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UNDERSTANDING THE KINETIC CHAIN

IN TENNIS PERFORMANCE AND INJURY

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INTRODUCTION

Injuries are common in tennis players of all ages and skill levels. Understanding the inherent demands placed on the body by the sport and how the body withstands these demands can help in evaluation, treatment and reduction of injuries. Key to this is an understanding of the kinetic chain. This is especially true for treatment of shoulder, elbow and wrist injuries.

The term 'kinetic chain' refers to the mechanical system by which athletes accomplish the complex tasks required for function in sport. It is especially important in the tennis serve motion. The tennis serving motion is developed and regulated through a sequentially co-ordinated and task-specific kinetic chain of force development and a sequentially activated kinematic chain of body positions and motions[1]. The kinematics of the tennis serve has been well described and may be broken down into phases[2–4]. These descriptions show how muscles can move the individual segments and show the temporal sequence of the motions. The kinetics are not as well described but are important due to the forces and motions that are developed. These forces and motions are applied to all of the body segments to allow their summation, regulation and transfer throughout the segments to result in performance of the task of throwing or hitting the ball. The term 'kinetic chain' is used collectively to describe both of these mechanical linkages. Alteration in the sequential activation, mobilisation and stabilisation of the body segments commonly occurs in association with sport dysfunction; either decreased performance or injury. This kinetic chain 'breakage' has been demonstrated in both young and older athletes in many anatomic areas as a result of repetitive, vigorous activities. It is usually acquired and can be created from many factors such as:

- remote injury,
- incompletely healed or rehabilitated injury,
- muscle weakness or imbalance,
- muscle inflexibility and
- joint stiffness or improper mechanics.

Kinetic chain breakage creates increased distal physiologic or biomechanical requirements (increased muscle activation or increased distal segment velocity, acceleration or mass to 'catch up' and develop the same kinetic energy or force at the distal segment), changes the interactive moment at the distal joint (increasing the forces that must be absorbed at the joint) or

decreases the ultimate velocity or force at the distal segment.

The shoulder faces high loads in playing tennis. Elite players reach rotational velocities of up to 1700 degrees/second, resulting in arm velocities of up to 35 miles per hour on the serve[5]. The one hand backhand stroke generates rotational velocities up to 900 degrees/second (arm velocities of 20 miles per hour), while the open stance forehand generates 280 degrees/second, which with trunk rotation through the kinetic chain, creates arm velocities of up to 46 miles per hour[5].

Ranges of motion are also found to be correspondingly large. Total arc of rotational motion (internal + external rotation) is between 160 and 180 degrees and the highest point of abduction is between 140 and 160 degrees[5].

Torques generated in the serve by these loads and motions have been found to be high at the two critical times:

- maximum external rotation and
- acceleration to ball impact.

At maximum external rotation, males recorded 65 Nm and females 46 Nm. At acceleration to ball impact, males recorded 70 Nm and females 50 Nm. Torques greater than 50 Nm are considered a significant and potentially injurious factor in loading of the upper extremity, so those inherent loads have the potential to create overload injury.

The deceleration force between the trunk and the arm at ball impact and follow-through is up to 300 Nm. This is required to stabilise and support the shoulder against the distraction forces that equal 0.5 to 0.75 times body weight.

These loads are placed on the shoulder with every stroke. The number of strokes per match varies greatly, depending on the type of match, skill level, opponent and playing surface. The average elite tennis match will involve at least 100 repetitions of 'game' serves and 250 repetitions of 'game' ground-strokes. In junior tennis tournaments in scholastic or collegiate tennis, these numbers are larger because two to three matches may be played per day. These numbers do not include the number of 'practice' strokes, which in most estimates is four to five times higher.

The kinetic chain is the biomechanical system by which the body meets these inherent demands of tennis. It generates the required forces and helps to regulate and modify loads seen at the joints, especially the high loads at the shoulder[5].

An effective athletic kinetic chain is characterised by three components[4]:

- Optimised anatomy in all segments.
- Optimised physiology (muscle flexibility and strength and well-developed, efficient, task-specific motor patterns for muscle activation).
- Optimised mechanics (sequential generation of forces appropriately distributed across motions that result in the desired athletic function).

