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Research article

Biomechanical Analysis of Abdominal Injury in Tennis Serves. A Case Report

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Abstract

The serve is an important stroke in any high level tennis game. A well-mastered serve is a substantial advantage for players. However, because of its repeatability and its intensity, this stroke is potentially deleterious for upper limbs, lower limbs and trunk. The trunk is a vital link in the production and transfer of energy from the lower limbs to the upper limbs; therefore, kinematic disorder could be a potential source of risk for trunk injury in tennis. This research studies the case of a professional tennis player who has suffered from a medical tear on the left rectus abdominis muscle after 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 in three dimensions the kinematic and kinetic aspects of the serve. We also performed isokinetic tests of the player's knees. We then compared the player to five other professional players as reference. We observed a possible deficit of energy transfer because of an important anterior pelvis tilt. Some compensation made by the player during the serve could be a possible higher abdominal contraction and a larger shoulder external rotation. These particularities could induce an abdominal overwork that could explain the first injury and may provoke further injuries.

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 et al., 2005; Johnson et al., 2006). However, the serve is extremely complex and requires a wide range of technical and physical skills (Elliott, 2006; Girard et al., 2005; Kovacs and Ellenbecker, 2011). This stroke is learned and improved upon throughout the entire player career development process, from beginner to professional level (Whiteside et al., 2013). Because of its repeatability and its intensity, this stroke is potentially deleterious (Kibler and Safran, 2005; Martin et al., 2013a; Renstrom and Johnson, 1985). It could lead to various muscular and articular pathologies of the upper and lower limbs (Campbell et al., 2014; Kibler and Safran, 2000; Perkins and Davis, 2006; van der Hoeven and Kibler, 2006) but also of the trunk (Maquirriain et al., 2007). The trunk is at the center of energy flow (Martin et al., 2014) observed during the proximo-distal sequence (Kovacs and Ellenbecker, 2011; Kibler and Van Der Meer, 2001; Liu et al., 2010). Previous studies show that abdominal muscle disorder could be a source of potential risk for local injury in tennis (Natsis et al., 2012; Sanchis-Moysi et al., 2010), however, it is not yet demonstrated that a specific serve kinematic could cause abdominal disorder during this energy transfer (Bahamonde, 2000; Girard et al., 2005; 2007b).

The two-dimensional method has been used for a long time to analyze tennis serving (Bahamonde, 2000; Sprigings et al., 1994). However, 3D methods enable more objective quantification of this stroke. Indeed, 3D methods precisely measure the kinematic of the body segments (Elliott et al., 2003; Tanabe and Ito, 2007). Authors collect high accuracy and high frequency 3D data in all three planes of space. In addition to 2D or 3D, researchers utilize force plates, radar and isokinetic dynamometer to evaluate performance (Antunez et al., 2012; Croisier et al., 2008; Elliott et al., 1986; Forthomme et al., 2013; Girard et al., 2007b; Julienne et al., 2012; Silva et al., 2006). The combination of all these techniques in a kinematic and kinetic analysis could be an original way to better understand the tennis serve mechanism and so optimize performance and prevent injury (Abrams et al., 2011; Elliott and Reid, 2008; Kovacs and Ellenbecker, 2011; Knudson, 2007).

Biomechanics play an important role in comprehension, prevention and management of injuries caused by sport practice (Abrams et al., 2011; Chan et al., 2008). The literature describes generalities of the tennis serve movement (Kovacs and Ellenbecker, 2011) but the throwing gesture, and particularly the service action itself is unique and specific for each individual player. It is therefore interesting to provide an individualized analysis of the player kinematic. In this case report, we performed a kinematic analysis of a high level tennis player with a previous history of abdominal injury. The injury originally appeared during a tennis service movement. We discuss retrospectively his kinematic 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 previously injured player with a non-injured reference group composed of five international

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Professional Tennis Association (ATP) ranked players. The aim of our study is to provide a hypothesis of the injury mechanism based on a biomechanical evaluation.

Case report

The injured athlete was a 22 year-old international tennis player (height: 1.80 m and weight: 69.8 kg). He is right-handed and was ranked in the top 50 of the ATP in 2014.

History: The player suffered from a medical tear on the left rectus abdominis muscle. According to the player, the pain "appeared in the beginning of the trunk flexion when the trunk was in extension and starting the flexion". At that moment of the stroke, abdominis muscles would have been at the end of eccentric contraction and at the beginning of concentric contraction.

A 12 mm tear located on third bottom of left rectus abdominis was objectified by clinic and para-clinic examinations. MRI (Magnetic Resonance Imaging) showed a hypertrophy of rectus abdominal muscle and was confirmed by ultrasound diagnosis. This hypertrophy had already been demonstrated for other professional players (Sanchis-Moysi et al., 2010) as a specific localized site of injuries caused by the tennis serve (Maquirriain et al., 2007, Natsis et al., 2012, Chow et al., 2009, Balius et al., 2012).

