A BIOMECHANICAL ANALYSIS OF THE STRUCTURE OF THE FULL BACK SQUAT

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SUMMARY

Considering the complexity of the exercise and the many variables related to performance, understanding squat biomechanics is of great importance for both achieving optimal muscular development and reducing the prospect of a training-related injury. To examine the kinematics, kinetics, and electromyographic activity of main (primary) muscles, i.e., the external and internal structure of the full back squat, depends on of the weight of loading, was the aim of the study. Eleven healthy men recreationally performing strength exercises voluntarily participated in the research. All subjects were tested under the same conditions in a laboratory setting. The subjects performed consecutive sets of a single repetition of the full back squat with increasing load (70, 80, 90 and 100% 1RM of the anticipated maximum weight – four test conditions) until the appointment of one maximum repetition.

A multidimentional movement analysis was made with the measuring system Smart-E (BTS, Italy), which consisted of six infrared cameras (120 Hz), synchronized with a wireless module to measure muscle bioelectric activity (Pocket EMG), and the force platform (Kistler 9182C, Switzerland). The set of passive markers permitting the calculation of some chosen parameters of the subject were applied. Modeling in 3D space as well as calculations of parameters were performed with Smart Analyzer software.

Bioelectrical activity was recorded using surface electrodes for muscles on both sides of the body (homologous): *tibialis anterior* (TA), the medial part of *gastrocnemius medialis* (G_{Med}), the long head of the *biceps femoris* (BF), *rectus femoris* (RF), *gluteus maximus* (G_{Max}) and the lumbar section of *erector spinae* (ES). The electrodes were placed above the sites of muscle motor activity, in accordance with the European SENIAM recommendations for surface electromyography [Hermens et al., 1999]. The EMG signals were sampled at a 1 kHz rate. All active channels had the same measuring range and were fitted to the subject (typically +/- 5 mV). Analog signals were converted to digital with 16 bit sampling resolution and collected on the measuring unit. The signals were transmitted immediately after a single trial,

to a computer via Wi-Fi Network. The raw EMG signal was filtered (pass band Butterworth filter, 10-250 Hz). Next, the full-wave was rectified and smoothed using the root-mean-square (RMS) method with 100 ms mobile window. Then the RMS EMG signals were normalized to maximal voluntary isometric contraction (MVIC) amplitudes, in accordance with European Recommendations for Surface Electromyography – SENIAM [Hermens et al., 1999; Konrad, 2005]. Normalization was performed for each muscle separately.

The vertical component of the ground reaction force was recorded using the Kistler 9182C piezoelectric force platform (0.4 m × 0.6 m, 240 Hz) using the Bioware v.1.0 software (Kistler Instruments, Winterthur, Switzerland). Next, the *R(t)* curves were normalized to time and to the weight of the athlete-barbell system. Then, for each of the 4 test conditions, all normalized characteristics were averaged. On the obtained *R(t)* charts, determined one characteristic peak in the descent phase and two peaks in the ascent phase.

With proper movement, squat injuries are rare [Watkins, 1999]. However, a bad technique or the wrong way to do a squat can lead to many ailments, especially in combination with heavy loads. It is highly recommended that an individual is first able to demonstrate proficiency during body weight back squat performance before advancing to more intense variations and derivatives of squatting such as externally loaded squats and plyometric training [Mayer et al., 2014]. The basic squat movement is considered by many professionals to be a valuable primary physical training exercise since it is a single compound maneuver that is highly sensitive to highlight biomechanical deficits. Deficits identified during the back squat that can impair performance can be categorized as either inefficient motor unit coordination or recruitment (neuromuscular), muscle weakness, strength asymmetry or joint instability (strength), and joint immobility or muscle tightness (mobility)[Schoenfeld, 2010].

During the full back squat, the level of bioelectrical activity of all examined muscles generally increased with increasing weight of the lifted barbell. Although only the differences in average EMG activity for extreme loads (70% and 100% 1RM) turned out to be statistically significant, this is confirmed by previous results, obtained, among others by Aspe and Swinton [2014] and Yavuz and Erdag [2017]. The EMG profiles obtained, i.e. the average linear envelopes of the electromyographic records of individual muscles, are very much consistent with the characteristics of Robertson et al. [2008] Yavuza et al. [2015] and Yavuza and Erdag [2017]. The average activity of individual muscles in the descent squat phase was generally lower than in the ascent phase. The exception is the *tibialis anterior* muscle, which in the descent phase showed greater activity, regardless of the size of the load.

The characteristics of the vertical component of the ground reaction force, due to their shape, regardless of the weight of the barbell being lifted, are similar; there is always one minimum value in the descent phase and two maximum values and two minimum values in the ascent phase. This is also confirmed by previous results, obtained among others by Zink et al. [2006] and Gullett et al. [2009]. The greatest force at the beginning of the ascent phase (R_{max1}) increases, and the lowest force of the descent phase (R_{min}) and a second minimum of the ascent phase (R_{min2}) decreases with increasing weight of the bar. However, only the differences in R_{max1} with an increase in load from 70% to 100% 1RM turned out to be statistically significant.

The effect of the force action is the velocity of a barbell. Therefore, the force characteristics are reflected in the velocity curve. In the full back squatting ascent-phase, at a load of 70% 1RM, the velocity reached one maximum, and in attempts at 80, 90, and 100% 1RM, there were two maximum and one minimum velocities. This decrease in the barbell velocity is called the sticking region [Newton et al., 1997; Duffey and Challis, 2007; van den Tillaar et al., 2014; Król and Gołaś, 2017]. Generally, the vertical component of a barbell velocity decreases together with increasing weight of the barbell. With an increasing load, the time of the descent and ascent phase also changed, so the rhythm of the full squat changed. However, only the differences between the extreme loads turned out to be statistically significant.

In general, the correlation relationships between selected kinetic parameters and kinematic parameters of the squat and bioelectric activity of selected lower limb and torso muscles proved to be high (Spearman's rank correlation coefficient $R = 0.6 \div 0.8$) only in sporadic cases, regardless of the weight of the lifted barbell. The kinetic and kinematic parameters of the squat were more often showed a high correlation with the activity of the *biceps femoris*, *gluteus maximus* and *erector spinae* muscles than with the *tibialis anterior*, *gastrocnemius* and *rectus femoris* muscles.