HOW BIOMECHANICAL ANALYSIS MAY HELP TO IDENTIFY ABDOMINAL INJURY CAUSES IN HIGH LEVEL TENNIS

François Tubez[1,2,3], Bénédicte Forthomme[1,3], Jean-Louis Croisier[1,3], Caroline Cordonnier[1,3], Olivier Brüls[1,4], Vincent Denoël[1,5], Cédric Schwartz[1,3]

Laboratory of Human Motion Analysis, University of Liège, Liège, Belgium[1]
Haute École Robert Schuman, Libramont, Belgium[2]
Department of Sport and Rehabilitation Sciences, University of Liège, Liège Belgium[3]
Department of Aerospace and Mechanical Engineering, University of Liège, Liège, Belgium[4]
Structural Engineering, Department ArGEnCo, University of Liège, Liège, Belgium[5]

This research studies the case of a professional tennis player who has suffered from a medical tear on the left rectus abdominis muscle after a tennis serve. The goal of the study is to understand whether the injury could be explained by an inappropriate technique. For this purpose, we analyzed the three dimensions kinematic and kinetic of the serve. We also performed isokinetic tests of the knees. We compared the player to five other professional players. We observed a possible deficit of energy transfer because of an important anterior pelvis tilt. Some compensations of the player during serve could be a possible higher abdominal contraction and a larger shoulder external rotation. These particularities could induce an abdominal overwork that would explain the first injury and may provoke a new injury.

KEY WORDS: kinematics, tennis, overarm throwing, performance, pathology, abdomen.

INTRODUCTION: The serve is an important stroke in high level tennis. A well-mastered serve is a substantial advantage for players (Girard, Micallef, & Millet, 2005). Because of its repeatability and its intensity, this stroke is potentially deleterious (Martin, Bideau, Ropars, Delamarche, & Kulpa, 2013). It could lead to various muscular and articular pathologies of the upper and lower limbs (Kibler & Safran, 2000) but also of the trunk (Maquirriain, Ghisi, & Kokalj, 2007). The trunk is at the center of energy flow transfer (Martin et al., 2014) observed during the proximo-distal sequence (Kibler & Van Der Meer, 2001). In this case report, we performed a kinematic analysis of a high level tennis player with a previous history of abdominal injury. The injury appeared during a tennis serve movement. We discuss retrospectively his kinematics during his serve. We expect that a combination of medical examination and kinematic analysis can help us to better understand the injury mechanisms. In order to have a reference, this study compares the injured player with a non-injured reference group composed of five international ATP ranked players. The aim of our study is to provide a hypothesis of the injury mechanism based on a biomechanical evaluation.

METHODS: The injured athlete was an international tennis player of 22 years (height: 1.80 m, and weight: 69.8 kg). He is right-handed and was ranked in the top 50 of the Professional Tennis Association (ATP) in 2014. The player suffered from a medical tear on the left rectus abdominis muscle after a serve. A 12 mm tear located on third bottom of left rectus abdominis was objectified by clinical and para-clinical examinations (Magnetic resonance imaging). We compared the results of the injured player with those of 5 professional players among the top 600 ATP rankings. All the players are right-handed, 22 years old (± 3), 75 kg (± 4) and 1.81m (± 0.02).
In the laboratory (Figure 1), we reproduced a half of a tennis court. After a general and specific warm-up, the players served 25 times. The instructions were to serve in the target

("T" area) with highest ball speed and minimal ball rotation (flat serve). Afterward, the three best serves were kept for analysis (Reid, Giblin, & Whiteside, 2014; Whiteside, Elliott, Lay, & Reid, 2014). Selection criterias were precision and highest forward velocity of the racket at impact (Reid et al., 2014; Whiteside et al., 2014). We used a three-dimension optoelectronic system (Codamotion™, Charnwood Dynamics, Rothley, UK) to measure the movements. We tracked the 3D positions of the player's racket, dominant arm and forearm, trunk, pelvis and legs with 28 markers. The acquisition rate was equal to 200 Hz.
We also measured the maximal ground reaction force and the impulsion with two force plates (Kisler™ type 9281 EA, Kisle AG, Switzerland).
With a Cochin goniometer (MSD™ Europe BVBA, Londerzeel – Belgium), we measured passive mobility (°) of the main joints and flexibility of main muscles (°).
We used a CybexNorm™ isokinetic dynamometer (Henley Healthcare, Sugarland, Texas) to measure voluntary maximal strength developed by quadriceps and hamstrings (maximal torque for concentric 240°.s^{-1}).

