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Full Length Research Paper

Optimization proposal for squatting exercise: An EMG analysis

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This study aims to evaluate the behavior of the neuromuscular muscle groups (rectus femoris and soleus) during the execution of the squat exercise in two different protocols under varying floor angles. To quantify the muscle recruitment during exercise, surface electromyography was used with the following conditions: Free Squats, Squats with Swiss Ball support and three different floors' positions: standard, decline (45^o of plantarflexion) and ascent (30^o of dorsiflexion). Ten healthy men were subjected to all possibilities for the exercise totaling six variations. EMG data were obtained from rectus femoris and soleus muscles bilaterally and the results of the data collection were determined by calculating the Root Mean Square (RMS). It was observed that higher values of RMS for the squat exercise on the proposed terms were obtained when the angle of the floor was at a sloping position. This result raises the possibility of choosing between the two proposed protocols, the one that is most appropriate for the patient in a specific condition, thereby generating a gain of muscle mass or strength, depending on the goals of rehabilitation.

Key words: Quadriceps, surface EMG, recruitment, squat.

INTRODUCTION

Muscle injuries are common in sports and physical activities, thereby creating the need for rehabilitation and reintegration of patients to their daily activities (Shelbourne and Nitz, 1992; Felier et al., 2004). For this reason, various protocols are proposed for rehabilitation professionals. Several exercises are frequently used in these protocols. Specifically, for the lower extremity, we can commonly cite: the recovery of the range of motion of the knee, the strengthening of the lower limbs, the recovery of the knee flexion, balance exercises, proprioception and return of the patient to social and professional routine (Manal and Snyder-Mackler, 1996; Bonfim and Pacola, 2000; Kerkour and Salgado, 2003).

The joints most affected by injuries are the knees and feet, although atrophy of the quadriceps is one of the main consequences of injuries in these joints. However, a practically common example is the atrophy after ACL reconstruction. To prevent and reduce the consequences of atrophy of the quadriceps muscle, some isometric exercises and electrical stimulation are often used. These exercises aim to provide a gain of the muscle mass which is only possible if exercises that stimulate open and closed kinetic chains are included in the treatment, followed by the overload principle (Folland et al., 2001).

For the quadriceps, specifically, there are several exercises proposed by experts that result in a gain in mass and strength among which the squat is more effective, but is also the most debated by professionals because their implementation must be done correctly,

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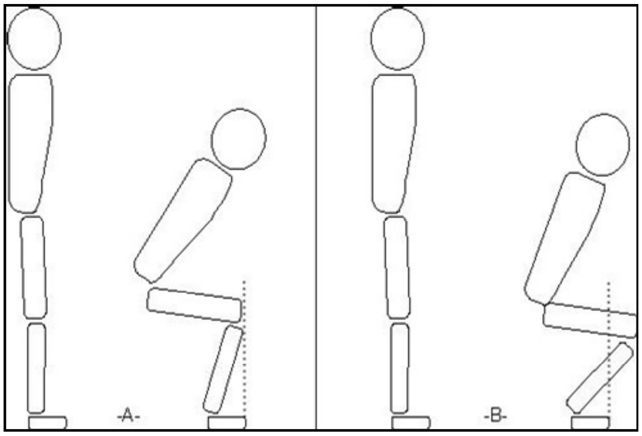

Figure 1. Squat exercise. A- Correct Technique. B- Incorrect Technique.

otherwise the results may be negative. Some studies report that the squat is safe for the ligaments when executed correctly, this being the most relevant point of discussion around the squat, and as such, it is widely described in the literature (Graham et al., 1993; Toutoung et al., 2000; Thompson and Floyd, 2002). The move done incorrectly allows the knees to move in front of the feet (Figure 1), which is responsible for several injuries. It is important to emphasize that the shins should remain perpendicular to the floor, preventing the forward translation of the tibia, in order not to strain the ACL (Thompson and Floyd, 2002).

According to the statement in the foregoing, proposals for measuring the quality of the squat and implementing more efficient methods are constantly published in the literature, mainly in Trauma-Orthopedics and Sports Physiotherapy journals. In this sense, scientific studies are developed to better understand the biomechanics of squat and its consequences in a rehabilitation process, but mainly, the studies define the best ways of doing this exercise (Beutler et al., 2002).

