Biomechanical analysis of three-point shot in basketball

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ABSTRACT

Background: A precise three-point shot (3S) is considered a key parameter of success in a basketball game, and therefore the factors that affect its success have always attracted the attention of researchers.

Aim: The aim of this research was a biomechanical-mathematical analysis of 3S in basketball, in order to determine the key parameters for performing a 3S.

Results: The research shows a model of shooting a basketball player from the central position of the shot with 6.75 m. The modeling led to the conclusion that the height of the throw, the speed and the angle of the throw of the ball have a positive and direct relationship with the angle at which the ball falls into the basket when it comes to a shot for three points.

Conclusion: The height of the throw, the speed and the angle of the ball have a positive and direct relationship with the angle at which the ball hits the basket when it comes to a shot for three points. Anthropometric characteristics of the player, such as the length of the arm, and the height of the player, directly lead to a positive relationship with the throwing angle.

Keywords: Basketball, Software, Sports

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1. Introduction

Basketball, as a sport, was founded more than a hundred years ago, and is one of the most popular sports in the modern world (1,2). The three-point shot (3S) is the basis of the game, and often represents an advantage in the game itself, and the very trend in modern basketball, brings a fairly fast, attractive game with a large number of 3S (3). Factors that contribute to a successful shot are: the trajectory of the ball, the coordination of segmental movements, and the variables that affect the performance of the shot (4). It is well known fact that longer shots require greater precision, and that with the increase of that distance the player must reduce release angle and the ball follows a flatter flight path, the ball has weaker trajectories which directly affects the possibility of scoring points (5). Players in the shooting phase (when they engage in the act of shooting) need an initial velocity to help them, meaning from a distance of 6.75 meters, players need more speed than when they are shooting from a distance of 6.25 meters (6). With an extra movement of the wrist, the player attains the needed velocity to begin with and can direct the ball in a way that the main part has a great effect on the direction, velocity, and angle of release of the ball (6). Because of the stated importance of the three-point shot, many coaches try to identify and find different methods to improve the performance of the shot. This is a problem since the shooting technique, although it looks similar, varies from player to player and is attributed to the style of each individual player. This observed phenomenon is a consequence of the different length of the upper and lower extremities, and can affect the occurrence of injuries in professional basketball, and their prevention should be imperative (7). Incidence of injuries is 7 to 10 injuries per 1000 athletic exposures, and it is considered that the shooting technique itself has an effect on the condition of the locomotor system, and the impact on individual segments could reduce their occurrence (8). Also, overuse-related injuries (tendinopathy, stress fracture), or traumatic ones (e.g., ligamentous sprains) can also be prevented by adequate professional work with the player, especially on physical fitness, as well as specific exercise programs (9,10). Ankle sprains (lateral ankle sprains more common) are the most common diagnosed injury in both male and female basketball players, accounting for approximately 25% of all injuries, and their appearance is related to the landing phenomenon, which is again affected by the kinetics of the shot itself). Finally, it is essential to assess only the load on the body, especially on the lumbosacral part of the spine, and 11.4% and 13.5% of all injuries in competitions and practices are associated with injuries of the lumbosacral part of the spine (11). After all the above, the aim of this research is a biomechanical-mathematical analysis of shooting for three points in basketball, in order to determine the key parameters for achieving a goal, with reference to the load on the lumbosacral spine in subjects.

2. Material and methods

In the CATIA V5 program (Dessault Systems, Vélizy-Villacoublay, France), a visual simulation was performed, i.e. a virtual modeling of the sports performance. This allows quality analysis, evaluation, redesign and optimization of work tasks and jobs in the workplace. The analysis took into account a female subject, 25 years old, height 175 cm, weight 70 kg. A basketball weighing 550 grams will be used in the analysis. The analysis of the load on the lumbosacral part of the spine was analyzed through three positions.

3. Results

3.1. Biomechanical position analysis

3.1.1. Biomechanical position analysis 1

The first position that is analyzed is the position when the basketball player takes the ball from the floor. Figure 1. shows a model of a basketball player in that position together with the actual picture in which the basketball player is represented in that position.

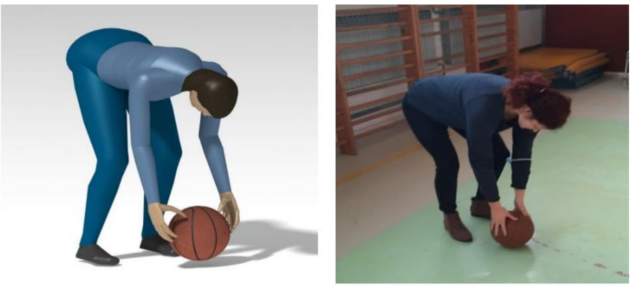

Figure 1. First position - picking up the ball from the floor

Mass of the basketball is 0.55 kg and it is equally distributed on both hands. The compression of the L4 / L5 vertebra is 2331 Newton (N) (Figure 2).

