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The Biomechanics and Muscle Function in Various Squat Techniques with a Rehabilitative and Training Approach: A Narrative Review

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Review Article

Abstract

Introduction: Nowadays, squat exercises are commonly used in rehabilitation centers to expand muscle power and strength. In this study, biomechanics and muscle function have been reviewed during squats. The aim of this study is to recognize the gaps and deficiencies of previous studies and provide suggestions to improve the application and safety of squats for rehabilitation and training purposes.

Materials and Methods: PubMed and ScienceDirect databases were searched for studies published in English between 2000 and 2020. The Google Scholar search engine was also used for this purpose. Adopting from Medical Subject Headings (MeSH) terms, the search was conducted with keywords Squat, Biomechanics, Muscle function, and Optimization as well as the combination of these terms. The final analysis was performed on more than 32 articles with a direct relationship to the review subject.

Results: The squat exercise was widely investigated for several purposes such as improving techniques, preventing injuries, and promoting muscle function. The most common parameters in kinematics, kinetics, and muscle function context were joint range of motion (ROM), joint maximum torque, especially maximum torque of the knee joint, and quadriceps and hamstring muscles function, respectively. Despite numerous studies examining muscle function, there was not enough information about profound muscles involved in the squat exercise. Furthermore, none of the squat methods were optimized in terms of motion pattern.

Conclusion: Performing wide-stance back squat (≥ shoulder width) with natural foot positioning, unrestricted movement of the knees, and full depth while the lordotic curve is maintained is an optimal technique to perform this exercise. But it should be noted that the use of musculoskeletal models to optimize motion pattern and make knowledge on the deep muscle function are beneficial to find gold standards and more use of the squat for clinical and rehabilitation purposes.

Keywords: Muscle; Function; Biomechanics; Rehabilitation

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Introduction

Squats are one of the most common exercises for strengthening the lower back and lower extremity muscles, which help to better perform basic skills in sports events and daily activities by expanding the strength and power of the muscles (1). Today, in medical centers, the use of this movement to repair damaged tissues has become more common and as part of the treatment of problems such as ligament lesions (2), patellar tendinopathy (3,4), ankle instability (5), and after anterior cruciate ligament (ACL) reconstruction surgery (6). Additionally, the stand up from a sitting position is repeated frequently during the day and is an important prerequisite for gaining functional abilities (7). Clinically, this movement is a vital task in people with movement disorders such as Parkinson's disease (8), paraplegia (9), hemiplegia (10), and cerebral palsy (CP) (7). Moreover, squats are the first of three powerlifting moves in the powerlifting sport and are used to test

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the strength of the lower torso muscles at maximum power. A standard squat movement begins at close range with full extension of the hip and knee joints, and the person should move down enough so that the femur is parallel to the ground then continue to move back to his original position (11).

In performing squats for training and rehabilitation purposes, the type of device used (barbell, dumbbells, Smith machine), the place of application of the load on the body (chest, back, side), the intensity of the load, and the position of the body organs (foot width, Squat depth, leg angle, heel height) have greatly diversified the methods of performing this movement (12). Therefore, depending on the type of exercise, it is possible to change the amount of muscle involvement and moment created in the joints during the movement and at the same time strengthen the target muscles, minimizing the possibility of injury (1). Although the possibility of injury in this movement does not seem to be significant, using the wrong techniques in its implementation, especially when carrying heavy loads, can apply unusual forces and torques to the body and increase the risk of injury (13). It should be noted that so far, efforts have been made to optimize squat motion in order to make it safer and increase its efficiency (14) to achieve the two main goals of biomechanical knowledge, i.e. improving technique and preventing injury.

Knowledge on safe and effective training protocols to rehabilitate and prevent injury is of particular importance to the therapist and the trainer, and the methods of performing squats are very diverse (12). Accordingly, the researchers in the present study tried to review the existing information in the field of biomechanics and function of muscles involved in different methods of performing squats in order to determine the more important and inferior indicators in the study of squats with a rehabilitative and training approach. Based on the results of the present study, it is possible to identify the shortcomings of previous studies and make suggestions for future studies as well as for more practical and safer implementation of this movement for rehabilitation and training purposes.