Treatment and back assessment: Following the diagnostic, the player performed 18 sessions of physiotherapy treatments. Thereafter, an experienced physiotherapist performed an isometric evaluation of the player trunk muscles (flexors, extensors, lateral-flexors and rotators) using specific trunk dynamometers (the David 110, 120, 130 and 150) and in accordance with the manufacturer's instructions regarding placement (David Back™, David Health Solutions Ltd, Helsinki, Finland) (Grosdent et al., 2014). Results showed a weakness of the right lateral-flexors (2.67 $N.m.Kg^{-1}$) in comparison with the left lateral-flexor muscles (3.32 $N.m.Kg^{-1}$). In addition, we observed that the agonist/antagonist ratio (flexors/extensors) for this player is 0.77 which is higher compared to the classical value seen in professional tennis players (0.57), highlighting dominance of flexors muscles of the player (Grosdent et al., 2014).

After treatment, and with the aim of better understanding the abdominal injury, the player carried out a 3D kinematic evaluation of his serve as well as functional evaluations: passive joint mobility and isokinetic force. Afterward, we compared the results of the player with the reference population who had performed the same assessments in standardized conditions.

Follow up: A few weeks after these evaluations, the player presented a new injury, a tear on the distal insertion of the right psoas muscle. This injury caused a temporary cessation of competition.

Methods

The study protocol reported is approved by the Medical Ethics Committee of the University of Liège. The established protocol provides reproducible results when analyzing the tennis serve.

Reference population: We compared the results of the injured player with those of five 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). At the time of testing, all players were considered as being fit for competitive practice. Except for our case study subject, no other player reported abdominal tear history. No players reported significant joint injury, history of pain or surgery on the dominant arm or their legs. They performed all the evaluations (a 3D evaluation, a passive joint mobility and an isokinetic force assessment) within a one to three week period.

3D kinematic and kinetic evaluation: In the laboratory, we reproduced one half of a tennis court (Figure 1). The width of our court was smaller (5.8 m) than the normal size (8.23 m) in order to fit into the laboratory. Players served from two force plates located behind the baseline. We placed the net at a regulatory distance and height (International Tennis Federation, Roehampton, England) from the baseline and ground.

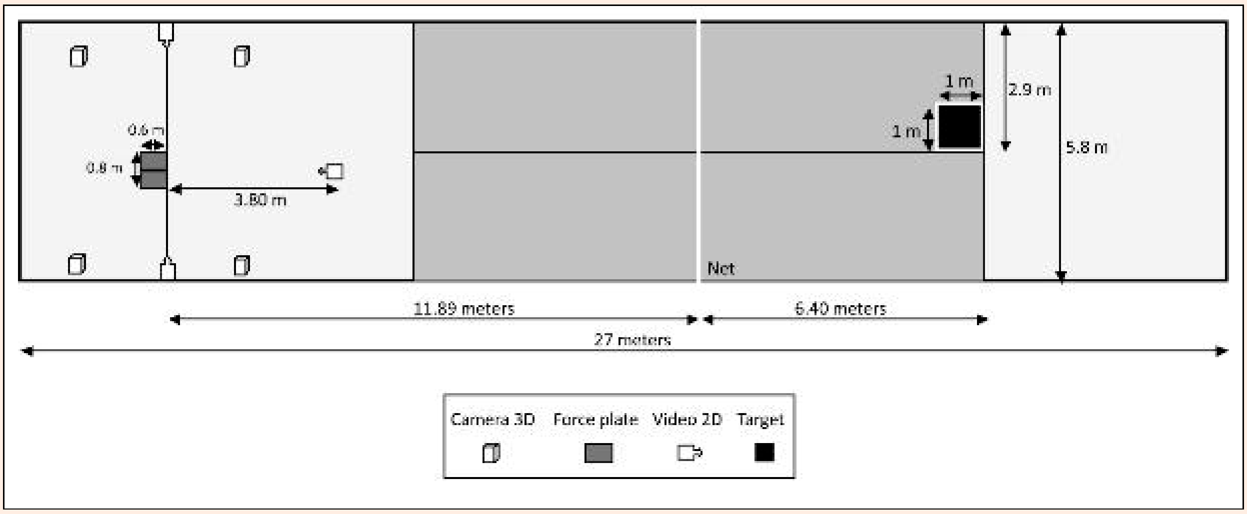

Figure 1. Representation of the tennis court in the laboratory.

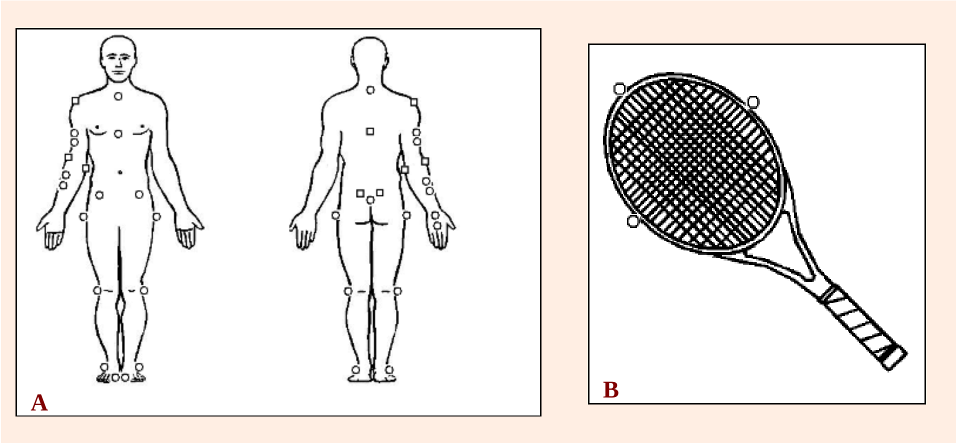

Figure 2. Representation of body (A) and racket (B) marker (circle) and additional anatomical points (square) placement.

