Research Paper

Modeling of the effect of backpack load position on the lumbar spine curvature

Abstract:

The aim of this study was to numerically calculate the lumbar spine curvature in standing from a healthy subject with a loaded backpack.The anthropometric data of a schoolboy were used,and then the modelwas built in BRG.LifeMOD (ver. 2007, Biomechanics Research Group, Inc., USA) based on these data. The backpack was loaded at 10, 15 and 20% of subject's Body weight (BW) (stage 1). Then, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase. Regression analysis between our numerical predictions of stage 1 and similar experimental literature led to a correlation gradient of 0.88 and 0.91 for L3-S1-horizon and T12-L3-S1 angles, respectively. The predicted G and H angles peaks at stage 2 were observedwhen the heavier boxwas in frontal plane at left or right side. This study demonstrated the feasibility of obtaining a range of variable boundary conditions (e.g. altered due to changing the location of the heavier box) and applying a simplified three-dimensional model that can predict lumbar spine curvature changes in relatively short solution time.

Keywords*:* Backpack modeling, backpack Load Placement, lumbar spine curvature

1. Introduction

Backpack users mostlyare students, military soldiers, mountain climbers, rescueworkers, recreational hikers. The average load usually movedbystudents is 22%of their (BW)(Motmans et al, 2006).Naturally more than $\frac{1}{3}$ of young students can carry more than 30% of their BW.But heavier loads for longer times are usually conveyed in industrial, military as well as recreational applications(Motmans et al, 2006).Most of the previous studies have been about schoolbackpacks that were done empirically (Chow et al, 2007; Reid et al, 2004; Singh, T. and Koh, 2009; Stephanie et al, 2007). Currently, experimental methods are typically used to determine biomechanical behaviors. However, such techniques are difficult, expensive, and sometimes have risks connected to them (Bahraseman et al, 2013). Numerical methods, although, have the potential to determine them removing the need for experimental procedures.

It was reported that carrying heavy backpacks mightresult in changes in trunk posture and finally lower back pain (LBP)(Al-Khabbaz et al, 2008). Also prolonged carrying of backpacks affectsthe fluid content of the intervertebral discs(Skaggs et al, 2006).The Most significant parameters were studiedbefore, include: the type of backpackand its design (Mackie et al, 2003; Motmans et al, 2006; Rashed et al, 2005), different weights of that [Chow et al, 2007], location of its'center of gravity (COG)(Abe et al, 2008; Devroey et al, 2007; Stuempfle et al, 2004),lateral stiffness elements in the suspension system of a backpack (Reid et al, 2004; Stephanie et al, 2007), backpack harness system [Stephanie et al, 2007; Hamish et al, 2005), spinal muscles activities (Al-Khabbaz et al, 2008; Motmans et al, 2006), musculoskeletal symptoms (especially trunk posture) (Al-Khabbaz et al, 2008; Chow et al, 2007; Skaggs et al, 2006; Grimmer et al, 2002), gender influence (Haex, 2004),physiological parameters(Stuempfle et al, 2004), maintaining balance(*Rashed et al, 2005)*andcomparison of static and dynamic stages(Singh et al, 2009).Stuempfle et al. (2004)reportedthatdouble pack could bemore physiologically efficient technique but is not easy enough.Head-loading and back-loading were compared and the results showed that whilst back-loading weremostly associated with more areas of discomfort than head-loading(Lloyd et al, 2010).Chow et al. (2007)examined the effect of increasing backpack load on the spine alignment and observed increasing trunk forward lean (TFL) with increasing backpack load.Stuempfle et al. (2004) foundthat electromyography activity of the erector spinaeand trapezius were significantly lower when the load was locatedhigh on the back.Devroey et al. (2007) reported morepostural changesat lumbar spineindynamic load carryingthan in static condition.It was reported thattheerector spinaeEMG activity decreases in carrying backpack, in contrast,rectus abdominisEMG activity increases(Al-Khabbazet al,2008; Motmans et al, 2006).Stephanie et al.(2007) indicated that putting a hip belt in a framed backpackmay transfer about 30% of backpack vertical force to the hip.

The purpose of this study is to modeling of the lumbar spine curvature in standing from a healthy subject with a loaded backpack. Firstly, the backpack is loaded at 10, 15 and 20% of subject's BW (stage 1). Secondly, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase.

2. Method

The model was included the anthropometric data of 15.2 years old boy (1.6 m height, 58.9 kg weight).Then an adaptedschool backpack was applied to the model (Fig 1). The BRG.LifeMod software version 2005 was applied to make a model and to perform the analysis. The software divides the spinal column intothoracic, cervical and lumbar parts and connects these three parts by joints. Respecting to theexactnessrequired in investigating the spinal alignment, the simulating of vertebrae has been executed to make the definition of joints between the vertebrae possible. For all body joints, except for intervertebral disks, the standard hybrid III values were used. To create the desired range of motion (ROM) and stiffness for vertebral column,the natural ROM and the joint damping coefficient of the joint were input (Leilnahari et al, 2011).

