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Original Research

Musculoskeletal Modeling of Optimal Soccer Kick to Evaluate Selected Muscles Function

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ABSTRACT

Electromyography is a common method to calculate muscle's function. But it has some limits. Musculoskeletal modeling is an indirect method to consider muscle's function, by using kinematic and kinetic characteristics of subject's movement. The purpose of this study was to investigate and compare some selected muscles of prefer leg during performing two different kick patterns which consist of subject kick pattern and optimal kick pattern which created from same subjects by mechanical model. OpenSim 3.2 platform and Computed Muscle Control (CMC) tool were used to simulate muscles function. After selecting a 3D model of leg which consists of six degree of freedom and nine vital muscles, biomechanical parameters of two kick patterns, entered into model and run. Afterwards data were normalized and filtered. Paired sample t- test was used to analyze data. After compared two kick patterns, there were significant difference in contraction force of iliopsoas, biceps femoris long head and biceps femoris short head, rectus femoris, vastus lateralis and tibialis anterior. In addition, vastus lateralis, rectus femoris, iliopsoas and tibialis anterior were must important muscles in forward swing phase of two patterns of soccer kick. Also, iliopsoas and quadriceps were more active in subjects and optimal pattern, respectively. The results revealed that, the interaction of muscles stimulation, joints motion and more activity of quadriceps, were main factors to increase the speed of optimal kick. Results from the musculoskeletal model, had a great similarity with the results of previous experimental studies. Incidentally this apparatus can simulate muscles activity, with high precision and considering the advantages of that, this method can be used in sports biomechanics and medicine research.

Keywords: Biomechanics, OpenSim, Optimal Kick Pattern, Muscle Activity

Introduction

Because the muscle contraction is the main cause of human body movements, it is important to study how it plays a role in human activities. Kicking is one of the most-used actions in soccer and a wide range of muscles (especially lower limb muscles) are used to perform this action with the maximum of power [1]. In the recent years, electromyography has been the most-used method to study the performance of muscles in sport activities especially kicking. Electromyography was used to measure and describe action potentials and muscular function [2- 4]. Using musculoskeletal model is another method to study the muscle's performance and simulate human body movements. Also, musculoskeletal systems are modeled to characterize geometry and dynamics of body segments [5]. To provide a low cost and efficient method to calculate numerous biomechanical parameters like: muscle activation patterns, joint torques and forces are the advantages of musculoskeletal models. Also helping to consider the influence of these parameters in sport activities, has made musculoskeletal model, very popular in biomechanical laboratories and rehabilitation centers [6, 7]. Since using musculoskeletal models requires some skills and abilities like programming, familiarity with motion equations and mechanical properties of muscles and body, researchers usually tend to use (especially in sports) electromyography for studying muscle's performance. OpenSim is a free platform for modeling and simulating different movements and analyzing neuro-muscular system. Computed muscle control (CMC) is one of the outputs of the OpenSim software that is used to produce muscle-driven simulations of observed motions and to anticipate subject's movement [5]. In the recent years, musculoskeletal model has mostly been used for clinical approachs like walking, running, jumping or for comparing healthy people with the people who are suffering from musculoskeletal disorders like cerebral palsy (CP), cerebrovascular accident (CVA), Parkinson and Osteoarthritis [8, 9]. Therefore musculoskeletal models are rarely been used to evaluate muscles function in sport research. One of the purposes of using model in sports biomechanics is to find optimal movement pattern of an special sport technique. Finding the best condition among all the possible conditions is a principle in optimization process [10]. The ability to change all the involved parameters separately, and to run for unlimited repetitions, is the reasons to use biomechanical models in optimization studies. Hajlotfalian, et al (2014), optimized the soccer kick pattern based on the ball speed [11]. In this study, the prefer leg of the subjects was simulated by using a mechanical model which created from subject's anthropometric data and joints range of motion. Then the forward swing phase of the subject's kick pattern, optimized to achieve the highest speed of the ball after kicking. The results of this study showed that, if the subjects performed optimal pattern, their kick power can be improved up to 62.5 percent [11]. Because the optimal kick pattern in this study is not performed directly by a subject in laboratory and it is created by some mechanical and differential equations, using electromyography to calculate the involved muscle's performance is not possible. In situations like this we can use musculoskeletal model. When using musculoskeletal model, we don't need to do some essential steps of electromyography like, preparing the skin, determining the position of electrodes, sticking the electrodes, steadying the wires, reducing the noise of electronic devices and so on, therefore the athlete can move freely without interfering wires and electrodes. In addition, by using musculoskeletal model, we can study performing of deep muscles, for which if we used electromyography that wasn't possible unless we used aggressive methods. Another advantage of using musculoskeletal model in comparison to electromyography is that it gives the muscle's force (Newton) instead of the muscle's electric potential (Volt) as the output.