Analysis	Value
L4-L5 Moment [Nxm]	142
L4-L5 Compression [N]	2331
Body Load Compression [N]	-39
Axial Twist Compression [N]	7
Flex/Ext Compression [N]	2360
L4-L5 Joint Shear [N]	144 Anterior
Abdominal Force [N]	129
Abdominal Pressure [N_m2]	4
Ground Reaction [N]	

Figure 2. First position - biomechanical analysis

3.1.2. Biomechanical position analysis 2

Figure 3. shows another position along with the model where the basketball player holds the ball in an upright body position. The load on the hands remains the same as in position 1, after which a biomechanical analysis is performed. It is possible to see that the compression of the lumbar vertebrae is 592 N (Figure 4).

Figure 3. Second position - upright body position

Analysis	Value
L4-L5 Moment [Nxm]	17
L4-L5 Compression [N]	592
Body Load Compression [N]	312
Axial Twist Compression [N]	0
Flex/Ext Compression [N]	279
L4-L5 Joint Shear [N]	12 Posterior
Abdominal Force [N]	0
Abdominal Pressure [N_m2]	0
Ground Reaction [N]	

Figure 4. Second position - biomechanical analysis

3.1.3. Biomechanical position analysis 3

Position 3 actually represents the position in which the basketball player kicks the ball to the basket (Figure 5).

Figure 5. Third position - 3S

Our model of a basketball player in the third position is placed at a certain distance from the basket, that is the distance that defines 3S in basketball - 6.75 meters. It is necessary to determine the default load on the hands that the basketball player bears when shooting a 3S. It was determined experimentally that the angle of ejection of the ball is 46^0. It was assumed that the time of ejection of the ball is 0.56 s (time (t)). The hoop of the basket is located at a height of 3.05 meters (Figure 6).

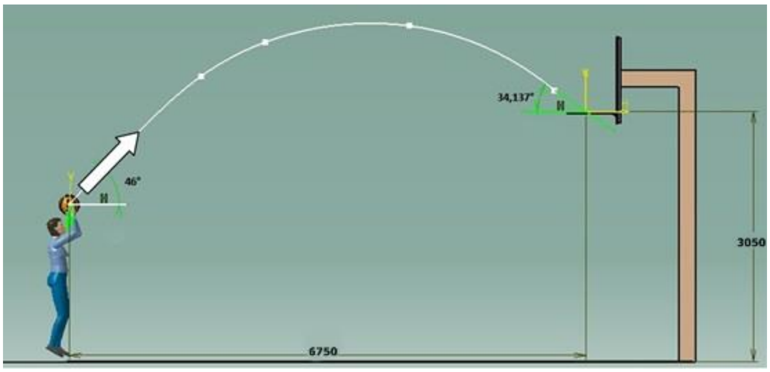

Figure 6. 3S simulation

Analysis	Value
L4-L5 Moment [Nxm]	9
L4-L5 Compression [N]	513
Body Load Compression [N]	315
Axial Twist Compression [N]	1
Flex/Ext Compression [N]	147
L4-L5 Joint Shear [N]	30 Posterior
Abdominal Force [N]	0
Abdominal Pressure [N_m2]	0
Ground Reaction [N]	

Figure 7. Third position - biomechanical analysis

The left hand is more loaded (the observed basketball player is left-handed) while the right hand is used to hold and direct the ball and withstands less load. The compression in the lumbar vertebra is 513 N (Figure 7). For the purpose of even less load, a ball of lower mass can be used. After all, the calculation of the thrust force of the throw was done when shooting the ball to the basket outside the line for three points.

The equations of oblique shot along the horizontal axis are:

$$\dot{x} = v_0 \cos\alpha, \quad x = v_0 \cos\alpha \cdot t, \tag{1}$$

and along the vertical axis are

$$\dot{y} = -gt + v_0 \sin\alpha, \quad y = -g\frac{t^2}{2} + v_0 t \sin\alpha + y_0. \tag{2}$$

Eliminating the time t from (1) and (2) follows the equation of the trajectory of the ball:

$$y = -\frac{g}{2}\frac{x^2}{v_0^2 \cos^2\alpha} + x \cdot tg\alpha + y_0. \tag{3}$$

At the end of the ball flight is: $x = 6{,}750 \quad m; \quad y = 3{,}05 \quad m.$

By including the above data in expression (3) it follows:

$$3{,}05 = -\frac{9{,}81}{2}\frac{6{,}75^2}{v_0^2 \cos^2 46^0} + 6{,}75 \cdot tg46^0 + 1{,}890,$$

where the required initial speed of the ball is obtained: $v_0 = 8{,}253 \quad m/s$.