Design of Modeling and boundary conditions:

Simulation was done at two stages. At stage1, loading of backpack was modeled at 10, 15 and 20% of boy`sBW by applying two single forces at the location of shoulder straps symmetrically.Initially a backpack frame was built by passing a spline next to the vertebrae mass centers (T_2 tillL_5) on sagittal plane and a polyline adds perpendicularly on frontal plane, then in MSC ADAMSversion 2005 these two frames were merged to one unit frame (Fig 1). Hence, massless backpack frame were made of aluminum (density: 2740 kg/m^3, young's modulus: 7.1705e+010 N/m^2, Poisson's coefficient: 0.33). Finally, the backpack was fixed in shoulders. The cubic volumes in MSC ADAMS 2005 were used to apply the load in the backpack. A box was attached to the backpack frame adjacent to T12 by fixed joint. At Each phase the box was weighed in 10%, 15% or 20% of the boy`s BW.

At stage2,The backpack included a weight within that is distributed in three boxes; they were 4, 4, and 12 kg in weight. These boxes attached to the backpack frame in three phases. At each phase, boxes were arranged in parallel to the sagittal (Fig 2a), frontal (Fig 2b), and transversal(Fig 2c) planes. In all phases, the location of the heavier box (12 Kg) was changed to assess probable effects on the lumbar angle. Thus totally nine cases were examined. Table 1 provides the relevant abbreviations ofThe heavy box location (12 Kg)in each plane related to its arrangement.

3. Results

3.1 Investigation of G and H angles changes due to variation in load (Stage 1)

The G angle was decreased with increasing load (Table 2, Fig 3). It was ranged from 28.1 to 24.8 degree when load was changed from 0 to 20% of BW. The mean slope of G angle changes to load variations was about -18.343 (degree/N) and the y-axis intercepts of that was 80.289 (degree). The percentage reduction of G angle was roughly 11.7.

The H angle was decreased with increasing load (Table 2, Fig 3). It was ranged from 79.1 to 75.8 degree when load was changed from 0 to 20% of BW. The mean slope of H angle changes to load variations was about -19.486 (degree/N) and the y-axis intercepts of that was 29.417 (degree). The percentage reduction of G angle was roughly 4.2.

The relationship between G and H angle was shown in Figure 4. A good correlation was determined using a quadratic polynomial equation, for our numerical simulations.

3.2 Investigation of G and H angles changes due to variation in loadarrangement (Stage 2)

The table 3 gives information on the prediction of lumbar angles ,included G and H, when the location of heavy box was changed at each plane.As provided in table 3, in sagittal plane, when the heavy box was located at top of the other boxes (SM), the G angle was calculated 23.9 degree. This is the biggest calculated G angle in sagittal plane as compared to prediction of that in ST(23.2 degree) and SB (22.9 degree) stages.

In frontal plane, when the heavy box was located at the middle of the other boxes (FM), the G angle was calculated 24.4 degree (Table 3). This is the least calculated G angle in frontal plane as compared to prediction of that in FLand FR stages which in bothof themthe same G angle of 25.1 degreewas calculated.

In transversal plane, when the heavy box was located at the TF stage, the G angle was calculated 24.6degree (Table 3). This is the biggest calculated G angle in transversal plane as compared to prediction of that in TN (24.1degree) and TM (24.4degree) stages.

As provided in table 3, in sagittal plane, when the heavy box was located at the middle of the other boxes (SM), the H angle was calculated 74.4 degree. This is the biggest calculated H angle in sagittal plane as compared to prediction of that in ST (73.4 degree) and SB (72.9 degree) stages.

In frontal plane, , when the heavy box was located at the middle of the other boxes (FM), the H angle was calculated 75.1 degree (Table 3). This is the least calculated H angle in sagittal plane as compared to prediction of that in FL and FR stages which in both of them the same G angle of 76.0 was calculated.

In transversal plane, when the heavy box was located at the TF stage, the H angle was calculated 75.4 degree (Table 3). This is the biggest calculated H angle in transversal plane as compared to prediction of that in TN (74.7 degree) and TM (74.1 degree) stages.

