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Case Studies

Isokinetic strength training of kinetic chain exercises of a professional tennis player with a minor partial internal abdominal oblique muscle tear – A case report

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ABSTRACT

Objective: To present a case of a right-handed professional tennis player with a left internal abdominal oblique muscle tear sustained while serving. We document the progress of a rehabilitation program consisting of primarily kinetic chain isokinetic strength training where symmetrical measurements (<10% side difference) of force and dynamic postural control were used as criteria for return to sport.
Methods: Isokinetic exercises (bilateral rotational pull, unilateral vertical press and unilateral anterior push) to target trunk specific demands of the serve (flexion, rotation and lateral flexion) were done using robotic resistance. Dynamic postural control was assessed using the hand reach star excursion balance test (HSEBT). The rehabilitation program lasted 3.5 weeks (eight sessions).
Results: At baseline isokinetic strength tests that imposed concentric muscle function demands of the injured muscle had lower force measurements (range: -32.1 to −71.9%). These force measurements improved (range: 166.1−296.5%) and were symmetrical (range: +1.6 to +7.3%) on return to sport. In addition, the HSEBT test with the greatest asymmetry (−20 cm) improved to symmetrical (+2 cm) on return to sport.
Conclusion: Symmetrical isokinetic force and dynamic postural control measurements were successful return to sport criteria as the player since has remained pain free (2 years).

1. Introduction

Muscle injuries are the most common type of injury in tennis players who participate in competition (Gescheit et al., 2017). Muscle strains are common at the abdominal site since they play an important role in force production, particularly during the serve (Dines et al., 2015; Maquirriain, Ghisi, & Kokalj, 2007). The serve is the most strenuous stroke in tennis (Elliott, Fleisig, Nicholls, & Escamilia, 2003) and the trunk is at the center of energy flow (Martin et al., 2014) by acting as a mechanical link between the lower and upper extremities. Consequently, it is not surprising that abdominal muscle strains lead to a decreased performance or inability to participate in training and competition (Connell et al., 2006). If not treated properly, recurrence of pain, prolongation of symptoms and a delayed return to sport may occur (Dines et al., 2015).

Since tennis has become a faster game with increased force and torque demands placed on trunk muscles (Abrams, Sheets, Andriacchi, & Safran, 2011), abdominal muscles may be more susceptible to injuries. Therefore, addressing trunk specific mechanical determinants, kinematic (i.e. position and velocity) or kinetic variables (i.e. angular momentum), of tennis serve performance may guide rehabilitation programs and return to sport decision making (Ardern et al., 2016). Kinematic analyses have established that the trunk moves into extension, ipsilateral lateral flexion and rotation in the preparation phase with a subsequent flexion, contralateral lateral flexion and rotation in the acceleration and follow-through phases (Elliott, 2006; Kovacs & Ellenbecker, 2011; Tubez et al., 2015; Wagner et al., 2014). Furthermore, trunk rotational angular velocity (Gordon & Dapena, 2006) and flexion and lateral flexion angular momentum (Bahamonde, 2000; Martin, Kulpa, Delamarche, & Bideau, 2013) significantly contribute to serve speed.

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Clinicians should preferable target these specific trunk mechanical determinants in rehabilitation. Also, it has been advocated that both testing and training of dynamic postural control, mobility, force, speed and power should be based on kinetic chain movements since they might have a greater potential to transfer to sport performance (Ellenbecker & Roetert, 2004a; Helland et al., 2017; Kibler, 1995). The HSEBT is a test of dynamic postural control that measure shoulder, trunk and lower extremity joint movement interactions similar to those observed during the different phases of the tennis serve (Elliott, 2006; Eriksrud, Federolf, Anderson, & Cabri, 2018; Kovacs & Ellenbecker, 2011; Tubez et al., 2015; Wagner et al., 2014). In fact, one HSEBT test has been reported to be correlated with serve speed (Eriksrud, Ghelem, Henrikson, Englund, & Brodin, 2018). Furthermore, useful exercises for strength and power from a standing position might be: 1) unilateral overhead press to target lateral flexion, 2) bilateral arm rotational pull to target trunk rotation and 3) unilateral arm anterior inferior press to target trunk flexion and rotation. In fact, the unilateral anterior inferior press is similar to the standing throwing test described by Signorle and co-authors who reported good to excellent correlations between peak torque and serve speed (Signorile, Sandler, Smith, Stoutenberg, & Perry, 2005). New technologies (e.g. robotic resistance) allow for quantification of force, speed and power of these tests, which can be used for objective documentation of baseline, progress, feedback and return to sport criteria. (Ardern et al., 2016).