An important point to be evaluated during the squat is the angle from the floor and its influence on the gain in mass and strength, as well as the reduced stringency of the ligaments during its execution. Some researchers concentrated on the study of stress on ligaments and tendons, disregarding the effect that the variation of the floor has on muscle recruitment in the quadriceps (Kongsgaard et al., 2006; Toutoungi et al., 2000; Yong et al., 2005). Accordingly, this study is interested in evaluating the squat under the influence of the change in the angle of the floor in two separate protocols. The data were generated through surface electromyography (SEMG), a technique already known among professionals and efficient in making such studies (Pullman et al., 2000; Farina et al., 2002; Farina et al., 2004; Reaz et al., 2006; Fonseca et al., 2009; Paiva et al., 2008).

Based on the previous studies (Thompson and Floyd, 2002; Kongsgaard et al., 2006; Toutoungi et al., 2000; Yong et al., 2005), the squat exercises may be safer when conducted with the ankle positioned in plantar flexion, but it is not known if this condition induces greater muscle activation. We hypothesized that squatting with floor declination could induce greater muscle activation; as such, measurements of EMG that were statistically processed were proposed. This study aims to understand not only the differences between the protocols, so as to seek one that generates the best cost benefit to the muscles and ligaments, but also to understand the influence of change in the angle of the floor and their influence on the proposed protocols and their consequences in the recruitment of muscle fibers. These responses will provide health professionals, from various fields' subsidies, the opportunity to choose the best way to do the exercise focusing on specific goals in a rehabilitation process.

METHODS

The volunteers are ten healthy males, between 18 and 30 years old, with no family history of blood pressure problems, metabolic diseases or degenerative joint disease. The criteria for exclusion include: hypertension, metabolic diseases, degenerative joint disease on the knee and articular pain on the knee.

All of the techniques used in the experiment, as well as its methodology are in compliance with resolution 251/97 and resolution 196/96 of the National Council of Health of Brazil. The work was approved by the Vale do Paraiba University ethic committee with protocol number: H150/CEP/2006. Although, the information collected during the experiment were used and published in the research study, the anonymity of the subjects was not compromised. The subjects were evaluated regarding the inclusion and exclusion criteria. They went through an anthropometric evaluation and performed 6 squatting exercises during two weeks, so as to homogenize the test sample. The exercises were divided into two groups: squatting exercises executed without the help of any kind of support, which are called "Free Squats"; and those which are executed with a 65 cm diameter Swiss Ball placed between the persons back and a wall. The first group contains three variations of Free Squats, while the second group comprised three variations of the Swiss Ball Squat. The first squat exercise variation is performed with the feet parallel to the floor (Neutral Free Squat and Neutral Swiss Ball Squat), while the second variation is performed with the feet supported on a foot pad which has a 30° inclination with relation to the floor (Dorsi Free Squat and Dorsi Swiss Ball Squat), and the third is performed with the feet supported on a foot pad, which has a 45° declination with relation to the floor (Planti Free Squat and Planti Swiss Ball Squat). Moreover, Figure 2 better depicts the three Free Squat variations and the three Swiss Ball Squat variations.

During each and every exercise, the individuals underwent bilateral surface electromyography (SEMG) of the rectus femoris and soleus muscles, with the intention of verifying the recruitment of the muscle fibers of these muscles. Furthermore, the knee angle was measured by a manual goniometer to avoid monitoring the range of motion and avoid excessive knee flexions.

The area where the electrodes were attached was disinfected with 70% alcohol before and after the shaving. The electrodes, which were used to monitor the rectus femoris muscle, were attached to the middle of an imaginary axis located between the Anterior Superior Iliac Crest of the Pelvis and the base of the