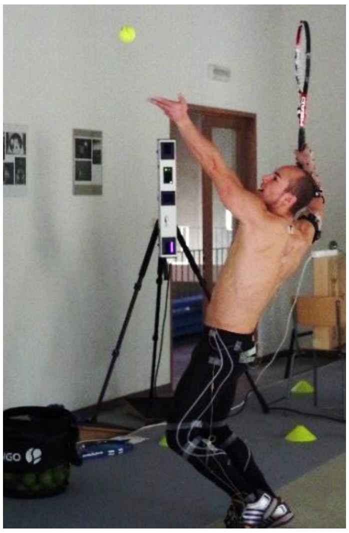

Figure 1: Player serve in the laboratory.

RESULTS: In our 3D kinematic evaluation, we measured linear velocity (m.s^{-1}), maximal angular velocities (°.s^{-1}), angular positions (°) and range of motion from maximal position to impact position (°). In our kinetic evaluation, we measured normalized peak ground reaction force (N.Kg^{-1}) and normalized impulsion (N.s.Kg^{-1}). Impulsion correspond to the integral of a force over the time (i.e., work) (Linthorne, 2001). Isokinetic results are evaluated in concentric mode at 240°.s^{-1} angular velocity for the quadriceps.

Table I
Major results of kinematic, kinetic and isokinetic evaluations.

	Player (n=1)	Group (n=5)
Kinematic		
Racket velocity at impact (m.s^{-1})	38.9 ± 0.4	37.4 ± 2.3
Knee extension maximal angular velocity (°.s^{-1})	D: 532.2 ± 18.5 ND: 431.1 ± 8.6	D: 519.2 ± 46.1 ND: 429.3 ± 61.8
Knee extension range of motion (°)	ND: 48.4 ± 0.3	ND: 63.7 ± 11.0
Knee flexion when leaving force plates (°)	D: 14.5 ± 2.6 ND: 27.6 ± 4.8	D: 8.8 ± 3.0 ND: 18.3 ± 4.8
Anterior pelvic tilt range of motion (°)	44.2 ± 1.9	22.0 ± 9.0
Pelvis sagittal maximal velocity (°.s^{-1})	439.3 ± 16.0	222.5 ± 28.9
Maximal external rotation for the shoulder (°)	132 ± 1	121 ± 9
Maximal shoulder internal rotation velocity (°.s^{-1})	1632 ± 149	1851 ± 381

Kinetic		
Relative forward ground reaction force ($N.Kg^{-1}$)	1.5 ± 0.4	2.7 ± 0.8
Relative vertical ground reaction force ($N.Kg^{-1}$)	20.2 ± 1.0	21.2 ± 2.7
Vertical leg drive impulsion ($N.s.Kg^{-1}$)	0.6 ± 0.2	1.1 ± 0.1
Isokinetic		
Quadriceps peak torque (conc 240 $°.s^{-1}$)	D: 2.18 ND: 2.07	D: 1.84 ± 0.14 ND: 1.78 ± 0.12

DISCUSSION: Despite similar knee extension maximal angular velocity (three dimension) and superior lower limb forces qualities (isokinetic), we observe lower ground reaction forces in the horizontal direction as well as lower vertical impulsion. The leg drive of the player seems to be incomplete as the player ankle plantar flexion and knee extension ROM are under the mean of the group. The important observed anterior pelvis tilt induces hamstrings tensions that may explain the uncompleted leg drive and consequently a lower energy transfer between the lower and upper limbs. Because of the incomplete energy flow transfer, we hypotheses that the abdominis work more to transfer energy from the pelvic girdle to the scapular girdle. Moreover, this increased anterior tilt of the pelvis can cause additional abdominal pre-stretch during the eccentric phase of the abdominal contraction (pre-stretched abdominal muscles). The eccentric phase, quickly followed by the concentric phase of the abdominal muscles, can cause a very important muscle request during the starting phase of trunk flexion (Maquirriain et al., 2007) and lead to a tear especially if an abdominal weakness is pre-existing.