We present a case report that describes the rehabilitation program targeting trunk specific mechanical determinants of the serve in a professional tennis player with a small internal abdominal oblique muscle tear (type 3A). Specifically, improvements to symmetrical measurements (<10% side difference) of kinetic chain isokinetic and dynamic postural control tests were used as return to sport criteria.

2. Methods

2.1. Case description

The player was a 39-year-old (92 kg, 192 cm) right handed professional double tennis player on the Association of Tennis Professionals tour. The player hurt himself during competition while serving. He reported a left anterolateral trunk pain toward the insertions of abdominal muscles at the ribs. Afterwards, all strokes became painful, particularly the smash and serve. At this time the player had pain at rest, with overhead activities and with activities that increased force demands (sit-up). Palpation around the insertions of the abdominals to the ribs were painful, too. The player consulted a physician who requested a Magnetic Resonance Imaging (MRI), which confirmed a small tear at the insertion of left internal abdominal oblique at 11th rib (type 3A) (Mueller-Wohlfahrt et al., 2013) (Fig. 1). The prognosis was good and expected to heal in three to four weeks.

2.2. Rehabilitation program

The rehabilitation program was managed using POLICE principle in the management of acute injuries (i.e. protection, optimal loading, ice and elevation) (Bleakley, Glasgow, & MacAuley, 2012). During the first week the primary focus was to control the inflammatory process using nonsteroidal anti-inflammatory drug (NSAID), cryotherapy, rest and light activities of daily living that did not provoke pain. However, the main emphasis of this case was optimal loading of trunk specific mechanical determinants of the tennis serve. Upon return home (one week after injury) the NSAID was discontinued and a training program was implemented which included (trunk mechanical determinant in parenthesis): 1) bilateral hands left and right rotational pull (rotation), 2) left- and right-hand vertical press (lateral flexion) and 3) left- and right-hand anterior push (rotation and flexion) (see Fig. 4 for images of exercises). All exercises were done using a robotic resistance (1080 Quantum, 1080 Motion Nordic AB, Stockholm, Sweden) which consists of a servo motor to control resistance load (concentric: 1–50 kg; eccentric: 1–60 kg) and speed (concentric: 0.1–8.0 m s^{-1}; eccentric: 0.1–6.0 m s^{-1}). The adjustable arm of the system allowed for different directions of external load and the above exercises to be performed in one system. For all exercises, the load was set to 5 kg for both the concentric and eccentric phase, while the speed was set to 0.5 m s^{-1} and 1.5 m s^{-1} for the concentric and eccentric phase, respectively (Fig. 2). The low resistance ensured that only low forces were needed to accelerate the external load to the set 0.5 m s^{-1} concentric speed limit. Once the concentric speed limit was reached the remainder of the movement was isokinetic and the resistance accommodated to the force applied. Thus, the injured player could determine the resistance experienced during a given exercise. This cannot be achieved using isoinertial free-weights or pulley systems, since a given external load will impose a force demand that is greatest during the acceleration phase with a subsequent decrease through the movement. Also, isokinetic resistance allowed the player to determine the resistance progression through the rehabilitation program as he could exert more force. During the repair phase a progression from isometric to isotonic and isokinetic strengthening without pain has been recommended (Baoge et al., 2012). However, early onset of rehabilitation has been found to be advantageous in muscle strain injuries with pain <5/10 on the pain Numeric Rating Scale (NRS) on range of motion exercises (Bayer, Magnusson, Kjaer, & Tendon Research Group, 2017).

