Estimating Load on the Spine Using Spinal Shrinkage

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Abstract

Changes in body height have been used as a measure of spine compression during loading. However, a gap exists in the literature as to the actual relationship that exists between spinal shrinkage and spine load as a result of load carrying or lifting.

This study proposed a mathematical model for the relationship between spinal shrinkage and spinal load. The model was validated using some load carriers in a major market in Ibadan, Oyo State, Nigeria. The spinal shrinkages obtained from the study did not differ significantly from those calculated using the proposed model, thus suggesting that the model may be valid. The model established a relationship between load on the spine, spinal shrinkage, spine length and chest area.

Keywords

Load Lifting; Spinal Shrinkage; Spine; Spine Load.

Introduction

The use of changes in body height known as spinal shrinkage as a measure of disc (spine) compression during loading was proposed by Eklund and Corlett [1]. Bourne and Reilly [2] studied the effect of a weightlifting belt on spinal shrinkage and observed that spinal loading due to weightlifting results in a loss of stature (spinal shrinkage). Similarly, [3] noted that exercises which involve repeated impacts give rise to spinal shrinkage. Dieen and Toussaint [4] had reviewed the possibilities of spinal shrinkage in ergonomic evaluation of working situations. They observed that since long term effects due to spinal loading are difficult to assess, short term effects of loading the spine such as spinal shrinkage could be used to obtain insights about the workload and its consequences based on an assumed predictive value regarding health effects. It was noted by Wallace and Reilly [5] that changes in stature during physical activity reflect the changes in spinal column length due to spinal loading. Similarly, [6] stated that spinal shrinkage reflects the creep behaviour of the intervertebral and vertebral endplate compression when loaded.

Spinal shrinkage during repetitive controlled torsional, flexion and lateral bend motion exertions was examined by Au et al. [7]. They concluded that repetitive torsional motions impose a larger cumulative loading on the spine when compared with controlled lateral or flexion motion tasks of a similar moment. Moreover, spinal loading during weight lifting results in loss of stature [2].

Also, [8] examined the effect of running speed on spinal shrinkage and noted that faster running speed (higher spinal load) resulted in greater spinal shrinkage. The effect of even gentle spinal loading may be differentiated sensitively by measuring the spinal shrinkage [9]. Kanlayanaphotporn et al. [10] observed that soft tissues below the sacrum could contribute up to 30% on average of spinal shrinkage. Similarly, [11] believed that the major gain in stature loss occurred in the lumbar spine. Moreover, [12] stated that there were no statistically differences in stature change between either sitting or standing posture suggesting that nearly all height changes occur in the spine. Reilly and Freeman [13] studied the effects of loading on spinal shrinkage in males of different age groups and concluded that for as long as load is related to individual capability, healthy older operators are not necessarily compromised by their age in activities that include handling and lifting of weights. Ismaila

[14] observed that differences in spinal shrinkage between individual could be due to the type of work undertaken by them.

Ismaila and Charles-Owaba [15] later studied the effects of type of work and age on spinal shrinkage and concluded that significant differences existed between spinal shrinkages due to heavy and light workloads. They confirmed the assertion of [13] that inter- individual variation in spinal shrinkage was not due to age but to workloads. McGill et al. [12] evaluated low back loading in the workplace using spinal shrinkage and observed that some subjects experienced more shrinkage in the static task while others experienced more in the dynamic task. They then suggested 'more quantification of the relationships that modulate spinal shrinkage is required to account for the variance in stature measurements'.

All these seem to suggest that not only that a relationship exists between the spinal shrinkage and spine load but that spinal shrinkage may be related to some other anthropometric variables. Thus, the main aim of this study was actually to propose a model for this relationship.

Material and Method

Model Formulation

For a gradually applied load, the Strain Energy (SE), is given by Ryder [17]:

$$SE = \frac{1}{2} F x \quad (1)$$

where F = Applied Load, N; x = Associated change in length, m.

Since the whole spine is surrounded by many layers of muscle and the contents of the abdomen and chest cavities, the spine together with the trunk muscle and other soft tissues may be regarded as weight-bearing unit [18].

There exists a property of the material (measure of rigidity) known as Spring Constant, k. For an axial force where it does not stress the material beyond the elastic range, this is given by [19]:

$$k = F/x = AE/L \quad (2)$$

where F and x are as previously defined

Assuming the cross-sectional area (A, expressed in m^2) of the chest to be elliptical,

$$A = \pi l_f l_s / 4$$

where l_f is chest length and l_s is chest width; E= Young Modulus of Elasticity, N/m^2

Thus, Load on the spine may be taken to be:

$$F=AEx/L \tag{3}$$

$$F=Ex\pi l_f l_s/4L \tag{4}$$

It should be noted that $F = W_L + W_B$; W_L is the weight of the load being lifted, W_B is the weight of the body, A is the chest area, E is the Young Modulus of the Articular Cartilage, x is the spinal shrinkage and L is the length of the spine (measured from first thoracic to last lumbar) in meters.

