Overview: Biomechanical approach to the kicking motion in soccer

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ABSTRACT

The main purpose of this paper is to take a quick view of the biomechanical analysis applying into the soccer world. Soccer requires many techniques; however, this study focuses on a particular basic technique, which is the kicking motion. In order to analyze the motion, many previous studies used high technological filming technique and equations. This study involves simple summaries of the biomechanical approach into the soccer world, so soccer's basic action – kick – is analyzed in many aspects; velocity, force, and moment. It is believed that the biomechanical analysis approach will be used for further analysis of sports injuries, such as ankle sprains.

Key Words: Biomechanics, Soccer, Inside kick, Instep kick, Motion analysis, Ankle injuries

When the word "kick" is used, it describes a leg action transforming forces from one leg to the other. When people are running or jumping, technically the foot kicks the ground, and then people moves forwardly. Not only running or jumping, the word "kick" is used in combative sports such as Karate and Kickboxing that provide damage to the opponent. Moreover, when looking up the English dictionary, the Merriam-Webster Collegiate Dictionary defines kick as "a blow or sudden forceful thrust with the foot; specifically**:** a sudden propelling of a ball with the foot." Thus, the word "kick" is used in football, rugby, and soccer. Not so many people have studied the accuracy of kicking the ball in soccer, but many people have analyzed the speed of kicking in soccer.

The purpose of this paper is to review the previous studies about the biomechanical approach to soccer and to expand this biomechanical study to understand ankle injures.

1. Foot and ball velocity

Levanon and Depena (5) analyzed the velocity relationship between full-instep and inside pass kicks in six college soccer players. They reported that the velocity of the foot in the center of mass before impact with the ball, and the ball velocity after impact have a significant relationship. Kicking in soccer can be said to be the result of the collision between the foot and ball,

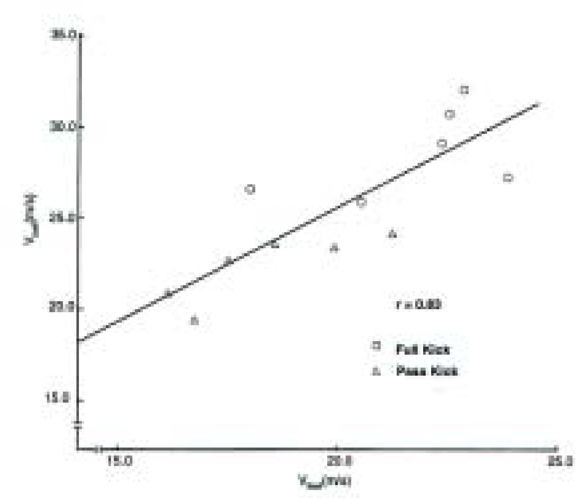

Fig 1 -- Relationship between the speed of the ball after impact (v_{ball}) and the speed of the c.m. of the foot before impact (v_{foot}) (5).

the foot velocity at the impact is the determining factor of the ball speed.

Moreover, Teixeira (8) reports that the initial ball velocity is slower than the player's foot speed. For example, changing from soccer to another impact sport; tennis, "the body segments are slowed down just before contact between the racquet and ball to prepare the effector system for the force of the impact. (6)" This is good evidence of Teixeira's report that when the ball speed in the pass kick is 18.3 [m/sec], the foot speed is 21.6 [m/sec] (5). As a result, the foot speed is 18 [%] faster than the ball's initial speed.

Fig 1 shows the relationship between the speed of the ball after impact (v_{ball}) and the speed of the c.m. of the foot before impact (v_{foot}) (5).

2. Catching the motion

A century ago, it was very difficult to observe quantitative change of human body or segments because at that time there was no way to record human motion. However, in this highly advanced modern era, human motion has been analyzed dramatically. Due to the improvement of the imaging technique, experimenters are able to see human motion exactly. After a sequential photographic method was established, more and more complicated motions have been recorded and analyzed by scientists and engineers.

