MICRO-FRACTURE SIMULATION IN HUMAN VERTEBRAL BODY DUE TO WEIGHT LIFTING

Harcharan Singh Ranu

College of Medicine, Department of Orthoaedics, King Saud University, Riyadh 11433 Saudi Arabia and American Orthopaedic Biomechanics Research Institute, Atlanta, GA 31139-1441. U.S.A.

INTRODUCTION

History of weight lifting is associated with man's fascination with physical prowess. Over 5,000-year-old Chinese writings suggest that soldiers used lifting weight as tests. Greek sculptures in ancient times also depict lifting feats. The modern day Olympics of 1896 included weightlifting as an official sport. But today there are eight classes of weight lifting for men and seven for women. In 2008 Olympics Super Heavyweight (+105 Kg Class) Gold Medal was awarded to Mathias Steiner of Germany, who lifted 461 Kg and Silver to Yevgeny Chigishev of Russia, for lifting 460 Kg.

Lumbar vertebrae are a heavily loaded component of the human body. They are subjected to repetitive loading in daily activities. It has been estimated that there are over 500,000 vertebral fractures and over 250,000 hip fractures each year in the United States alone and the associated annual cost to treat them exceeds $10 billion [1]. In the past several years, a substantial number of experimental & clinical studies have been carried out on human vertebrae. Results from these studies provide considerable variation and it is often very difficult to interpret the data. However, limited information on failure mechanism of lumbar vertebrae are available to date. Thus, the need to develop an analytical model to predict stress-fracture characteristics of vertebral body.

MATERIALS AND METHODS

A linear elastic fracture mechanics approach has been considered and a mathematical model has been proposed so that the predictions can be made more easily related to the occurrence of the injury.

Number of repetitive loading necessary to cause the micro-fracture has been obtained by using the following equation Bannantine, Comer & Handrock [2]:

$$N_f = \int_{a_j}^{a_f} \frac{da}{C\,\Delta K^m} \quad (1)$$

where, N_f is number of cycles of loading, a is the crack length, ΔK is the cyclic range of stress intensity factor, and C and m are constants. Resultant compressive force applied in weight lifting was derived from Lander et al [3]. It is reasonably accurate to use $\Delta K = 1.12$, Fc/A, where Fc is total applied load on vertebrae and A is an average cross-sectional area of lumbar spinal disc. In order to calculate net compressive force an extended discretized model of human body is proposed (Figure 1). Extended discretized model is appropriate for present analysis to incorporate effect of muscles and other segments of human body. Net compressive loading at various flexion angles (0 to 60 degrees) can be evaluated by using the equations:

$$F_c = - [F + W \cos \alpha + \Sigma^2_{i=1} W_i \cos \alpha] - (2)$$

Where $F = (W.x + \Sigma^2_{i=1} W_i,x_i)/x_3$

and α is the flexion angle in radian. Substituting equation 2 in equation 1 and integrating numerically with an increment of 10×10^{-6} m, the number of repetitive loading (N_f) to cause fracture of vertebrae have been calculated. Following data have been used in this study: $a_i = 10.0 \times 10^{-8}$ m, C $= 1.0 \times 10^{-8}$, m=-3, A= 465×10^{-4} m^2 and the final value of crack length (a_f) 10×10^{-6}m.
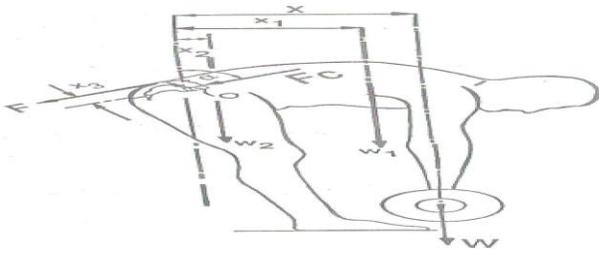
Fig. 1. A model of discretized human body and spine subjected to external and internal loadings while lifting a weight.