Before the tests, the players performed a general cardio-vascular warm-up with lower limb, (skipping rope, running and/or ergometric bicycle) and upper limb (rubber band) exercises. Afterward, they undertook a general short stretching routine for legs and arms. Finally, players engaged in a specific warm-up procedure for tennis serves, first without markers and then with markers placed on the skin. This specific warm-up allowed players to get familiar with the laboratory context (field, target and markers on the skin). Each player decided the number of serves necessary for warming-up and for familiarization with a maximum of 30 serves allowed in order to avoid fatigue.

After the general and specific warm-up, the test began and the players served 25 times each, with 30 seconds between each serve. The instructions were to serve in the target ("T" area) with the highest ball speed possible and minimal ball rotation (flat serve). Afterward, the three best serves were kept for analysis (Reid et al., 2015, Whiteside et al., 2014) in order to consider the derivation of accurate and representative movement kinematics (Mullineaux et al., 2001). The selection criteria were precision (serve performed successfully in the 1 m^2 area or "T" zone of the deuce square (Gillet et al., 2009)) and highest forward velocity of the racket at impact (Reid et al., 2014, Whiteside et al., 2014).

We used a three-dimensional 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 and four Codamotion CX1 units. The acquisition rate was equal to 200 Hz.

We placed three markers on the trunk, three markers on the pelvis, four markers on both legs, four markers on the dominant arm, four makers on the dominant forearm and three on the dominant hand in accordance with the recommendations of the International Biomechanical Society (ISB) (Wu et al., 2002; 2005) (Figure 2A). We also placed three markers on the racket: one on each side and one on the top (Martin et al., 2014, Martin et al., 2012) (Figure 2B). We identified additional anatomical points by reference to the placed markers: T8, left and right posterior-superior iliac spine, dominant side lateral epicondyle, dominant side medial epicondyle and center of dominant side glenohumeral joint (Figure 2A).

The marker placement allowed us to measure the ankle, knee, pelvis and shoulder joints and segments' amplitude (°); the linear velocity ($m \cdot s^{-1}$) of markers and anatomic points for pelvis, shoulder, elbow, wrist and racket; also the ankle, knee, pelvis and shoulder angular velocity ($° \cdot s^{-1}$) in frontal, transverse and/or sagittal plane(s). We additionally analyzed the kinematic chain (Kibler et al., 2013) with the observation of the sequence of motion (Liu et al., 2010). To achieve that goal, we measured the maximal forward linear velocity of dominant side markers.

The most important position in the tennis serve is the moment of impact (ball-racket contact). During a serve, the impact position timing corresponds to the maximal forward linear velocity of the racket (Tanabe and Ito, 2007, Gordon and Dapena, 2006). We measured the racket velocity with the centroid of the three racket markers to better align the racket speed with ball impact location.

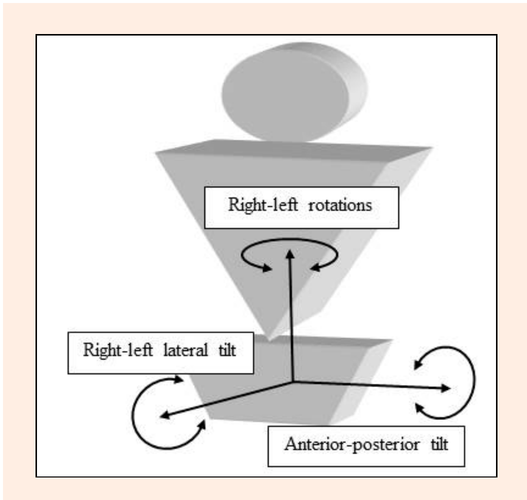

Figure 3. Representation of pelvis and trunk motions in frontal (right and left lateral tilt), sagittal (anterior-posterior tilt) and transverse (right and left rotations) planes.

In our 3D kinematic evaluation, we measured the maximal external rotation of the shoulder. For pelvis and trunk motion analysis, we measured the maximal rotation in frontal (right and left lateral tilt), sagittal (anterior-posterior tilt) and transverse (right and left rotations) planes in reference to the ground (Figure 3).

We also measured the maximal ground reaction force and the impulsion with two force plates (Kisler™ type 9281 EA, Kisle AG, Switzerland). Each force plate measured 60 cm by 40 cm so the players were able to push on both feet for either foot-up or foot-back technique. The results represent the normalized peak ground reaction force (N·Kg^{-1}) and normalized impulsion (Ns·Kg^{-1}) (Linthorne, 2001).

Passive joint mobility and muscle flexibility: With a Cochin goniometer (MSD™ Europe BVBA, Londerzeel – Belgium) used in accordance with suggested guidelines (Swann and Harrelson, 2012), we measured passive mobility (°) of the main joints including ankles (flexion-extension) and shoulders (glenohumeral rotations) (Moreno-Perez et al., 2015, Forthomme et al., 2013). We also evaluated hamstring length using a straight leg raise flexibility test (Neto et al., 2014). These procedures were performed before the 3D warm-up and carried out by the same examiner.