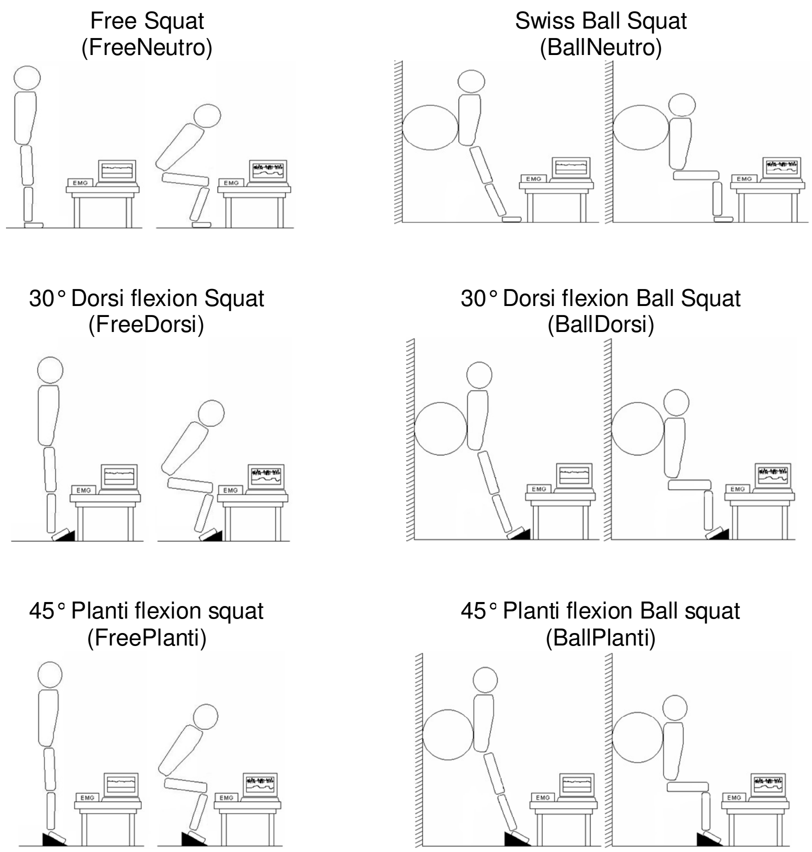

Figure 2. Illustration showing 6 variations of the squatting exercise.

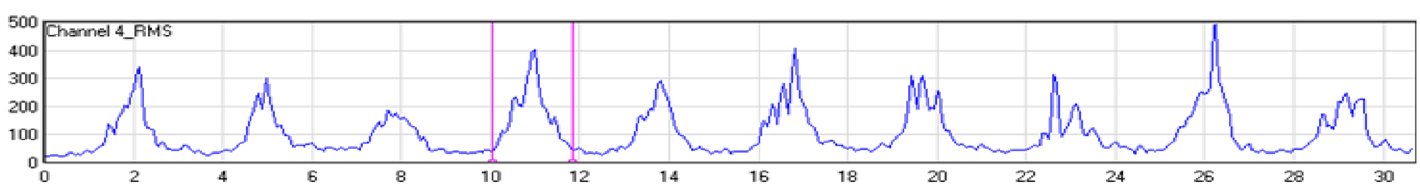

Figure 3. A graph demonstrating the interval where the root mean squares (RMS) were calculated disregarding the minimum values (valleys).

Patella. The electrodes, which were used to monitor the soleus muscle, were attached to the distal 1/3 medial side of the leg, above an imaginary axis located between the medial malleolus and the medial epicondyle of the femur (Hermens et al., 1999). The distance between the centers of each electrode was 2 cm and the ground electrode was placed in the right hand of the subject. A dermographic pen was used to mark the position of the electrodes on the skin, so that they could be attached to the same place during the subsequent days.

The volunteers did 10 sets of exercises for each variation of the squat where the choice of this was done randomly in compliance with the protocol of rest between the different protocols. Specifically, each protocol was done in one day, thus avoiding muscle fatigue. The pace of the exercise was dictated by a metronome set to produce an acoustic pulse every 1.5 seconds, forcing the volunteer to maintain the same contraction time.

The electromyography used to collect the myoelectric signal was an “EMG System Brazil LTDA” connected to the data analysis and acquisition system called “WinDaqXL”, with a cut frequency of 10Hz in the high passing filter and 500Hz in the low passing filter. This was amplified 1000 times and subsequently converted by an A/D converter having a sampling rate of 2 KHz for each channel and an input signal swing of 5 mV. Afterwards, the myoelectric signal was converted into a .txt file so that it could be opened with DelSys EMGwork Analysis, version 3.1.1.1 – 2005. Next, the Root Mean Square (RMS) of the SEMG signal was calculated considering the concentric and eccentric muscle contractions while disregarding the valleys of the myoelectric signal (Figure 3).

