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Biomechanical Computation of Shoulder Strain During Multi-Directional Forceful Arm Exertions

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Abstract: Musculoskeletal modeling software was used to perform simulations of static force exertions of the right upper limb. A series of 36 force exertions in directions at 30° intervals in the transverse, sagital, and frontal planes were performed using three muscle recruitment optimization algorithms. The 36 exertions were performed first using a force of 40 N and then again with 80 N, to compare the effect of amount of force exerted. A previously validated strain index equation was used to calculate risk injury for each force exertion based on the magnitude and direction of the resultant glenohumeral force. Generally, highest strain values were found in the downward, backward, and leftward direction and lowest strain values were found in the upward, forward, and rightward direction, or, in other words, during force exertions opposing forces in those directions. In general, all three recruitment strategies agreed except polynomial recruitment in the transverse plane. In regard to the two different forces, the trends for the 40 N and 80 N trials were similar. In all three planes, the variability of the range of strain values was reduced with an increase in force. Strain values in the transverse plane reduced in almost every direction, suggesting that a stronger force in the backward direction may not increase the strain on the shoulder.

Keywords: Musculoskeletal modeling, static force exertions, shoulder strain

1. Introduction

The three major bones that make up the shoulder are the clavicle, humerus, and scapula. The medial portion of the scapula is comprised of the glenoid cavity, which connects with the humerus head. The interaction between the head of the humerus and the glenoid cavity create the concavity compression mechanism. More specifically concavity compression is the stability obtained between the compression of the humerus head into the concave glenoid fossa (Lippitt & Matsen, 1993). A net compressive force is created through the concavity compression mechanism that acts the translational forces created from a load compressed on the shoulder (Konrad, Jolly, Labriola, McMahon & Debski, 2006). Different tasks will carry a different load creating different translational and compressive forces. The directions of the compressive and translations reaction forces can be measured using the inverse tangent function. Tasks' strain indexes were used to categorize their effect on the shoulder. This study was performed to gain a better understanding of how tasks with various force directions can be strenuous on the shoulder. We hypothesized that the forces pushing down on the hand would cause the highest shoulder strain.

2. Methods

2.1 Simulation

For this study, static force exertions were studied in three anatomical planes: sagittal, which splits the body between left and right, frontal, which splits the body in front and back and transverse, the top and bottom of the body. The study was completed using simulations within AnyBody Modeling System and completed in each of the three planes. Within each plane 12 directions were studied, each located at 30° intervals, for a total of 36 trials. Two sets of trials were completed: the first with a 40 Newton force and the second with an 80 Newton force. In the simulation, the model was standing upright with 15° of glenohumeral flexion, 10° of glenohumeral abduction, elbow flexion of 75°, and 0° of glenohumeral external rotation, elbow pronation, and wrist abduction and flexion. Each of these 72 simulations were run with the polynomial, quadratic, and min/max strict recruitment strategies.

2.2 Calculation

The output of the simulations were three force vectors that were used as inputs in the strain index calculations. A compressive force (F_c) in the medial direction, as well as a force in the inferior-superior ($F_{I/S}$) and anterior-posterior ($F_{A/P}$) directions is given in the output file. The interaction between these three forces was used to create the strain index value (Chowdhury, 2016).

3. Results

3.1 40 Newton Force

The strain index values varied from a minimum of 0.6 to a maximum of 86.7. A minimum strain index of 0.6 was produced from a force located at 0° in the sagital and frontal planes. The maximum strain index value achieved was from a force located 150° from the origin in the transverse plane. In terms of recruitment strategies, the quadratic recruitment strategy produced the overall study minimum index of 0.6, and a maximum value of 74.4 located 240° from the origin in the sagital plane. The polynomial recruitment strategy showed a minimum strain index value of 0.8-produced form a force located at 0° in the sagital and frontal planes, and a maximum value of 80.3 located 240° from the origin in the sagital plane. Finally, the min/max recruitment strategy produced a minimum value of 7.2 located at 0° in the sagital and frontal planes, and the maximum value was that of the overall study. In both the sagital and frontal planes the minimal value is less than one while the maximum is around 70. However, in the transverse plane the minimum is almost 3.5 and the maximum is over 85.

3.2 80 Newton Force

The strain index values varied from a minimum of 0 to a maximum of 96.3.A minimum strain index value of 0 was found in the transverse plane located 30° from the origin. The maximum value of 96.3 occurred 240° from the origin in the frontal plane. The minimum strain index occurred using the polynomial and quadratic recruitment strategy (both in the same plane and location), while the maximum was found using the min/max strategy. In regard to the other recruitment strategy, the quadratic, a minimum strain index value of 0 was an overall minimum when 80 Newtons of force was applied and a maximum value of 70.9 was achieved in the sagital plane 240° from the origin. The polynomial recruitment strategy showed the overall minimum and a maximum of 74.8, in the sagital plane, 240° from the origin. In terms of the min/max recruitment strategy, the minimum value was achieved in the transverse plane and the maximum was the overall maximum for the 80 Newton trial set. The sagital plane had a minimum of about 15 with a maximum around 80, in the frontal plane the minimum was around 20 with a maximum over 95 and finally, the transverse plane had a minimum of 0 and maximum of 80.

4. Discussion

Generally, forces in the downward, leftward, and backward direction resulted in the highest strain values, regardless of recruitment pattern, meaning force exertions in the upward, rightward, and forward direction were the most strenuous. Overall, when progressing through the 12 directions the force would increase to a maximum, usually around the 240° point and then gradually decrease again. In terms of the recruitment strategies, all of the strategies followed the same trend except for the polynomial in the transverse plane with all the strain indices remaining relatively low. In the transverse plane, all values were considered low, with the exception of one direction, suggesting that a stronger force in the backward direction may not increase the strain on the shoulder. When comparing the 40 Newton force with the 80 Newton force an increase in force decreased the amount of variability in the strain index values. Based on these results, when designing workplace tasks, activities that involve pulling backward and pushing downward should be given preference to tasks that involve pushing forward and lifting, when appropriate.

4. References

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