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Correlation Model of High Intensity Volleyball on Exercise-induced Skeletal Muscle Fatigue Based on Nonparametric Random Forest Model

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Abstract:

In order to study the effect of high intensity volleyball on exercise-induced skeletal muscle fatigue model, this paper established a one-year mobilization skeletal muscle model of volleyball. Random forest has fast operation speed and excellent performance in processing big data. Random forest does not need to worry about the problem of multicollinearity faced by general regression analysis, and there is no need to choose variables. The established musculoskeletal model was verified by surface electromyography. Three excellent fefemale volleyball players were selected as subjects. Nine vicon MCAM2 optical cameras (250 Hz), two three-dimensional force measuring plates (1000 Hz) and surface electromyography (sEMG) were used to collect the data synchronously. The data were processed by MATLAB and anybody software, and the intrinsic dynamic parameters of lower limbs were calculated by the inverse process of dynamics. The results show that the main muscle groups of volleyball block take-off action are vastus lateralis, vastus medialis, rectus femoris, tibialis anterior and gastrocnemius. The trend of sEMG was the same as that of the simulated values: biceps femoris, medial femoris, lateral femoris, rectus femoris, lateral head of gastrocnemius and medial head of gastrocnemius. Semitendinosus, semitendinosus and tibialis anterior have different tendency. The data show that the predicted value is closely related to the sEMG signal by using the kinematic data to drive the musculoskeletal model, and the established musculoskeletal model is verified to be in line with the actual muscle activation.

Keywords: *Nonparametric random forest model, Volleyball, exercise-induced skeletal muscle, fatigue model, surface electromyography.*

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I. INTRODUCTION

About 60% of the musculoskeletal injuries in Volleyball occur in jumping spiking or blocking. The research shows that the rate of ACL injury caused by knee valgus of fefemale volleyball players is 3.3 times that of female volleyball players. Therefore, the prevention of sports injury caused by jumping and landing of fefemale volleyball players should be paid attention to [1-2]. According to Thelen, in order to prevent the accidental injury of specific movements in sports, we should establish the muscle model during movements through biomechanical analysis, simulate the activation of lower limb muscles, and verify the established muscle model with sEMG, so as to strengthen the main muscles and improve the effective action training, so as to prevent the injury. At present, there is no final conclusion about how the human body recruits muscles for specific actions. But this problem can be known by three-dimensional musculoskeletal simulation [3]. Musculoskeletal model can be used to evaluate the performance of individual muscles in various human movements.

Inverse kinematics and inverse dynamics can be used to know the angle and force of the joint respectively, and also to calculate the muscle control, so as to find out the most effective action process with the minimum muscle contraction and metabolic consumption of muscle strength [4-5]. Forward dynamics is the study of simulating muscle activation by giving limb movements. The special feature of forward dynamics is that the obtained muscle activation value is obtained under the condition of unmeasured sEMG.

In the past, few studies used 9 EMGs to record volleyball block completely, and the skeletal muscle model simulated in this study is very important in training evaluation, which can effectively provide training needs. Therefore, this study not only simulates the lower limb muscle movement of volleyball block, but also verifies the skeletal muscle model [6]. In conclusion, motion capture system was used to obtain kinematic data. Surface electromyography was used to collect the data of hamstring, quadriceps, gastrocnemius and tibialis anterior muscles, and the differences between EMG data and simulated muscle signals were compared, And verify whether the simulated muscle signal trend is correct, understand the volleyball players in situ take-off muscle sequence, improve the understanding of block take-off [7-9]. After verifying the correctness of the model, using forward dynamics in future training can prevent injury and provide more effective training.

II. METHODS

2.1 Basic information about the experiment

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The kinematic photography system is equipped with 9 sets of MCAM2, vicon MX, Oxford metrics digital lenses made in the United States, and the sampling frequency is 250 Hz. Before the experiment, static and dynamic spatial coordinates were corrected. Thirty 14 mm diameter reflective balls were glued to each limb segment of the body, including pelvis (anterior superior iliac spine, posterior superior iliac spine), thigh (trochanter, lateral thigh, lateral femoral condyle, medial femoral condyle), leg (fibula capitulum, tibial trochanter, lateral superior malleolus, medial superior malleolus and heel, scaphoid trochanter, lateral superior malleolus, medial superior malleolus and heel) The first trochanter, the second trochanter and the fifth trochanter).

