Research on the mechanism of elbow flexion based on AnyBody

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Abstract. In order to analyze the dynamic characteristics of the upper limbs including the musculoskeletal system in elbow flexion, a human upper limb movement model including the musculoskeletal system was established based on the biomechanical analysis software AnyBody, and the overall model was subjected to inverse dynamics simulation and muscle force analysis to obtain the human body Muscle strength and muscle activity of upper limb muscle groups during elbow flexion exercise. Taking the human biceps as an example for analysis, the muscle strength of the biceps during elbow flexion exercise was obtained. When the loaded load is within a reasonable range, the muscle force will change regularly with the increase and decrease of the load, indicating that the training effect of flexion exercise needs to control the loading load within a certain range, which provides scientific theoretical support for upper limb muscle rehabilitation training.

1. Introduction
According to China’s classification criteria for permanent dysfunction, human upper limb function accounts for about 60% of the body's total body function [2]. Stroke is the main cause of upper limb motor dysfunction, and China is gradually entering an aging society, with more than 2.5 million new stroke patients appearing each year, the incidence rate is increasing year by year and the incidence of the population is younger [3]. Functional disorders of the upper extremities mainly include abnormal posture, muscle weakness, upper limb spasms, and movement disorders. These functional disorders seriously affect the ability of patients to live a normal life. It has been clinically proven that in addition to clinical drug treatment and surgical treatment, scientifically correct rehabilitation training plays a very important role in the rehabilitation and improvement of upper limb motor function [1].

AnyBody is a revolutionary technology for human musculoskeletal calculation and analysis, making ergonomics a discipline that can be quantitatively analyzed. AnyBody software can perform a complete analysis of the musculoskeletal system, calculate the mechanical properties and deformation of each muscle, bone and joint in the model, and analyze the elastic properties and various characteristics of tendons [4].

2. Geometric analysis of human upper limbs
By combining the upper limb anatomy and kinematics theoretical knowledge to understand the physiology and movement characteristics of the body, as well as the characteristics of bones, muscles.
and bone connections, the upper extremity musculoskeletal model is established according to the relevant parameters of the human upper extremity. By specifying the trajectory of the upper extremity skeletal muscle model for simulation, and then using inverse dynamics, combined with multi-rigid kinematics, external forces and optimization methods, to achieve the simulation of muscle force in the upper extremity model [5].

Due to the complex physical structure of the upper limbs of the human body, we can think of the upper limbs as consisting of bones and muscles. Among them, the muscles provide the driving force, thus the muscles and bones are regarded as a whole. Assuming that the upper torso of the human body is a fixed point, the structure of the shoulder can be regarded as two rigid rod-like structures at a fixed end [3], and the dynamic analysis of the simplified model of the upper extremity is carried out, as shown in Figure 1.

![Fig 1. Simplified upper limb model.](image)

The length of the upper arm is \( l_1 \) and the length of the forearm is \( l_2 \), but because of its uneven mass, the center of mass coordinates of the upper arm \((x_1, y_1)\), the center of mass coordinates of the forearm are \((x_2, y_2)\), \(d_1\) and \(d_2\) are the upper end of the two rods to the center of mass Distance, \(p_1\) and \(p_2\) are two generalized coordinates, and the centroid coordinates are expressed as:

\[
\begin{align*}
  x_1 &= d_1 \sin p_1 \\
  y_1 &= d_1 \cos p_1 \\
  x_2 &= l_1 \sin p_1 + d_2 \sin p_2 \\
  y_2 &= l_1 \cos p_1 + d_2 \cos p_2
\end{align*}
\]  

(1)

(2)

Since velocity is the derivative of displacement with respect to time, the equations (1) and (2) are derived to obtain the velocities in the horizontal and vertical directions, and then the kinetic energy of the system is obtained. The first-order, second-order differential of the generalized coordinate \(p\) and the kinetic energy are substituted into the Lagrange dynamic universal equation to obtain the generalized force:

\[
\begin{align*}
  m_1 l_1^2 \ddot{p}_2 + m_2 l_1^2 \ddot{p}_1 + m_2 l_1 d_2 \ddot{p}_2 \cos(p_1 - p_2) - m_2 l_1 d_2 \dot{p}_1 \dot{p}_2 \sin(p_1 - p_2) + \\
  m_2 l_1 d_2 \ddot{p}_2 \sin(p_1 - p_2) (\dot{p}_2 - \dot{p}_1) &= \sum_{i=1}^{n} \overrightarrow{F}_i \cdot \frac{\partial \ell_i}{\partial p_1} \\
  m_2 d_2^2 \ddot{p}_2 + m_2 l_1 d_2 \dot{p}_1 \cos(p_1 - p_2) - \\
  m_2 l_1 d_2 \dot{p}_2^2 \sin(p_1 - p_2) &= \sum_{i=1}^{n} \overrightarrow{F}_i \cdot \frac{\partial \ell_i}{\partial p_2}
\end{align*}
\]  

(3)
The above equations obtain the generalized force of the muscle in two generalized coordinates, the masses m1 and m2 in the equation, the lengths l1 and l2 of the upper arm and forearm, and the distances d1 and d2 of the center of mass of the two arms can be determined. By integrating the three formulas, the work done by the muscles on the two arms can be obtained. Combined with the physiological characteristics of the human body and anatomical knowledge, the work of each muscle force can be determined, and then the muscle force of each muscle bundle can be obtained.