Microsoft Excel was employed to calculate the averages and standard deviations. The statistical tests were carried out on GraphPad InStat v.3.05 -2000 and the graphical plotting was done on Microcal Origin 7.0. Additionally, the signals were also analyzed using ANOVA with post-hoc Tukey’s test (a=0.05).

RESULTS

The averages and the standard deviations of the height,

Table 1. The averages and standard deviations (S.D.) of the anthropometric parameters which were evaluated by the stature, mass, thigh perimeter, leg perimeter and thigh skin folds' thickness.

Statistic	Stature (cm)	Mass (Kg)	Right thigh (cm)	Left thigh (cm)	Right leg (cm)	Left Leg (cm)	Thigh skin folds thickness (mm)
Mean	177.6	80.59	55.28	55.39	37.78	37.78	16.75
S.D.	7.40	14.49	5.21	4.78	3.42	3.35	6.26

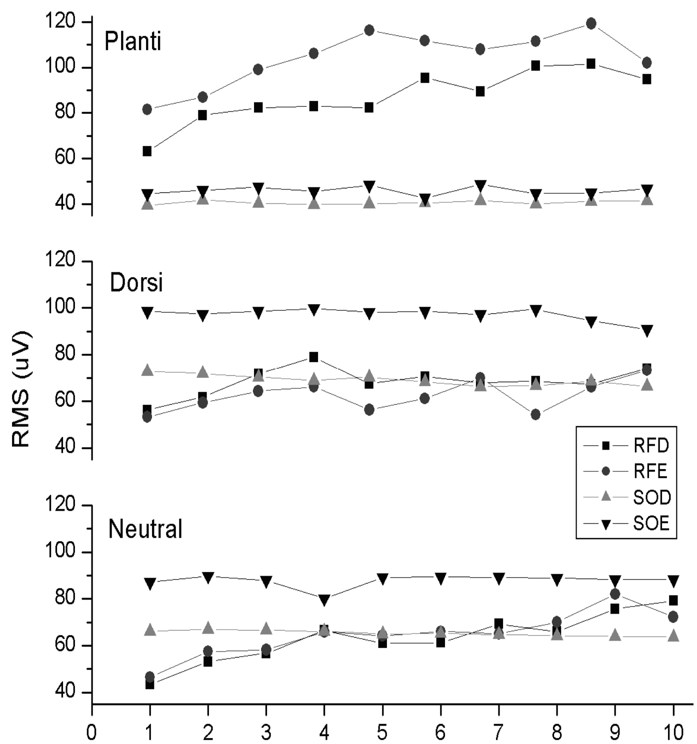

Figure 4. RMS of each of the 10 repetitions of the three variations of the Free Squat (Neutral, Dorsi and Planti).

mass, right thigh, left thigh, right leg, left leg and thigh's cutaneous crease of 10 subjects are presented in Table 1. The subjects were 25± 5 years.

The Root Mean Square (RMS) of each of the 10 repetitions that form the three variations of the Free Squat (Neutral, Dorsi and Planti) are presented in Figure 4. The Free Squats carried out on the Neutral position had an average muscle recruitment of 63 uV for the right rectus femoris (RRF), 64 uV for the left rectus femoris (LRF), 65 uV for the right soleus (RSO) and 87 uV for the left soleus muscle (LSO); the Free Squats performed on the Dorsi Position had an average muscle recruitment of 68 uV for the RRF, 62 uV for the LRF, 68 uV for the RSO and 97 uV for the LSO; and the Free Squats executed on the Planti position had an average muscle recruitment of 87 uV for the RRF, 104 uV for the LRF, 40 uV for the RSO and 45 uV for the LSO.

The RMS of each of the 10 repetitions that form the three variations of the Swiss Ball Squat (Neutral, Dorsi and Planti) are presented in Figure 5. The Swiss Ball Squats carried out on the Neutral Position had an average muscle recruitment of 84 uV for the RRF, 92 uV for the LRF, 72 uV for the RSO and 96 uV for the LSO. The Swiss Ball Squats performed on the Dorsi position had an average muscle recruitment of 66 uV for the RRF, 78 uV for the LRF, 67 uV for the RSO and 106 uV for the LSO. Finally, the Swiss Ball Squats executed on the Planti position had an average muscle for the recruitment of 90 uV for the RRF, 105 uV for the LRF, 38 uV for the RSO and 45 uV for the LSO.