Materials and Methods

For this study, the articles published on the biomechanics of squat motion were searched in the PubMed and ScienceDirect databases. Besides, the Google Scholar search engine was used. In this search, which was limited to studies from 2000 to 2020, the keywords Squat, Kinematics, Kinetics, Muscle Function, Optimization, and a combination of them based on the Medical Subject Headings (MeSH) keywords were used.

The study inclusion criteria included valid articles indexed in the abovementioned databases that examined squat biomechanics to achieve training and rehabilitation goals. In the present study, an attempt was made to review the topics emphasized in previous studies and to avoid repeating the topics studied in previous review articles and were not much related to the purpose of the present study (Figure 1). The aim was to retrieve all studies except qualitative and validity review studies. The references used in all qualitative studies and systematic review were examined by cross-reference method.

Results

As a result of searching based on the study strategies, nearly 4000 articles were found in the above-mentioned databases, which considering the title and abstract of the articles and taking into account the inclusion and exclusion criteria, the duplicate and unrelated articles were discarded, thus selecting about 50 studies for full text review. Finally, the results of 32 articles were in line with the purpose of the present review study. Based on this group of studies, one can determine to what extent individuals can achieve the physical and functional characteristics of movement, similar to what healthy people perform, during exercise processes and with exercise therapy during rehabilitation processes or following therapeutic interventions.

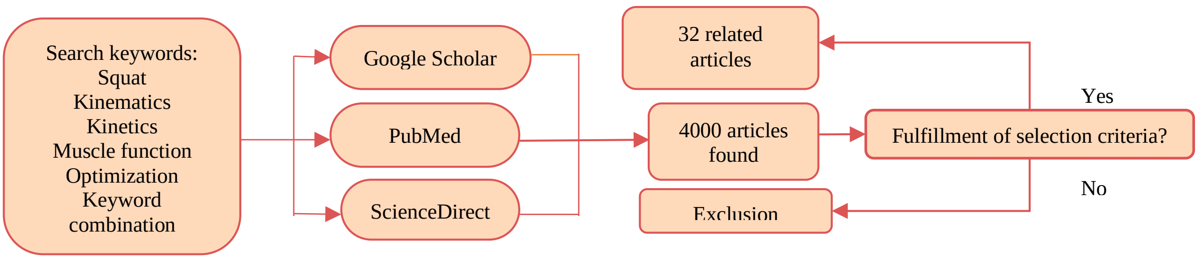

Figure 1. Selection of articles

The studies found were reviewed in three general areas: The biomechanics of squats, which included studies that examined the kinematic and kinetic parameters of squats. In total, 20 papers were reviewed in this field, 4 and 16 of which were related to kinematics and kinetics of squat, respectively. Examining muscle function in various squat techniques was another area that was reviewed for use in training and rehabilitation protocols. 17 valid articles were reviewed in this field, 9 of which overlapped with the articles reviewed in kinematics and kinetics of squat. In addition, in relation to the optimization of the squat movement pattern, 4 related articles were found which were reviewed. The general information of the studies that were finally reviewed is presented in table 1.

Discussion

Squat movement has been extensively studied for various purposes such as rehabilitation (2,14,25-27), injury prevention (26), technique improvement (14), and improving muscle function (15,17,20). In most of these studies, several different methods of performing squats from different aspects such as reducing the forces on the limbs (17) and ligaments (2,12), reducing the moment applied to the joints (17), increasing the record (23), and strengthening the desired muscle groups (16) have been compared and the most optimal method has been introduced.