3. Model building

3.1. Anatomical posture
Internationally, anatomical postures are used as standard postures in order to clarify the morphology, position, and interrelationship of various parts and structures of the human body. In order to accurately describe the musculoskeletal of the elbow joint, the description of the human model involved in this subject is based on the anatomical posture, as shown in Figure 2.

![Fig 2. Human Anatomy Standard Posture.](image)

As shown in the figure, in the anatomical posture, three planes perpendicular to each other are set. A plane parallel to the ground and dividing the human body into upper and lower parts is set as a horizontal plane. The plane perpendicular to the horizontal plane and dividing the human body into the left and right parts is set as the sagittal plane. The plane perpendicular to the horizontal plane and dividing the human body into the front and back parts is set as the coronal plane. The elbow flexion movement studied in this subject is a movement completed on a certain sagittal plane.

3.2. Muscle recruitment
The AnyBody musculoskeletal model is divided into two types: forward dynamics model and inverse dynamics model. Forward dynamics refers to applying a driving force directly to the model and then finding the trajectory of motion. Inverse dynamics is to specify its motion and use the laws of mechanics to solve the expression of movement that changes the object. For the human body, inverse dynamics is based on various kinematic data obtained to calculate the muscle torque of each joint of the human body.
or the internal and external constraints of the system. This article chooses to establish a reverse dynamics model.

The key to inverse dynamics analysis is to balance the external load to calculate the force of each muscle. The human body has a large number of muscles, so it is prone to muscle redundancy. That is, the number of muscles included in the system is much greater than the number of muscles required to balance the load. The muscle recruitment in the software's reverse dynamics is to determine which muscles are involved in balancing the load. The balance equation that AnyBody builds the musculoskeletal system is:

\[
Cf = d
\]  

In the formula: \( C \) is the matrix of equation coefficients; \( f \) is the vector sum of unknown muscle and joint forces; \( d \) is the vector sum of known external forces and inertial forces.

3.3. Musculoskeletal model of upper limb

The Any Script linguistic model is used to build the human upper limb musculoskeletal model. The model parameters are called by the AnyBody musculoskeletal system's own standard human model parameter library. Its skeletal physical parameters, muscle geometric parameters, and mechanical characteristics all strictly follow human anatomical characteristics. The maximum contractile force of the muscle is set to 300N. After the model is established, constraints are added to the human joints. Keep its movement in the same sagittal plane. Finally, add the dumbbell model in STL format to AnyBody, and set the geometric parameters and physical parameters such as model position, size and weight. The musculoskeletal model of the upper limbs after the introduction of dumbbells is shown in Figure 3.

![Fig 3. Human musculoskeletal model with a dumbbell.](image)

4. Reverse dynamics simulation analysis

Inverse dynamics is the core part of AnyBody software and is a simulation of a given movement or posture in situations involving forces. Inverse dynamics can simulate the muscle and joint forces of the human body in complex movements.
Drive the human upper limb musculoskeletal model, simulate the elbow flexion movement, and finally perform inverse dynamic analysis on the muscle force of the upper limb musculoskeletal system. Figures 4 and 5 show the changes of biceps muscle force during elbow flexion under different load sizes. The abscissa represents the proportion of the completion of the action, and the ordinate represents the biceps muscle force.

Fig 4. (a) Muscle strength of biceps without dumbbell load (b) Biceps muscle strength with 3 kg dumbbell load (c) Biceps muscle strength with 6 kg dumbbell load.
Analyze the muscle force curve, because the simulation model sets the maximum muscle contraction force to 300N. As shown in Figure 5, the muscle force curve has a straight line that reaches the maximum endurance value, and the three curves in Figure 4 are smooth and reasonable curves.

5. Conclusions
Aiming at the mechanism of elbow flexion of human upper limbs in this paper, a stick diagram model of upper limb musculoskeletal was established, and the biceps muscle force simulation analysis was carried out on different dumbbell loads, and the curve relationship between muscle force and load was obtained. The relationship between the elbow flexion training and the load size was verified, and it was proved that the load size should be kept within a reasonable size range during muscle training in order to achieve both the exercise effect and no damage to the muscles. This topic not only provides scientific theoretical support for upper limb muscle rehabilitation training, but also provides a certain theoretical reference for ergonomics and rehabilitation engineering.

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