Since understanding the role of each muscle in optimal kick, helps the athletes to understand the pattern of kicking and because of the advantages of musculoskeletal model, in this study we have made musculoskeletal model of the prefer leg while kicking and assimilated the stimulation of muscles. Finally, we have compared these two kicking patterns (optimal kick and subjects kick) based on the role of each muscle and its activities. The goal of this study is to make a musculoskeletal model to understand the function of muscles in an optimal kicking based on the ball speed and to expand the use of musculoskeletal model in biomechanics functional studies and in sports medicine.

Material and Methods

Participants and Test protocol

Because anthropometrics, kinematics and kinetics parameters are preconditions of musculoskeletal modeling in OpenSim [5] and this information acquired from Hajlotfalian, et al (2014) research [11], the process of obtaining this information is explained in next paragraph.

The ages of the participants were 25.2 ± 2.2 years (mean ± SD), their height 1.733 ± 0.065 m, and their masses 70.6 ± 6.6 kg. The aim of Hajlotfalian, et al (2014) research was to find the optimal soccer kick pattern in forward swing phase to achieve a maximum speed kick. The solution approach which is suggested to produce the optimal technique is to use the mechanical modeling by applying the motion equations. To optimize soccer kick, motion constrains including joint angle and joint torque limitations were satisfied and anthropometric parameters of body-skeletal system including segmental mass, length, inertia and the distance of the center of mass of segments, were calculated and applied to dynamic model. A two-dimensional four-link dynamic model is introduced and by applying the appropriate constraints, the genetic algorithm is used to achieve the optimal technique. The computed pattern was compared to six skill subject's patterns that Acquired by cameras (240Hz).

After data processing, model running and carry out the optimization protocol, the sagittal plane angular displacement-time graph of the lower extremity joints (Hip, Knee and Ankle) of subject's pattern and optimal pattern calculated and monitored in Fig 1. According to Fig 1, the range of motion of subjects and optimal patterns joints, were similar but because of differences in interaction between joints and segments, if a subject used optimal pattern, could be improved his velocity of kick to 62.5 percent.

