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Biomechanics of Front and Back Squat exercises

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Abstract— --Squat constitutes one of the most popular exercises to strengthen the muscles of the lower limbs. It is considered one of the most widely spread exercises for muscle sport training and is part of the competition movements comprised within olympic weight-lifting. In physical rehabilitation, squats are used for muscular recovery after different injuries of the lower limbs, especially the knee. In previous anterior cruciate ligament injuries, the mini-squats are generally used, in a knee flexion motion range from 0º to 50º because in this range the shear forces, the tibiofemoral and patellofemoral compression forces decrease related to greater flexion angles. The aim of this work is to make a comparative bidimensional study of the kinematic and dynamic variables of the excecution of the parallel squat exercise with the front and back bar. It is observed in the knee a better development of energy with the front bar, allowing a better muscular exercise with the same load. The mean power absorbed by the hip with the back bar is considerably greater, associated to the speed of the gesture.

1. Introduction

Usually, within the popular knowledge, it is thought that squat is only synonymous of the quadriceps muscle work, but this is a extremely limited vision.

In the scope of sport biomechanics, exercises are classified into closed kinetic chain (CKC) in which the distal end remains fixed – as in squat – and the open kinetic chain exercises (OKC) in which the distal end of the segment that moves is free, as the seated knee extensions [1][2]. In the CKC, in addition to the quadriceps work it is originated a better recruitment and activation of hamstrings, gluteus maximus and gastrocnemius muscles, as regards to the majority work of the quadriceps such as in OKC exercises [3].

In addition, there is an important activation of muscles locking of the trunk, mainly abdominal and spine muscles, this activation becomes better during the unstable execution of squat [4], [5].

It is shown in previous data, according to the adopted lumbar position during the execution of the exercise, there will be variations in the patterns of rectus abdominis, spine and latissimus dorsi muscles [6].

Related to the contribution of the gluteus maximus muscle, a better recruitment is observed during deep squat in the concentric phase. There are not significant differences between the relative contribution of the biceps femoris and vastus during this phase [7]

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In the last years the reached speed and the peak of power produced in the force exercises have been estimated with enough precision using force platforms and contact carpets [8].

As regards the cruciate ligaments, the peak of stress in the posterior cruciate ligament (PCL), is double in exercises in CKC, and it is increased mean while the flexion of the knee is also increased. However, the peak of tension of anterior cruciate ligament (ACL), takes place in the exercise of OKC and near the total extension of the knee [3].

During ACL rehabilitation it is possible to minimize the shear forces by doing mini squat in angles until 50º of knee flexion and the compression forces in the tibiofemoral and patelo femoral compared to bigger flexions of this joint. [9].

Russell and Phillips [10] show that no significant differences exist at the maximum peak of the knee extensor moments, when comparing front and back squad exercises. The slight differences exist in favour of front squat exercises.

Concerning the maximum extensor moments of the trunk, these are slightly higher in front squat compared with back squat [10].

In relation to the maximum compression forces, are better in back squat, and shear forces are slightly better in front squat, at lumbar level. The differences in trunk inclination change these forces and also the risk of injuries at the level of the lumbar spine [10]. However, a quantification of the muscular power has not been made in each joint during the exercise. There is no record of an estimation of the energy generated and absorbed by muscles in the different variants of the squat exercise.

In the present work we evaluated parallel squat, in which, starting off from the raised position, the knees are flexed until the thighs are parallel approximately to the horizontal plane, in both variants. Later, during the phase of ascent, the knees are extended, until returning again to the initial position. It is compared the kinematics, dynamics, the power and the energy in the different joints during the complete cycle from the exercise in the different variants of squat.

2. Materials and methods

The correct way to do parallel back squat is to straight up the segment trunk as well as possible so as to minimize the forces that the lumbar spine can support. The opening of the feet must preferably be comfortable, with a similar separation to the wide one of shoulders. The bar must be firmly placed on shoulders, it is grip near them for exerting more pressure on the bar, and preventing that the back is curved, generating an undesired effort on the lumbar spine. In front squat, the bar is hold up on clavicles and the superior part of the chest, with the elevated elbows towards the front and with the most erect trunk, preventing the risk of fall of the bar towards ahead [11].