Study of squat biomechanics for rehabilitation: Due to the variety of the implementation methods and countless applications of squats in exercise and rehabilitation, this movement has been investigated and analyzed from several biomechanical aspects (2,14-29). The kinematic analysis of this technique is one of these aspects that examines the movements of the joints involved and the sequence and timing of their movements. In fact, the purpose of performing a kinematic analysis is to study the angular displacement, angular velocity, and angular acceleration of the joints as well as the linear displacement, velocity, and acceleration of the center of gravity of the limbs, which depending on the objectives, all or part of these indices can be reported in any study. In general, in squats, the athlete starts from a standing position and, depending on the squat depth, flexes the hip, knee, and carpal joints and then returns to the starting position (30). Kinematics of squats can be used as a test to assess lower limb function before and after surgery or as a training and rehabilitation course. Given the role of movement speed and applied load in the amount of kinematic indices and the extent of squat methods and more attention to the kinetics of squat motion, few researchers have specifically analyzed these indices for training and rehabilitation purposes (18,23,28,29) and have mostly addressed the angle of the joints and limbs in different planes and their ROM (18,29). Hemmerich et al. reported that the mean ROM of the hip and knee joints in flexion was 95 ± 27 and 152 ± 11 degrees, respectively, and that the wrist dorsiflexion was 35.4 ± 5.5 degrees; they also stated that squats without heel lift required at least 38.5 ± 5.5 degrees of dorsiflexion is in the wrist (18). Furthermore, during the knee flexion and extension in squat motion, external and internal rotation occurs in the femur, respectively (18).

Another area in the biomechanical study of a movement is its kinetic analysis, examining the forces and moments exerted on the athlete by external objects such as the ground, barbells, or dumbbells, as well as the internal forces and torques produced in the joints and by muscles to create or resist movement. In the inverse dynamics process, for a kinetic analysis, it is required to examine the kinematic information of motion in the concurrent recording of ground reaction forces (GRF), and most researchers use this process to calculate the torque and forces acting on joints, limbs, and ligaments (15-27). Many researchers have studied the kinetic parameters of squat motion for different purposes (2,11,17,24-26). Some studies have examined the tensile, shear, and compressive forces applied on ligaments and joints during squats for pathology and rehabilitation purposes (2,12,14,25-27). Comparing different methods of knee rehabilitation in terms of stress on the cruciate ligaments, Toutoungi et al. found that squatting to rehabilitate quadriceps muscles in people with ACL injury was more appropriate and safer than open chain exercises (2). In another study, Escamilla et al., comparing squats and leg presses, declared that the squat muscles were more active in the squat movement, and that the squat could be used in rehabilitation exercises due to the lower force applied on ACL in the squat (12).

Additionally, many studies have compared the kinetic indices, especially the maximum torque, in different methods of performing squat motion (16,19,27). In overhead squats, the front torso muscles are more active in the sitting phase, and in back squats, the back torso and lower torso muscles are more active in the standing phase. Therefore, it seems that in order to rehabilitate the lower torso muscles, back squats are more appropriate than overhead squats (27).

Table 1. Studies in the field of kinematics, kinetics and muscle function in performing various squat methods