The flight time of the ball is: $t_1 = \frac{x_1}{v_0 \cos\alpha} = \frac{6{,}75}{8{,}253 \cdot \cos 46^0} = 1{,}177$ s.

Some intrusion velocity projections are:

$\dot{x}_1 = \dot{x}_0 = v_0 \cos\alpha = 8{,}253 \cdot \cos 46^0 = 5{,}733$ m/s,

$\dot{y}_1 = -gt_1 + v_0 \sin\alpha = -9{,}81 \cdot 1{,}177 + 8{,}253 \cdot \sin 46^0 = -5{,}609 \quad m/s,$

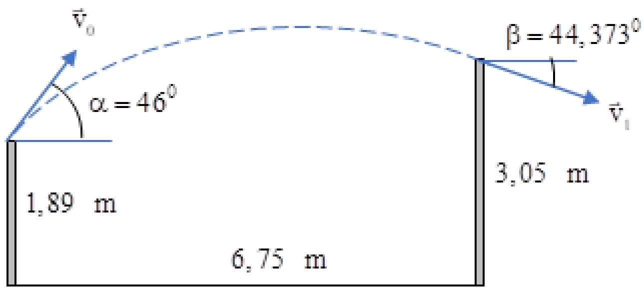

Figure 8. Detailed calculation of 3S

so that the angle at which the ball falls into the basket:

$$\beta = arctg\left|\frac{\dot{y}_1}{\dot{x}_1}\right| = arctg\frac{5{,}609}{5{,}733} = 44{,}373^0.$$

For a time of t = 0.7 s we can calculate the acceleration created by throwing the ball:

$$a_0 = \frac{v_0}{t} = \frac{8{,}253}{0{,}7} = 11{,}79 \quad ms^{-2}.$$

The force acting on the ball is:

$F = m_L \cdot a_0 = 0{,}55 \cdot 11{,}79 = 6{,}485$ N ,

m_L- ball mass.

4. Discussion

The allowable force on the lumbosacral part of the spine is up to 3000 N, and this is the force due to which there should be no load on the spine and injury (12). In the first position, when the basketball player bends down and takes the ball, there is a reversal of the spine of 2331 N. In position 2, in the upright position, the load is 592 N, and during the shot for three points, it is 513 N. The load itself is allowed, and is not burdened for the key post. In general, key factors effective in the 3S are kinematic and anthropometric variables. This was obtained in this study but also several previous (4,6). In performing 3S the body`s link system is classified as an open kinetic chain. This study showed that the higher the ball is released (46°), provides the better the angle at which ball enters the basket. The position of the body at ball release is also related to the trajectory of the ball.

The imperative of any professional basketball player is injury prevention (13). Injuries are divided into acute and chronic, and on endogenous and exogenous (14). Work on the coordination of the movement should be at the base of the preparation of basketball players (15,16). Good developed coordination of movements leads to a reduced number of injuries, but allows the basketball players to adjust during unnatural movements. Coordination training should contain a large number of diverse contents, various natural forms of movement should be forced in the training itself, and basic coordination factors should be improved, with spatial orientation in the foreground (professionals should know the characteristics of the sport itself and harmonize the preparation with sports needs) (17,18).

Adequate load on trainings is a must, since unprepared muscle during intense matches could easily lead to various injuries, in particular rotator cuff injury (rotator cuff tear) which could weaken the players shoulder for a long time (19). Injury prevention program should include special exercises on training sessions, in order to prepare the muscles and tendons for the high-intensity competion performance (20). Sometimes, surgery is the only option for a player, but with uncertain results for elite basketball level (21). So, shoulder is at high risk for injury during the overhead sports, especially if we take into consideration the three-point shot. Three risk factors have been defined that may form the basis for recommendations for the prevention of recurrent injury and return to play after injury: glenohumeral internal-rotation deficit; rotator cuff strength, in particular the strength of the external rotators; and scapular dyskinesis, in particular scapular position and strength (22).

5. Conclusion

The height of the throw, the speed and the angle of the ball have a positive and direct relationship with the angle at which the ball hits the basket when it comes to a shot for three points. Anthropometric characteristics of the player, such as the length of the arm, and the height of the player, directly lead to a positive relationship with the throwing angle. Analyzing the trajectory of the ball, it is possible to suggest that a higher throw angle and ball drop height combined with a lower drop speed are a more desirable combination in order to score points in basketball. This is confirmed by the fact that the higher the height of the ball, the result is a smaller horizontal trajectory of the ball and thus reduces the requirements of players to create force and speed of throw. Through the mentioned biomechanical analysis, it was determined that the loads of the subjects on L4 / L5 are within the allowed limits.

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