4. Discussion

Study findings

The study has used Numerical model to calculate the lumbar spine curvaturein standing from a healthy subject with a loaded backpack. To our knowledge this is the first time that lumbar spine curvature has numerically been examined. Firstly, the backpack was loaded at 10, 15 and 20% of subject’s BW (stage 1). This was resulted in G and H angles reduction by about 3.3 degree. Chow et al.(2007) found these changes about 3.75 degree.Our numerical model led to a good G angle correlation with the previous similar literature values (r = 0.88), in addition a good correlation (r = 0.91) was achieved for H angle. These good correlation factors between our numerical method and previous experimental study can validate our simulation technique. Secondly, three boxes (4, 4 and 12 Kg in weight) were attached in the backpack (stage 2). They were arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase. The G angle peaks were observed at stages of SM (23.9 degree), FL (25.1 degree), FR (25.1 degree) andTF (24.6 degree).Similarly, The H angle peaks were observed at stages of SM (74.4 degree), FL (76.0 degree), FR (76.0 degree) and TF (75.4 degree). Also, the most reduction in lumbar angle is observed at incorrect backpack carrying methods atSBcase that this means flattening in lumbar lordosis.Despite the use of a simplified model, our predicted values of G and H angles changes were approximately to within 88% of the values of experimental-measured reported in the literature (Chow et al, 2007). The numerical model reliably predicted lumbar spine curvature over a range of different loads. Predictions of around 88% of experimental measurement(Chow et al, 2007) would present limitations in clinical use, therefore, linear correlations have been used. This enables estimations derived from our simulation to be obtained which are highly accurate (e.g. r = 0.88 and 0.91 for G and H angles, respectively).

This study demonstrates the feasibility of obtaining a range of variable boundary conditions (e.g. altered due to changing the location of the heavier box) and applying a simplified three-dimensional model that can predict lumbar spine curvature changesin relatively short solution time.

Comparison to literature and validation

Following a literature search we have not found a previous comparable numerical study that used numerical approach to predict lumbar spine curvatureat different conditions of loading. In our study, subject specific G and H angles ,measured between three adjacent markers as the curvature for that load, were predicted at a range of loading. However, our study compares well to theexperimental study used to predict lumbar spine curvaturefor a subject in standing with a loaded backpack.

Regression analysis between our numerical predictions and similar previous literature (Chow et al, 2007)led to a correlation gradient of 0.88 and 0.91 for G and H angles, respectively (Figs5a and 5b). Therefore, there was a strong correlation between the two methods and similar values were predicted. These regression analysis enable true values to be calculated from predicted model data (using the equations provided in figs5a and 5b).As can be seen in figure 3, there is a linear relationship between changes of our predicted G and H values and the changes of percentage of BW. This is in good agreement with the Chow et al (2007) findings. However, the mean differences of 3.4 and 8.1degree are observed for G and H angles values respectively.

As shown in figure 4, The relationship between G angle and H angle of our numerical simulation has a good correlation which was calculated using a quadratic polynomial equation. This also is in good agreement with Chow et al findings(Chow et al, 2007) (Fig 4). As noted by Motmans et al. (2006), with a load on the back, the combined center of gravity of the trunk plus the backpack shifts backward. This creates an extension moment (Bobet and Norman, 1984). In order to counterbalance the weight on the back, a Trunk forward lean occurs (Al-Khabbaz et al, 2008; Filaire et al, 2001;Goh et al, 1998; Heather et al, 2009; Motmans et al, 2006; Pascoe et al, 1997; Singh et al, 2009). A forward displacement can already be seen with loads less than 10% BW (Grimmer et al, 2002). All these are in agreement with our results in the region of lumbar spine.Grimmer et al. (2002) reported that when backpack was positioned at T7 level produced the largest trunk forward lean that is in good agreement with our results when heavy box was located in SM.However, low load placement resulted in greater postural adaptations than high load placement (Heather et al, 2009).Nevertheless, Stuempfle et al. (2004) proposed high load placement (ST) considering physiological factors and muscle activities that is in contrast to our findingsat stage 2. Lots of articles have found thatbackpack`s COG should be as close as possible to trunkdue tothe least load momentum, energy consumption and spine displacement as well as maintain balance (Devroey et al, 2007; Legg&Mahanty, 1985; Motmans et al,2006; Stuempfle et al, 2004). This is in agreement with our results in Transversal plane.

Limitations and future trends

We only have reported the lumbar spine curvature. This is mainly because that review of the surveys shows the importance of LBP on adolescents and its relation to the load carrying (Sheir-Neiss et al, 2003). Hence this study focused on lumbar region to be paid more attention to it. Motmans et al. (2006) concluded that, reduced erector spinae EMG activity and increased Rectus abdominis muscle activity in backpack carrying are disproportionate and asymmetric with increasing backpack load and Finneran et al. (2003) remarked that such condition is similar to acute or chronic LBP patients.

Korovessis et al. (2004) researched the relevance of backpack carriage with anthropometric parameters (gender, height, weight) scoliosis, kyphosis in thoracic, lordosis in lumbar and sports activities; also its effect on LBP and Dorsal Pain (DP) in children and adolescents between 9-15 years old. After investigating the influence of various factors on LBP he stated that there are many potential impacts on spine symptoms so discovering the direct causal relevance between load carrying and LBP is difficult.But Goh et al.(1998)perceived Disproportionate increment in lumbosacral joint force during walking with a backpack. Considering different factors, Korovessis et al. (2004) are not very farfetched but the effect of carrying backpack on LBP cannot be ignored specially in adolescents whose spine is growing and getting stronger (Heather et al, 2009; Sheir-Neiss et al, 2003).