References	Domain	Type of task	Results
Toutoungi et al. (2)	Kinetics	Squats without external load	More safety of squats than open chain exercises
Escamilla et al. (12)	Kinematics and kinetics	Squats and leg presses	In squats, less force is applied to the ACL and this movement is more suitable for rehabilitation.
Escamilla et al. (11)	Kinetics	Squats with different feet distances	Squats with medium to high feet distance are more effective in strengthening the muscles of the thighs, knees, and wrists.
Caterisano et al. (15)	Kinetics and function of muscles	Back squat at different depths	Squat depth increase increases the involvement of hip extensions.
Anderson and Behm (16)	Kinetics and muscle force	Squat with free weight and the Smith machine	Squat with free weight strengthens muscles more than the Smith machine.
Cotterman et al. (17)	Kinetics and muscle force	Squat with free weight and the Smith machine	Using the Smith machine in the early stages of rehabilitation is better than free weight squats.
Hemmerich et al. (18)	Kinematics	Squats without external load	Reporting ROM of lower torso joints
Gullett et al. (19)	Kinetics and muscle force	Back and front barbell squats	For rehabilitation purposes, front barbell squats are more appropriate than any other method.
Pereira et al. (20)	Kinetics and muscle function	Comparison of squats with different angles of external hip rotation	External rotation of hip up to 30 degrees can increase involvement of the hip adductors in squat movements.
McBride et al. (21)	Kinetics and muscle performance	Normal squat and chair squats	The presence of a SSC in regular squats helps to produce more muscle force and is useful for advanced rehabilitation stages.
Schoenfeld (22)	Kinematics and kinetics	Squats without external load	Detection of knee movements in different squat phases on horizontal plane
Lamontagne et al. (23)	Kinematics	Full squats without external load	Squat effect as a performance measurement test in the rehabilitation period
Cotterman et al. (17)	Kinetics	Traditional and powerlifting squats	The powerlifting method is more effective in strengthening the thigh muscles; while the traditional method is more effective in rehabilitating the muscles of the wrist and spine.
Drinkwater et al. (24)	Kinetics	Complete and Semi Squats	In Semi Squats, low ROM of the joints may not be adequate in the advanced stages of rehabilitation.
Lorenzetti et al. (25)	Kinetics	Squat with and without restriction of forward knee movement	To rehabilitate the quadriceps muscle, use the free knee method; because it applies more load on the knee and less pressure on the back.
Fry et al. (26)	Kinetics	Squat with and without restriction of forward knee movement	For rehabilitation purposes, a small amount of forward knee movement is necessary.
Aspe and Swinton (27)	Kinetics and muscle force	Back and overhead squats with barbell	For rehabilitation purposes, back squat with barbell is more appropriate than the other method.
Comfort et al. (14)	Kinetics, Kinematics, and muscle	Review of different squat methods	Providing the most efficient squat method for rehabilitation
Demers et al. (28)	Kinematics	Squats with different feet distances	Squats with large feet distances are more suitable for people with limited wrist dorsiflexion and long lower torso lengths.
Lee et al. (29)	Kinematics and muscle performance	Heel height change in back squat with barbell	Heel height change has no effect on trunk and knee kinematics and function of knee and back-lumbar extensor muscles.

ACL: Anterior cruciate ligament; ROM: Range of motion; SSC: Stretch-shortening cycle

Back squats increase the compressive force and extensor torque of the knee, and in this maneuver, the load position has no effect on the knee shear force and muscle activity. However, muscle activity is greater when standing up than when sitting down. For this reason, front squats are a better method for rehabilitation exercises due to less force applied to the knee and spine joints (19). In another study to strengthen the trunk stabilizing muscles, it was found that performing squats with free weights and in the unstable position was more useful than performing this movement with the Smith machine. In other words, muscles contract more in unstable conditions (16). Although squats with the Smith machine require less balance than free weights and provide greater safety in rehabilitating injured people (17), since the use of free weights strengthens more muscles (16), it can be claimed that in individuals with lower limb injuries, it is better to use the front squat with the Smith machine in the early stages of rehabilitation and then use free weights to strengthen more muscles.

One of the factors influencing the kinematics and kinetics of squat is the position of the limbs relative to each other during this movement. Numerous studies have been performed on foot width and ROM as well as position of limbs during squats (11,12,15,17,19-21,24-27). In this regard, Escamilla et al. investigated the torque generated in the joints at different feet distances. They were one of the few researchers to calculate the amount of torque in the wrist joint in addition to other joints, concluding that squats with medium to high feet distances were more effective in rehabilitating the thigh, knee, and wrist dorsiflexor muscles (11). Demers et al. examined the effect of step width on ROM of the joints and its effect on the development of rehabilitation protocols, finding that squats with a large feet distance are more appropriate for individuals with limited wrist dorsiflexion and long lower torso length (28). In their study, Lee et al. studies the effect of heel height changes during back squatting and observed that it had no effect on trunk and knee kinematics and knee and dorso-lumbar extensor muscle function (29).