The kinetic chain has several functions:

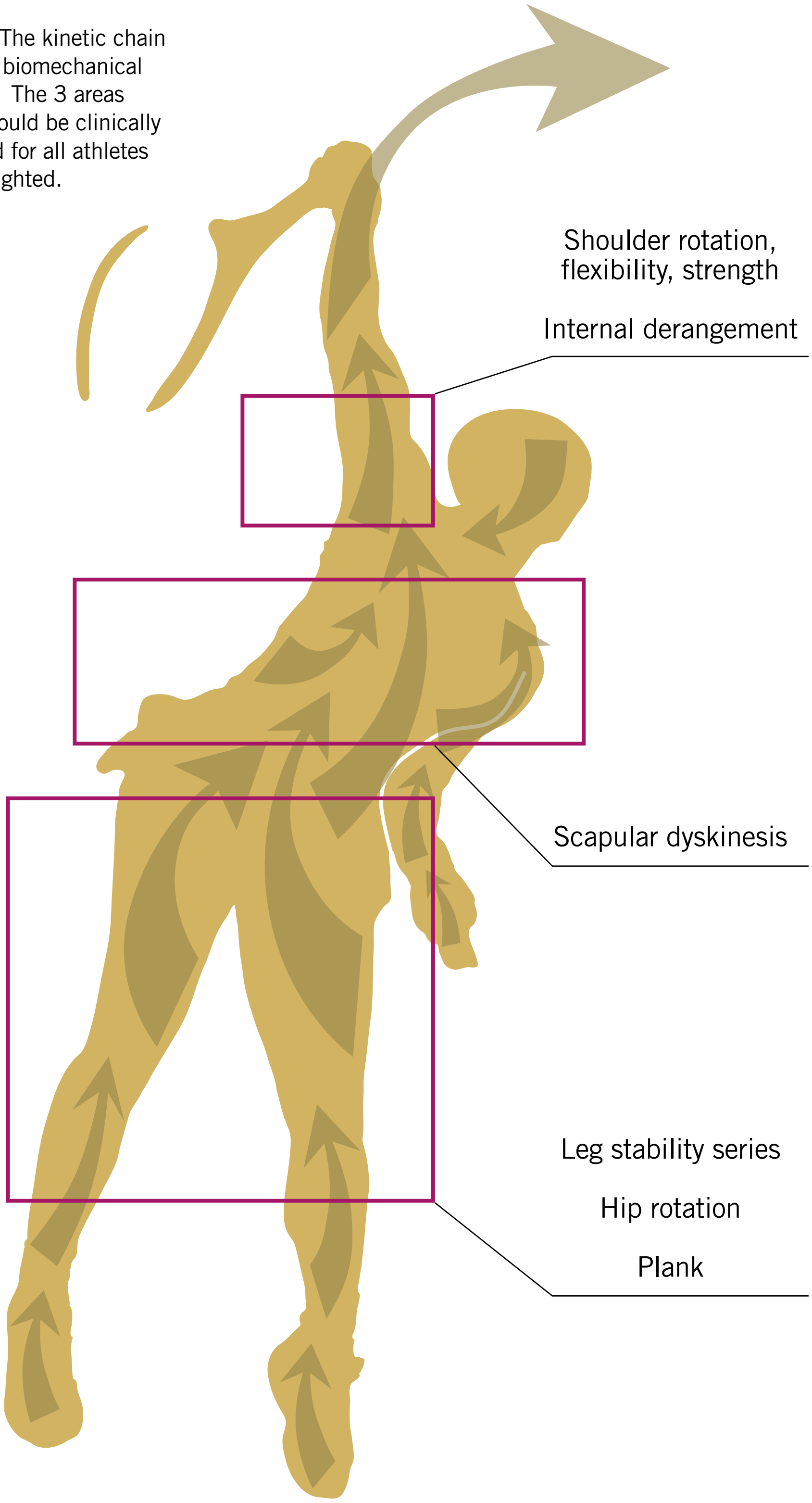
- Using integrated programmes of muscle activation to temporarily link multiple body segments into one functional segment (e.g. the back leg in cocking and push-off, the arm in long axis rotation prior to ball impact) to decrease the degrees of freedom in the entire motion[2].
- Providing a stable proximal base for distal arm mobility.
- Maximising force development in the large muscles of the core and transferring it to the hand[2].
- Producing interactive moments at distal joints that develop more force and energy than the joint itself could develop and decrease the magnitude of the applied loads at the distal joint[6].