A 15 years old boy was selected for modeling on account of growing spine at this age which is formable with personal habits and they are nonetheless an ‘at-risk’ group as well (Chow et al, 2007). Also, Korovessis et al. (2004) obtained the most LBP prevalence for 15 years old boys. But it should be noticed that children findings cannot be generalized to adults (Grimmer et al, 2002). Furthermore,Hong Y and Li (2005) surveyed the role of age difference in trunk kinematics at different loads of 6-12 years old children, perceived larger TFL amplitude in 12 years old children. Gender influence should be notified in the future as well; according to results of Korovessis et al. (2004), girls experienced more LBP and DP than boys. Reviewing the scientific research reveals the importance of changes in any part of spine in carrying backpack which should be notified in subsequent studies.This study was carried out in static condition and the impact of time and consequent fatigue was ignored.

5. Conclusion:

We have introduced a simulated model of lumbar spine which was able to reliably predict the lumbar spine curvature in standing from a healthy subject with a loaded backpack. Strong correlation were determined for our prediction and similar experimentally literature($R = 0.88$ for G angle and $R=0.91$ for H angle) which enables correction of the numerical values predicted using regression equations. The model developed was used to make predictions while the backpack was loaded with three boxes (4, 4 and 12 Kg in weight) arranged in the sagittal, frontal and transversal planes and the position of the heavier weight was changed at each phase.The G and H angle peaks were similarly observed at stages of SM, FL, FRand TF. The most reduction in lumbar angle is also observed at incorrect backpack carrying postures in SB.The advantage of using a simple model was the relatively quick solution time.

References

Chow, D. H. K., Leung, K. T. Y. and Holmes, A. D. (2007): Changes in spinal curvature and Proprioception of schoolboys carrying different weights of backpack. Ergonomics. 50(12), 2148 — 2156.

Motmans, R. R. E. E. , Tomlow, S. and Vissers, D. (2006):Trunk muscle activity in different modes of carrying schoolbags. Ergonomics. 49(2), 127 — 138.

Reid, SA, Stevenson, JM and Whiteside, RA (2004): Biomechanical assessment of lateral stiffness elements in the suspension system of a backpack. Ergonomics. 47(12), 1272 — 1281.

Singh, T. and Koh, M. Koh. (2009): Effects of backpack load position on spatiotemporal parameters and trunk forward lean. Gait & Posture. 29, 49–53.

Stephanie A. Southard, Gary A. Mirka.(2007): An evaluation of backpack harness systems in non-neutral torso postures. Applied Ergonomics. 38, 541–547.

Bahraseman HG, Hassani K, Navidbakhsh M, Espino DM, Sani ZA, Fatouraee N. (2013): Effect of exercise on blood flow through the aortic valve: a combined clinical and numerical study. Comput Methods Biomech Biomed Engin, In Press. DOI: 10.1080/10255842.2013.771179.

Al-Khabbaz, YSSM, Shimada, T. and Hasegawa, M. (2008): The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. Gait & Posture. 28, 297- 302.

Skaggs DL, Early SD, D'Ambra P, Tolo VT, Kay RM. (2006): Back pain and backpacks in school children. J PediatrOrthop. 26(3), 358-63.

Mackie HW, Legg SJ, Beadle J, Hedderley D. Comparison of four different backpacks intended for school use. ApplErgon. 2003 May;34(3):257-64.

Rashed LA, Hawas HA, Hozaim NA. (2005): Effect of Different Types of Bag on Balance & Center of Gravity, [dissertation], KING SAUD UNIVERSITY.

Devroey C, Jonkers I, de Becker A, Lenaerts G, Spaepen A. (2007): Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures. Ergonomics.50(5), 728-42.

Abe D, Muraki S, Yasukouchi A. (2008): Ergonomic effects of load carriage on the upper and lower back on metabolic energy cost of walking. ApplErgon. 39(3), 392-8.

Stuempfle KJ, Drury DG, Wilson AL. (2004) Effect of load position on physiological and perceptual responses during load carriage with an internal frame backpack. Ergonomics. 47(7), 784-9.

Reid, SA, Stevenson, JM and Whiteside, RA (2004): Biomechanical assessment of lateral stiffness elements in the suspension system of a backpack. Ergonomics. 47(12), 1272 — 1281.

Hamish W. Mackie, Joan M. Stevenson, Susan A. Reid, Stephen J. Legg. (2005): The effect of simulated school load carriage configurations onShoulder strap tension forces and shoulder interface pressure. Applied Ergonomics. 36, 199–206

Grimmer K, Dansie B, Milanese S, Pirunsan U, Trott P. (2002): Adolescent standing postural response to backpack loads: a randomised controlled experimental study. BMC MusculoskeletDisord. 17, 3:10.