We evaluated 10 sportsmen familiarized with the execution of the 2 variants of the exercise, which do not present previous injuries of knees or lumbar spine.

The load to mobilize in the exercises is calculated on the basis of 50% of a maximum repetition (1 RM) of back squat [12]. The same load is used for both variants of the exercise.

Markers were placed to delimit the articulate segments, which are hemispheric of 10 millimeters of diameter covered by retro reflective material. In figure 1 is the location of the markers: fifth metatarsal, lateral malleolus, heel, fibula head, femoral lateral epicondyle, greater trochanter, iliaca crest and the rib cage. The markers are placed in both sides of the body. Another retro reflective marker was placed at the end of the bar.

The performers were filmed with a videocamera at 25 frames/sec. (corresponding to 50 fields of image/sec) from the sagittal view with one of their feet on the force platform. The exercise was done in the parallel line of the film plane.

During each session of exercises, the athletes does 4 consecutive repetitions of front squat, after that repose 15 minutes before does 4 consecutive repetitions of back squat. Every man is instructed about does the exercises at its normal speed of execution. This session is repeated with a day of difference alternating the order of execution of the two variants. For each subject, eight repetitions of each variant of the exercise by session are processed (four of the right lower limb and four of the left

one). Mean comparison were made considering the ten sportman, two sessions, four repetitions for each leg, then 160 gestures for each variant of squat.

Angles between segments, positions and displacements of the centers of mass and speeds of the anatomical segments, forces exerted on the force platform and between the segments and muscular net moments in the joints in each variant of the exercise are evaluated. Also the net powers and energies in each joint are calculated. The movements are considered bilateral and symmetrical, and they are only developed in the sagittal plane, being considered the fifth metatarsolphalangeal joint of the foot fixed to the floor.

In the present work a lot of care was taken for the correct execution of the exercise. Consequently the lateral motions in the frontal plane or those of rotation in the transverse plane are not considered because the movement ranks are small and of few relevance in the analysis.

The data are digitalized and filtered using a Butterworth filter. A link segment model is used to evaluate the dynamic changes in which joints are considered pin joints and the forces are concentrated in a point in each joint.

With the resolute model the muscular powers and the energy generated and absorbed are obtained in each joint. In order to be able to apply a processing ANOVA (analysis of variance) [13] represent each one of the variables according to the percentage of the cycle of exercise, corresponding 0% at the moment at which the athlete leaves the raised position and the end of the cycle (100%) corresponds at the moment at which the athletes returns again to the initial position. This procedure allows to obtain the averages and the deviations of each variables.

