Analysis of muscle moment and reaction force of elbow joint during flexion movement

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Abstract: Since its coming of age in the mid 1960s, continuum biomechanics has contributed much to understanding of human health as well as to disease, injury, and their treatment. Nevertheless, biomechanics has yet to reach its full potential as a consistent contributor to the improvement of healthcare delivery. In this research elbow flexion has been analysed and the moment of muscles and the reaction force exerted on the elbow is calculated in the range of motion The moment of muscles indicate the performance of movement and the reaction force of the joint is believed to be one of the most important causes of damage, something which has not been studied thoroughly enough in previous researches. The elbow joint has been modelled in CATIA software and we use ADAMS software for the analysis which is one of the most powerful ones available in dynamics analyses. The results indicate that the maximum torque of the arm occurs at 94 degrees and it decreases in the beginning and the end of flexion. The reaction force of the elbow in the beginning of motion is at maximum amount and then decreases to 100 degrees, and from that point on it increases up to the end of the motion. These results indicate that the optimum range of elbow flexion occurs in the mid-range of flexion, approximately at 60–140 degrees.

Keywords: muscle moment; elbow flexion; elbow reaction force; ADAMS; CATIA.

Reference to this paper should be made as follows: Pujari, S., Venkatesh, T. and Kumar, M.D.S. (2016) 'Analysis of Muscle moment and reaction force of elbow joint during flexion moment', *Int. J. Biomedical Engineering and Technology*, Vol. 22, No. 4, pp.370–376.

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1 Introduction

Estimation of muscle forces in the musculoskeletal system of human being has been a concern of many researchers utilising different techniques and finding out different results. The musculoskeletal system is usually redundant, that means the number of unknown muscle forces exceeds the number of equilibrium equations of the biomechanical model. Muscle architecture is the primary determinant of muscle function. Understanding this structural and functional relationship is of great practical importance to provide a basic understanding of the physiological basis of muscle force production in human movement. Skeletal muscle architecture is defined as "the arrangement of muscle fibres within a muscle relative to the axis of force generation" (Lieber and Fridén, 2001). In biomechanics, the unknown muscle and joint forces are commonly determined mathematically, because they cannot be easily measured directly. On the other hand, motion can be measured using experimental techniques. Determining the intersegment forces and moments based on kinematic data requires solution of the inverse dynamic problem (Lou et al., 2001). Activation of a specific muscle group occurs voluntarily through the firing of the respective alpha motor neurons under the control of the central nervous system (CNS) and modulated by external stimuli (Winter, 2005). These external stimuli, normally referred to as "external load" because they act externally on a system of levers, i.e. in the human body, can be objectively classified according to the torque they produce (Remaud et al., 2007). This torque, known as resistance torque, can be quantified (scalar quantity) by the product between the resistance force and the moment arm, which is defined as the shortest distance between the line of action of a force and its rotation axis (Otis et al., 1994). Preliminary study where one C6 quadriplegic patient and control were analysed during a reach to grasp task. Apart from elevation, results show the patient's joint angles are six to seventy percent of angles used by the control. Muscle activity was 1.14 to 5.85 times higher for patient compared to control, concluding that the patient is using kinematic compensatory strategies. The C6 patient compensated a task change primarily in the elbow compared to the all joint recruitment in the control subject (Jacquier-Bret et al., 2008). Nine subjects performing a grasp movement to a cylinder that was perturbed. Results show the final arm position and wrist trajectory showing that final posture is planned in advance and used as control variable in the central nervous system (Gréa et al., 2000).