Aspe and Swinton compared three types of traditional (low feet distance), powerlifting (long feet distance), and chair squats (sitting on a chair and then standing up) in terms of biomechanical parameters at different loads and reported the maximum torque in different cases. Accordingly, it can be said that the powerlifting method is more effective in strengthening the thigh muscles; while the traditional method is more effective in rehabilitating the wrist and spine muscles (27). McBride et al. compared the kinetic parameters and muscle function in squats and box squats with the aim of examining the stretch-shortening cycle (SSC) of the muscles in the squat standing phase. They concluded that muscles performed better in squats compared to the chair squats and performing usual squats that were accompanied by SSC, could be useful for rehabilitation purposes (21). Drinkwater et al. compared partial and full squats at different loads in terms of kinetic parameters and stated that despite the importance of performing partial squats with moderate loads for rehabilitation purposes, the small ROM of joints during partial squats could not meet the goal of exercise and resistance protocols (24). Additionally, Caterisano et al. found that increasing the range of the squat increased the involvement and participation of the gluteus maximus muscle (15). The results of a study by Pereira et al. indicated that by creating 30 degrees of external rotation in the thigh, it is possible to increase the involvement of the thigh adductor muscles in squatting to optimize the position of the limbs to strengthen this group of muscles (20). Lorenzetti et al. compared the torque and angles of joints during squats with free knee movement and squat with the limited movement of this joint and concluded that in squats with free knee movement, the knee torque and thigh torque increases and decreases, respectively, and the knee flexion angle in the sitting position is more than the other position. Therefore, to rehabilitate the quadriceps muscle, it is preferable to use the free knee method; because more load is applied to the knee and less pressure to the back (25). In a study with a similar protocol, the effect of anterior displacement of the knee joint during barbell squat on knee and hip torque was measured, with the results suggesting that preventing forward knee movement despite the reduced torque on the knee joint increased the torque applied to the hip and waist joints, and in order to perform a safe and appropriate squat for rehabilitation purposes, a small amount of forward knee movement is required (26).

To put the above-mentioned studies in a nutshell in order to find the most suitable method of performing squats in terms of distance, range, and position of feet for clinical and rehabilitation applications, one can refer to the findings of the study conducted by Comfort et al. (14). Revising their former study, the carried out a study with a pathological approach and reviewing studies on the effect of squat depth and limb position on the force applied to joints and muscle function. In this study, they introduced squats with feet distances equal to or greater than the shoulder width with normal position of the feet and the possibility of forward and free moving of the knee and doing squats at full depth, provided that the lumbar arches are maintained, as the optimal squats (14).

In summarizing the above issues, it can be claimed that less kinematic indices were considered as the researchers' goal to select the most appropriate method from the methods studied (18,23,28,29) and the standard functions mostly included kinetic indices such as minimum torque and force on the joints and limbs and the amount of activity and function of the muscles (15-27). In other words, most researchers changed the pattern and method of performing the movement (kinematic) to find the most appropriate way to achieve their goal, which mostly included kinetic indicators. It can also be inferred that the goal of most researchers who studied indicators such as force and torque on limbs and joints was to examine injury indicators and select the most appropriate technique in terms of safety and performance to be used in rehabilitation exercises (2,14,25-28). The main approach in the studies that examined muscle function was to increase squat movement efficiency and optimize movement to strengthen the desired muscles for rehabilitation purposes (16,17,19-21).

Muscle function: Muscles are the only contractile agent creating movement in the limb and its role in the development of various sports skills is of particular importance. Since more than 200 muscles are activated during squats, this movement is known as a good exercise for rehabilitation and increasing strength (31). The main approach in the studies that examined muscle function (1,16,19-21,27,32-38) was to increase the efficiency of squat movement and optimize movement to strengthen the desired muscles for rehabilitation purposes. One of the most common methods for assessing muscle function in sports skills is electromyography (EMG), which is performed to describe the muscle role and level of activity. In this way, many researchers have studied and compared the function of different muscles of the body while performing different squat methods, with a summary of the studies presented in table 2.