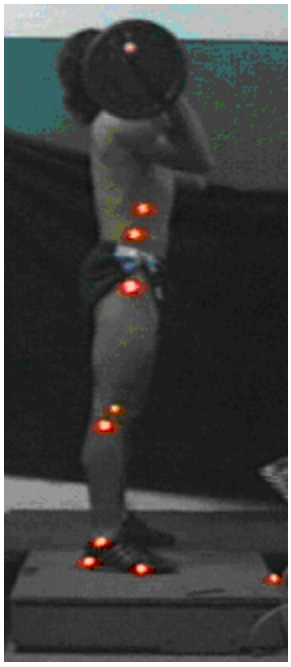
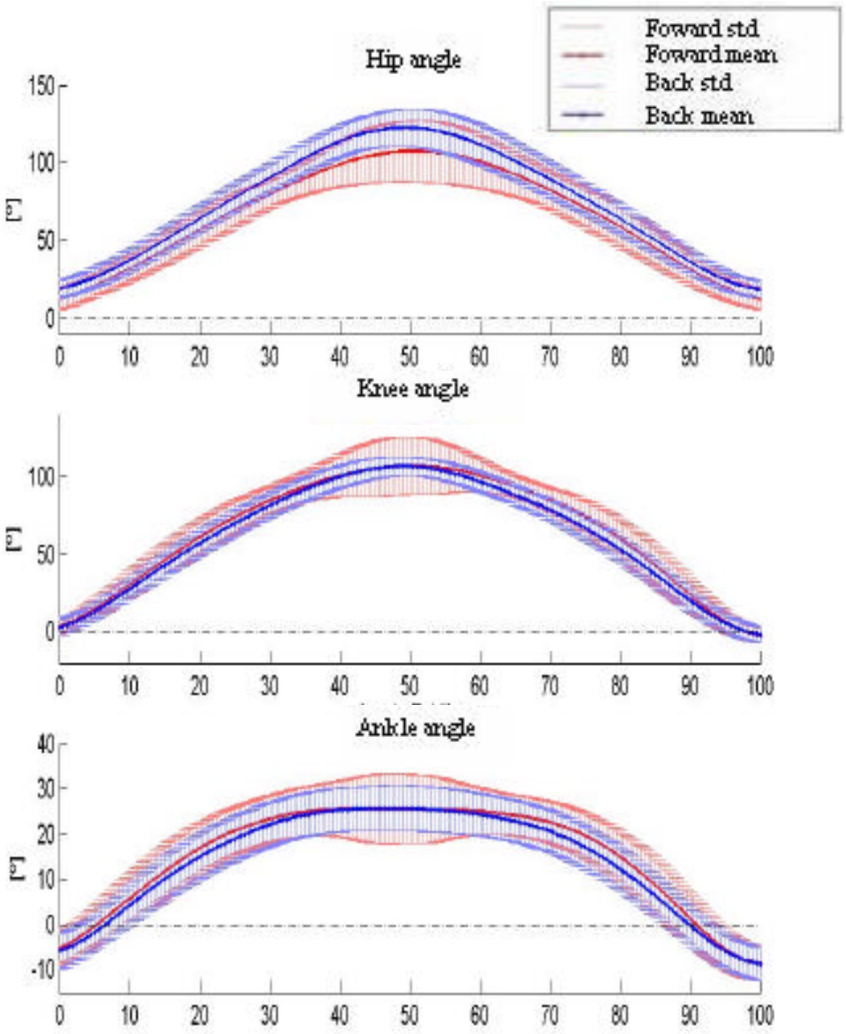


Figure. 1: Disposition of anatomical markers

3. Results

The average angles of the hip, knee and ankle and their standard deviations appear in figure 2. The X-axis represents the percentage of squat cycle.



The curves of average obtained in the frontal exercise of squat are red. The back squat curves are blue. The angle of the hip for back squat is greater than the other variant. This indicates a greater compromise at low back due to the possible lumbar shear forces. The mean values for the knee and ankle joints are similar for both variants of the exercise. The smaller deviation observed in the curves of angles indicates a better stability in the repetitions of the exercise for the backward variant.

Figure 2: Joints angles in function of the average of cycle for each repetition.

The average and the deviation (Figure 3) of the net muscular moments of hip, knee and ankle are normalized with the weight of the athlete plus the load used during the exercise. A significant difference for both variants is not observed at the hip, knee and ankle.