Two JP 6060 multi-dimensional force measuring platforms were used to monitor the three-dimensional force changes of subjects' feet on the ground. The surface of the dynamometer is basically in the same level with the runway, and the data sampling frequency is 1 000 Hz. The je-tb1010a 10 channel wireless sEMG instrument was attached to the waist of the subjects to monitor the EMG changes of the main muscle groups of the lower limbs during forward and backward walking. The right leg was measured, including rectus femoris, biceps femoris, internal femoris, external femoris, semitendinosus, Semimembranous, anterior tibialis, medial gastrocnemius and lateral gastrocnemius.

The synchronizer is composed of a wireless synchronizer connected with the trigger module of the multi-dimensional force measuring platform, a wireless synchronizer connected with the surface electromyography and a light-emitting diode. The subjects triggered the synchronous remote controller, multi-dimensional dynamometer and sEMG to collect data at the same time, and LED LED made the camera synchronize with multi-dimensional dynamometer and sEMG. Finally, the light spot trajectory, surface electromyography and ground reaction force signals were collected at vicon 624 datastation.

This study is divided into two parts: 1) analyze the performance of kinematics, dynamics and EMG activation of subjects in 12 squat jumps, and make sure that the trend of EMG signal in 12 squats is the same; 2) Simulation analysis of volleyball block take-off action, including inverse dynamics, muscle simulation control and forward dynamics. The subjects are long-term trained fefemale volleyball players. First of all, the two feet respectively entered the dynamometer board to simulate the jumping action of the block. After hearing the jumping command, they tried their best to jump up. The data of 12 jumps were collected for lower limb EMG analysis and comparison. After confirming that there is no difference in 12 jumps, take one experimental data for muscle simulation. Matlab 7.0 was used to write the program for data processing and import into anybody for muscle simulation.

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2.2 Simulation process

(1) Kinematic analysis

After obtaining the reflector position, Butterworth low frequency filter (4th The order Butterworth low-pass filter is used to filter the noise, and the cut-off frequency is 10 Hz. The static kinematic data is used to optimize the dynamic kinematic data of each limb segment, and the Euler parameters are used to calculate the joint angle of the limb segment [10]. After smoothing the data with MATLAB 7.0 program software, the anybody modeling system (AMS) software (anybody technology a / s, Aalborg, Denmark) version 3.40 was used to analyze the data, and the nonlinear and nonconvex optimization method of gaitapplication 2 program was used to solve the problem of over determining the kinematic equation. This optimization method can also be used to optimize the skeletal muscle size, local reflector coordinates and dynamic model data, so that the position error of skeletal muscle model and measured trajectory can be minimized.

(2) Establishment of skeletal muscle model

Gaitunimiami is used as the human body model for human skeletal muscle data. Kinematic data and dynamometer board data are optimized by gaitapplication 2 and input into anybody modeling software as the muscle simulation of volleyball block take-off. In this model, the human body parameters of the subjects are input and adjusted to the actual shooting size. The error between the measured local coordinate system of each limb segment and the muscle model is minimized by using the optimization method. This method optimizes the skeletal muscle model. In this study, 20 reflective ball markers were used as the driving force of skeletal muscle model, and at least 3 reflective balls were marked as the input parameters of trajectory optimization for a limb segment. The hip joint was modeled as a spherical joint with 6 degrees of freedom; The knee joint was modeled as a revolute joint with 6 degrees of freedom; The ankle joint is modeled as a universal joint, and 30 reflective balls are needed for kinematics and dynamics calculation.