We hypothesize that a particular pelvis kinematic induced a lack of leg drive and consequently of energy transfer, which leads to various compensations including abdominal overwork and larger shoulder external rotation. Overwork on a link of the kinetic chain increases the risk of injury. In our opinion, the abdominal muscle overwork may explain the injury mechanism. The player compensates for the lack of energy transfer by important abdominal pre-stretch. This specific movement in combination with an important external rotation of the shoulder can cause important contraction of the abdominis at the start of the cocking stage.

However, because retrospective approach of our study, we cannot affirm that this specific kinematic is the cause rather than the consequence of the abdominal injury. However, without modifications of the player’s kinematic, we identify a risk of new injury. In the case of this player, it would be judicious to propose a specific leg drive work using complete knee extension jumps as well as pelvis stabilization exercises with abdominal bodycore strengthening. A complete leg drive would be associated to a controlled pelvis kinematic that could potentially limits the strength of the abdominis muscles contraction and the shoulder external rotation compensation. Monitoring the muscle activity of the abdominis muscles with surface electromyography could help to evaluate the effectiveness of the rehabilitation program

CONCLUSION: The case study player’s racket velocity at impact was superior to the mean of group. To overcome a deficit of energy transfer due to an uncompleted leg drive and a specific pelvis kinematic, it is likely that the player compensated involuntarily thanks to other parameters involved in the production of racket velocity (Kovacs & Ellenbecker, 2011). We observe an important external rotation during the serve. The incomplete transmission of the energy of the legs to the pelvis may also have been compensated by a larger abdominis contraction. These particularities could be a retrospective explanation of medical history concerning the abdominal muscles and also highlight the risk of future pathologies.

Similarities between the observations of the experienced eye and the 3D analysis are numerous. However, the 3D kinematic evaluation is an indispensable tool for an objective evaluation of the kinematic in the tennis serve. Coaches are familiar with the performance analysis of the serve but less so with its preventive counterpart.

In this case report, we demonstrate that three dimension analysis is an effective solution to better understand and highlight some injury mechanisms. Also, we conclude that the application of several evaluation techniques together helps to provide a more complete overall and individualized comprehension of the athlete.

REFERENCES:

Girard, O., Micallef, J.P., & Millet, G.P. (2005). Lower-limb activity during the power serve in tennis: effects of performance level. *Medicine and Science in Sports and Exercise, 37*(6), 1021-1029.

Kibler, W.B., & Safran, M.R. (2000). Musculoskeletal injuries in the young tennis player. *Clinics in Sports Medicine, 19*(4), 781-792.

Kibler, W.B., & Van Der Meer, D. (2001). Mastering the kinetic chain. In P. Roetert & J. Groppel (Eds.), *World-Class Tennis Technique* (Champaign ed., pp. 99-113).

Kovacs, M., & Ellenbecker, T. (2011). An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. *Sports Health, 3*(6), 504-513.

Linthorne, N.P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics, 69*(11), 1198-1204.

Maquirriain, J., Ghisi, J. P., & Kokalj, A. M. (2007). Rectus abdominis muscle strains in tennis players. *British Journal of Sports Medicine, 41*(11), 842-848.

Martin, C., Bideau, B., Bideau, N., Nicolas, G., Delamarche, P., & Kulpa, R. (2014). Energy Flow Analysis During the Tennis Serve: Comparison Between Injured and Noninjured Tennis Players. *American Journal of Sports Medicine*.

Martin, C., Bideau, B., Ropars, M., Delamarche, P., & Kulpa, R. (2013). Upper limb joint kinetic analysis during tennis serve: Assessment of competitive level on efficiency and injury risks. *Scandinavian Journal of Medicine and Science in Sports*.

Reid, M., Giblin, G., & Whiteside, D. (2014). A kinematic comparison of the overhand throw and tennis serve in tennis players: How similar are they really? *Journal of Sports Sciences*, 1-11.

Whiteside, D., Elliott, B., Lay, B., & Reid, M. (2014). The effect of racquet swing weight on serve kinematics in elite adolescent female tennis players. *Journal of Science and Medicine in Sport, 17*(1), 124-128.

Acknowledgement

The authors wish to thank the Wallonia-Brussels Federation for their assistance in this study.