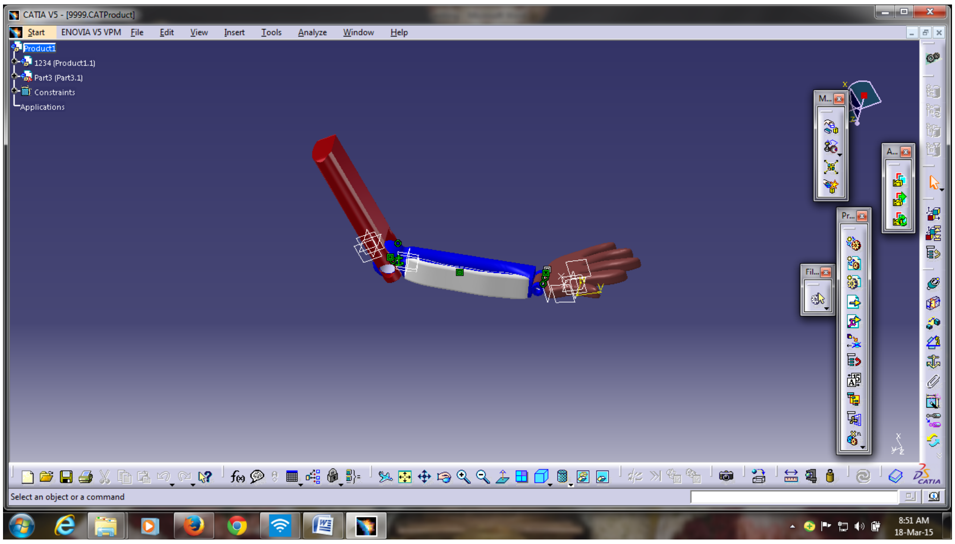
The results comprise three dimensional trajectories of the arm and torsion of the upper arm as function of the lower arm torsion with respect to the upper arm. Data show that a linear relation exists between upper and lower arm torsion, making the components of the arm rotate in coordination with one another. Arm rotation only accommodated for about half of the reorientation required to align grasp with the block. The formation of hand and fingers must therefore account for a large portion of the required tensional rotation. These observations show that the entire arm-hand system contributes to grasp orientation (Marotta et al., 2003). A study on the external forces and moments at the shoulder and elbow while subjects performed everyday tasks. From this article four additional studies, retrieved from the reference list, found to provide useful information (Murray and Johnson, 2004). The assumption of forces must be predicted exactly, so the stress distribution may be accurate. The maximum von Mises stress, contact pressure, contact radius and mean contact pressure to yield strength ratio using two-dimensional finite element model of acetabular component was developed for the different material combinations (Shankar et al., 2013). There are ten subjects to establish a database of upper limb kinematics and kinetics. Data on ranges of motion and external forces and moments were collected. Greatest range of motion (111.9°) and maximum moment (14.3 Nm) at the shoulder occurred during reach and lift tasks. For elbow flexion reaching the back produced the greatest elbow flexion (164.8°) but greatest elbow flexion moment (5.8 Nm) occurred in a lifting task. Kontaxis (2009) proposed a framework for the definition of standardised protocols for measuring upper limb kinematics. Summarising essential steps in a motion analysis protocol, basic recommendations are formulated and problems identified. Buckley (1996) studied a review of the current knowledge on dynamics of the upper limb during ADL. Discussing the few published results on upper limb kinematics, they found differences in methods and joint axes definitions. These differences make it difficult to compare the results. It is also noticed there is a lack of data on limb segment orientations, velocities and accelerations. Available results suggest that current rehabilitation manipulators and orthoses move at far lower speeds than the healthy human arm.

Morrey et al. (1981) studied 33 subjects on elbow movement during fifteen ADL. Functional arc of motion of elbow flexion was found to be 100 degrees, 30 to 130 degrees. Tests could be accomplished with 50 degrees of pronation and 55 degrees of supination. Rotation of the forearm is difficult to measure clinically as the zero position can only be approximated and carpus rotation cannot be excluded. Barker et al. (1996) used flexible electrogoniometers to measure shoulder, elbow and wrist angular motion in three dimensions during simulated ADL on seven healthy subjects. Motions produced by muscles controlling multiple joints were plotted against each other to study joint co-ordination. Two parameters were derived to mathematically describe the shape and orientation of the angle-angle graphs. Slope, to represent the relative magnitude of changes in the joint angles used, and movement area quotient to say something about the timing difference between the relative motions of the two joint variables. Besides these additional five articles, another source of information was the thesis submitted by Murray in 1999, to obtain his Ph.D degree. Murray (2002) reported on the determination of upper limb kinematics and dynamics during everyday tasks, providing information regarding length, mass, and inertia properties of the segments of the upper limb. Apart from the body parameters, a model of the upper limb was made using the robotics toolbox in Mat lab studied that the approximate maximum moment at an angle of 90 degrees although their graph indicates that maximum moment occurs at an angle more than 90 degrees and evaluated that asymmetries in elbow torque output between preferred and non-preferred limbs. They obtained moment curve in five angles with the maximum moment at 90 degrees. It should be noted that moment curve was calculated only at specific angles. And torque was not calculated at an angle between 90 and 120. If moment values had been calculated at more angles, moment curve and maximum angle could have been different.

