Racquet string tension directly affects force experienced at the elbow: implications for the development of lateral epicondylitis in tennis players

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Abstract

Background: Lateral epicondylitis (LE) occurs in almost half of all tennis players. Racket-string tension is considered to be an important factor influencing the development of LE. No literature yet exists that substantiates how string-tension affects force transmission to the elbow, as implicated in LE development. We establish a quantitative relationship between string-tension and elbow loading, analyzing tennis strokes using rackets with varying string-tensions.

Methods: Twenty recreational tennis players simulated backhand tennis strokes using three rackets strung at tensions of 200 N, 222 N and 245 N. Accelerometers recorded accelerations at the elbow, wrist and racket handle. Average peak acceleration was determined to correlate string-tension with elbow loading.

Results: Statistically significant differences ($p < 0.05$) were observed when average peak acceleration at the elbow at 200 N string-tension (acceleration of 5.58 m/s^2) was compared with that at 222 N tension (acceleration of 6.83 m/s^2) and 245 N tension (acceleration of 7.45 m/s^2). The 200 N racket induced the least acceleration at the elbow.

Conclusions: Although parameters determining force transmission to the elbow during a tennis stroke are complex, the present study was able to control these parameters, isolating the effect of string-tension. Lower string-tensions transmit less force to the elbow in backhand strokes. Reducing string-tension should be considered favourably with respect to reducing the risk of developing LE.

Keywords

biomechanics, elbow, lateral epicondylitis, string-tension, tennis

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Introduction

Recent decades have seen an ever-increasing demand for higher performance in athletes. Driven to train intensely for longer periods, they are vulnerable to acute and overuse sports injuries. Additionally, as a result of improved health awareness and an increase in leisure time, more individuals of all ages perform recreational and competitive sports, increasing the overall incidence of sports-related pathologies.¹

Lateral epicondylitis (LE), the second most commonly diagnosed orthopaedic condition in the upper limb, affects 40% to 50% of all tennis players in their lifetime.^{2,3} LE occurs from excessive use of wrist

extensors and forearm supinators. The force imparted by ball-onto-racket during a backhand stroke is transmitted via wrist extensors to the common tendinous origin at the lateral epicondyle. The lack of wrist

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stability during backhand strokes and repetitive movements of the elbow hastens the progression of this condition.³ The primary site of injury is the origin of extensor carpi radialis brevis. The involvement of the origin of extensor digitorum communis is also seen in one third of patients with LE.⁴

Although the natural course of LE appears benign, with spontaneous recovery within 1 year or 2 years in most patients,⁵ there is significant detriment to quality of life, associated with severe pain accompanying activities of daily living, which produces significant handicap. Despite being first described in 1873,⁶ treatment modalities for LE remain debatable. Although a myriad of treatments are described, insufficient evidence exists to support one treatment over another.⁵ LE thus remains a significant cause of disability and work-related absence.

Several studies^{7–13} have investigated the effect of various factors influencing the development of LE in tennis players (racket head size, grip size, racket stiffness, vibration dampers, faulty technique).

However, no literature currently exists that describes, by practical observation, how varying string-tensions can impact force transmission through the wrist and elbow, and thus influence the risk of development of LE. The present study aimed to quantify the relationship between string-tension and force transmission during backhand tennis strokes, as well as the implications that this may have for development of LE, given that force dissipation through the wrist and arm are important factors in the development of LE.^{14,15} The general consensus is that lower string-tension transmits less force to the elbow, thereby reducing the risk of developing LE.

Backhand tennis strokes have been shown to invoke higher load transfer to the elbow via the extensor muscle group than forehand strokes in several studies^{7,10,11,12,16,17} and thus backhand stroke, which involves higher stresses on the elbow, was chosen for analysis.