Table 2. Muscles studied in various studies conducted on different methods of performing squats

References	Study objective	Muscles examined
McCaw and Melrose (32)	Comparison of three different feet distances at 65% and 75% ROM	Vastus medialis, Vastus lateralis, Rectus femoris, Gluteus maximus, Gluteus medius
Zink et al. (33)	Comparison of performance with and without a belt in 90% ROM	Vastus medialis, Biceps femoris, Gluteus maximus, Gluteus medius
Caterisano et al. (34)	Comparison of three different feet distances at zero to 125% of body weight	Vastus lateralis, Rectus femoris, Biceps femoris, Gluteus maximus, Gluteus medius
Anderson and Behm (16)	Comparison of squats with free barbell with Smith machine	Vastus medialis, Biceps femoris, Gastrocnemius, Rectus abdominis, erector spinae, lumbar erector
McBride et al. (35)	Comparison of stable and unstable dynamic squats at 70, 80, and 90% ROM	Vastus medialis, Vastus lateralis
Hamlyn et al. (36)	Comparison of squats at 0 and 80% ROM with isometric trunk exercise	Rectus abdominis, external oblique upper lumbar erector, lumbar erector
Paoli et al. (37)	Comparison of three different feet distances in three loads of 0, 30, and 70% ROM	Vastus medialis, Vastus lateralis, Rectus femoris, Biceps femoris, Semitendinosus, Gluteus maximus, Gluteus medius, Adductor magnus
Schwanbeck et al. (38)	Comparison of back squat with barbell using Smith machine	Vastus medialis, Vastus lateralis, Biceps femoris, Gastrocnemius, tibialis anterior, Rectus abdominis, erector spinae
Gullett et al. (19)	Comparison of back and front squats with barbells	Vastus medialis, Vastus lateralis, Retus femoris, Biceps femoris, Semitendinosus
McBride et al. (21)	Comparison of squat with box squat	Vastus medialis, Vastus lateralis, erector spinae
Pereira et al. (20)	Comparison of squats with different angles of hip external rotation	Soleus, Adductor group,
Aspe and Swinton (27)	Comparison of squats with barbells with overhead squats	Vastus medialis, Vastus lateralis, Rectus femoris, Gastrocnemius, gluteus maximus, Rectus abdominus, external oblique upper lumbar erector, lumbar erector
Kubo et al. (1)	Knee biomechanics in squat with different angles	Vastus medialis, Vastus lateralis, Vastus intermedius, Rectus femoris, Biceps femoris, semitendinosus, Semimembranosus, Adductors

Among the hip joint muscles, the gluteus maximus is activated at the beginning of the squat movement and, with its extrinsic contraction, controls hip extension and, with the help of the iliotibial band, also contributes to the pelvic and knee stability and unlike the hamstrings, as the depth of the squat increases, the function of this muscle increases as well (41). Additionally, to further strengthen and engage the adductor and gluteus maximus muscles in rehabilitation exercises, the transverse distance of the feet can be increased in the squat movement (37). A common denominator in all studies was the study of a limited number of muscles out of about 200 muscles active in squats (31).

Of course, it should be noted that in most of these studies, the muscles that were most effective were selected, and since muscle activity was recorded by EMG, it was not possible to examine a large number of muscles simultaneously. Besides, in the above-mentioned studies, only the function of the body superficial muscles was examined and the record of the function of the deep muscles was discarded due to ethical considerations and the impossibility of using aggressive methods in humans.

The use of musculoskeletal models is another way to evaluate muscle function (42). These models are based on anthropometric parameters of the body and muscle behaviors and try to simulate the movement of limbs and muscle function. Cost-effectiveness (43) and the possibility of calculating various biomechanical parameters such as muscle activity pattern, joint torque, and force exerted on the limb (44) and helping to investigate the role of these factors in athletic skills (45) and movement disorders (46), have led to the increasing use of musculoskeletal models in biomechanical laboratories and rehabilitation centers. Using these models, it is possible to evaluate the performance of a larger number of muscles simultaneously in different types of squats, and there is no limit in terms of the superficiality or depth of the muscles studied (47).

Optimizing squat motion pattern for rehabilitation purposes: Modeling human movements is used to solve direct and inverse dynamics problems in a variety of situations. In many studies, the human body has been modeled in closed chain movements such as squats, and the forces and torques applied to the joints have been obtained by the inverse dynamic method (14,25-27). One of the applications of inverse dynamics is its use to predict motion. Thus, both motion and force are unknown and must be calculated through the optimization process (48). Optimization is an attempt to make changes to an initial idea using information already obtained (43). The purpose of optimization is to find the best acceptable solution taking into account the constraints and requirements of the problem (43).