2 Materials and methods

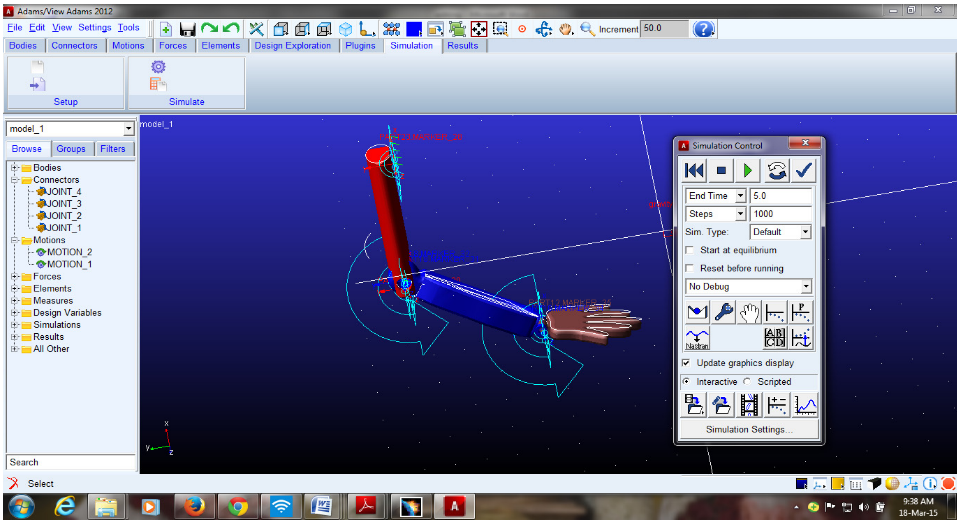
The method of this study is to model the elbow joint using CATIA software and is analysed by ADAMS software. The application is made by the MSC Software Corporation and is a powerful tool for analysing kinetic & kinematic analysis and is widely used in science and engineering. ADAMS simulation software and its add-on tool, Human Figure Modeller, developed and marketed by Mechanical Dynamics Inc. This software is used in analysing human movement too.

Figure 1 Elbow joint model in CATIA software



For modelling process we should perform these steps. The first step for modelling the movement of flexion is to build the parts of the arm. These parts are made by the CATIA software and making use of appropriate geometric shapes. In the second step the organs must be bound and in this research the connections between humerus and ulna are made using hinged joints. In the third step, export the model to ADAMS software then muscular forces obtained from the EMG data are applied with respect to the specified ratio. Then, in the fourth step the software application is provided with the required information such as moment, the joint reaction force etc. And finally the motion is run in the range 0–150 degrees and as a result the software reports the results in the form of a chart that was requested in the last step. Addition the base of calculation of software is the laws of physics and dynamic. The process in like to manual calculation of laws dynamic that the software perform quickly and easily. Figure 1 shows the constructed shape of model in CATIA software in this study. Figure 2 shows simulation of elbow joint in ADAMS software. When the model creates in the software completely and the motion is run. The software calculates the results. In the other hand the software performed the manual calculation relation to equilibrium force and moment quickly and the high accuracy. And it reports the results simultaneous. This software is powerful dynamic analysing software.

Figure 2 Simulation of elbow in ADAMS software



3 Results and discussions

1 The angular velocity of arm in the motion range as shown in Figure 3. Angular velocity indicates pressure on musculoskeletal system. When the velocity is low it means the pressure on musculoskeletal system is high and when the velocity is high it means the pressure on musculoskeletal system is low.

2 The moment of muscle in the motion range as shown in Figure 4. This moment is minimum in the beginning of motion and it increase to 94 degree of flexion and then decrease to end of motion.

3 The investigation of the reaction force exerted on the elbow joint is as shown in Figure 5. This force is potentially capable of causing damage to the joint. The study showed that the reaction force is at maximum amount at the beginning and then reduces to a 100-degree angle and then increases toward the end of the motion.