Isokinetic force: We used a CybexNorm™ isokinetic dynamometer (Henley Healthcare, Sugarland, Texas) to measure voluntary maximal strength developed by quadriceps and hamstrings. We assessed absolute peak torque (PT; N.m) and body mass relative to peak torque (per kg; Nm·Kg^{-1}).

We performed lower limb measurements on quadriceps (Q) and hamstrings (H) using protocol modalities based on previous studies (Croisier et al., 2002). Selected isokinetic speeds are 60°·s^{-1} and 240°·s^{-1} in concentric mode and 30°·s^{-1} in eccentric mode. We also measured agonist-antagonist ratios (Hamstrings/Quadriceps) and determined a mixed ratio (combination of antagonist PT in the eccentric 30°.s^{-1} mode and agonist PT in the concentric 240°.s^{-1} mode) to represent more specifically muscle contractions in a knee extension.

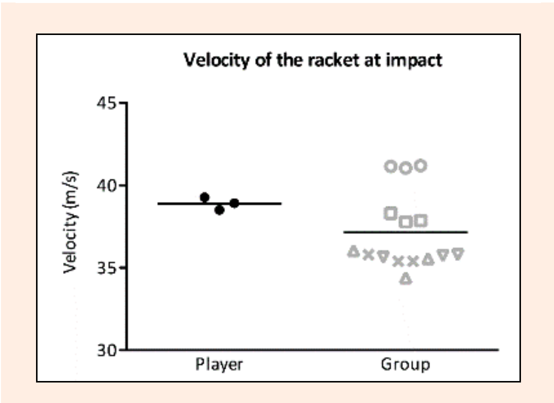

Figure 4. Velocity of the racket at impact for player and group. Each plot represents one of the 3 best serves of the player. Each symbol represents a different player. We express means of player and group as meter per second (m·s^{-1}). Values for the player (n = 1; black) and the group (n = 5; grey).

Results

We analyzed kinematics, muscular and joint information of the injured player ('the player') compared to the control group ('other players', 'the group'). We select and describe remarkableresults in this section.

3D analysis during tennis serve

Velocity of the racket at impact: Racket velocity of the player (38.9 ± 0.4 m·s^{-1}) is higher than for four out of five of the other players (37.4 ± 2.3 m·s^{-1}) (Figure 4).

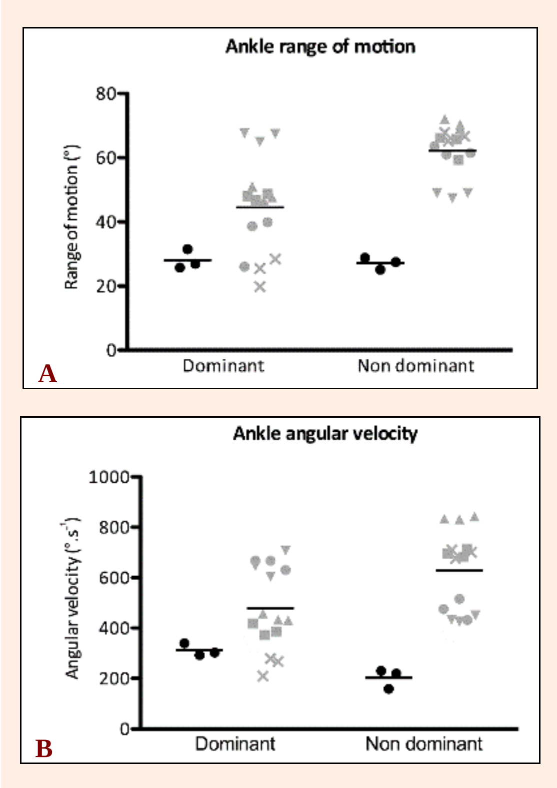

Figure 5. Range of motion (A) and maximal angular velocity (B) of ankle plantar flexion for player and group. Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as degree (°) or degree per second (°·s^{-1}). Values for the player (n = 1; black) and the group (n = 5; grey).

Range of motion and maximal angular velocity of ankles and knees joints: Bilaterally, the ankle plantar flexion ROM and maximal angular velocity during the serves is lower for the player compared to the group (Figure 5A; 5B). This difference occurs mainly on the non-dominant side.

We observe similar knee extension maximal angular velocity (°·s^{-1}) for the player and the group (dominant: 532.2 ± 18.5 °·s^{-1} vs 519.2 ± 46.1 °·s^{-1}; non-dominant: 431.1 ± 8.6 °·s^{-1} vs 429.3 ± 61.8 °·s^{-1}). However, the non-dominant knee extension ROM (front knee) is lower for the player than the group (48.4 ± 0.3° vs 63.7 ± 11.0°) (Figure 6A). Moreover, when the player leaves the force plate, he has bilaterally a more important knees flexion (dominant: 14.5 ± 2.6°; non-dominant: 27.6 ± 4.8°) in comparison to the group (dominant: 8.8 ± 3.0°; non-dominant: 18.3 ± 4.8°) (Figure 6B).

Pelvis range of motion and maximal angular velocity: From maximal position to impact position, anterior pelvic tilt ROM is higher for the player than for the group (44.2 ± 1.9° vs 22.0 ± 9.0°) (Figure 7A). Concerning frontal and transverse planes, we observe no particular difference (Frontal: 23.2 ± 1.1° vs 24.3 ± 6.4°; Transverse: 82.6 ± 2.2° vs 75.2 ± 16.9°).