RESULTS

Study reveals that for a person weighing 1334 N and lifting a weight of 345 kg during squat exercise causes vertebral micro-fracture at 12 repetitive standing lifting. While the same load at lowest position (hip angle = 49.9 degrees) yields stress-fracture at less than 3 lifting.

Numerical study shows that for change of position from standing to lowest position the resultant compressive force acting on spine increases by two times whereas the possibility of stress-fracture increases by five times. Similarly at dead lift exercise, lifting 325 kg from standing to lowest position increases resultant compressive forces on vertebrae by 2.5 times (Figure 2). This however, increases the stress-fracture ratio by six times. Hence, a similarity of stress-fracture characteristics for different exercises have been observed. The model presented here is being extended to include a complex geometry of the spinal disc, force & torque will be applied to simulate the micro-fracture of the vertebrae.
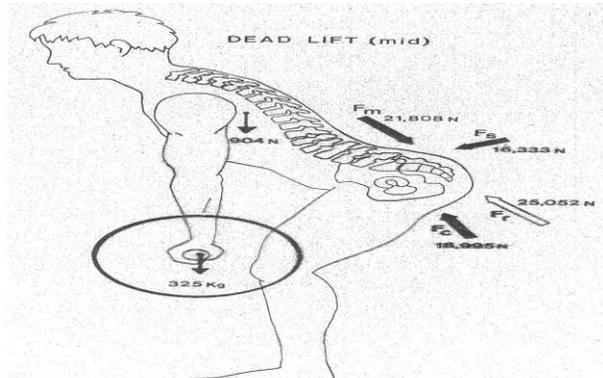
Fig. 2. Dead lift exercise simulated lifting a weight of 325 Kg.
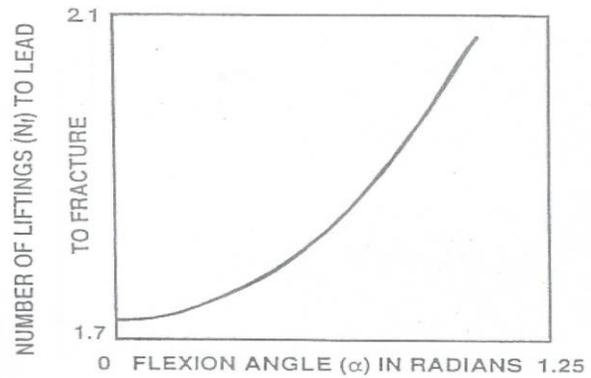
Fig. 3. Predicted stress-fracture response of human vertebrae. Number of lifting's (N_f) against flexion angle (α).
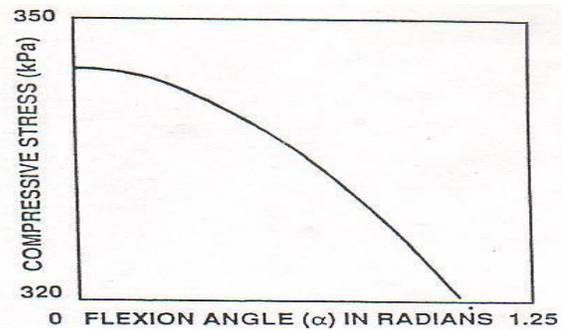
Fig. 4. Predicted compressive stress on human vertebrae while lifting a weight of 900 N. Compressive stress against flexion angle (α).

The study reveals that for a person weighing 800 N (height=1.8 m) & lifting a weight of 900 N, the vertebrae can be subjected to stress-fracture by three cyclic lifting (Figure 3). The rate of injury is also dependent on flexion angle i.e. as flexion angle increases, so does the rate of injury (Figures 3 and 4).

DISCUSSION

For the first time stress-fractures in human body are simulated. Previous work by Bannantine et al [2] in other materials allows us to use this technique for human body. But it has its limitations because of complexity of human body structure. However, these stress-fractures do occure in real life in different sports Telford [4]. So this simulation provides a yard stick for coaches of different sports, but weight lifting in particular to be careful of injuries which can do more harm than good to the athlete's body.

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