Figure 3 Angular velocity of forearm in the motion range (see online version for colours)

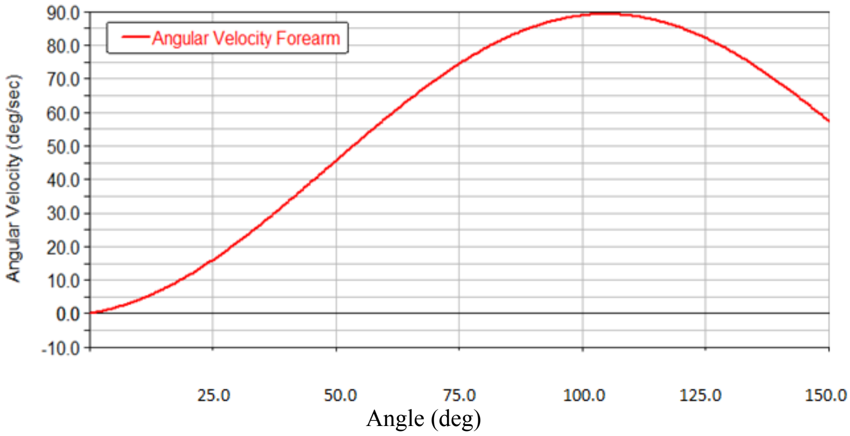


Figure 4 Moment of muscle in the motion range (see online version for colours)

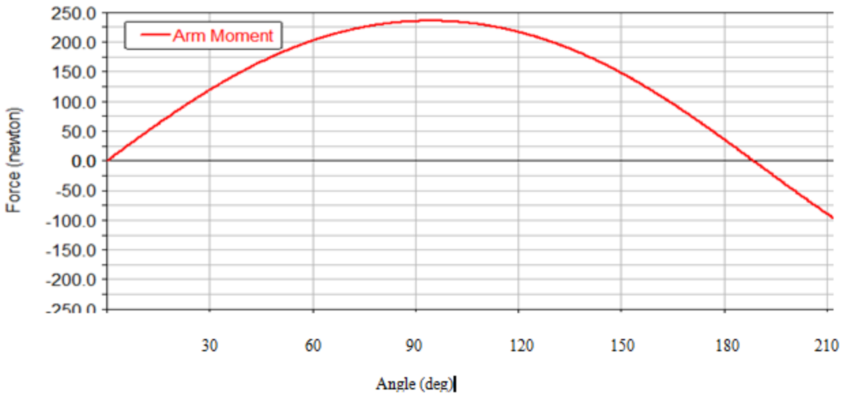
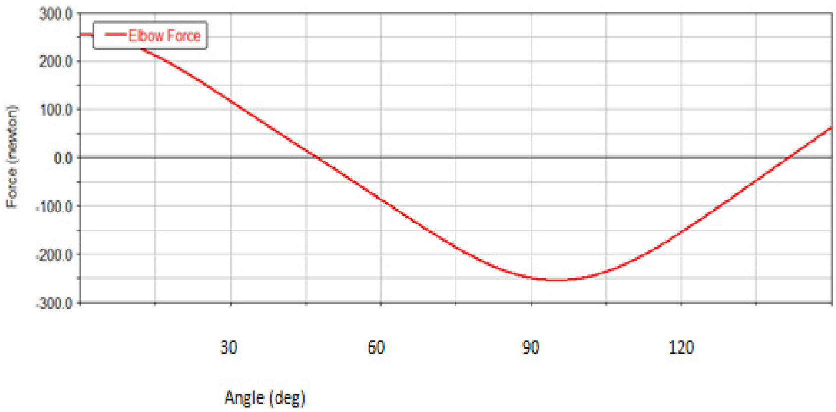


Figure 5 The reaction force exerted on elbow joint in the motion range (see online version for colours)



4 Conclusions

The main results of the analysis and modelling of elbow flexion movement elbow flexion muscles in the range of motion, The results show that maximum muscle moment of the arm occurs at an angle of 94 degrees and at the start and end of the flexion is much less. Moreover, the reaction force of the elbow which is one of the most important potential damage to the joint (100 degree). Therefore, combining these two results shows that the efficiency of flexion is in the range of 60 to 140 degrees.

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