A MODEL OF FEMORAL COMPRESSION AND SHEAR DURING STANDING FOR INDIVIDUALS WITH COMPLETE SPINAL CORD INJURY

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INTRODUCTION

Osteoporosis is a serious medical complication following spinal cord injury (SCI). Bone mineral density (BMD) in the lower extremities can decrease by approximately one-third in the first six months after injury (Garland, D.E., et al., 1992; Roberts, D., et al., 1998). Correspondingly, for individuals with complete SCI, the rate of long-bone fracture is more than 20% greater than for the general population (Frisbie, J.H., 1997). Although several studies have investigated the effects of various forms of limb loading exercise on BMD in individuals with SCI, no studies included estimates of the bone loads generated. To determine a dose-response curve for exercise induced bone loading following complete SCI, the mechanical loads from an intervention must be assessed. The purpose of this study was to develop a mathematical model to predict compression and shear forces in the distal femur during passive and active standing exercise in individuals with SCI.

METHODS

Individuals with SCI are able to stand independently with the use of a standing frame. One example of such an apparatus provides kneepads for anterior support, a hip belt for posterior support, and optional upper extremity support. Standing may be performed either passively, relying on the kneepads to maintain knee position, or actively with the addition of electrical stimulation of the quadriceps muscle. Higher quadriceps muscle forces may be obtained with added resistance to knee extension (only with active condition) for increased levels of muscle training.

A quasi-static model, based on the standing frame described, was developed using a two-bar linkage representing the thigh segment and the shank segment of one lower limb. External forces included ground reaction forces, kneepad reaction force, and hip-belt reaction force. The weight of the head, arms and trunk were assumed to act downward at the hips (single force vector); the weights of the segment links were assumed to act at their respective centers of mass. No internal muscle forces were included for the passive model; however, a simplified quadriceps muscle force was included in the active model. The quadriceps force was modeled at the precise moment the kneepad normal reaction force was reduced to zero. Thus, the resultant quadriceps force across the patella (horizontal component) was assumed to be equal to the kneepad force at rest (passive condition) plus any added resistance to knee extension. The compression and shear forces in the distal femur were modeled at a distance of 85% of femur length from hip to knee for both the active and passive conditions. This location was chosen to approximate a common site of pathological lower limb fractures in individuals with SCI.

Matlab computer software (version 5.3) was utilized for all equations. The model was generalized such that body weight and height were inputted to the model. All limb lengths and center of mass values were based on anthropometric standards (Chaffin, D. and Andersen, G., 1998) and thus were a function of height. Model parameters, e.g. coefficients of friction and segment angles, were determined from experimental data resulting from a hand-held goniometer, a custom-instrumented kneepad force transducer, and a Kistler force plate. The sensitivities of the model parameters were evaluated by altering one parameter at a time over a range of expected values, leaving the remaining parameters constant. The model was most sensitive to alterations in the internal knee angle and the coefficient of friction between the foot and the ground (u_{gr}). Based on the experimental findings taken at five different standing positions, u_{gr} was set equal to 0.2 and the belt angle was set equal to 10°. Upper extremity support and frictional forces at the kneepad and hip belt were assumed to be negligible.

RESULTS AND DISCUSSION

The distal femur compression estimates for the passive condition were in the range ~40-75 percent body weight (%BW), varying with segment angles. The compression estimates for the active condition (no added resistance) were approximately two times larger than for the passive condition (range ~70-130%BW). The addition of 100 lbs of resistance behind the knee (extreme condition of 77% BW horizontally, using 130 lbs BW as model input) increased the femoral compression forces by three to four times the passive condition (range ~175-200%BW). The modeled shear forces at the distal femur were low for all conditions (range ~1 – 20%BW). Segment angles of the thigh and shank (with respect to horizontal) had a substantial influence on the compression, shear, and muscle force predictions of the model as seen in the range of values reported above.

This model provides a simple method for estimating loading dose for a standing exercise in persons with SCI. If movement is allowed, then the quasi-static nature of the preceding model may be in error. However, most movements would likely have relatively low displacements and velocities, as movement deceleration is a critical issue in individuals with complete SCI.

SUMMARY

Overall, this model provides potentially valuable information regarding the compression and shear in the distal femur during passive as well as active standing. Shear force predictions never exceeded 20%BW even when the compression force predictions peaked at ~200%BW, suggesting that this type of exercise is a reasonably safe option for individuals with SCI.

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