Table 1

	Node	Normal mechanics	Pathomechanics	Result	To be evaluated
1	*Foot position*	*In line, foot back*	*Foot forward*	*Increased load on trunk or shoulder*	*Hip and/or trunk flexibility and strength*
2	*Knee motion*	*Knee flexion greater than 15°*	*Decreased knee flexion less than 15°*	*Increased load on anterior shoulder and medial elbow*	*Hip and knee strength*
3	*Hip motion*	*Counter rotation with posterior hip tilt*	*No hip rotation or tilt*	*Increased load on shoulder and trunk; inability to push through increasing load on abdominals*	*Hip and trunk flexion, flexibility and strength*
4	*Trunk motion*	*Controlled lordosis; X-angle ~30°*	*Hyperlordosis and back extension; X-angle <30° (hypo), X-angle >30° (hyper)*	*Increased load on abdominals and "slow arm"; increased load on anterior shoulder*	*Hip, trunk, and shoulder flexibility*
5	*Scapular position*	*Retraction*	*Scapular dyskinesis*	*Increased internal and external impingement with increased load on rotator cuff muscles*	*Scapular strength and mobility*
6	*Shoulder/ scapular motion*	*Scapulohumeral rhythm with arm motion (scapular retraction/ humeral horizontal abduction/humeral external rotation)*	*Hyper angulation of humerus in relation to glenoid*	*Increase load on anterior shoulder with potential internal impingement*	*Scapular and shoulder strength and flexibility*
7	*Shoulder over shoulder*	*Back shoulder moving up and through the ball at impact, then down into follow-through*	*Back shoulder staying level*	*Increased load on abdominals*	*Front hip strength and flexibility, back hip weakness*
8	*Long axis rotation*	*Shoulder internal rotation/forearm pronation*	*Decreased shoulder internal rotation*	*Increased load on medial elbow*	*Glenohumeral rotation*

Table 1: Tennis nodes and possible consequences. X-angle=measurement of hip/trunk separation angle, the angle between a horizontal line between anterior aspect of both acromions and horizontal line between both ASIS when viewed from above first described by McLean and Andrisani, ASIS=anterior superior iliac spine. Note: Numbers 1 to 6 occur prior to the acceleration phase of the service motion while numbers 7 to 8 occur after ball impact.

Figure 1: The kinetic chain model of biomechanical function. The 3 areas which should be clinically examined for all athletes are highlighted.



- Producing torques that decrease deceleration forces[6].

In the normally operating kinetic chain, the legs and trunk segments are the engine for force development and the stable proximal base for distal mobility. This link develops 51 to 55% of the kinetic energy and force delivered to the hand, creates the back leg to front leg angular momentum to drive the arm forward and because of its high cross-sectional area, large mass and high moment of inertia, creates an anchor which allows centripetal motion to occur.

The functional result of this stable base is considered to represent core stability. In addition to generating force in the trunk and leg segments, kinetic chain activation through the core also generates force in the distal segments through the creation of interactive moments or forces generated at joints by the position and motion of adjacent segments. At the shoulder, the interactive moment produced by trunk rotation around a vertical axis is the most important factor in generating forward arm motion and the interactive moment produced by trunk rotation around a horizontal axis from front to back is the most important factor in generating arm abduction.

The remaining kinetic chain segments play smaller roles in intrinsic force generation, mainly due to their smaller cross sectional area and the production of interactive moments. The shoulder only produces 13% of the total kinetic energy for the entire service motion. The high velocities and forces seen at the shoulder are predominantly produced through kinetic chain activation. The high muscle activations seen in the shoulder muscles are mainly directed towards co-contraction force couples to stabilise the joint. This allows the shoulder to function in the kinetic chain primarily as a funnel, transferring the forces developed in the engine of the core to the delivery mechanism of the hand.

DEGREES OF FREEDOM

Efficient mechanics in the kinetic chain can be improved by decreasing the possible degrees of freedom (DOF) throughout the entire motion. There are 244 possible DOF in the body from the foot to the hand. Most models of maximum efficiency in body motions find that limiting DOF to about six to eight maximises the total force output and minimises effort and load.

The average elite tennis match will involve at least 100 repetitions of 'game' serves and 250 repetitions of 'game' ground-strokes

The limited number of independent DOF are called nodes and represent key positions and motions in the overhead tasks[2]. These key positions have been correlated with optimum force development and minimal applied loads and can be considered the most efficient methods of co-ordinating kinetic chain activation. There may be multiple individual variations in other parts of the kinetic chain, but these are the most basic and the ones required to be present in all motions.

The tennis serve motion can be evaluated by analysing a set of eight 'nodes' or positions and motions that are correlated with optimum biomechanics (Table 1)[2]. These include optimum foot placement, adequate knee flexion in cocking progressing to knee extension at ball impact, hip/trunk counter rotation away from the court in cocking, back hip downwards tilt in cocking, hip/trunk rotation with a separation angle around 30°, coupled scapular retraction/arm rotation to achieve cocking in the scapular plane, back leg to front leg motion to create a 'shoulder over shoulder' motion at ball impact and long axis rotation into ball impact and follow-through[2–4]. These nodes can be evaluated by visual observation or by video recording and analysis.