(3) Simulation process

In this study, the musculoskeletal model was determined according to the height of the subjects. Each foot contained the starting point, ending point and muscle model of 27 muscles. In the simulation, inverse dynamics is used to get the muscle strength from the kinematic data. The muscle activation simulation is to standardize the muscle strength by using the max / min criterion, and to drive the musculoskeletal model by using the optimized method based on the

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kinematic data of the reflective ball captured by the camera system. Surface electromyography data can be used to support the joint torque calculated by inverse dynamics, but it is impossible to evaluate the strength of individual muscles. Most of the muscle activation characteristics of skeletal muscle system after simulation are compared with sEMG signals. Muscle strength can not be measured directly, but the activation can be estimated by the obtained sEMG characteristics. In the past, the collection of muscle electrical signals was often limited to the study of movements, and the muscle activation during the complete jump and take-off movement could not be accurately understood. Therefore, nine muscle electrical signals were used to collect the muscle signals of unilateral lower limb in this study.

(4) Comparison of EMG signal and muscle simulation

The noise was filtered by Butterworth low-frequency filter. The cut-off frequency was 9 Hz, which was used as a linear envelope signal to observe the muscle force application. Finally, the maximum spontaneous contraction in the last 3 seconds was used as the muscle electrical signal standardization, and the muscle simulation signal was used as the standardization.

(5) Mathematical statistical analysis

Firstly, it is determined that the electrical signals of 12 jumping muscles have the same trend. In this study, we define the time series Arima normalized BIC (Bayesian) to evaluate whether the trend of EMG and lower limb muscle simulation signal is consistent. Results STDev < 1 was the same action. After confirming that the trend of 9 muscle electrical signals was consistent, one test data was randomly selected for inverse kinematics and dynamics analysis to observe the muscle activation of right leg posterior muscle group, quadriceps femoris muscle group, gastrocnemius muscle group and tibialis anterior muscle group of habitual foot. The BIC was normalized by the appropriate metric parameter of time series to evaluate whether the trend of muscle electrical signals and lower limb muscle simulation signals were consistent. In this study, we defined normalized BIC difference more than 1 as different trend, and difference less than 1 as same trend.

III. RESULTS

Fifteen healthy female volleyball volunteered to participate in this study. All the subjects didn't have any history of musculoskeletal complaints. Their age range (20-50) years, mean weight 84.75±15 Kg and mean height 175±8.5 cm. All the subjects were in good condition at the start of the experiments. Right hand, biceps brachii and triceps brachii muscles (Table 1) of each volunteer were included in this experiment. Differences in age of the subjects were chosen

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to investigate the effect of age on muscle fatigue. Differences in age of the subjects were chosen to investigate the effect of age on muscle fatigue, therefore according to the ages of our volunteers; we divided them into three groups as illuminate in Table 2.

TABLE I. Muscles location and their actions

MUSCLE NAME	LOCATION	ACTION
Biceps brachii	on the upper arm between the shoulder and the elbow	flexes the elbow and forearm
Triceps brachii	on the back of the upper limb	extends forearm

TABLE II. Age groups of volunteers

GROUP	AGE RANGE (YEAR)
A	20-29
B	30-39
C	40-49

All the exercise procedures carried out according to the Helsinki Declaration. The subjects consented to exercise after a fully explained about the purpose and procedures of the experiment. They gave written informed consent:

(1) The surface EMG signals were obtained from the right biceps brachii and triceps brachii muscles;

(2) The skin was cleaned gently with alcohol and shaved carefully to improve the electrode-skin contact;

(3)Six surface EMG electrodes (M-OO-S), were placed on the muscles according to standard procedures perpendicular to the fiber direction and away from the muscle innervation zone;

(4)Two channels, two EMG preamplifier cables (ME6P) and EMG Bio-monitor (ME6000 8ch.) device were used to record the electrical activity of the muscles.

(5)The signals were preamplifier, rectify and filtered using a band-pass Butterworth filter (l-

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500Hz) and 2000 Hz sampling rate.

Subjects were asked to perform two isometric exercises, each one for a muscle (biceps brachii, triceps brachii). After putting the surface electrodes on the right dominant arm, the experiment began by measuring EMG signals of each volunteer for lifting weight exercise (2.7 Kg), each exercise consists of three periods of which lasted 5 min, about 2 min of rest time was allowed between. The three periods represent the beginning, middle and final stages of lifting exercises of maximum voluntary contraction (MVC). Because there is no direct method to estimate muscle fatigue. Figure 1 shows the structure of arm muscle. We compare our results with the mathematic equations. Moreover, we ask our volunteers to repeat the exercise after one week to be sure of the data is still the same for everyone. The two exercises, shown in Fig. 2, can illustrate as follow:

Biceps-brachii muscle exercise: upper arm sits on a horizontal surface, as in Fig. 2A, the forearm flexed from the horizontal position to a 900 angle vertical on elbow point, carrying 2.7 Kg in the hand.

