Biomechanical Modeling of Materials Lifting Activities for Exploring Relation between Low Back and Knee Loading leading to Low Back Pain and Knee Arthritis

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Abstract

This paper investigates the relationship between low back loading (force) and knee loading (force) during manual materials lifting activities by biomechanical modeling. Improper loading on L5/S1 joint and knee joint can result in low back pain and knee arthritis. A six link two dimensional sagittal plane biomechanical model based has been used here to find out the Compressive, Shear and resultant forces on both the joints for various combinations of body angles describing the posture permitted by the body balance condition. A statistical analysis of these data revels that low back and knee forces are inversely correlated and the correlations are very high and significant. The variations of these correlations with load height and load weight were also found out. Effect of increase of body weight, which normally happens with ageing, was also considered. Finally the paper provides recommendations for the body posture for manual materials lifting activities.
Keywords: Biomechanical model, Low back pain, Knee arthritis, Lifting posture, body weight

1. Introduction

Biomechanical models can help in investigating problems and risks of manual materials lifting activities, which are common in many work places and can suggest remedial actions to avoid risks. Researchers have proposed many such models each having certain specific objectives and limitation of their own. In case of materials lifting tasks, these models are helpful in analyzing the forces and torques that develop at different important body segments and joints (Garg et. al., 1975, Todd, 2005). In case of lifting activities where the whole body is involved, the low back (L5/S1) and the knees are the most important joints at risk. For low back problems, it is often recommended to have lifting with more stress on knee to reduce the loading on low back. But as low back pain and disorder is a very widely recognized problem, knee arthritis due to improper use of knee is also a major problem. However, the occurrence of low back pain is the most common between age group of 35 to 40 years, whereas knee arthritis usually appears later in life with peak above the age of 65 years (Bejjani et al, 1984). It is thus important to see how these two important joints are interrelated during manual material lifting activities. Researchers have reported the existence of inverse correlation between the loading of the two joints ((Bejjani et al 1984). But further investigation is required to overcome the limitations of earlier studies. This paper provides an improved and more generalized modeling to derive conclusion and recommendation in this regard.

2. The model

The model used here is a two dimensional static one having six links in sagittal plane. The link lengths are derived from the over the body dimensions using empirical relations of Dempster (Garg et.al, 1975, Chaffin, 1969) as described below.

Over-the-body-dimensions
Stature= D1
Standing Elbow Height= D2
Wrist to Grip Centre= D3
Lower Arm Length= D4
Lower Leg Length= D5
Foot Length= D6
Body Wight= W

Links
Hand grip to elbow, $L1 = 1.0709 \times D4 + D3$

Ankle to knee, $L2 = 1.0076 \times D5$

Elbow to shoulder, $L3 = 5.806 + 0.9646 \times D4$

Knee to the center of Hip, $L4 = 13.2817 + 0.8172 \times D5$

The center of hip to L5/S1 disc, $L5 = 0.195 \times D10$, where

$$D10 = (D2+L3) - (D9+L2+L4)$$
$$D9 = 0.304 \times D6$$

L5/S1 to the center of shoulder, $L6 = 0.806 \times D10$

Link weights derived from body weight
Link weights are derived from body weight using relationships of Dempster and other researchers (Garg et.al, 1975), which are as follows:
Hand grip to elbow (each), $WL1 = 0.025 \times W$
Ankle to knee (each), $WL2 = 0.046 \times W$
Elbow to shoulder (each), $WL3 = 0.031 \times W$
Knee to the center of Hip (each), $WL4 = 0.105 \times W$
The center of hip to L5/S1 disc, $WL5 = 0.191 \times W$
Head neck and Trunk above L5/S1 disc, $WL6 = 0.363 \times W$