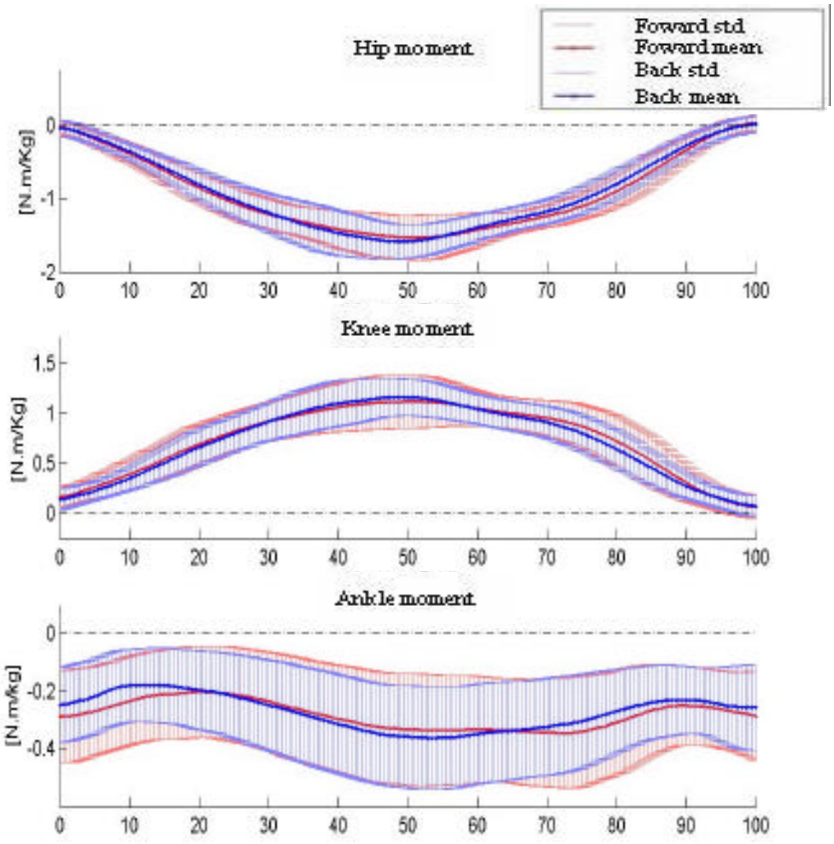


Figure 3: Normalized net muscular moment of the joints of the lower limb based on the percentage of the cycle of each repetition.

The average and the deviation (Figure 4) of the net muscular power of hip, knee and ankle are normalized with the weight of the athlete plus the load used during the exercise.

We observed a maximum difference of 22% in the averages of the net powers for the hip (corresponding to 34% and 58% of the cycle of squat), being greater for the backward variant. On the other hand, few differences in the curves morphology for net power of the knee and ankle for both variants are observed.

4. Discussion

In addition to the analysis of the powers throughout the cycle of squat, it is interesting to study of the net joint powers in energy terms. First, the total energy absorbed or generated in each repetition is evaluated. For the absorbed energy,

$$Ea_j = \int_{t_i}^{t_f} Power_j(t)\, dt \qquad (1)$$

where *j* is j-nth repetition, *t* is the time and *ti* and *tf* are the initial and final times in which the power is negative. The average for the N repetitions of both gestures,