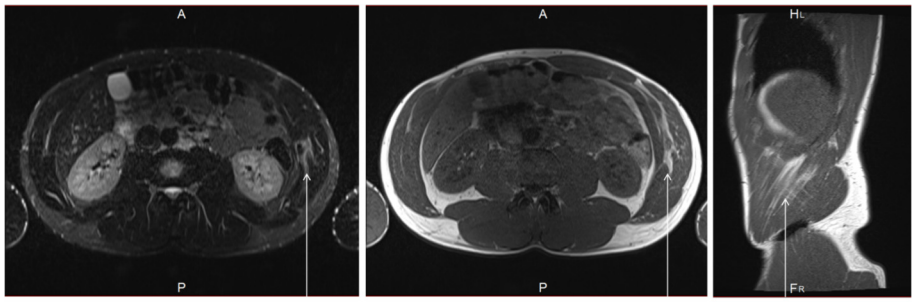

Fig. 1. MRI of injury site (indicated by arrow) showing edema with fatty atrophy of the internal abdominal oblique muscle. Inferior view using STIR sequence (A) and T1 weighted image (B). Lateral view using T1 weighted image (C).

Fig. 2. All exercises were done using robotic resistance. Start position of the left, right or both feet, could be defined by X and Y coordinates in cm on a marked raster on the floor. Orientation of the player was defined based on degrees in relation to the machine ensuring reproducible positions of the athlete between sessions.

Unfortunately, Bayer and co-authors did not identify maximum pain-level for their strength training program (Bayer et al., 2017). Thus, we started with isokinetic strength training after seven days with a more conservative pain-level (NRS<3/10). Based on an effective isokinetic strengthening program for performance in golfers (Parker, Lagerhem, Hellstrom, & Olsson, 2017) three sets of five repetitions of each exercise were performed. The exercises were alternated between left and right hand or direction of movement (rotation). All exercises were kept at the same load and speed settings over the course of the four weeks (eight sessions).

General mobility exercises of the hip and shoulder were carried out during the first two weeks of the program. Specifically, hip extension, internal and external rotation mobility exercises where performed in standing and half kneeling, which will impose a small mobility demand on the trunk based on the pelvis moving relative to the thorax. Shoulder horizontal abduction with scapular retraction and shoulder external rotation exercises were also performed in standing. After two weeks, thoracic and trunk mobility exercises were introduced. Specifically, bilateral rotation was done in quadruped and standing, while bilateral lateral flexion and extension were done in standing. Each exercise was performed dynamically in three sets of 30 repetitions, five to seven times per week.

2.3. Tests

Isokinetic force measurements were obtained from the rehabilitation exercises previously described. A coordinate system on the floor was used to ensure the same player position relative to external load for each set and session. The force data were collected from the first set (five repetitions) of each exercise in each session. For each repetition the mean force was calculated. The repetitions with highest and lowest mean force (N) were ignored and the mean of the three remaining repetitions was calculated and used as outcome measurement. This was done for all exercises and for all eight training sessions.

Dynamic postural control and functional mobility were assessed using the HSEBT, which consists of 10 hand reaches performed on each foot (stance foot) (Eriksrud, Federolf, Sæland, Litsos, & Cabri, 2017). Procedures and reach direction definitions have been described in detail previously (Eriksrud et al., 2017). Based on similarity of elicited hip, trunk and shoulder joint movements (Eriksrud, Federolf, et al., 2018) to the different phases of the tennis serve (Elliott, 2006; Tubez et al., 2015) four horizontal reaches (L45, R45, L135, R135) and two rotational reaches (LROT and RROT) were tested on each foot. The reaches were performed on a testing mat designed for this purpose (Athletic Knowledge Nordic AB, Stockholm, Sweden - Fig. 3). Three to five practice trials were allowed, after which three valid reaches were recorded and the maximum value used for further analysis. These tests were performed in session one and seven (three weeks between tests). Evaluations of the all HSEBT outcome measures were carried out using minimal detectable change (MDC) from session one to session seven (Eriksrud et al., 2017).

3. Results

At session one exercises that required concentric function of the left internal abdominal oblique (bilateral hands left rotational pull, right hand unilateral vertical press and right hand anterior unilateral push) had lower force measurements (−32.1 to −71.9%) than

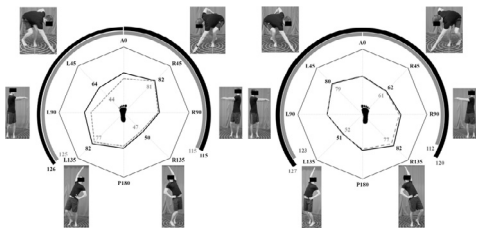

Fig. 3. Visual representation of HSEBT reach measurements (photographs) on the left and right foot with reach distances for session 1 (grey numbers and dotted lines) and session 7 (black numbers and whole line).