Lloyd R, Parr B, Davies S, Cooke C. (2010): Subjective perceptions of load carriage on the head and back in Xhosa women. Applied Ergonomics. 41, 522–529.

Leilnahari K, Fatouraee N, Khodalotfi M. (2011): Spine alignment in men during lateral sleep position: experimental study and modeling, Biomed Eng Online.10, 103.

Bobet J, Norman RW.(1984): Effects of load placement on back muscle activity in load carriage. European Journal of Applied Physiology. 53, 71 – 75.

Pascoe DD, Pascoe DE, Wang YT, Shim DM, Kim CK.(1997): Influence of carrying book bags on gait cycle and posture of youths. Ergonomics, 40: 631–641.

Filaire M, Vacheron JJ, Vanneuville G, Poumarat G, Garcier JM, Harouna Y, Guillot M, Terver S, Toumi H, Thierry C.(2001): Influence of the mode of load carriage on the static posture of the pelvic girdle and the thoracic and lumbar spine in vivo. Surgical and Radiologic Anatomy. 23, 27–31.

Goh J-H, Thambyah A, Bose K. (1998): Effects of varying backpack loads on peak forces in the lumbosacral spine during walking. Clinical Biomechanics. 13(1), S26–31.

Heather M. Brackley, Joan M., Stevensonand Jessica C. Selinger. (2009): Effect of backpack load placement on posture and spinal curvature in prepubescent children. Work. 32, 351–360

Grimmer, K., DANSIE, B., MILANESE, S., PIRUNSAN, U. and TROTT, P. (2002) Adolescent standing postural response to backpack loads: a randomised controlled experimental study. BMC MusculoskeletDisord. 3, 10.

Haex B. (2004): Back and bed. Ergonomic aspect of sleeping. 2 editions. New York: CRC press.

Legg, S.J., Mahanty, A.(1985): Comparison of five modes of carrying a load close to the trunk. Ergonomics. 28 (12), 1653–1660.

Sheir-Neiss GI, Kruse RW, Rahman T, Jacobson LP, Pelli JA. (2003) The association of backpack use and back pain in adolescents. Spine. 28(9), 922-30.

FINNERAN, M.T., MAZANEC, D., MARSOLAIS, M.E., MARSOLAIS, E.B. and PEASE, W.S.(2003): Large-array surface electromyography in low back pain: a pilot study. Spine, 28, 1447–1454.

Korovessis P, Koureas G, Papazisis Z. (2004): Correlation between Backpack Weight and Way of Carrying, Sagittal and Frontal Spinal Curvatures, Athletic Activity, and Dorsal and Low Back Pain in Schoolchildren and Adolescents. J Spinal Disord Tech.17(1), 33-40.

Hong Y, Li JX. (2005): Influence of load and carrying methods on gait phase and ground reactions in children's stair walking. Gait and Posture. 22(1),63–8.

Tables:

Table 1. Abbreviations for the position of heavier box (12 Kg) at different plans.

Plane	Sagittal			Frontal			Transverse		
Heavier BoxPosition	In top of two other boxes	In the middle of two other boxes	In bottom of two other boxes	In left of two other boxes	In the middle of two other boxes	In right of two other boxes	The nearest box to the body	In the middle of two other boxes	The farthest box to the body
Abbreviation	ST	SM	SB	FL	FM	FR	TN	TM	TF

Table 2. The lumbar spine angles at different backpack loads. Note, BW refers to Body weight.

Angle	0% of BW		10% of BW		15% of BW		20% of BW	
	Chow et al.(2007) findings	Present study	Chow et al. (2007) findings	Present study	Chow et al. (2007) findings	Present study	Chow et al. (2007) findings	Present study
G (T12-L3-S1)	21.6	28.1	18.9	27.3	18.2	25.9	17.8	24.8
H (L3-S1-horizon)	76.9	79.1	75.1	78.9	74.3	77.1	73.2	75.8

Table 3. The lumbar angles at different location of heavier load (12 Kg) in sagittal, frontal and transverse planes.

Location of heavier load	ST	SM	SB	FL	FM	FR	TN	TM	TF
G angle (T12-L3-S1)	23.2	23.9	22.9	25.1	24.4	25.1	24.1	24.4	24.6
H angle (L3-S1-horizon)	73.4	74.4	72.9	76.0	75.1	76.0	74.1	74.7	75.4

Figure captions:

Figure 1. The model of subject with a backpack.

Figure2. The model with weights located on sagittal, frontal and transverse plans.

Figure 3. G (L3-S1-horizon) and H (T12-L3-S1) angles changes due to variation in amount of backpack load.