Most of the above studies, which have been conducted with a comparative approach between squat techniques, can be considered as optimization studies (15-27) that tried to find the best pattern or method of performing squats according to the patient’s characteristics and the goal defined in the study and use them in bodybuilding and rehabilitation exercises. The importance of this issue becomes clear when in many rehabilitation and training protocols, a person may become overloaded and re-injured due to choosing an inappropriate movement pattern, or the exercises may not be effective for him (49).

In recent years, most optimization studies have been focused on hand and upper body movements (50,51), but the importance of whole body movements in clinical and industrial programs such as rehabilitation and ergonomics of workers or employees has led many researchers to optimize movements such as lifting, bending, walking, and running (52-55). However, there were few studies in which, using dynamic modeling, the optimal squat pattern was obtained in terms of time sequence of movement, interference with the order of limbs, and interactions between limbs and joints for training and rehabilitation purposes (except in a few cases) (49,56). Gundogdu et al. in their study, by choosing the torque index as a factor that could be effective in the incidence of joint damage, presented a pattern of squat movement that, if performed, applied less torque to the joints and brought more safety to the person (53).

Hajlotfalian et al. optimized squat movement in four different load application positions. In their study, they tried to provide a type of movement patterns that applied the least possible torque to the hip joint and increased the ability of people to perform squats, and concluded that performing squats by applying loads from behind is a more efficient method compared to other methods (56). In another study, Hajlotfalian et al. used a multi-objective cost function to optimize the squat movement pattern to evaluate the function of the body’s central nervous system (CNS). After optimization, the resultant joint torque, mechanical energy of movement, maximum knee joint torque, and imbalance index decreased and they concluded that the implementation of the optimal movement model in addition to reducing the costs applied to the individual, also increases movement safety. Thus, they suggested that the optimization process be implemented in clinics and rehabilitation centers in a practical way so that clients can receive appropriate treatment appropriate to their problem (56). Matsui et al. proposed a pattern of squat movement that minimized energy consumption when implemented. Accordingly, since the models designed based on the characteristics of each individual were scaled specifically, it was possible to suggest a specific optimal model for each individual (58).

Limitations

The quality of the studies in the present study was not analyzed. By performing a qualitative evaluation of the studies reviewed, the clinical and laboratory applications of various squatting techniques will be addressed in more detail.

Recommendations

It is suggested that in future studies, different patterns of this exercise be optimized with different standard functions such as minimum torque, minimum energy and work, maximum balance, etc. so that they can be applied to rehabilitate and increase muscle strength in safe conditions. Additionally, by building skeletal-muscular models simulating the body while doing squats, more muscles will be examined and information on the function of deep muscles will be obtained. Furthermore, performing the present study in the form of a systematic review will be valuable.

Conclusion

In conclusion, it can be said that in terms of implementation method, back squatting with a barbell, with a feet distance equal to or greater than shoulder width, with normal feet position and the possibility of the knee forward and free moving and squatting at full depth provided that the waist arches are maintained, is a good way to perform this movement. Of course, it should be noted that subjects with various problems and disorders need to perform squats with special specifications, which is provided by biomechanical modeling. By constructing a biomechanical model, selecting appropriate cost functions, and optimizing the movement pattern in people with lower extremity functional disabilities, squat movements can be properly trained and squat exercises be designed to maximize the effect of rehabilitation and safety for the patient with any personal, age, and gender characteristics.

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Authors' Contribution

Mostafa HajLotfalian: Study design and ideation, attracting financial resources for the study, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Mohammad Hadi-Honarvar: Study design and ideation, supportive, executive, and scientific study services, analysis and interpretation of results, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments;: Parastoo Shamsekohan: Study design and ideation, support, executive, and scientific study services, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments.

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Conflict of Interest

The authors declare no conflict of interest. Dr. Mostafa HajLotfalian has a PhD in sports biomechanics and has been a member of the Scientific Core of Support Systems in Health Development at Yazd University. Dr. Mohammad Hadi-Honarvar is an Assistant Professor in the Department of Mechanical Engineering, School of Mechanical Engineering, Yazd University, and a member of the Scientific Core of

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