Nowadays, recording devices have advanced from an ordinary picture to the motion pictures and to video capturing. Moreover, further advances in the computers' power and connections between the VCR and computer have analyzed human motion from two-dimensional calculation to a three-dimensional one. This three-dimensional analysis is becoming common to understanding human motion and mechanics. This kind of imaging technique and motion analysis using the computer system have been applied from their original purpose, which was to observe the motion, to the other new types of fields such as making movie and designing the TV games.

In Teixeira's report (8), the soccer motion was recorded using three high-speed (180 [Hz]) cameras which were placed on the right side of the experimental players. In order to measure the velocity of the foot and the ankle displacement of right leg, these three cameras were used.

On the other hand, in Levanon and Depena's report, "the kicks were filmed using three Locam motion picture cameras (Redlake Corporation, Morgan Hill, CA) loaded with 16-mm Eastman Ektachrome 400 ASA Video News film. The cameras were set at nominal frame rates of 200 [fr/sec]." (5) These cameras, which height was 1.5 [m], with another one 10 [m] behind and 10 [m] to the right of the ball, with the other was 6 [m] in front of the experimenter, were also set on the right side of the experimental players.(5) After recording the kicking motion, "the locations of 21 body landmarks (vertex, chin-neck intersect, suprasternale, and right and left sholders, elbows, wrists, knuckles, hips, knees, ankles, heels, and toes) in the film images were digitized manually in each frame between the takeoff of the right foot and the impact of the foot with the ball. (5)" The center of the ball was also digitized. In order to analyze the players' motion precisely, these digitized data were inputted to a DEC system

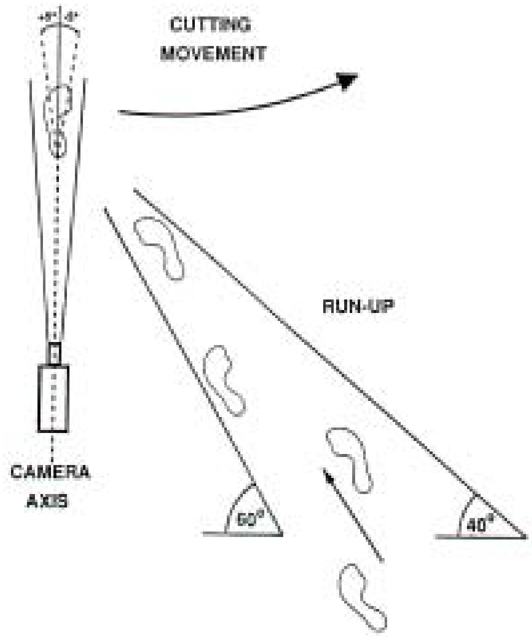

Fig 2 -- The set-up of study about ankle injuries (7).

5840 computer (5). It can be said that Levanon and Dapena's motion recording and analysis were the latest method to dig into the human motion.

Previous motion capturing is focused on the foot motion, especially kicking motion; however, if the study focuses on the ankle injuries, Stacoff, Steger, Stüssi, and Reinshmidt (7) narrowed their attention to the ankle movement. They were only interested in ankle injuries, so the camera was placed behind the specimens. Fig 2 indicates their recording method.

By capturing the kicking motion in soccer, during the instep kick action, many studies indicate that the consecutive motion occurs from the rotation at the pelvis, winding of the waist, to the extension of the knee. The kicking motion can be considered to be similar to the whip action. Moreover, in order to increase the kicking velocity as well as force, it is better to approach to the ball from the oblique position. (Fig 3.) This is because when the player approach to the ball from the oblique position, the player can easily make a big rotation of the waist. From the motion analysis, it is reported that skillful players can produce large impact velocity and force to the ball because their joints can move more widely than unskilled players.

3. Deriving the equations

In order to determine the reaction force of the joints, the joint moment, and the velocity of the foot, many previous studies have tried to define the equations.