Figure 4. The relationship between G (L3-S1-horizon) and H (T12-L3-S1) angles.

Figure 5. Regression analysis between numerical predictions of and similar previous literature for G (L3-S1-horizon) (Fig 5a) and H (T12-L3-S1) (Fig 5b) angles.

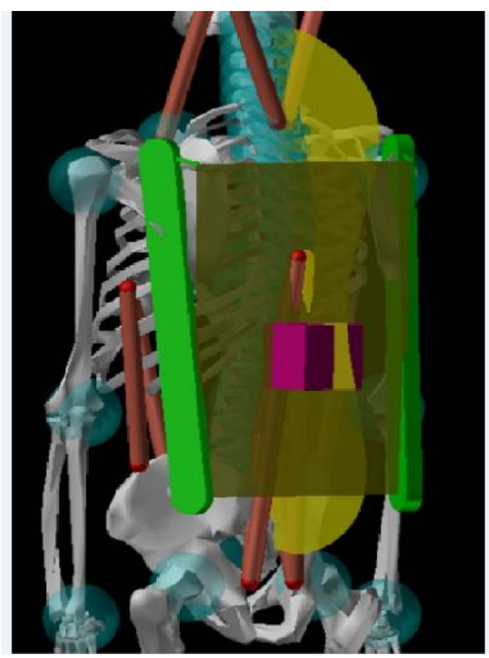


Fig 1

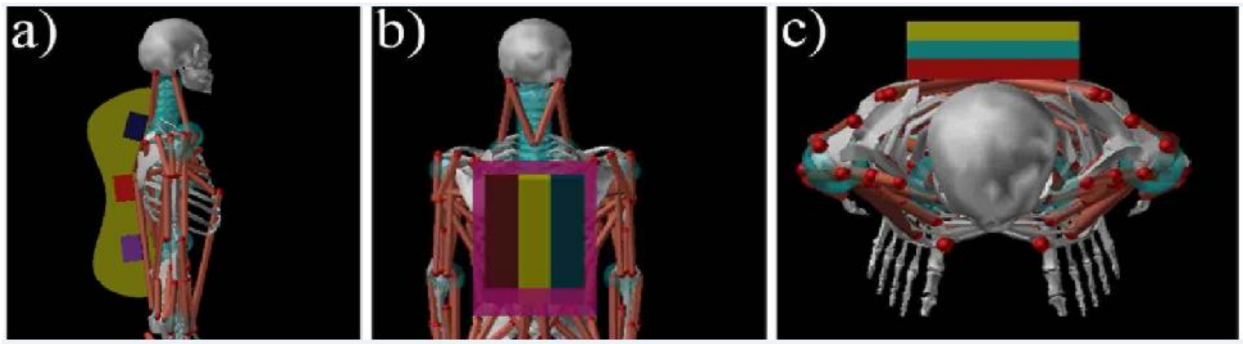

a)
b)
c)