Materials and methods

Participants

A total of 20 tennis players were recruited for this study [mean (SD) age 37.85 years (17.06 years)], which included 17 male and three female participants, with varying levels of experience, from recreational tennis players to regular tennis club coaches. All participants were right-handed and none had active elbow pathology on the day of study. Informed consent was obtained from the volunteers after the project was explained to them.

Experimental set-up and data collection

Three Karakal Coach 27 tennis rackets (Figure 1) were used and were strung at the most common tensions of 200 N, 222 N and 245 N, respectively. The rackets were otherwise identical (aluminium frame, string, 280 g frame weight, 710 cm² head size, grip size 10.47 cm) and were coded so that only the researcher could differentiate between rackets. A Tennis Cube TMB 180 ball machine (Figure 2) was used to project new Wilson US open (pressurized) tennis balls at a stationary racket held by each volunteer. Fifteen consecutive measurements of ball speed were made using Vicon®

Figure 1. Prepared subject.

Figure 2. Illustration of trial selection based on video recording.

motion analysis system (Vicon, Oxford, UK) and the mean (SD) speed of the ball at 2 m from the ball machine was found to be 15.66 m/s (0.46 m/s).

Volunteers were advised to hold the racket in a stationary backhand stroke position with the elbow flexed and at a distance of 2 m from the ball machine (Figure 1). They were also asked to hold the racket handle at the same place with a grip strength that would simulate their natural recoil and to maintain the same grip strength with all the three rackets. To standardize impact location, a circular area, with a diameter equal to that of a tennis ball, at the geometric centre of the racket face was chosen as the impact location. Video recording of the ball and racket interaction in all the trials was used to identify the impact location and to eliminate trials with off centre shots.

Accelerometers secured to the handle of each of the rackets, at the ulnar styloid and at the lateral epicondyle of the humerus recorded accelerations during ball–racket interaction. At the racket handle and at the wrist, dual axis accelerometers (MMA3202D; Freescale Semiconductor, Inc., Austin, TX, USA) with a sensitivity range of $\pm 100/50$ g each were used. A three-axis accelerometer (ADXL326; Analog Devices Inc., Norwood, MA, USA) with a sensitivity range of ± 16 g and frequency range of 0.5 Hz to 550 Hz was used at the elbow. At the racket handle, the accelerometer was secured firmly so that accelerations in the direction perpendicular to the face of the racket could be recorded. At the wrist and elbow, the accelerometers were fastened to the skin over the respective bony landmarks.

All volunteers were given a warm-up session with a separate racket dedicated solely for this purpose. Once the volunteers were confident, experimental trials were carried out with the rackets under investigation. The sequence in which the rackets were used for the trials was randomized for each volunteer to eliminate systemic bias that may arise as a result of the learning curve associated with this project. To accommodate off centre shots as a result of human error, each volunteer had to perform 15 trials per racket, out of which three proper trials were selected per racket for further analysis.

Selection of valid trials was determined by reference to video recordings of each of the trials. Frame-by-frame analysis of the video was performed for all trials. If, in the frame during ball strike, at least five strings were clearly visualized above and below the ball in contact, and seven strings clearly visualized between the ball and the tip of the racket, this indicated that the ball–racket interaction was within the target impact location defined for this study (Figure 2). Three such trials were selected per racket in each of the subjects for processing and analysis.

Data reduction and analysis

All electronic and digital data were recorded and processed on a desktop computer. The data from the accelerometers and from the camcorder were synchronized using Nexus, version 1.7.1 (Vicon) interface. Accelerations were recorded simultaneously from all three accelerometers and sampled at 400 Hz.

Accelerometers provide information about the rate of change in velocity, which is directly proportional to the force that initiated the movement. As soon as the ball struck the racket, a high acceleration was recorded by the accelerometer, which was immediately followed by acceleration in the opposite direction as a result of the elastic nature of the tissues, leading to an oscillating vibration that dampened over time (Figure 3). The recorded vibration signals had three different frequency patterns superimposed upon each other. Each of these signals had high-frequency waves (as a result of string vibration) that followed a mid-frequency pattern (as a result of a relatively slow soft tissue oscillation), which, in turn, followed a low frequency pattern (as a result of gross movement of the arm during recoil).

