X.T. Study of sitting comfort of automotive seats, SAEConference 1994, SAE no 945243 (1994)..

[19] Park, S., and Kim, C. The evaluation of seating comfort by objective measurements, SAE970595, SAE Conference(1997).

[20] Warner, C.Y., Stother, C.E., James, M.B., and Decker, R.L., Occupant protection in rear-end collisions: II. The role of seat back deformation in injury reduction, Proceedings of the 35stStapp Car Crash Conference (1991) 379-390, SAE no912914.

[21] Plagenhoef, S., Evans, F.G., and Abdelnour, T. Anatomical data for analyzing human motion, Research Quarterly for Exercise and Sport, 54 (1983)169-178.

[22] Leva, P. Adjustments to Zatsiorsky-Seluyanov's Segment Inertia Parameters. Journal of Biomechanics, 29(9) (1996). 1223-1230.

[23] Majumder, J. Anthropometric dimensions among Indian males — A principal component analysis. Euras J Anthropol, 5(2) (2014) 54−62.

[24] Ashby, P. Ergonomics handbook 1: Human factors design data: Body size and strength. Pretoria: Tute Publication(1975).

[25] Saha PN.. Anthropometric characteristics among industrial workers in India. Proceedings of International Symposium on Ergonomics in Developing Countries, Jakarta, Indonesia, (1985) 158-161.

[26] Hu, H., Li, Z., Yan, J., Xiao, H., Duan, J., and Zenga., Li. Anthropometric measurement of the Chinese elderly living in the Beijing area. Journal of Industrial Ergonomics, 37(4) (2007) 303-311.

[27] Cengiz, TG. A pilot study for defining characteristics of Turkish women via anthropometric measurements. Work, 49(4) (2014) 713–722.

[28] Macias, N., Quezada, A. D., Flores, M., Valencia, M. E., Denova-Gutiérrez, E,,Quiterio-Trenado, M., Gallegos-Carrillo, K., Barquera, S. and Salmerón, J. Accuracy of body fat percent and adiposity indicators cut off values to detect metabolic risk factors in a sample of Mexican adults. BMC Public Health, 14(1) (2014) 341 doi: 10.1186/1471-2458-14-341.

[29] Duthie, G. M., Pyne, D. B., Hopkins, W. G., Livingstone, S., and Hooper, S. L. Anthropometry profiles of elite rugby players: quantifying changes in lean mass, Br J Sports Med, 40 (2006) 202-207.

[30] Massidda, M., Toselli. S., Brasili, P. and Caló, M. C. Somatotype of elite Italian gymnasts, Collegium anthropological - PubMed, 37(3) (2013) 853-857.

[31] Bansal, H. Mathematical validation of eigenvalues and eigenvectors of different human body segments in sitting posture, MEng. Thesis, Thapar University (2013).

[32] Hyun, D., Yoon, S., Kim, M., And Juttler, B. Modeling and Deformation of Arms and Legs Based on Ellipsoidal Sweeping. Proceedings of the 11th Pacific Conference on Computer Graphics and Applications (2003).

[33] Mirzaali, M. J., Schwiedrzik, J. J., Thaiwichai, S., Best, JP, and Michler, J. Mechanical properties of cortical bone and their relationships with age, gender, composition, and micro indentation properties in the elderly, Bone, 93(2016) 196-211.

[34] Zhang, Y., Zhong, W., Zhu. H., Chen, Y., Xu, L., and Zhu, J. Establishing the 3-D finite element solid model of femurs in partial by volume rendering, International Journal of Surgery, 11(2013) 930-934.

[35] Wildman, E. C. Foundations of the Human Body. Advanced human nutrition, 1st ed (2000).

[36] Zhang, L., Xu, D., Makhsous, M., and Lin, F. Stiffness and viscous damping of the human leg, The American Society of Biomechanics (2000)

[37] Amar, M.R.S, Estimation of Mechanical Properties of Soft Tissue Subjected to Dynamic Impact, Nebraska: The Graduate College at the University of Nebraska, (2010) 28-31.

[38] Nikooyanz, A. A., and Zadpoor, A. A. Mass–spring–damper modeling of the human body to study running and hopping – an overview, Journal of Engineering in Medicine. 225(J), (2011) 1121-1135.