Fig 2

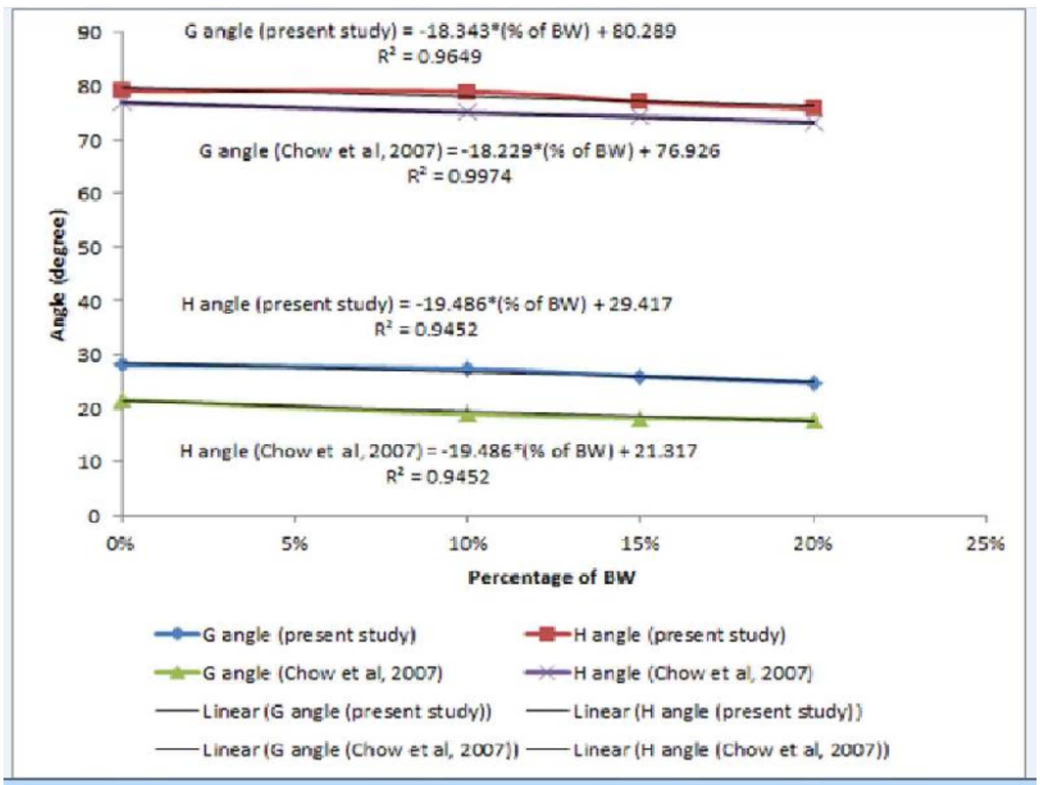
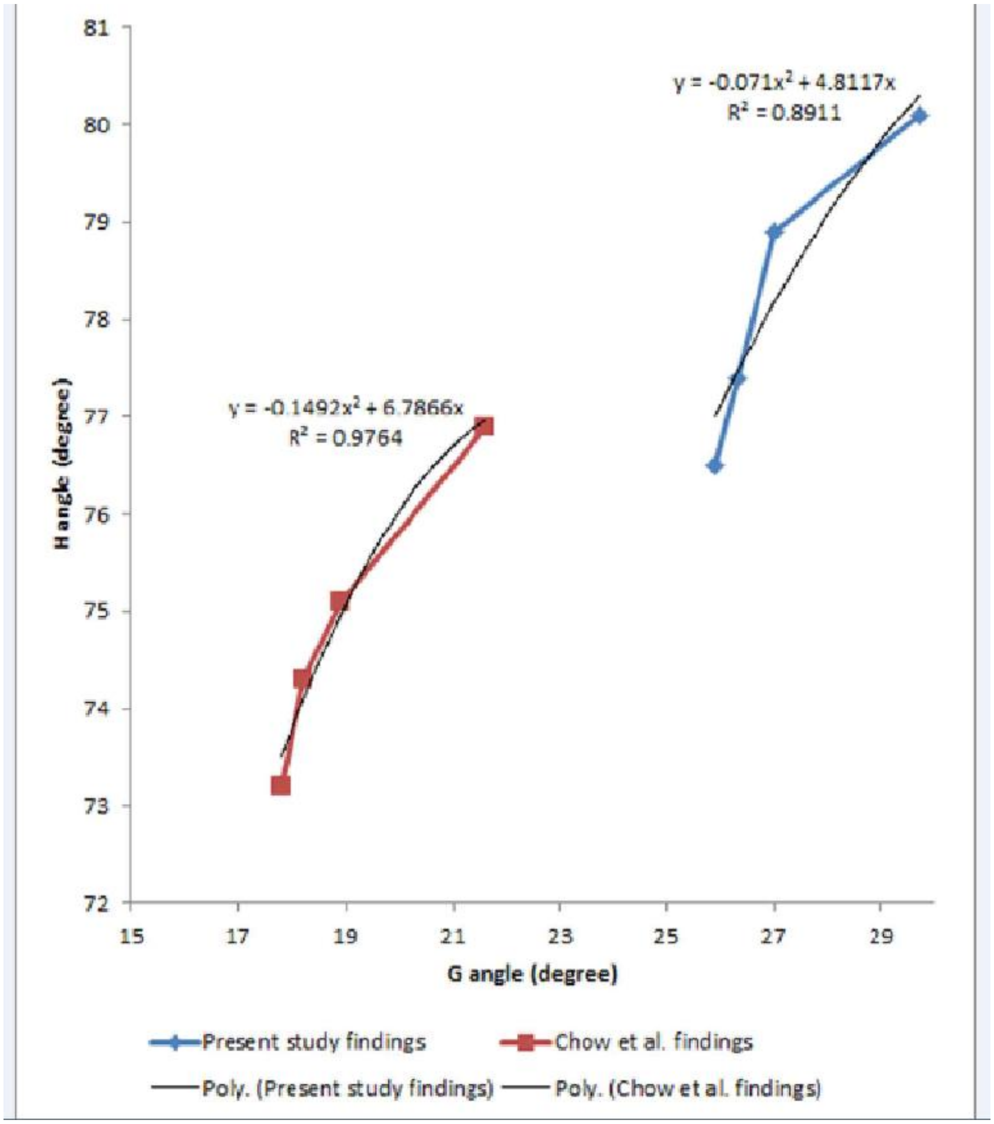
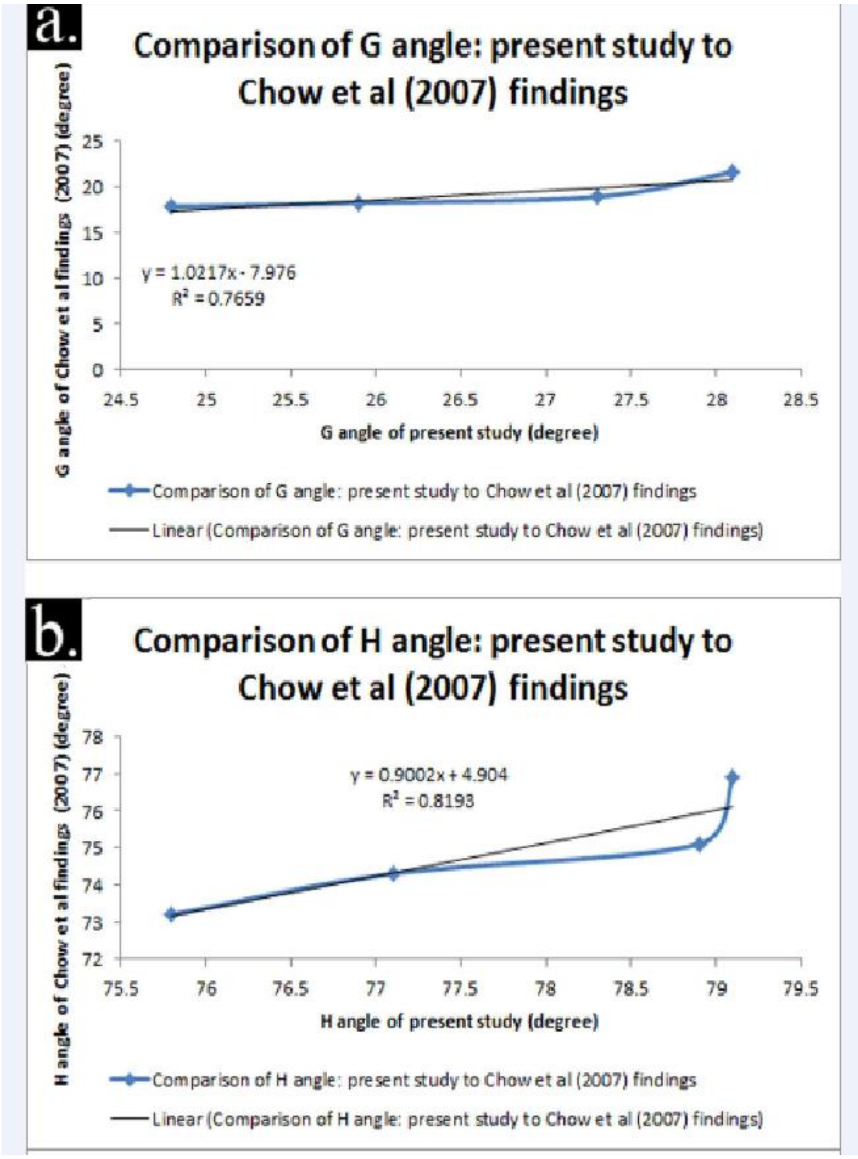