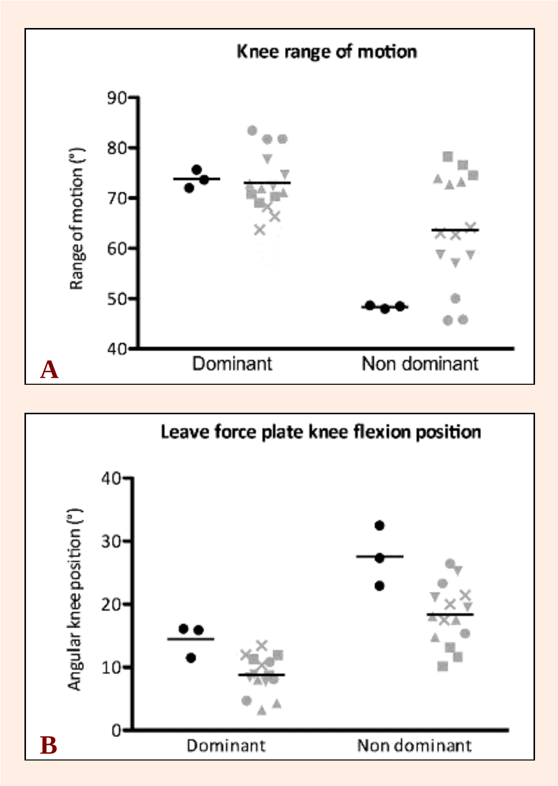

Figure 6. Extension knee range of motion (A) and knee angular flexion when leaving force plate (B) for player and group. Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as degree (°).Values for the player (n = 1; black) and the group (n = 5; grey).

The pelvis maximal angular velocity of the player is particularly higher compared to the group in sagittal plane (439.3 ± 16.0 $°\cdot s^{-1}$ vs 222.5 ± 28.9 $°\cdot s^{-1}$) (Figure 7B). We observe no material difference in the frontal and transversal planes (Frontal: 191.2 ± 3.5° vs 184.4 ± 62.3°; Transverse: 456.9 ± 11.9° vs 423.0 ± 49.6°).

Maximal forward linear velocity of anatomic points: Regarding the kinetic chain, we observe that the maximal forward linear velocity is similar for the player and the group on the pelvis (1.1 ± 0.1 $m\cdot s^{-1}$ vs 0.9 ± 0.2 $m\cdot s^{-1}$), elbow (8.4 ± 0.3 $m\cdot s^{-1}$ vs 8.0 ± 1.1 $m\cdot s^{-1}$) and wrist (12.0 ± 0.1 $m\cdot s^{-1}$ vs 11.9 ± 0.9 $m\cdot s^{-1}$). However, on the dominant shoulder, maximal forward linear velocity is higher for the player (5.3 ± 0.4 $m\cdot s^{-1}$ vs 4.4 ± 0.5 $m\cdot s^{-1}$) (Figure 8).

Active shoulder external rotation: During the serve, we observe a larger maximal external rotation for the player compared to the group (132 ± 1° vs 121 ± 9°) (Figure 9). However, we do not observe a higher shoulder internal rotation maximal angular velocity (Player: 1632 ± 149 $°\cdot s^{-1}$; Group: 1851 ± 381$°\cdot s^{-1}$).

Passive mobility (Goniometry)

We do not observe particularities for passive dominant shoulder external rotation by the player. Concerning lower limbs, we observe a bilateral ankle rigidity in plantar and dorsal flexion for the player compared to the group (Table 1). Also, we do not observe greater hamstring flexibility for the player from the straight leg raise flexibility test (Table 2).

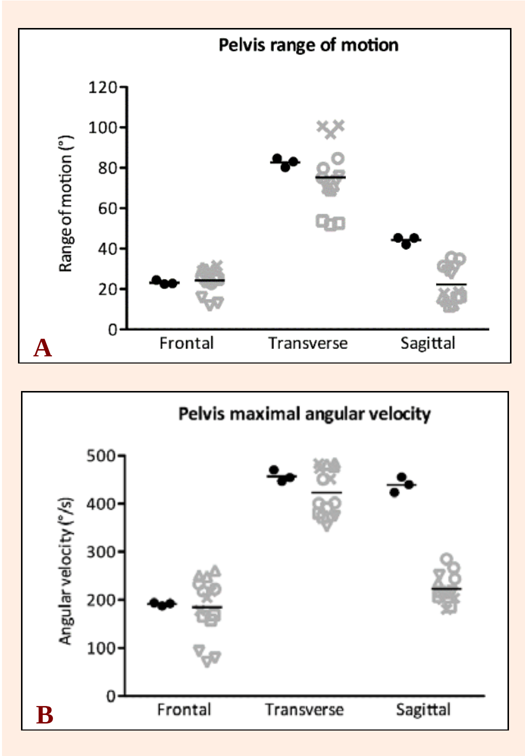

Figure 7. (A) Pelvis range of motion (ROM) from the maximal lateral flexion/rotation/tilt position until the impact position in the 3 planes (frontal, transverse, sagittal). (B) Maximal angular velocity of pelvis girdle in the 3 planes (frontal, transverse, sagittal). Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as degree (°) and degree per second ($°\cdot s^{-1}$). Values for the player (n = 1; black) and the group (n = 5; grey).