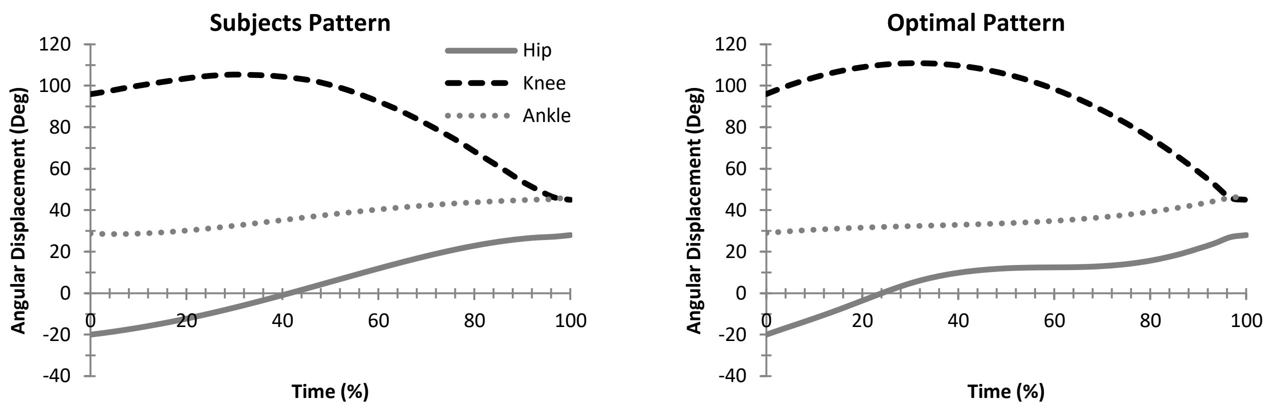

Figure 1. Trajectory of hip, knee and ankle joints according to optimal and subjects' pattern [11]

Musculoskeletal modeling

In the recent years, muscle-actuated simulations of movement, required high computational cost and computer time. But today, dramatical development in methods of robotic control techniques significantly reduced the cost and time of such biomechanical simulations [12]. CMC is one of these fast simulation methods which in this research, used to calculate muscles excitation of soccer kick patterns. Because simplification is essential in modeling, we used a simple model of lower extremity (Fig 2). This one leg model, have six degree of freedom and nine muscles (iliopsoas, gluteus maximus, long and short head of biceps femoris, rectus femoris, vastus lateralis, soleus, gastrocnemius and tibialis anterior).

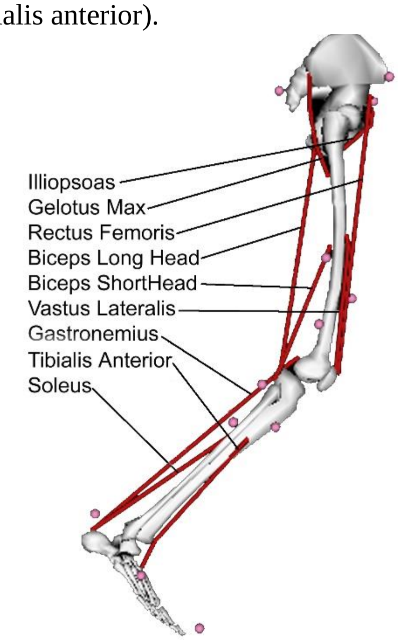

Figure 2. OpenSim leg model with nine muscles

Scaling is the first step to create a dynamic simulation in OpenSim [5]. In this step, anthropometric parameters of subjects' body, entered to OpenSim to adjust musculoskeletal model. Anthropometric characteristics of individuals were estimated from regression equations of height and weight of subjects [13] which participated in Hajlotfalian, et al (2014) research [11]. Calculation of joint angles and translations from raw marker data obtained from motion capture is named inverse kinematics problem. Because joints kinematics (joint angles) and kinetics (ground reaction forces and moments) parameters of both kicks, previously calculated by dynamic model and optimization process [11], the trajectory and ground reaction force of lower limb joints directly entered to software. Then residual reduction algorithm applied to improve dynamic consistent between kinematic and kinetics data and finally computed muscle control is used to extract set of muscle excitations of subject's and optimal kick patterns.

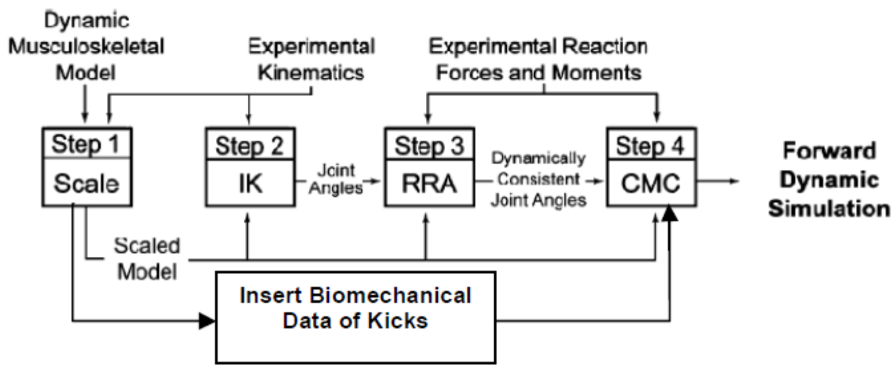

Figure 3. Steps for generating a muscle-driven simulation of a subject's motion with OpenSim [5]

Statistical analysis

The Kolmogorov–Smirnov test was used to examine normal distributions for muscles' force data. paired-t-test was applied to compare muscle activity of optimal and subjects' kick patterns. Statistical significance was set at $P \leq 0.05$. SPSS Software (Version 16.0, SPSS Inc.) was used for all statistical analysis.

