Ergonomic Aspects in Biomechanical Analysis of the Glenohumeral Joint

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Introduction

Musculoskeletal disorders of the upper extremities due to work factors are common and occur in nearly all sectors of our economy. More than $904 million in workers’ compensation costs were spent in 1998 (data from a large worker’s compensation insurance company for work related upper extremity disorders, unpublished data). Workers’ compensation costs undoubtedly underestimate the actual magnitude of these disorders. The highest rates of these disorders occur not only in the industries with a significant amount of forceful work in high arm positions during concentric contractions, but according to biomechanical studies by Sporrong et al. (1999), the supraspinatus muscle is also heavily loaded during eccentric contractions in arm positions of 0 to 30 degrees of abduction.

Current scientific research has yielded important insights into the etiology of work-related upper extremity musculoskeletal disorders, but important ergonomic questions still remain. How do we access individual load limitation? Which element of the joint is the weakest during different types of work? Van der Helm (1994) surmised that the geometry of each muscle should be regarded with respect to the geometry of the whole shoulder, which means that only functional aspects of morphology can be compared. However, in these models a number of important aspects have not been considered with respect to biomechanical analyses of this joint within the workplace environment. The mathematical models did not take into account:

- the irregularity of the working bone surfaces,
- the dependence of the type of contact surface on the gender and age of the person under examination (Saha, 1961)
- the length of the ligaments and
- the occurrence of looseness in the joint.

Method

A new model of the glenohumeral joint has been proposed and investigated for its applicability to ergonomic studies (Gielo-Perczak, 1989). The most important feature of the proposed model is that the internal loading – which means the forces at the bone-on-bone contact point, or in the muscles, or in the ligaments – can be expressed as the multivariable function of its articular geometry. For example, the formula for the deltoid muscle force (acromial part) is a function of multivariable parameters:

\[ FM_1(N) = f(P, M, FM_2(N), FL_2(N), L_1, L_2, L, YP(N), Z(N), \alpha, \phi(N), \psi, \tau, v_1, v_2, v_3, \gamma, \epsilon, \mu) \]

This method of analysis takes into account individual differences in geometry of the glenohumeral joint (GHJ) with different types of work. Central to the study is an investigation of the individual influence of joint geometry on the Maximum Acceptable Workload (MAW) applied to the hand.

The biomechanical model of the GHJ provides information on the force-mediated response of musculoskeletal tissues through various types of work (Fig.1). The proposed model provides sets of
humerus positions that are acceptable in terms of muscle and ligament strength and stresses at the bone-on-bone contact points. The contact point positions of the head of the humerus with the glenoid fossa, for the given load, depend on the individual geometric features of glenoid fossa.

The maximum acceptable workload of each element of a joint can be calculated individually as a function of the external load, the geometry of the articulating surfaces, and the muscles and ligaments.

Results & Discussion

The force applied at the hand is a critical element in assessing individual force limitations during different activities. The calculations have been performed for the different joints and loading, and the results show that when an individual pushes an object on a table, the bone-on-bone forces have the greatest influence on the Maximum Acceptable Workload. For example, the subject with a known geometry of the glenohumeral joint performs two tasks: I. Carrying a 2 kg object, and II. Pushing a 2 kg object on a table. The calculations proved that during pushing an object on a table, the bone-on-bone forces have the greatest influence on the Maximum Acceptable Workload.

The notion of Maximum Acceptable Workload can be applied to work tolerances. In a pulling activity, if the arm is moved about 30 degrees from the side, and the angular position of a handle is:

- 170 degrees, then the maximum acceptable load can be 971 N;
- 160 degrees, then the maximum acceptable load can be 414 N;
- 150 degrees, then the maximum acceptable load can be 271 N.

So, the maximum weight of the pulled object depends on the geometry of a joint and position of the arm, and on the position of the handle. In all work related disorders of the glenohumeral joint, biomechanics knowledge is essential for a more complete understanding of the mechanism of injury. This glenohumeral joint model can:

- contribute to prevention of likely shoulder injuries during static and repetitive work,
- examine the forces in ligaments, chosen muscles, and between bones of the glenohumeral joint for external loads and for specific joint geometry,
- assist during designing of the workplace.
As a further benefit of this biomechanical model, changes in stress within the glenmeral joint due to degeneration of bones with age can be better understood. The results of this approach can assess the suitability of the designed human-machine system and to determine possible improvements.

This method can be a useful tool for:

- minimizing incompatibilities between the capabilities of workers and the demands of their jobs,
- prevention of likely shoulder injuries during work.

With this GHJ model, it is possible to reduce musculoskeletal injuries by assessing individual acceptable loads during carrying, pushing and pulling. This model can help reduce the risk of shoulder injuries during static and repetitive work, and can help researchers examine the forces in ligaments, selected muscles, and between bones for specific joint geometry. This method can be useful for minimizing incompatibilities between the workers’ physical capabilities and their job demands towards preventing work-related shoulder injuries.

References