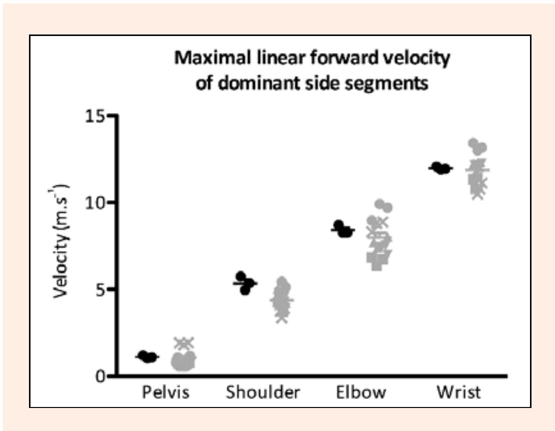

Figure 8. Maximal forward linear velocity (MFLV) of dominant side joints in the kinetic chain. We express values in meters per second ($m\cdot s^{-1}$) for markers and anatomic points placed on pelvis, shoulder, elbow and wrist. Values for the player (n = 1; black) and the group (n = 5; grey).

Ground reaction force and impulsion: We observe lower vertical leg drive impulsion for the player than for the group (0.6 ± 0.2 $Ns\cdot Kg^{-1}$ vs 1.1 ± 0.1 $Ns\cdot Kg^{-1}$) (Figure 11A). Compared to the group, the player has a lower maximal ground reaction force ($N.Kg^{-1}$) in the forward direction (1.5 ± 0.4 $N\cdot Kg^{-1}$ vs 2.7 ± 0.8 $N\cdot Kg^{-1}$) (Figure 10) and similar maximal ground reaction force ($N.Kg^{-1}$) in the vertical direction (20.2 ± 1.0 $N\cdot Kg^{-1}$ vs 21.2 ± 2.7 $N\cdot Kg^{-1}$) (Figure 11B).

Table 1. Passive amplitude in degrees (°) of plantar and dorsal ankle's flexion and shoulder's external rotation. Passive measure of straight leg raise flexibility test. D = dominant (right); ND = non-dominant (left). Data are means (±SD).

	Ankle				Shoulder	
	D		ND		D	ND
	Plantar	Dorsal	Plantar	Dorsal	RE	RE
Player (n =1)	32 °	5 °	32 °	4 °	92 °	80 °
Group (n=5)	64 (7) °	12 (2) °	64 (11) °	10 (3) °	96 (7) °	92 (9) °

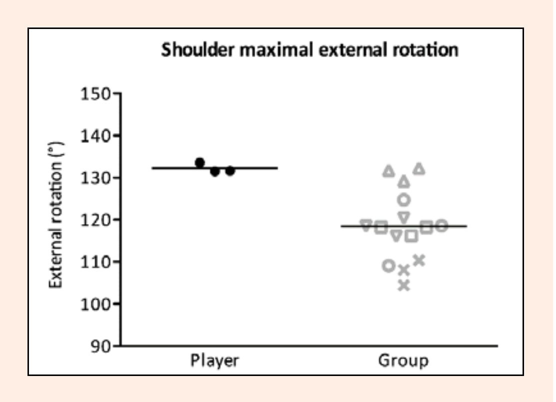

Figure 9. Maximal external rotation for shoulder. Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as degree per second (°·s^{-1}). Values for the player (n = 1; black) and the group (n = 5; grey).

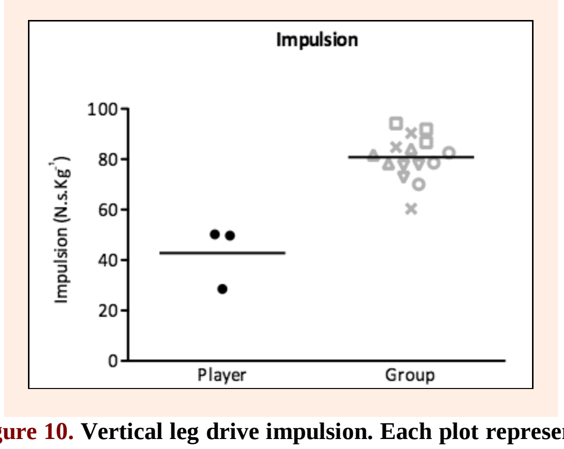

Figure 10. Vertical leg drive impulsion. Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as relative impulsion (Ns·Kg^{-1}). Values for the player (n = 1; black) and the group (n = 5; grey).

Table 2. Passive measure of hamstrings flexibility with straight leg raise flexibility test. D = dominant (right); ND = non-dominant (left). Data are means (±SD).

	Hip	
	Hamstring	
	D	ND
Player (n =1)	80 °	85 °
Group (n=5)	86 (6) °	87 (7) °

Isokinetic assessment: Peak torque relative to body mass of the player is generally higher for the player than for the group in all conditions (hamstrings and quadriceps; fast and slow speed; concentric and eccentric mode). We observe better performances for hamstrings in eccentric mode and quadriceps in fast concentric mode for the player than for the group. Mixed ratios are also higher for the player compared to the group (Table 3).