Findings

After ran the model, activity information of nine selected muscles that involved in soccer instep kick, extracted from two patterns and checked. To normalize data, productive contraction force of any muscles, presented as a percentage of strongest muscle which was vastus lateralis in optimal pattern and smoothed by Savitzky-Golay filter in Matlab. Finally, the statistical analysis was applied. The results of t-test showed, there was significant difference between two kick patterns in contraction force of iliopsoas, long and short head of biceps femoris, rectus femoris, vastus lateralis and tibialis anterior. Also vastus lateralis, created maximum contraction force in both patterns to provide a large part of knee extension torque.

In addition, to find percentage of participation of muscles in soccer kick task, area under muscles contraction force curve, calculated by Trapezoidal Integral. According to Figure 5, in both optimal and subjects' patterns, vastus lateralis, rectus femoris, iliopsoas and tibialis anterior, respectively had higher participation rates than other muscles.

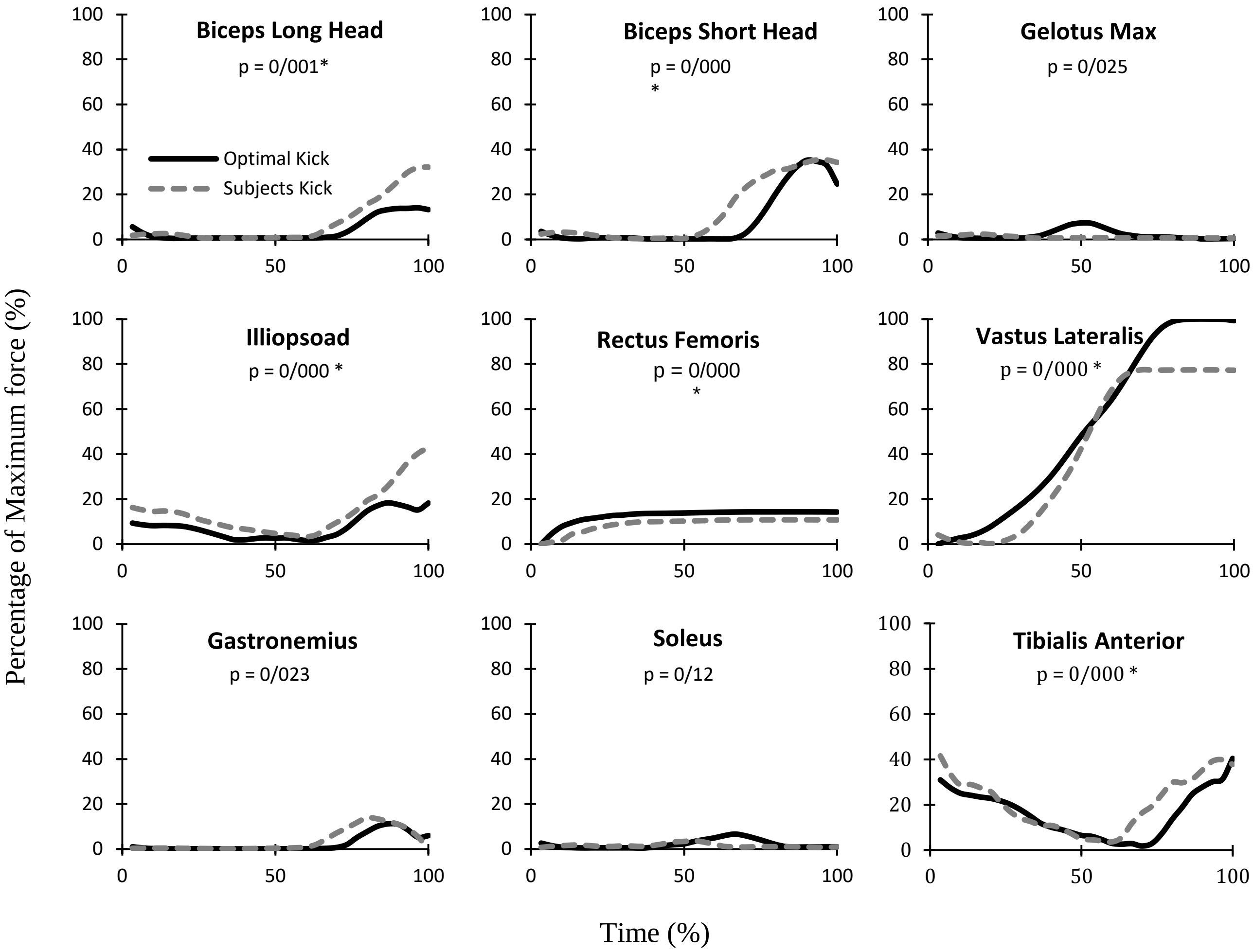

Figure 4. Contraction patterns of nine involved muscles in forward swing phase of soccer kick

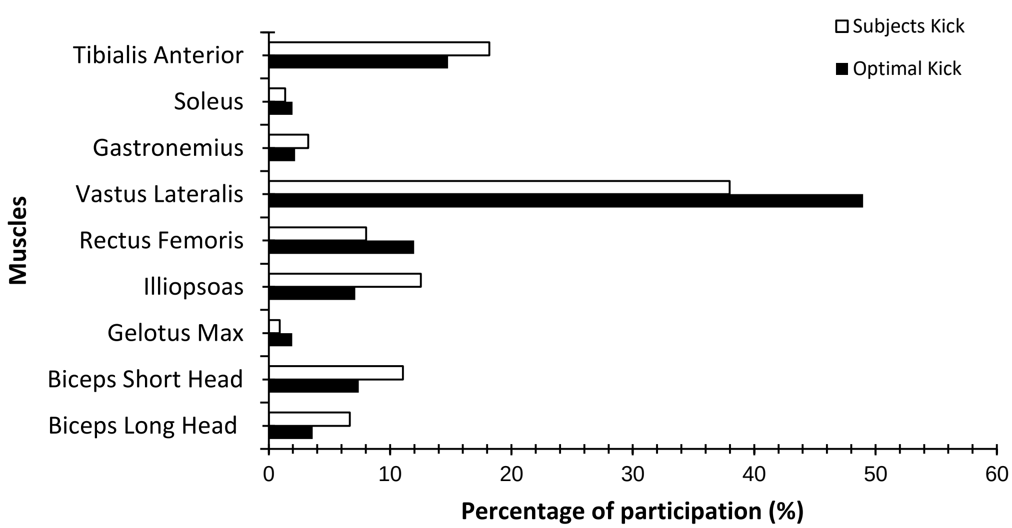

Figure 5. Percentage of participation of nine involved muscles in forward swing phase of soccer kick

Discussion

The purpose of this study was to introduce and use of musculoskeletal modeling as a convenient and practical method for evaluating the function of the muscles in different sports skills. So with the help of this method, muscle functions of two different kick patterns were examined and compared. In musculoskeletal modeling, unlike electromyography, muscle function estimated indirectly by using subject movement information. Although OpenSim is a wonderful platform for modeling and is a valid and reliable software and has been used in many research [7, 14], but comparing output data with past experimental studies is necessary to ensure from present results.