Putnam (6) introduced very organized equations, which involved the resultant joint moment (RJM) and force (RJF). The RJM is "the vector sum of the moments of all muscle, ligament, and bony contact forces acting on or across the joint, where these moments are measured relative to the joint center," and the RJF is "the vector sum of all muscle, ligament, and bony contact forces acting on or across the joint and is applied to the joint center. (6)" In addition, the RJF is a "gravity-dependent and motion-dependent terms. (6)" Putnam defined the equations from two parts of segments which FBD is shown in Fig 4. and derived these following equations;

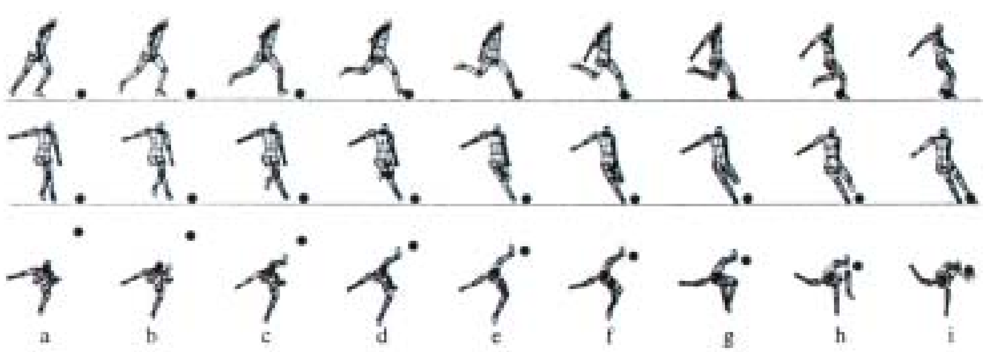

Fig 3 -- Three-view sequence of a instep kick by a typical subject. Frame "a" corresponds to the toe-off and "i" to impact (5).

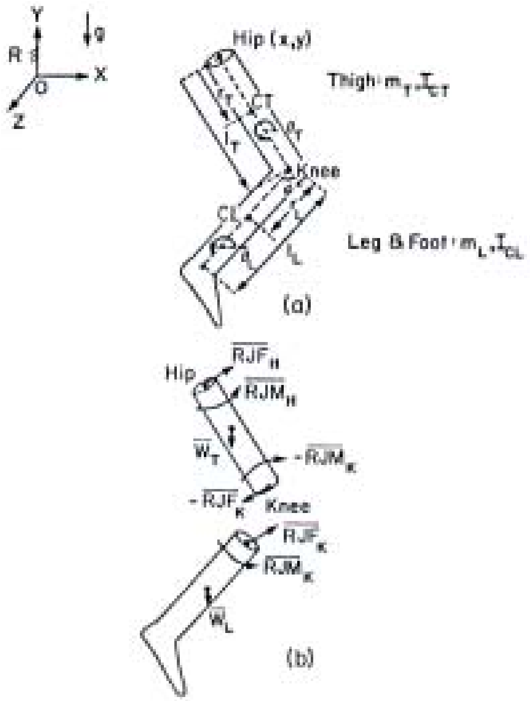

Fig 4 -- Two-segments planar system representing the lower extremity (a) and a free body diagram of each segment (b). All symbols are defined in the nomenclature (6).

LEG:

$$RJM_K - K_1\cos\phi\ddot{\theta}_T - K_1\sin\phi\dot{\theta}_T^{\,2} + K_5\sin\theta_L\ddot{x} - K_5\cos\theta_L\ddot{y} - K_5\cos\theta_L g = K_3\ddot{\theta}_L$$

THIGH:

$$\begin{aligned} &RJM_H - \left(K_1\cos\phi + K_2\right)\ddot{\theta}_T - K_1\sin\phi\dot{\theta}_T^{\,2} \\ &-\left(K_1\cos\phi + K_3\right)\ddot{\theta}_L + K_1\sin\phi\dot{\theta}_T^{\,2} \\ &+\left(K_4\sin\theta_T + K_5\sin\theta_L\right)\ddot{x} - \left(K_4\sin\theta_T + K_5\sin\theta_L\right)\ddot{y} \\ &-\left(K_4\sin\theta_T + K_5\sin\theta_L\right)g = K_6\ddot{\theta}_T \end{aligned}$$