$$Ea = \frac{\sum_{j=1}^{N} Ea_j}{N} \qquad (2)$$

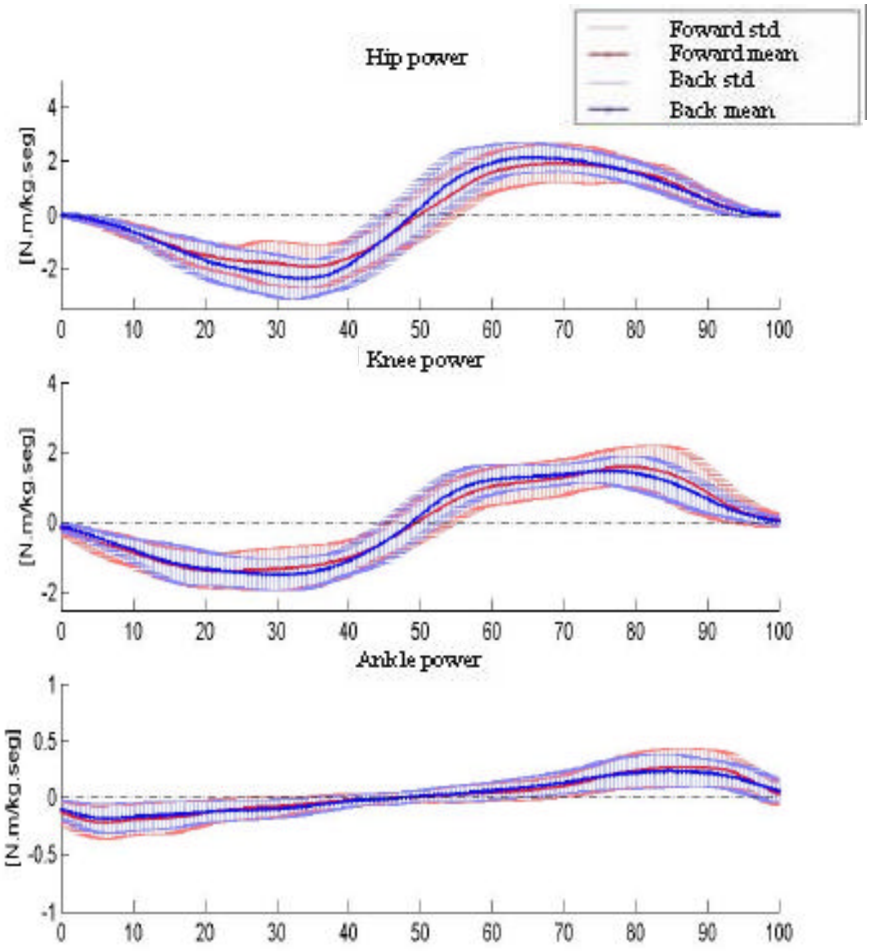


Figure 4: Normalized net muscular power of the joints of the lower limb based on the percentage of the cycle of each repetition.

The standard deviation are also obtained. Equivalent expressions are used to obtain the generated energy.

The energies absorbed and generated in both variants of squat are shown in Tables 1-2 where,

1. Front: front squat,
2. Back: back squat,
3. Gen: Generated energy
4. Abs: Absorbed energy.

Table 1. Absorbed and generated energies in the hip, knee and ankle front exercises

Joint	Front-Abs (mean)	Front-Abs (standard deviation)	Front-Gen (mean)	Front-Gen (standard deviation)
Hip	-77,50	17.40	79.97	17.95
Knee	-63.06	16.04	64.45	17.18
Ankle	-7.42	4.41	9.31	3.95

Table 2. Absorbed and generated energies in the hip, knee and ankle back exercises

Joint	Back-Abs (mean)	Back-Abs (standard deviation)	Back-Gen (mean)	Back-Gen (standard deviation)
Hip	-79.69	12.62	78.62	11.81
Knee	-58.71	12.03	59.93	11.69
Ankle	-6.31	3.36	8.43	3.54

The mean powers absorbed and generated in each variant of squat are reported in Tables 4 - 5 for each joint. For the absorbed power of each repetition in a joint it is obtained,

$$PMa_j = \frac{1}{(t_f - t_i)} \int_{t_i}^{t_f} Power_j(t)\, dt \qquad (3)$$

The standard deviation means are obtained too.

Table 3. Percentage difference between the energies absorbed and generated for both variants, calculated according to the expression:

$$\% = \left({}^{front-back}/_{back} \right) * 100$$

Joint	Percentage Abs (mean)	Percentage Gen (mean)
Hip	-2.75	1.7
Knee	7.4	7.5
Ankle	17.6	10.44

Table 4. Absorbed and generated power mean for front squat

Joint	Front-Abs (mean)	Front - Abs (standard deviation)	Front - Gen (mean)	Front - Gen (standard deviation)
Hip	-1.16	0.20	1.29	0.24
Knee	-0.97	0.29	1.05	0.26
Ankle	-0.12	0.07	0.15	0.07

The percentage differences in the absorbed and generated average powers for each joint are shown in Table 6.

Table 5. Absorbed and generated power mean for back squat

Joint	Back-Abs (mean)	Back-Abs (standard deviation)	Back-Gen (mean)	Back-Gen (standard deviation)
Hip	-1.34	0.38	1.35	0.28
Knee	-0.99	0.29	1.01	0.22
Ankle	-0.11	0.06	0.14	0.07

Table 6. Percentage difference between the absorbed and generated mean power for both variants, calculated according to the expression:

$$\% = \left({}^{front-back}/_{back} \right) * 100$$

Joint	Percentage Abs (mean)	Percentage Gen (mean)
Hip	-13.43	-4.44
Knee	-2.02	3.96
Ankle	9.09	7.14

In the knee, the total energy in front squat is greater than back squat in a 7.5%, this would allow a greater muscular exercise for the same load. In addition, the back squat exercise is performed (in average) in less time so the mean powers in the knee have similar values (Tables 4, 5 and 6).

Particularly, in back squat the absorbed mean power hip is considerably greater, i.e. an average of 13.43%. This basically would be associated to fact that the exercise is done faster due to the greater stability obtained in locating the bar backwards.

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