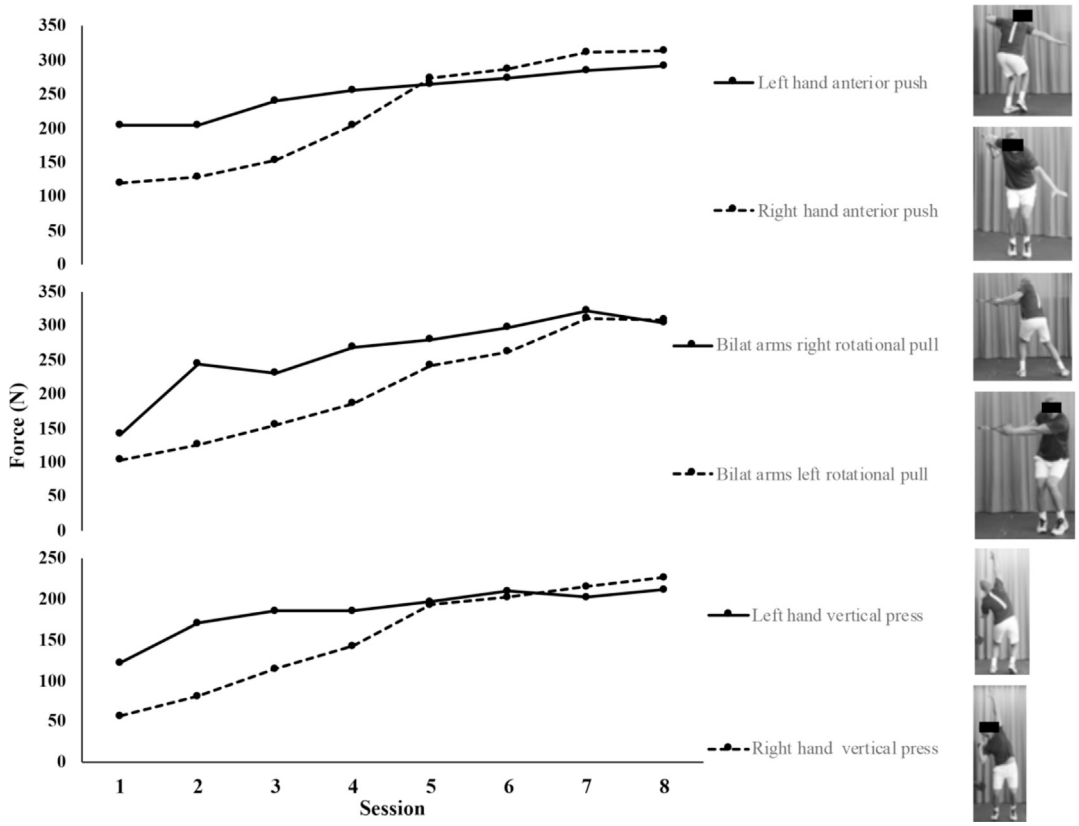

Fig. 4. Mean isokinetic force measurements for all exercises (images) over eight sessions (four weeks). Dotted and whole lines show exercises that require concentric muscle function of the left and right internal abdominal oblique respectively.

their contralateral counterparts (Table 1, Fig. 4). Furthermore, of the dynamic postural control tests only the left foot L45 reach had a lower measurement when compared to the contralateral test using MDC values (Table 2, Fig. 3). After session six (2.5 weeks) all exercises were performed without pain and the player to returned to practice forehand and backhand strokes with pain-level (NRS <3/10) determining intensity. The player was an active decision maker as both coach and player agreed not to return to competition due to asymmetry of trunk rotational force (−12.6%), apprehensive in attempting to serve (psychological readiness of Step 2 of the Strategic Assessment of Risk and Risk Tolerance (StARRT)), and not willing to take the risk of missing an upcoming Grand Slam Tournament (Step 3 StARRT) (Shrier, 2015). At session seven the greatest improvement in dynamic postural control measurements was observed for the left foot L45 reach (20 cm) (Table 2). Also, left foot L135, right foot R135 reach and right foot right rotational reach measurements improved more than established MDC values (Table 2). At session eight (3.5 weeks) force measurements for all exercises had improved (43.8–296.5%), and a greater symmetry of rotational force was observed (+1.6%) (Table 1). Also, the greatest improvements in force measurements were observed in the exercises that required left internal abdominal oblique concentric muscle function (166.1–296.5%) (Table 1). At this time the player started to practice serves with a pain-level (NRS <3/10) determining intensity. The player returned to sport one month after the start of the rehabilitation and five weeks after the injury. At two year follow up no recurrent injury to this anatomic site was reported.