Model Validation

To validate the model, fifteen (15) subjects were randomly chosen from the load carriers ('ALABARU') at Bodija Market in Ibadan, Oyo State were the subjects. The ages of the subjects were between 18 and 40 years (mean of 30.2 years). The market is noted for sale of foodstuffs and there are people who engage in carrying load for others for a fee. They were told that they would lift and carry different kilograms of rice from the market to the bus stop and some measurements would be obtained. Five of the subjects carried a bag (50 kg) of rice, another five carried 40kg of rice while the remaining five carried one-half (25 kg) of rice. They carried the different kilograms of rice from the market to the bus-stop, a journey that took about 10minutes. The statures of the subjects were measured just before they lift and carry the load in the morning with the aid of Standiometer. This was their first task for the day. Their chest lengths and widths were measured using Vernier Calliper. The statures were again measured just after the loads were dropped. The side and frontal lengths were measured with the use of a Vernier Calliper which was opened to accommodate the respective lengths on the subjects. The readings were read from the scale on the Calliper.

Measurements of the length of the spine without the cervical vertebrae were done using a meter rule. The measurements were done from the first thoracic (T_1) to the last lumbar (L_5). Measurements of the side and frontal lengths as well as the spine were done just before the commencement of work only.

Results

The data obtained from the study and the calculated spinal shrinkages using the proposed model are shown in Table 1.

Table 1. Data Obtained from the Study and Calculated Spinal Shrinkages

Weight of Rice (kg)	Measured Shrinkage (m)	Chest Area (m^2)	Length of Spine (m)	Age (years)	Weight of Subject (kg)	Calculated Shrinkage (m)
25	0.007	0.033	0.490	28	72	0.006
25	0.007	0.033	0.450	28	75	0.006
25	0.005	0.034	0.500	30	66	0.005
25	0.005	0.035	0.460	20	70	0.005
25	0.006	0.039	0.500	30	68	0.005
40	0.006	0.037	0.580	35	77	0.007
40	0.010	0.031	0.700	38	76	0.011
40	0.008	0.039	0.500	38	74	0.006
40	0.007	0.041	0.480	39	78	0.006
40	0.006	0.046	0.650	40	76	0.007
50	0.006	0.039	0.500	18	76	0.007
50	0.010	0.038	0.540	25	78	0.007
50	0.008	0.033	0.520	25	77	0.008
50	0.008	0.036	0.500	29	68	0.007
50	0.009	0.036	0.530	30	79	0.008

Discussion

The model shows that the load on the spine is directly proportional to chest area, Young Modulus of Elasticity of the Articular Cartilage of the spine, spinal shrinkage and inversely proportional to the spine length.

Thus, spinal shrinkage is load dependent. The proposed model seems to confirm the assertion of Ayuob et al [20] that pressure at the chest area produces an extensor moment that reduces the stress on the spine during loading as the chest area is proportional to the load on the spine.

A Young Modulus of Elasticity of the cartilage endplate of $2.4 \times 10^6 N/m^2$ reported by Sokoloff [21] was used in the model.

Deursen et al. [22] also found a good correlation between spinal shrinkage and intradiscal pressure while Hodges et al. [23] observed that increase in spinal stiffness was positively correlated with the size of the intra abdominal pressure. The model established that there exists an association between load on the spine and spine length (body height) as noted by Schenk [24]. Chaffin and Andersson [25] had observed that the ability of carrying load steadily declines with increase in height of people. The model seems to explain the reason why weight lifters build muscles at the chest area. The results obtained from the study confirm the above assertions. In fact, a strong correlation exists between the weights on the spine and the associated spinal shrinkages (r = 0.62). Similarly, a significant correlation exists between the spinal shrinkages obtained from the study and length of spine (r = 0.78).

The obtained spinal shrinkages from the study were also compared with the calculated ones using the model and F-Test conducted. The results confirmed that the shrinkages were not significantly different at 0.05 level of significance (F = 3.96 was less than $F_{critical}$ = 4.54). The model established a linear relationship between load on the spine and spinal shrinkage which Tyrell et al [26] found to be nonlinear.

Conclusions

The current study proposed a model that may be used to estimate load on the spine given the spinal shrinkage, chest area of the subject, length of spine and Young Modulus of Elasticity of Articular Cartilage. The model may explain the reason why weight lifters built muscles at the chest area and are usually short in stature. The spinal shrinkages obtained from the study, were tested (at 0.05 level of significance) with the calculated ones using the model and it was confirmed that there were no significant differences between the two. Conversely, the model may be used to obtain spinal shrinkage given a specific load on the spine.

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