Triceps-brachii muscle exercise: upper arm fixed to the top, horizontal to trunk and parallel to the head, as in Fig. 2B, the forearm flexed backward from the vertical position to a 90° angle horizontal with the head, carrying 2.7 Kg in the hand.

An EMG signal was recorded from the subjects during the three-consecutive activity of the muscles (biceps brachii, triceps brachii). The three exercises represent the signal activity of the muscle at the beginning, middle and final of the experiment to show the difference in signals at constant MVC levels. Mean power frequency (MPF) obtained by programming it by MATLAB using the equations mentioned above.

Our proposed Fuzzy Fatigue Model (FFM), as we have mentioned, consists of two parts (fuzzy network); the first part estimates the MPF from the EMG signals. This part or fuzzy network shows the change in muscle activity due to muscle fatigue according to changes in the frequency domain, the second part estimates the muscle fatigue index from the original signals (raw EMG) without any processing applied to it. The schematic architecture of our whole processing is depicted in Fig. 3.

Different number of nodes and layers, and different types of function were examined for the two networks of FFM. The configuration of the research model, the number of inputs, nodes, epochs, membership and type functions that were used in each part is shown in table 3.

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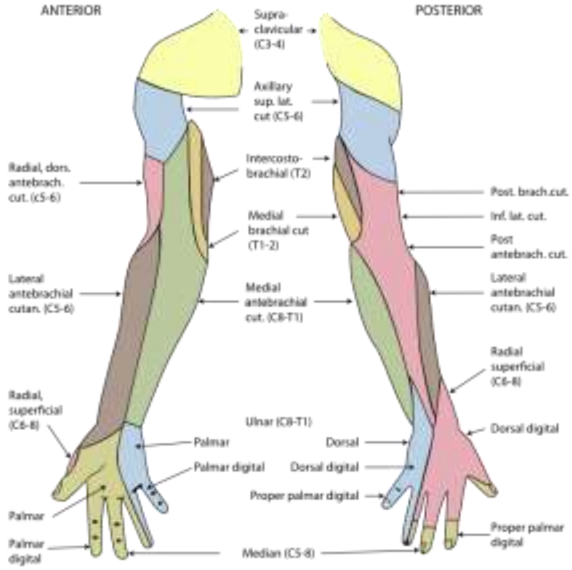

Fig 1: The structure of arm muscle

(A) (B)

Fig 2: Lifting volleyball experiment: A. biceps brachii exercise, B. triceps brachii exercise.

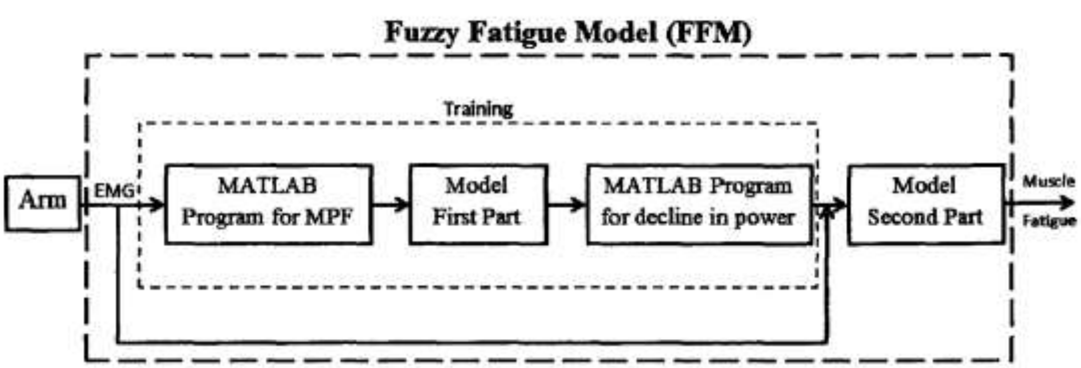

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Fig 3: Our method schema.