Location of Center of gravity of links
For analysis it may be assumed that the link masses are concentrated at the center of gravity of the link. Location of the Centre of Gravity (CG) for link segments were also thus derived according to Dempster's relations from the link lengths (Garg et.al,1975) as described below:
Elbow to C.G. of Lower Arm, $LG1 = 0.430 \times L1$
Ankle to CG of Lower Leg, $LG2 = 0.567 \times L2$
Shoulder to CG of Upper Arm (Each), $LG3 = 0.436 \times L3$
Knee to CG of Upper Leg (Each), $LG4 = 0.567 \times L4$
Centre of Hip to CG of Trunk Between Hip and L5/S1 Disc, $LG5 = 0.5 \times L5$
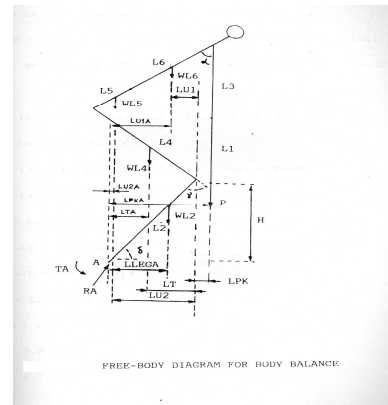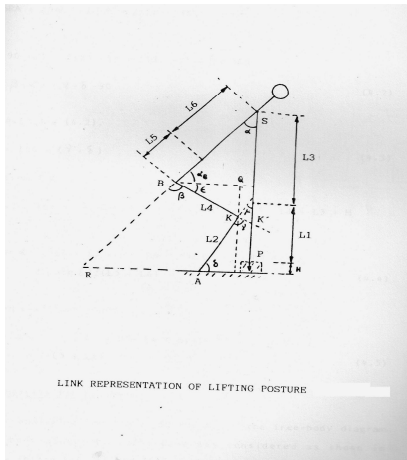L5/S1 Disc to CG of Trunk above L5/S1, Neck and Head, $LG6 = 0.4321 \times L6$

Fig. 1 Link representation of lifting posture   Fig 2. Free body diagram for body balance

Body angles
To describe the human body in any activity by the model, these links are joined together appropriately. The angle between any two links represents the postural angle between the limbs represented by the links. These angles have a limited range of values due to limitations imposed by human physiology. The angles considered here are (Bejjani et. al, 1984):
Angle of flexion of the back, α
Angle of flexion of the hip, β
Angle of flexion of the knee, γ
Angle of flexion of the foot and the leg, δ
Angle between the thigh and the horizontal, ε

The load
The load has been described by the force P.
The height of the load is H.

The body balance equation
When a person lifts a load the load and the body together forms a system at equilibrium. So the posture must be such that body balance is maintained. Thus the model parameters must satisfy the condition of body balance with reference to Fig 2.as described below:
$(W+P) \times LAT \geq TA$ for $TA \geq 0$
and
$(W+P) \times LAH < -TA$ for $TA < 0$
where   P= external load

TA= Torque at ankle
W= Body weight of the person
LAT= Distance from ankle to toe
LAH= Distance from ankle to heel

Torque at ankle, TA= P×LPKA + (2×WL4 × LTA+ WL5×LU2A +2×(WL1+WL3) × LPKA + WL6×LU1A + 2×WL2×LLEGA),
Where
LPK= (L5+L6) × Sin α - L4 × Cos(180-γ - δ)
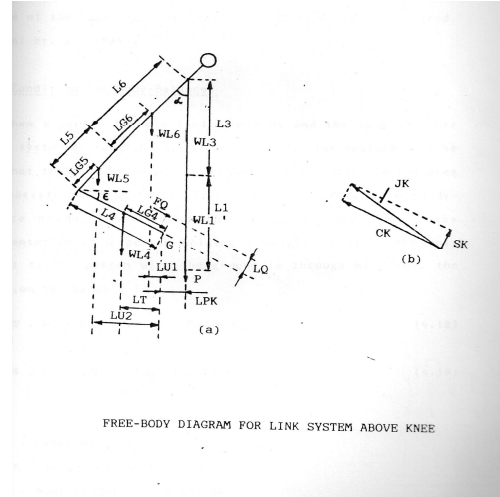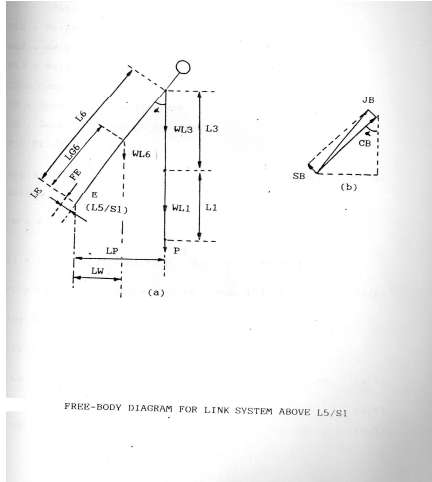
Fig 3. Free body diagram for low back (L5/S1)   Fig 4. Free body diagram for
Knee joint