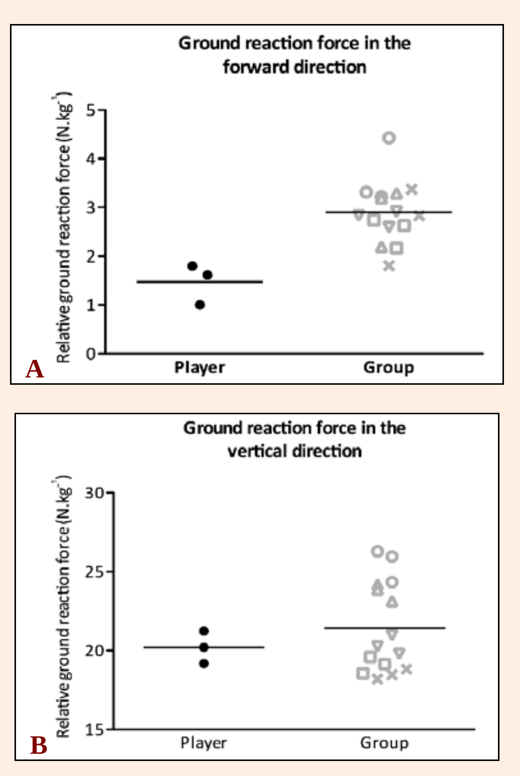

Figure 11. Maximal ground reaction forces in the forward (A) and vertical (B) directions. Each plot represents one of the 3 best serves of a player. Each symbol represents a different player. We express means of player and group as relative force (N·Kg^{-1}). Values for the player (n = 1; black) and the group (n = 5; grey).

Discussion

This case study relates to a top level tennis player with a particular medical history. The player presented a muscle tear on the non-dominant rectus abdominis. The goal of our analysis was to be able to discuss retrospectively, through the analysis of the stroke action of the player, the potential injury mechanism. We performed several kinematic and kinetic analyses. We performed tests to assess muscle strength, passive articular amplitudes, muscular measures and 3D kinematic of the tennis serve.

In the kinetic chain, the pelvis is the link between legs and trunk, and abdominis the link between the pelvis girdle and the shoulder girdle. Pelvis and trunk are the vital links in the sequence of actions during service (Kibler and Van Der Meer, 2001; Martin et al., 2014) and abdominis muscles are essentials part of the pelvis and trunk link (Maquirriain et al., 2007). During the cocking phase, players move the racket to the back with an abduction and an external shoulder rotation. Then, lumbar spine

Table 3. Peak torque (PT, Nm·kg^{-1}) and body mass relative to peak torque (per kg) of the player and the group observed for quadriceps and hamstring by isokinetic test. Data are means (±SD).

	Dominant (D) leg					
	Hamstring			Quadriceps		Mix Ratio
	Conc 60°·s^{-1}	Conc 240°·s^{-1}	Exc 30°·s^{-1}	Conc 60°·s^{-1}	Conc 240°·s^{-1}	
Player (n = 1)	1.71	1.23	2.61	2.77	2.18	1.20
Group (n = 5)	1.55 (.27)	1.00 (.16)	1.65 (.33)	2.73 (.50)	1.84 (.14)	.90 (.21)
	Dominant (D) leg					
Player (n = 1)	1.96	1.23	2.39	2.60	2.07	1.15
Group (n = 5)	1.51 (.23)	1.01 (.17)	1.59 (.28)	2.52 (.41)	1.78 (.12)	.90 (.16)

Conc = concentric, Ecc = eccentric. Mix ratio “hamstring (Ecc30)/quadriceps (conc240)”. D = dominant; ND = non-dominant.

gets in hyperextension. This movement allows an increased racket distance that generates speed and power to the racket and the ball at impact (Maquirriain et al., 2007). The eccentric contraction of non-dominant rectus abdominis followed by concentric contraction during the cocking phase of the serve motion is related as a specific tear injury mechanism (Maquirriain et al., 2007) as encountered in our case.

We observed that our case study player had one of the best serving performances in comparison to the group. Indeed, we noted our player’s better racket speed compared to the mean of the group (38.9 ± 0.4 m·s^{-1} vs 37.4 ± 2.3 m·s^{-1}). There is a correlation between the racket velocity at impact and ball speed (Gordon and Dapena, 2006; Tanabe and Ito, 2007), which is a contributor to overall service performance (Girard et al., 2007b; Fleisig et al., 2003; Tanabe and Ito, 2007).

There is a proximo-distal sequence to perform the serve in tennis (Elliott, 1986; 2003, Ellenbecker, 2004, Marshall and Elliott, 2000; Martin et al., 2013b; Pugh et al., 2003). Legs are the start of the energy production from the lower limbs to the upper limbs (Elliott and Colette, 1993; Elliott et al., 2003; Girard et al., 2005). According to Elliott and Colette (1993), "*It is significant to understand that power (force) is not developed by the trunk and arm. The primary source of power is generated from the ground in the form of ground reaction forces*" (Elliott and Colette, 1993). So, leg extension is a key parameter in the search for efficiency in the tennis serve (Elliott and Colette, 1993; Girard et al., 2007a; 2007b) and rapid leg extension is a contributor of serve speed (Campbell et al., 2014; (Girard et al., 2007a; Reid et al., 2008).