Because the amplitude of the high-frequency waves caused by the string vibration was of prime importance in the present study, the mid and low frequency waves were filtered using purpose designed software to reveal the high frequency waves (Figure 4). These high-frequency waves caused by string vibration were found to be at around 140 Hz. The filtered data from all the three axes at the elbow were combined to reveal the resultant acceleration (Figure 5). The peak amplitude of the resultant acceleration in each trial was extracted by the software. The acceleration data at the racket handle and wrist were processed similarly. The average of three peak amplitudes per racket per volunteer was calculated and used for further statistical analysis.

Figure 3. Typical accelerometer recording.

Figure 4. Pre- and postfilter graphs.

Figure 5. Resultant acceleration.

Results

Statistical analysis was performed using SPSS, version 17.0 (SPSS Inc., Chicago, IL, USA). The combined data from all volunteers were grouped racket wise

Table 1. Average peak acceleration at the elbow.

String-tension (N)	Average peak acceleration (m/s ²)	SE	95% Confidence interval	
			Lower bound	Upper bound
200	5.581	0.526	4.480	6.682
222	6.837	0.551	5.683	7.990
245	7.452	0.537	6.327	8.576

and analyzed using general linear model. $p < 0.05$ was considered statistically significant. Table 1 summarizes the global average of the peak accelerations recorded at the elbow with the three rackets.

Pairwise comparison of the accelerations recorded at the elbow revealed a statistically significant difference

Table 2. Pairwise comparison of string-tension (Significant *p* values in bold).

(I) tension (N)	(J) tension (N)	Mean difference (I – J)	SE	Significance	95% Confidence interval for difference	
					Lower bound	Upper bound
200	222	–1.256	0.247	0.000	–1.773	–0.738
	245	–1.870	0.358	0.000	–2.620	–1.121
222	200	1.256	0.247	0.000	0.738	1.773
	245	–0.615	0.323	0.072	–1.292	0.062
245	200	1.870	0.358	0.000	1.121	2.620
	222	0.615	0.323	0.072	–0.062	1.292

($p < 0.05$) between string-tensions of 200 N and 222 N, as well as 200 N and 245 N. However, no statistically significant difference ($p > 0.05$) was noted between string-tensions of 222 N and 245 N (Table 2). Nevertheless, the actual accelerometer readings showed a sequentially increasing peak amplitude with increasing racket tension.

Discussion

The literature reveals numerous studies that have explored the physics of tennis to explain how the variation of racket string-tension influences the mechanics of the sport. Several studies, however, have investigated the role of string-tension in improving the rebound speed or accuracy of the shot^{2,3,18-21} and one study analyzed the role of string-tension in the development of elbow pain.^{18,19} The vast majority of studies that investigate the effect of string-tension on forces transmitted to the elbow are based on finite element analysis and other computer simulations^{8,9,21,22} and very few are participant based. These have suggested that lower string-tensions provide more power and less impact on the arm, whereas higher tensions offer greater control.¹⁹ These simulations are, however, based on computer modelling, which idealizes the game environment, and several assumptions were thus made regarding variables that may interfere with energy transfer to the forearm.

Although rare, literature describing practical measurement of forces involved at the elbow during tennis strokes does exist. Walther et al.¹⁸ studied loading of the elbow during backhand tennis strokes but had a limited sample size and did not investigate the role of string tension.