4. Discussion

To our knowledge this case study is the first to use a kinetic chain isokinetic strength training program to target established trunk specific mechanical determinants of tennis serve performance on a player with a partial tear of internal abdominal oblique muscle (Type 3A) (Mueller-Wohlfahrt et al., 2013). Furthermore, this case provide insight into how symmetrical measurements of sport specific kinetic chain exercises, isokinetic and dynamic

Table 1
Isokinetic tests with side differences and changes.

Test	Session 1		Session 6		Session 8		Change
	Force (N)	Asymmetry (%)	Force	Asymmetry (%)	Force (N)	Asymmetry (%)	Session 1 to 8 (%)
Bilateral hands left rotational pull	102	−32.1	261	−12.6	309	+1.6	202.9
Bilateral hands right rotational pull	141		296		304		115.6
Left hand unilateral vertical press	121	−71.9	210	−4.4	211	+6.9	74.4
Right hand unilateral vertical press	57		201		226		296.5
Left hand anterior unilateral push	203	−53.0	272	+5.0	292	+7.3	43.8
Right hand anterior unilateral push	118		286		314		166.1

Note. − and + sign denotes percentage asymmetries of tests that concentrically imposes a demand on the left relative to the right internal abdominal oblique muscle.

Table 2
Hand reach star excursion balance tests measurements with side differences and improvements.

Test	Session 1		Session 7		Improvement	MDC
	Measure	Difference	Measure	Difference	Session 1 to 7	
L foot R45 reach (cm)	81	2	82	2	1	1.8–2.8
R foot L45 reach (cm)	79		80		1	1.7–2.4
L foot L45 reach (cm)	44	17	64	2	20	1.5–1.7
R foot R45 reach (cm)	61		62		1	2.1
L foot L135 reach (cm)	77	0	82	0	5	3.9–4.2
R foot R135 reach (cm)	77		82		5	3.3–3.9
L foot R135 reach (cm)	47	5	50	1	3	5.5–7.9
R foot L135 reach (cm)	52		51		−1	5.7–7.2
L foot LROT reach (deg)	125	2	126	1	1	5.2–6.3
R foot LROT reach (deg)	123		127		4	5.2–6.6
L foot RROT reach (deg)	115	3	115	5	0	4.7–5.1
R foot RROT reach (deg)	112		120		8	5.1–7.2

Note. R = Right, L = Left; 45 = 45° relative to anterior surface of body; 135 = 135° relative to anterior surface of body: ROT = Rotation; cm = centimeter; deg = degrees; MDC = Minimal detectable change.

postural control, can be used in the return to sport decision-making process.

Current strength and power tests and exercises used to target serve performance include the standing throwing test (Signorile et al., 2005), isolated isokinetic tests (Roetert, McCormick, Brown, & Ellenbecker, 1996), static back extension (Baiget, Corbi, Fuentes, & Fernandez-Fernandez, 2016) and different medicine ball throws (Maquirriain et al., 2007; Roetert et al., 1996; Ulbricht, Fernandez-Fernandez, Mendez-Villanueva, & Ferrauti, 2016). Of these tests only the standing throwing and medicine ball throws capture the trunk mechanical determinants associated with the tennis serve action in kinetic chain movement patterns. However, quantification of these tests have been limited to mostly throwing distance (Fernandez-Fernandez, Ulbricht, & Ferrauti, 2014), with the exception of Signorile and co-authors who measured peak torque, average power and total work in a diagonal inferior push using a standard isokinetic dynamometer (Signorile et al., 2005).