TABLE III. The configuration parameters of the FFM

CONFIGURATION	PART 1	PART 2
Number of inputs	2	3
Epochs	4000	5000
Membership	2	3
Nodes	3 in each member	3 in each member
Function	Gaussian, Generalized bell	Gaussian, Generalized bell, Gaussian

IV. DISCUSSION

The muscle simulation signals were similar to sEMG in biceps femoris, rectus femoris, vastus lateralis, vastus medialis, lateral head of gastrocnemius and medial head of gastrocnemius. The greater differences were found in semitendinosus, Semimembranous and anterior tibialis. From the volleyball block take-off action, it can be found that there are some slight differences between the muscle simulation value and the surface EMG value. By observing the muscle activation of quadriceps femoris in the take-off action, it is found that the muscle activation time of rectus femoris simulation value and surface EMG signal is the same, but the muscle simulation value is smaller in the take-off action.

It is speculated that the activation trend of quadriceps femoris muscle is from rectus femoris to lateral femoris and medial femoris during take-off. Therefore, the activation time sequence of biceps femoris, lateral femoris and medial femoris is slower than that of muscle simulation, and the relative sEMG is higher than that of muscle simulation in the activation of rectus femoris. Under the same kinematics, sEMG and muscle simulation should have the same results. However, when the muscles simulate the rectus femoris take-off blocking action, the activation value is relatively low, and the activation time of biceps femoris, lateral femoris and medial femoris is relatively early, but the activation trend is the same. The semitendinosus shows an unstable trend in order to maintain the balance of the body during the jump, The surface electromyography also had obvious co contraction. The simulation value of gastrocnemius muscle and sEMG have the same trend. The activation time of sEMG is longer than the simulation value. The sEMG value of tibialis anterior muscle is unstable to maintain body balance. Biceps femoris, rectus femoris, gastrocnemius and lateral femoris had the same activation trend. The model of this study is 42 lower limb muscles, which is simpler than the

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above two lower limb models. The muscle strength of this study may be distributed in more muscle groups, so the results are different.

In the experiment, it is impossible to directly measure the muscle strength, so the method of measuring surface electromyography is used to evaluate the muscle activation, and the simulated value is further compared with the surface electromyography. The surface electromyography is usually used as the reference value of muscle strength. This method can effectively evaluate the trend of muscle activation in action, However, it can not be used to verify the muscle strength. Therefore, it is a trend to directly establish human parameters and define the muscle strength of muscle energy load on the muscle model. The experimental data required for muscle simulation is an important key to affect the simulation results. In the calculation of joint angle and joint torque, the wrong experimental data will change the amplitude of simulated muscle strength, especially using inverse dynamics and static optimization. Therefore, this study uses the optimization method to drive the musculoskeletal model, and optimizes the static data to estimate the whole movement process. According to the research results, the main muscle groups of volleyball block take-off action are vastus lateralis, vastus medialis, rectus femoris, tibialis anterior and gastrocnemius. Therefore, it is necessary to strengthen the training of these muscle groups in the future to facilitate the completion of volleyball block jump action.

V. CONCLUSION

The knee joint, ankle joint and other lower limb injuries of volleyball players are the most common injuries in sports, which can shorten the sports life, so it can not be ignored. In order to ensure the elite athletes to reduce the lower limb injury in training or competition, and to confirm the correctness of the experimental data, individual skeletal muscle models were constructed. In this study, we used kinematic data to drive the musculoskeletal model. It was found that the predicted value was closely related to the surface electromyography signal, and verified that the established musculoskeletal model was consistent with the actual muscle activation. The skeletal muscle model of knee joint driven by surface electromyography can predict the torque of knee joint. The main functional muscle groups of volleyball block take-off action are vastus lateralis, vastus medialis, rectus femoris, tibialis anterior and gastrocnemius. Therefore, these muscle groups must be strengthened in training in order to complete volleyball block jump action and reduce sports injury.

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