LT= LG4 × Cos(180-γ - δ)
LU1= L4 × Cos(180-γ - δ) – (L5+LG6) × Sin α
LU2= L4 × Cos(180-γ - δ) – LG5 × Sin α
LPKA= L2 × Cos δ + LPK
LTA= - LT + L2 × Cos δ
LU2A = –LU2 + L2 × Cos δ
LU1A = L2 × Cos δ - LU1
LLEGA= LG2 × Cos δ
LAT= 0.8 × D6
LAH= 0.2 × D6

Relationship of body angles
It can be shown (Dasgupta, 1991) that the body angles described above are tied up by the following relationship.(Fig 1)
Cos α = (L1+L3+H – L4 × Sin (γ+δ) – L2 × Sin δ) / (L5+L6)

Low Back Forces
Considering the free body diagram (Fig3) of the joint at low back, the compressive (CB), shear (SB) and resultant forces (JB) can be found out as follows:
CB=WL6 × Cos α + (2 × (WL1 + WL3) +P) × Cos α + FE, where

FE= $((2 \times (WL1+WL3) + P) \times LP + WL6 \times LW)/LE$

SB= $WL6 \times \sin \alpha + (2 \times (WL1+WL3) + P) \times \sin \alpha$

JB= $\sqrt{(CB^2 + SB^2)}$

Knee Forces

Similarly considering the free body diagram (Fig 4) of the joint at knee, the compressive (CK), shear (SK) and resultant forces (JK) can be found out as follows:

CK=$((WL6+WL5)/2 + WL1 + WL4 + WL3) \times (\sin (\gamma + \delta)) + FQ$, where

FQ= $(WL6 \times LU1 + WL5 \times LU2 + 2 \times WL4 \times LT - P \times LPK - 2 \times (WL1+WL3) \times LPK)/2 \times LQ$

SK= $((WL6+WL5+P)/2 + WL1 + WL4 + WL3) \times (-\cos (\gamma + \delta))$

JK= $\sqrt{(CK^2 + SK^2)}$

3. Materials and Method

Over the body dimensions D1 to D6 and body weight of seventeen male subjects have been considered which were measured with standard anthropometer.

With these data Low back and Knee joint forces were calculated for all possible combinations of body angles (varied in steps of 5 degree), which are allowed, by the condition of body balance for different load heights and load weights for each persons. A computer program was written for this. The low back and knee joint forces were then analyzed statistically.

4. Results and Discussions

- Very high linear inverse correlations (in the order of -0.87, -0.89, p<0.001) have been found between the back and the knee forces for all the subjects.
- The correlation between the back and the knee joint forces (Compressive, Shear and Resultant) found to be increasing up to a certain load height when load weight is kept constant.
- The correlation between the back and the knee joint forces (Compressive, Shear and Resultant) found to be increasing with load weight when load height is kept constant.
- With the high load and high load height the correlations were as high as 0.9 (p<0.001) between two joint forces.
- High inverse correlations indicate that if the low back loading is reduced by adjusting the posture, knee loading will increase and the vice versa.

Recommendations
- Thus for the low back patients when knee lifting is recommended, it is to be seen that they are of much lesser age group than 65. Otherwise it may increase the probability of knee arthritis. For people in the age group of 65 and above, load magnitude must be selected in such a way that both low back and knee loadings are less.

- In the expressions of Low back and Knee joint forces if P=0 is substituted, the expression for low back and knee joint forces are obtained for no load condition and these are proportional to body weight. So if body weight of the person is increased, these forces will also increase. Thus for people engaged in manual material lifting tasks, increase of body weight, which naturally happens with age, is a serious disadvantage. But they should not be underweight either, as this will according to body balance equation allow them to lift lesser weight.

5. Conclusions

It can be concluded that the model is more general than ones used in earlier studies and uses body balance condition for postural angles. The paper investigates the relationship between low back and knee joint forces considering variation of load weight and load height and effect of increased body weight. The paper also provides recommendations based on findings. However, it is also felt that there is scope of further studies considering other related factors in this direction.

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