G angle (present study) = -18.343*(% of BW) + 80.289
R^2 = 0.9649
G angle (Chow et al, 2007) = -18.229*(% of BW) + 76.926
R^2 = 0.9974
H angle (present study) = -19.486*(% of BW) + 29.417
R^2 = 0.9452
H angle (Chow et al, 2007) = -19.486*(% of BW) + 21.317
R^2 = 0.9452
Angle (degree)
90
80
70
60
50
40
30
20
10
0
0%
5%
10%
15%
20%
25%
Percentage of BW
G angle (present study)
H angle (present study)
G angle (Chow et al, 2007)
H angle (Chow et al, 2007)
Linear (G angle (present study))
Linear (H angle (present study))
Linear (G angle (Chow et al, 2007))
Linear (H angle (Chow et al, 2007))

Fig 3



y = -0.071x² + 4.8117x
R² = 0.8911
y = -0.1492x² + 6.7866x
R² = 0.9764
81
80
79
78
77
76
75
74
73
72
H angle (degree)
15
17
19
21
23
25
27
29
G angle (degree)
Present study findings
Chow et al. findings
Poly. (Present study findings)
Poly. (Chow et al. findings)

Fig 4


a.
Comparison of G angle: present study to Chow et al (2007) findings
G angle of Chow et al findings (2007) (degree)
G angle of present study (degree)
y = 1.0217x - 7.976
R² = 0.7659
Comparison of G angle: present study to Chow et al (2007) findings
Linear (Comparison of G angle: present study to Chow et al (2007) findings)
b.
Comparison of H angle: present study to Chow et al (2007) findings
H angle of Chow et al findings (2007) (degree)
H angle of present study (degree)
y = 0.9002x + 4.904
R² = 0.8193
Comparison of H angle: present study to Chow et al (2007) findings
Linear (Comparison of H angle: present study to Chow et al (2007) findings)

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345 Fig 5