On the other hand, Levanon and Dapena (3) reported the other type of equations which contributed to the linear velocity of the foot center of mass. First of all, they determined the angular velocity using Fig 5. Then, the following equation was derived. "The velocity of the center of mass (c.m.) of the foot v_f is a function of the absolute linear velocity of the right hip, of the absolute angular velocity of the pelvis relative to

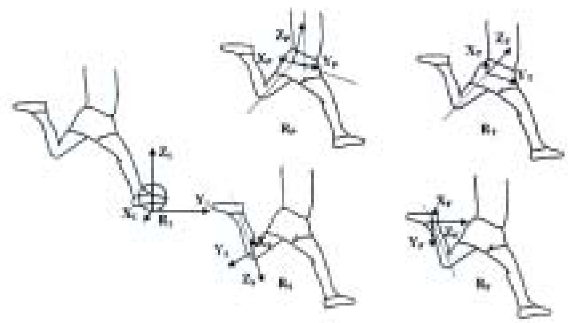

Fig 5 -- Reference frames. R_1 is and inertial reference frame with its Y_1 axis aligned with the horizontal direction of the kicked ball; R_P, R_T, R_S, and R_F are noninertial reference frames attached to the pelvis, thigh, shank and foot, respectively (5).

the ground, and of the angular velocities at the right hip, knee, and ankle joints. (3)"

$$\begin{aligned} V_F = V_H &+ \left(\omega_{Pftl/btl} + \omega_{Pltl/rtl} + \omega_{Pint/ext}\right)\times r_{F/H} \\ &+ \left(\omega_{Hfl/ex} + \omega_{Hab/ad} + \omega_{Hint/ext}\right)\times r_{F/H} \\ &+ \left(\omega_{Kfl/ex} + \omega_{Kab/ad} + \omega_{Kint/ext}\right)\times r_{F/K} \\ &+ \left(\omega_{Afl/ex} + \omega_{Aab/ad} + \omega_{Aint/ext}\right)\times r_{F/A} \\ &+ V_{K/H:rad} + V_{A/K:rad} + V_{F/A:rad} \end{aligned}$$

Based on Biomechanics lecture to this study, this following equation is derived. Due to the simplification of the equation, following conditions were assumed; rotation does not occurred at the waist, the center of mass of each segment was not concerned, and while the player is moving forward at the velocity V. Fig 6 indicates frame set and the Free Body Diagram of this assumption, and the equation is determined by these conditions. Because the equation is derived from the hip joint to the foot, the length of each segment is identified following way: length from Hip to Knee (L_{HK}), length from Knee to Ankle (L_{KA}), and length from Ankle to Foot (L_{AF}).

$$\begin{aligned} \bar{v}_F = &\left(V_i - L_{HK}\dot{\theta}_H\sin\theta_H - L_{KA}\dot{\theta}_K\sin\theta_K - L_{AF}\dot{\theta}_A\sin\theta_A\right)i \\ &+\left(L_{HK}\dot{\theta}_H\cos\theta_H + L_{KA}\dot{\theta}_K\cos\theta_K + L_{AF}\dot{\theta}_A\cos\theta_A\right)j \end{aligned}$$