The average RMS from 10 repetitions in each protocol are presented in Figure 6. It is evident that on the Free Squat Exercise Protocols, the exercise was optimized when the feet were positioned on a declination of 45° (Free Squat Planti), since there was more muscle recruitment of the rectus femoris on this variation, than there was on the Neutral Free Squat and Dorsi Free Squat variations. Furthermore, it is also clear that there is little

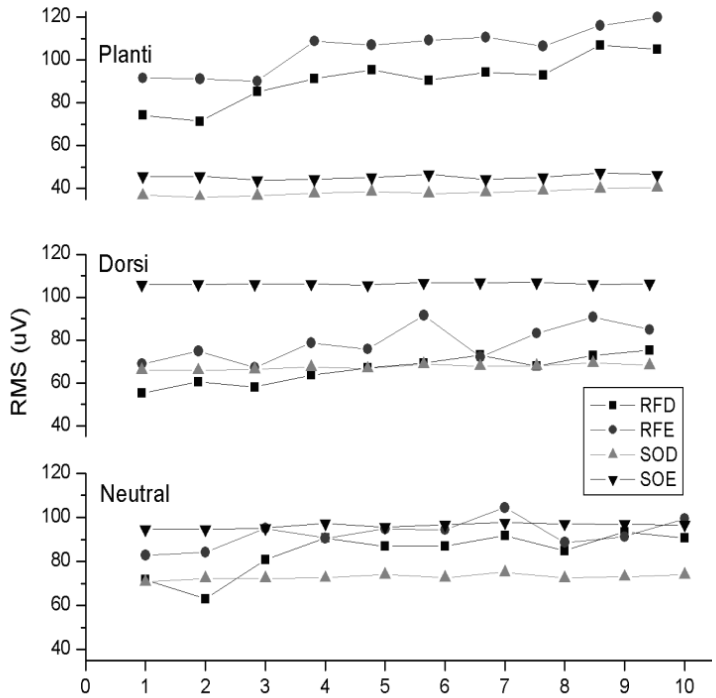

Figure 5. RMS of each of the 10 repetitions of the three variations of the Swiss Ball Squat (Neutral, Dorsi and Planti).

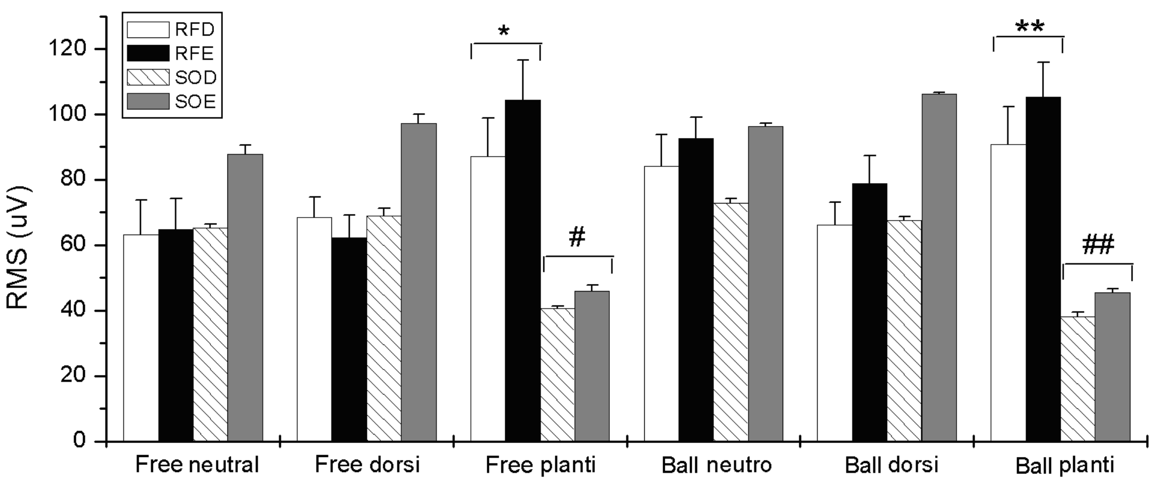

Figure 6. The graph illustrating the average behavior of the 10 repetitions of each squatting protocol. Data are the mean ± the standard deviation. (*) Increase when compared to the Neutral Free Squat and Dorsi Free Squat. (#) Decrease when compared to the Neutral Free Squat and Dorsi Free Squat. (**) Increase when compared to the Dorsi Swiss Ball Squat. (##) Decrease when compared to the Neutral Swiss Ball Squat and Dorsi Swiss Ball Squat ($p<0.05$).