Doing a quick and powerful kick is depending on several factors which organized muscles contraction and segments intervention, are most influential factors. To perform a successful soccer kick, organized activity of hip flexor and knee extensor muscles are important. Many researchers examined proximal-distal sequence in forward swing phase of soccer kick and they stated, iliopsoas, rectus femoris and knee extensors were activated respectively in this phase [15, 16]. In addition, at the end of this phase, hamstring group as an antagonist muscle activated and decrease acceleration of the leg with its eccentric contraction [17]. Also, the tibialis anterior as a dorsiflexor muscles played an important role at the moment of ball impact and have a great help to increase kick speed [18]. According to present study, to perform a powerful soccer kick, iliopsoas, rectus femoris, vastus lateralis and tibialis anterior muscles, have greater effect than others (Fig 5). As shown in Fig 4, biceps femoris muscle that was among the hamstring group, activated at the end of the forward swing phase and it was similar with Orchard et al. (2001) results [16]. Based on previous study, collateral muscles of quadriceps during soccer kick, demonstrated greater activity than middle muscles [17] which these studies were consistent with results (Fig 4 and 5). To perform a speedy and strong kick, EMG of some involved muscles in soccer kick investigated by some researchers [2, 4]. Dorge et al. (1999) reported collateral knee extensors; iliopsoas and rectus femoris are major involved muscle in soccer kick, which had a great match with current study results [2]. According to current results, it is noteworthy that tibialis anterior is a vital muscle in soccer kick, but must researchers have focused on the muscles around knee joint and a few of them studying on the other lower limb joints [2, 4]. Contraction pattern of rectus femoris, vastus and tibialis anterior which was calculated by surface electromyography during soccer kick is shown in Fig 6 [19].

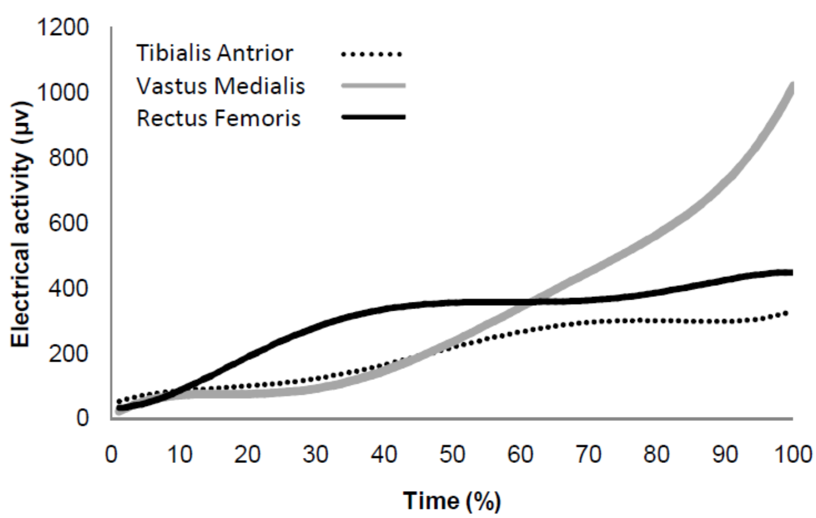

Figure 6. Contraction pattern of rectus femoris, vastus and tibialis anterior during soccer kick, reported by Hajlotfalian et al. (2013) [19]

As can be seen, contraction pattern of these muscles in forward swing phase of kick, were similar with muscle contraction patterns which provided by musculoskeletal modeling in current study (Fig 4).