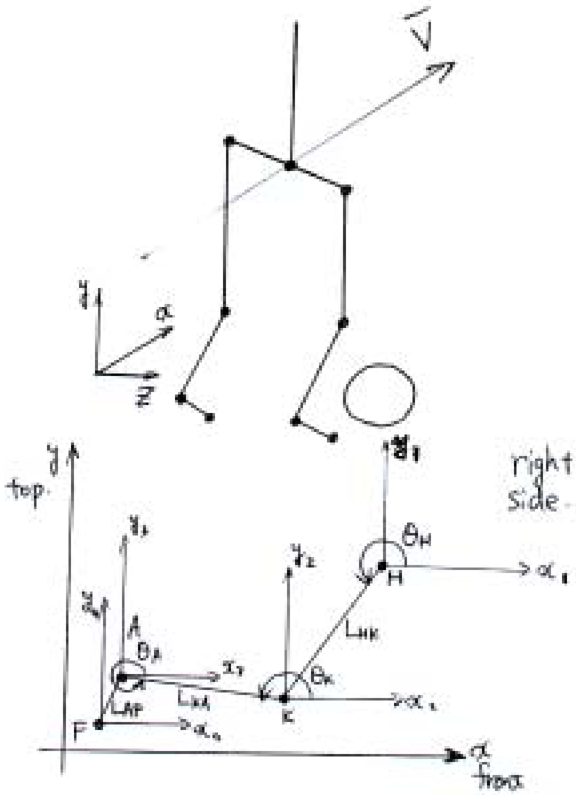

Fig 6 -- The other calculation frame set and its FBD, which are defined by the present writer.

For future study, it is hoped that these equations will be examined more closely because the motion analysis in soccer is still in experimental stages.

4. Various Results: Force and Velocity

From the motion capturing and the experimental equations, maximum force of each segments and the ball velocities were investigated by many of previous studies.

Many studies reported that when the player kicks the ball, the joint force at the hip joint is about 1000 [N], and the joint force at the ankle is about 350 [N]. It is also reported that, about the joint moment at the lower limb, the hip joint moment is the highest numbers (220 ~ 300 [Nm]), the second is the knee joint (90 ~ 160 [Nm]), and the smallest moment is at the ankle joint. Also, comparing the dynamic joint moment between the instep and inside kick, the instep kick needs a big hip joint's flexure and knee joint's extension.

Using the high-speed camera, the impact time between foot and ball is assumed. The impact time between foot and ball is an average 12 [ms]. When the foot impacts the ball, the foot is influenced an average 1100 [N] of reaction force, and the maximum reaction force is sometimes reached about 2200 [N].

Barfield (1) reported that a skilled player could produce 25.9 [m/sec] of kicking speed; on the other hand, an unskilled player is 23.4 [m/sec]. "Before ball contact, a large extension torque at the knee (230 [Nm]) is produced at, or immediately following ball contact is larger than the extensor torque. (1)" Fig 7 shows the joint velocities of each segments. Levanon and Dapena (5) also reported that the average velocity of inside kick was 18.3 [m/sec], and the instep kick was 21.6 [m/sec]. In addition, Putnam (6) reported " the speed of the ankle joint at ball contact for the four kicking trials ranged from 19.0 to 21.2 [m/sec]." Also, "the running and walking speeds ranged from 3.8 to 5.2 [m/sec] and 1.4 to 1.9 [m/sec], respectively."

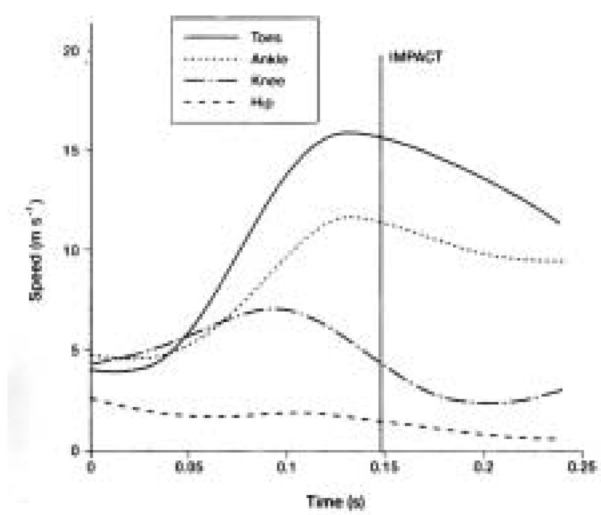

Fig 7 – Typical linear joint speeds for a placed ball instep kick showing the sequencing of joint actions and the increase in proximal joint velocity (4)