Energy from the legs is transmitted along the kinetic chain (Martin et al., 2014). In the case of our player we observe a lower leg drive impulsion result. This observation is not due to a deficit of strength because the isokinetic results show better muscle qualities. Also, it is not due to a deficit of knee extension velocity because we observe similar maximal angular velocity of knees (serve kinematic). However, during leg drive, we note our player’s ankle maximal angular velocity and ROM in plantar flexion is below the mean of the group and there is incomplete knee extension at the instant of leaving the force plate. This lack of energy generation must be recovered by other movements in the kinematic chain in order to obtain one of the best performances of serve velocity. Lintner and al. (2008) describe this kind of compensation in terms of a “catch-up” concept (Lintner et al., 2008). The compensations required to produce better racket velocity may appear along all the kinematic chain.

The pelvis maximal forward linear velocity is not higher for the player than the group but the dominant shoulder maximal forward linear velocity reaches a higher peak for the player, indicating higher energy generation between pelvis and shoulders for the player. Distally, from elbow to racket, we observe no particularities. Indeed, the player’s dominant shoulder for linear and angular velocity, the forearm pronation, the wrist flexion and the ulnar deviation are similar to the rest of the group. These observations highlight absence of distally compensation and possible compensation between pelvis and shoulder.

Because of the incomplete leg drive, we hypothesize that the abdominis work more to transfer and add energy from the pelvic girdle to the scapular girdle. In the energy flow (Martin et al., 2014) of our player, this lack of energy potentially appears at the pelvis level.

In fact, we observe that the pelvis moves with a larger anterior tilt ROM and maximal angular velocity. The important observed anterior pelvis tilt induces additional hamstring tension that may explain the incomplete leg drive and consequently a lower energy production from the lower limbs. This increased anterior tilt of the pelvis induces a specific lumbar lordosis in combination with development of 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.

The maximal external rotation dominant in the player’s values as observed in passive measure (goniometer) are similar to the group but are larger during the active motion (3D) assessment suggesting the addition of constraints on the shoulder in dynamic situations. This could also add higher lumbar lordosis in addition to the abdominal eccentric tension.

We hypothesize that the particular pelvis kinematic induces a lack of leg drive and consequently of energy flow, 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 can cause important contraction of the abdominis at the start of the cocking stage.

Because of the retrospective approach of our study, we cannot affirm if this specific kinematic is the cause rather than the consequence of the abdominal injury. Forced external rotation in combination with a pelvis anterior tilt and an abdominal eccentric tension could also be a risk of following injury in the shoulder and the abdominis. However, we observed a new injury in a pelvis muscle (psoas) a few weeks after the tests. This development was not entirely surprising because the psoas muscle is actively involved in pelvic anterior tilt movement. A significant contraction of the psoas-iliac muscle can explain the important pelvis anterior tilt observed and an important lumbar lordosis. Repeated contractions of this muscle may also explain the origin of this new lesion. This prospective follow-up injury is supported by our previous observations.

Our study contributes to the need for awareness by medical staff of the importance of a pre-season check-up. We would suggest to the medical staff (trainer, physic trainer, doctor, and physiotherapist) a corrective program based on these particular observations. In the case of this player, it would be judicious to propose specific leg drive exercises using complete knee extension jumps, associated to a controlled pelvis kinematic with abdominal core strengthening. This could potentially limit the strength of the abdominis and psoas 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.

Limitations of the study

Our study highlights the importance of measuring tools to improve and objectivize players' kinematics. These technologies could ameliorate player performance and prevent lesion risk. We also demonstrate through our work the benefit of a multidisciplinary analysis of a gesture using several techniques simultaneously. In the future, it would be also interesting to combine our evaluations with electromyography (EMG). These measures are focused on muscle activity and may provide further insights into injury mechanisms.

1. This retrospective study cannot establish with certainty if our observations are a cause or a consequence of the injury. If our observations are the cause of the injury, there is a risk of recurrence and it would be interesting to continue to provide prevention work in the pelvis region. It would also be interesting to perform a prospective study to evaluate the effect of a specific rehabilitation program.
2. Our reference group is small. It limits us in the comparison analysis of data. However, our participants are amongst the highest international level players, which improves the relevance of data. We also checked the reproducibility of the whole protocol on ten participants. These unpublished results showed that the kinematic, kinetic and clinical measurements are reproducible.
3. Three dimensional technology with an active markers system is a source of pitfalls in the context of a complex and fast gesture analysis such as that as encountered in throwing sports (Abrams et al., 2011, Gordon and Dapena, 2006).

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 and 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 analysisan 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.

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Key points

- In the proximal-distal sequence, energy is transmitted from lower limbs to upper limps via trunk.
- The 3D analysis tool is an indispensable test for an objective evaluation of the kinematic in the tennis serve.
- Multiple evaluations techniques are useful for fuller comprehension of the kinematics and contribute to the awareness of the player’s staff concerning pathologies and performance.

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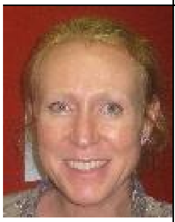

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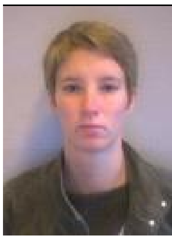

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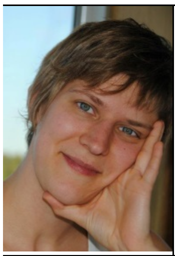

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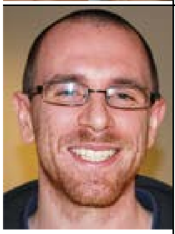

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