Tennis players with shoulder, elbow or wrist injuries have been shown to have a multitude of possible causative factors contributing to the presenting complaints of pain and decreased function, either by causing the anatomic injury or increasing the dysfunction from the injury. These may be alterations in anatomy, physiology and/or biomechanics and can combine to produce an alteration in the normal mechanics, resulting in pathomechanics that may create decreased efficiency in the kinetic chains, impaired performance, increased injury risk or actual injury[5–7].

The examination of tennis players with shoulder symptoms should include evaluation of the proximal factors that may influence shoulder loading. Specific attention should be paid to evaluation of the scapula, trunk and hip/leg (Figure 1). This type of examination can identify anatomic areas and mechanical motions that may be contributing to the symptoms and suggest areas for more detailed evaluation.

The kinetic chain exam should include a screening evaluation of leg and core stability, observational evaluation for scapular dyskinesis and evaluation of various elements in the shoulder. It should be supplemented by a detailed examination of the areas highlighted by the symptoms or evaluation[8] (Table 2).

The shoulder exam should be comprehensive, emphasising evaluation of the anatomy (labrum, biceps and/or rotator cuff internal derangement), physiology (muscle weakness/imbalance, flexibility) and mechanics (scapular dyskinesis, glenohumeral internal rotation deficit, total range of motion deficit).

Treatment should also involve a comprehensive approach, including restoration of all kinetic chain deficits, altered mechanics and functional joint stability. Rehabilitation should address all of the physiological and mechanical factors[1,9]. This would include restoration of hip range of motion and leg strength, core stability and strength, scapular control, shoulder muscle flexibility and strength and glenohumeral rotation. Surgery should address repairing joint structures to optimise the capability for functional stability[1].

CONCLUSION

Optimal performance of the overhead throwing task requires precise mechanics that involve co-ordinated kinetic and kinematic chains to develop, transfer and regulate the forces the body needs to withstand the inherent demands of the task and to allow optimal performance. These chains have been evaluated and the basic components, called nodes, have been identified.

Impaired performance and/or injury can be associated with alterations in the kinetic chain mechanics. The pathomechanics can occur at multiple locations throughout the kinetic chain. They must be evaluated and treated as part of the overall problem.

Observational analysis of the mechanics and pathomechanics using the node analysis method can be useful in highlighting areas of alteration that can be evaluated for anatomic injury or altered physiology. The comprehensive kinetic chain exam can evaluate sites of kinetic chain breakage and a detailed shoulder exam can assess joint internal derangement of altered physiology that may contribute to the pathomechanics.

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Table 2

Examination emphasis	Normal	Abnormal	Result	Evaluation
One leg stability: stance	*Negative trendelenburg*	*Positive trendelenburg*	*Decrease force to shoulder*	*Gluteus medius strength*
One leg stability: squat	*Control of knee varus/ valgus during decent*	*Knee valgus or 'corkscrewing' during decent*	*Alters arm position during task*	*Dynamic postural control*
Hip rotation	*Bilateral symmetry within known normal limits*	*Side-to-side asymmetry and/or not within normal limits*	*Decrease trunk flexibility and rotation*	*Internal and external rotation of hip*
Plank	*Ability to maintain body position for at least 30 seconds*	*Inability to maintain body position*	*Decreased core stability and strength*	*Dynamic postural control in suspended horizontal position*
Scapular dyskinesis	*Bilateral symmetry with no inferior angle or medial border prominence*	*Side-to-side asymmetry or bilateral prominence of inferior angle and/or medial border*	*Decreased rotator cuff function and increased risk of internal and/or external impingement*	*Scapular muscle control of scapular position ('yes/no' clinical evaluation[10], manual corrective manoeuvres)*
Shoulder rotation	*Side-to-side symmetry or internal and external rotation values less than 15° or less than 5°*	*Side-to-side asymmetry of 15° or more in internal and/or external rotation or 5° or more of total range of motion*	*Altered kinematics and increased load on the glenoid labrum*	*Internal and external rotation of glenohumeral joint*
Shoulder muscle flexibility	*Normal mobility of pectoralis minor and latissimus dorsi*	*Tight pectoralis minor and/or latissimus dorsi*	*Scapular protraction*	*Palpation of pectoralis minor and latissimus dorsi*
Shoulder strength	*Normal resistance to testing in anterior and posterior muscles*	*Weakness and/or imbalance of anterior and posterior muscles*	*Scapular protraction, decreased arm elevation, strength, and concavity-compression*	*Muscle strength from a stabilised scapula*
Joint internal derangement	*All provocative and stress testing negative*	*Pop, click, slide, pain, stiffness, possible 'dead arm'*	*Loss of concavity-compression and functional stability*	*Labral injury, rotator cuff injury or weakness, glenohumeral instability, biceps tendinopathy*

Table 2: Proximal to distal kinetic chain evaluation.