In recent years, kinematic and kinetic factors of soccer kick, investigated by several researchers [20- 24]. Naito et al. (2010) indicated that, there is a direct relationship between hip flexion and knee extension velocity during forward swing phase of soccer kick [21]. In other words, the centrifugal affect because of the proximal joint, substantially increase distal joint velocity. In present study, activity of iliopsoas as the most important hip flexor muscles was lower in optimal pattern. Nevertheless, rectus femoris can actuate flexion torque in hip joint and compensate shortage of iliopsoas contraction. Therefore, hip flexion torques of two patterns was same approximately and Motion-Dependent-Moment in distal segment cannot be the reason of higher velocity and quality of optimal pattern. Most of previous studies, acknowledging the importance of hip flexion angular velocity, introducing angular velocity of knee extensor are the most important factor to create powerful kick [21, 22]. Cabri et al. (1998), just like Narci et al. (1988), acquired a high correlation between strength of knee extensors and ball velocity [23-25]. The results of this study indicated that in the forward swing phase, there was a significant difference in contraction level of the knee extensor muscles between two kick patterns. Same as previous studies [23, 24], strong contraction of vastus lateralis and biceps femoris in optimal pattern, was the most important factor for increasing ball velocity. Also, the sequence and rhythm of muscles contraction to create interaction between joints, segments and enhance Motion-Dependent-Moment is necessary in a high-quality soccer kick, but the findings of this research showed the powerful contraction of quadriceps muscle was the most important reason for increasing ball velocity in optimal kick. Eventually, for improving soccer kick velocity, increasing knee extensors strength and intervention between adjacent joints, are essential.

Conclusion

By using musculoskeletal models, can be acquired the performance of deep muscles with acceptable accuracy, without invasive methods. Also, evaluation of optimal kick muscles function was another accomplishment of this research which already not found in previous studies. In a nutshell, this research, introduce a new technique for calculating muscle function, which can be used in sport biomechanics and sport medicine researches.

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چکیده فارسی

مدل‌سازی اسکلتی عضلانی شوت بهینه‌ی فوتبال، به منظور بررسی عملکرد عضلات منتخب

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الکترومایوگرافی به‌عنوان روشی رایج در محاسبه‌ی فعالیت عضلات، همواره با محدودیت‌هایی همراه بوده است. مدل‌سازی اسکلتی عضلانی یک روش غیر مستقیم برای بررسی عملکرد عضلات، به‌کمک اطلاعات کینماتیکی و کینتیکی حرکت است. هدف از انجام این مطالعه، مقایسه‌ی عملکرد منتخبی از عضلات پای برتر حین اجرای الگوی شوت توسط تعدادی آزمودنی ماهر، و الگوی شوتِ بهینه شده‌ی آن‌ها با استفاده از مدل‌سازی مکانیکی بود. از پلت فورم اوپنسیم ۳/۲ و ابزار CMC برای شبیه‌سازی تحریک عضلات استفاده شد. پس از انتخاب یک مدل سه‌بعدی از پا که دارای شش درجه آزادی و نه عضله اصلی بود، پارامترهای بیومکانیکیِ حاصل از میانگین شوت آزمودنی‌ها و شوت بهینه وارد مدل شد و اجرا گردید. پس از اجرای مدل، داده‌های مربوط به عملکرد عضلات، به‌صورت درصدی از حداکثر فعالیت، نرمال و سپس فیلتر شد. از آزمون تی زوجی برای مقایسه‌ی عضلات در دو الگوی شوت استفاده گردید. دو الگوی شوت بهینه و شوت آزمودنی‌ها در شش عضله با یکدیگر اختلاف معنی‌دار داشتند و عضلات پهن داخلی، راست رانی، سوئز خاصره و ساقی قدامی، موثرترین عضلات فاز رو به جلوی حرکت، در هر دو الگو بودند. همچنین در الگوی آزمودنی‌ها، عضله‌ی سوئز خاصره و در الگوی بهینه، عضله‌ی چهارسر ران بعنوان دو گروه عضلانی مهم در فاز رو به جلوی شوت، بیشتر از الگوی دیگر فعالیت کردند. مداخله‌ی به ترتیب عضلات و اندام و فعالیت بیشتر عضله‌ی چهارسر ران، دو عامل اصلی افزایش سرعت شوت بهینه نسبت به شوت آزمودنی‌ها بود. با توجه به تطابق نتایج این پژوهش با نتایج مطالعات الکترومایوگرافی محورِ گذشته، می‌توان گفت مدل‌سازی اسکلتی عضلانی می‌تواند به‌عنوان یک ابزار مناسب در بیومکانیک و طب ورزش بکار گرفته شود.

واژگان کلیدی : بیومکانیک، اوپنسیم، الگوی شوت بهینه، فعالیت عضلانی