5. Mechanism of ankle injuries

This section focuses on ankle injuries using the motion analysis techniques. Almost every sports player forgets they are facing the high risk of ankle injuries. Statistically, in European soccer, 47 [%] of the players have some kind of ankle injuries, such as ankle sprain. (7)

Stacoff, Steger, Stüssi, and Reinschmidt assumed that “an ankle sprain occurs when the external inversion moment at the ankle is larger than the internal eversion moment provided by structures such as muscles (foot everters) and ligaments. The external moment depends on the acting force (ground reaction) and the leverage between the point of application and the point of rotation at the ankle joint. (7)” Fig 8 indicates their assumptive mechanism of the ankle sprain.

Beside soccer, ankle injuries are the most considerable troubles in sports world. However, modern technology helps to maintain a better understand the mechanism of ankle injuries, and the improvement of sports equipments also helps to avoid injuries in players. The biomechanical point of view can be used as the prevention of these sports injuries.

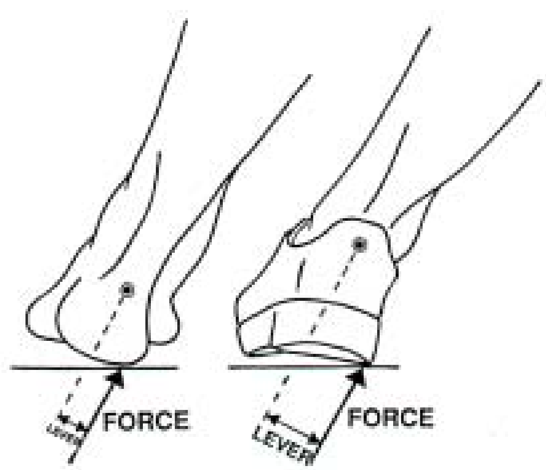

Fig 8 – Sideward cutting movements between barefoot and shod. Indicated are the possible levers between the ground reaction force and the estimated axis of the subtalar joint (7).

6. Conclusion

Overall, the biomechanical approach in soccer is still in an undeveloped region as compared to the other major sports such as baseball, swimming, and track and field. The motion analysis in human motion, especially biomechanical analysis in sports, is still having difficult problems, but the other advanced engineering or technology help to analyze the human motion. Moreover, the popularity of the sports invites many participants (young to old, male and female). In order to do so, soccer has to be analyzed more scientifically because it is still considered a dangerous sport, but science can help reduce the risks of sports injury capabilities.

REFERENCE

1. BARFIELD, W. R. The biomechanics of kicking in soccer. *Clinics in Sports Medicine*. 17:711-728, 1998.
2. DAVIDS, K., LEES, A., and BURWITZ, L. Understanding and measuring coordination and control in kicking skills in soccer: Implications for talent identification and skill acquisition. *Journal of Sports Sciences*. 18:703-714, 2000.
3. FUKAYO, C., SAKURAI, S., HIRANO, Y., and AEI, M. Sports Biomechanics. 2000. Asakura Syoten. Tokyo, Japan.
4. LEES, A., and NOLAN, L. The biomechanics of soccer: A review. *Journal of Sports Sciences*. 16:211-234, 1998.
5. LEVANON, J., and J. DAPENA. Comparison of the kinematics of the full-instep and pass kick in soccer. *Medicine and Science in Sports Exercise*. 30:917-927, 1998.
6. PUTNAM, C. A. A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Medicine and Science in Sports Exercise*. 23:130-141, 1991.
7. STACOFF, A., J. STEGER, E. STÜSSI, and C. REINSCHMIDT. Lateral stability in

sideward cutting movements. *Medicine and Science in Sports Exercise*. 28:350-358, 1996.

8. TEIXEIRA, L. A. Kinematics of kicking as a function of different sources of constraint on accuracy. *Perceptual and Motor Skills*. 88:785-789, 1999.