The use of robotic resistance allowed us to obtain force measurements of kinetic chain exercises that targeted trunk mechanical determinants to the serve action in every session. This was valuable information for us in the return to sport decision making process. Since the isokinetic exercises were based on serve specific trunk mechanical determinants, the most painful of the tennis strokes after injury, we were confident that trunk function was improving. However, it can be argued that the kinetic chain exercises used in the current case were not specific enough in isolating and targeting the left internal abdominal oblique muscle. Furthermore, multiple trunk muscles contribute to the trunk movements associated with the different exercises. Nonetheless, the observed force impairments at baseline are consistent with the partial left internal abdominal oblique muscle tear (type 3A) diagnosis as tests that require concentric muscle function of flexion (right hand anterior push), left lateral flexion (right hand unilateral press) and rotation (bilateral hands left rotational pull) showed a force deficit ranging from −32.1 to −71.9% (Table 1). Based on these observations and the absence of reference values, different cohorts and the player himself, the symmetrical isokinetic force measurement criteria (Step 1 of the StARRT framework) (Shrier, 2015) for return to sport seemed reasonable. It is important to note that this was a shared decision with the player (Ardern et al., 2016).

The established return to sport criteria proved to be important at session six since there was no pain during any of the exercises, but there were asymmetrical force measurements ranging from −12.6 to +5.0%. During this session both the coach and the player agreed that return to competition should be postponed based on the force symmetry criteria, and that the player felt apprehensive in attempting to serve. Then, at session eight, when the player returned to sport, no mean force deficits were observed and the player was more confident in the serve.

The symmetrical force measurement criteria for the different exercises was considered a minimum as handedness could influence the force output in these exercises. Since we did not have any reference values the criteria was based on previously reported trunk isokinetic strength measurements of symmetrical rotation (Ellenbecker & Roetert, 2004a). However, greater isokinetic strength in lateral flexion toward the non-dominant side have been reported (Andersson, Sward, & Thorstensson, 1988). Furthermore, electromyography (EMG) studies indicate that asymmetrical findings could be expected since asymmetrical trunk muscle function with high normalized activity have been observed (Chow, Park, & Tillman, 2009; Chow, Shim, & Lim, 2003). In addition, asymmetrical hypertrophic changes of abdominal muscles have also been reported (Connell et al., 2006). Thus, the symmetrical isokinetic force measurement criteria for return to sport might therefore be a minimum requirement. Since this case study is the first to quantify kinetic chain isokinetic exercises specific to the tennis serve, it provides a start from which reference values can be explored. In fact, such isokinetic profiles have been called for (Ellenbecker & Roetert, 2004b).

In combination with average isokinetic force, the HSEBT measurements were also used in the return to sport decision making. Specifically, the left foot L45 reach had the greatest side difference (17 cm) and subsequent improvement (20 cm). Consistent with the findings of the isokinetic exercises, this reach might require a greater concentric contribution of the internal abdominal oblique since flexion, left rotation and lateral flexion are the trunk movements elicited by this reach (Eriksrud, Federolf, et al., 2018). However, it was surprising that none of the reaches that challenge the internal abdominal oblique muscle eccentrically (L135 and R135) had a side difference greater than the reported MDC values (Eriksrud et al., 2017). We speculated that these findings could be due to all L135 and R135 reaches tested at session 1 being affected. However, it appears that only two of these reaches were affected, since the left foot L135 and right foot R135 reach improved beyond reported MDC values (5 cm) (Eriksrud et al., 2017). Furthermore, it might be that L135 and R135 reach measurements are still limited at session seven. This is supported by comparisons to the greater reported reach measurements in national and international level tennis players, where the dominant foot L135 reach was reported to be significantly correlated with serve speed (Eriksrud, Ghelem, et al., 2018). Since dynamic postural control tests have not been widely used to assess tennis players (Eriksrud, Ghelem, et al., 2018),

it might be that other hand reach based test such as the Upper Quarter Y-Balance reach test (Gorman, Butler, Plisky, & Kiesel, 2012) can be applied, especially considering that it has been used to assess other overhead sports (Borms & Cools, 2018; Bullock et al., 2018). Regardless, based on the observed improvement of the left L45 reach it appears that both HSEBT reaches and functional isokinetic exercises can be used to explore the influence of abdominal muscle tear injuries on kinetic chain movement patterns in tennis players.

5. Conclusion

This case study describes the progression and outcome of an early loading rehabilitation program that primarily consisted of kinetic chain isokinetic strength training targeting trunk specific mechanical determinants of serve performance. Symmetrical mean isokinetic force and HSEBT measurements were helpful in the return to sport decision-making process. No re-injury was reported during a two year follow up.

Conflicts of interest

The first and second authors are shareholders in 1080 Motion Nordic AB that commercially distributes 1080 Quantum.

Ethical statements

Written informed consent and permission to use information was obtained from the patient.

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