recruitment for the soleus muscle fibers during the Planti Free Squat, when compared to the Dorsi Free Squat and Neutral Free Squat. It is also possible to note in Figure 6 that the recruitment of the rectus femoris muscle is higher during the Planti Swiss Ball Squat than during the Dorsi Swiss Ball Squat. Moreover, the soleus muscle was recruited less during the Planti Swiss Ball Squat than during the other two variations of the Swiss Ball Squat.

DISCUSSION

Our findings show that the Swiss ball has little influence on the gain of muscle recruitment, but the change in the angle of the floor during the execution of the squat generates significant differences in the ability to recruit the muscle groups studied. Additionally, the results indicate that the protocol in planti flexion, which promotes greater recruitment of the rectus femoris muscle fibers and lower recruitment of the soleus muscle fibers, can be useful in some clinical application of the gain in strength and mass in a specific muscle group.

The decrease in the recruitment of the soleus muscle occurred because the feet were positioned on a 45° declination with relation to the floor. This position shortens the soleus muscle, which in turn creates a mechanical inefficiency. It is important to emphasize that on the squat variations which had little demand for the soleus (Planti Free Squat and Planti Swiss Ball Squat), there was an optimization of the rectus femoris. This probably occurs due to the fact that the function of the soleus is plantiflexion. This muscle is not demanded in the Planti Free Squat and the Planti Swiss Ball Squat, due to the fact that the utilization of the rectus femoris is increased in order to compensate for the lack of muscular synergism in a closed kinetic chain.

In order to better evaluate and compare the different squatting protocols, the averages of the RMS of each repetition were analyzed. This value represents the average behavior of each of the muscles which were analyzed for each protocol. These values indicate that the squatting variations, whose feet position are on declination with relation to the floor, independent of whether a swiss ball is used or not, obtain more muscle fiber recruitment. Nonetheless, it must be highlighted that these variations are more appropriate when the objective is to promote the recruitment of the rectus femoris.

Some research studies, about squatting, mainly focus on evaluating the muscle recruitment relation of the vastus lateralis and the vastus medialis (Mirzabeigi et al., 1999; Bevilaqua-Grossi et al., 2005; Sacco et al., 2005). These studies vary with regards to the internal and external rotations of the tibia (which limits its range of motion) and the position of the hips (Hung et al., 1999; Monteiro-Pedro et al., 1999; Herel et al., 2004); although they presented conflicting results.

Kongsgaard et al. (2006) also observed a greater myoelectric signal of the rectus femoris on the exercises, where the feet were positioned on a declination with relation to the floor, when compared to standard squatting. In addition to this, it was observed that the soleus muscle was also activated more, which is a statement that conflicts with the data collected during this experiment. This discrepancy might have occurred because of a methodological difference, in view of the fact that this experiment employed a 45° declination, while the other experiment opted for a 25° declination.

This research study also observed that there was a greater myoelectric signal on the muscles of the side of the body opposite to the subject's dominant side (data not illustrated in the figures). This took place because the dominant member has more motor adaptation, since it is more demanded during athletic activities and daily routine activities. For this reason, during an exercise that is not performed at its limit, the dominant side is recruited less, while on the other side, more muscle fibers are recruited, so that the movement can be executed completely and harmoniously (Duchateau et al., 2006).

Conclusion

The variation of the technique used to perform the squatting exercise can optimize the myoelectric signal of the rectus femoris. In addition, the squatting exercise variation, where the feet are positioned on a 45° declination with relation to the floor and the back, supported by a Swiss Ball (Planti Swiss Ball Squat), is the variation that is more appropriate for the recuperation of the rectus femoris, due to the fact that it recruits more muscle fibers of the rectus femoris and also because the swiss ball gives the patient back support while executing the exercise. It is also important to emphasize that this piece of data is valuable, in that the Planti Swiss Ball Squat permits the squat exercise to be enhanced, without any additional cost.

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