Casolo and Ruggieri¹⁴ showed that an increase in either string-tension or ball speed resulted in greater energy dissipation throughout the arm. It has also been shown that lower string-tensions enable greater rebound velocity, although higher string-tensions

produce lower rebound angles, greater accuracy, and greater control of shot.^{23,24}

The present study aimed to determine the effect of racket string-tension on the amount of force transmitted to the elbow during backhand tennis strokes using tennis players as volunteers, with a practical, demonstrable, consistent methodology allowing control of almost all other variables involved in the backhand stroke. The clinical significance of this was to assess how string-tension can modulate forces dissipated at the elbow, a known factor in the risk of development of LE.

Measuring the forces going through the elbow during a tennis stroke has always been a challenging task because there is a lack of a practically feasible method that can be used to measure the forces quickly and in a large group of people. To calculate force, the racket–arm segment has to be considered as a separate unit in space. Because it is impossible to measure the exact mass of a body segment, the calculation of these forces can be achieved only if certain assumptions are made regarding the racket–arm segment. The two most commonly used methods to analyze the forces are by determining the forearm muscle firing patterns during a stroke using electromyography^{6,11,16,18,20} and by measuring the accelerations at the elbow by using accelerometers placed on bony prominences.^{1,20,25} Both of these parameters directly relate to elbow loading. By measuring the accelerations at the elbow, the present study aimed to determine the influence of string-tension on elbow loading.

Every aspect of the game of tennis is a variable that could potentially influence force transmission to the elbow during a stroke (properties of the racket, properties of the ball, property of the court, game conditions including ball speed, player dependent variables including grip strength, posture and experience, and so on). In an experimental set-up, it is difficult to control all such variables to evaluate one single factor. One of the most

difficult parameters to control is grip strength, which is also an important parameter in determining force transmission to the arm.^{8,11,17} It is predictable that, with higher grip strength, more force would be transmitted from the racket to the forearm, and thereby to the elbow, than with lower grip strength.

Previously, studies have tried to minimize the errors caused by variability in grip strength by comparing the accelerations recorded at the racket and those recorded at the wrist.^{22,26} Therefore, forces at the racket and wrist would be similar in all trials across the study and the variable would affect only the reading at the elbow. This enabled the use of the readings at the racket and wrist to control grip strength. In the present study, however, the variable under investigation was string-tension, which influences accelerometer readings at all three regions, namely racket, wrist and elbow. Hence, a similar method could not be adopted to control grip strength.

Only backhand tennis strokes were analyzed in the present study. Although both forehand and backhand strokes could potentially cause tennis elbow, one-handed backhand strokes cause a higher load transfer to the elbow via the extensor muscle group than forehand strokes.^{11,18} The volunteers in the present study were asked to hold the racket in a stationary one-handed backhand stroke position. Although this may not entirely represent a game condition, it allowed the monitoring and control of the impact location of the ball on the racket. Double-handed backhand techniques, although not investigated in the present study, could result in lower load transfer to the elbow. It could be hypothesized that, in two-handed backhands, the impact of the ball on the racket is dissipated through two upper limbs and across two elbows; thus, at each respective elbow, a lower force should be experienced. However, little evidence exists in the literature comparing single-handed with double-handed backhand strokes in force transmission at the elbow. Future studies should be directed towards determining this effect and the forces generated in this regard, which, in turn, may additionally affect risk of developing LE.

A close control on the impact location was necessary in the present study because, for the same string-tension, an off-centred shot produced an acceleration amplitude that was almost three times that of a shot on the defined target location. Trial selections in the past have been determined by subjective 'feel' of the player²² where trials that were categorized as 'ideal' by the players were selected for analysis. However, this is a subjective method of trial selection and does not ensure similar impact locations in all trials across the study. Other studies have centred on computer-modelled simulations^{2,22} with no practical trials performed. In some studies, trial selections were based on whether the player was able to strike the ball and

make it land on a target area.^{13,24} This method of trial selection need not necessarily mean that the ball–racket interaction was constantly in the middle of the racket in all trials. By these methods, consistency of impact location cannot be ensured. In the present study, trial selection was based on analysis of video recordings and only trials whereby the ball struck the racket within the defined impact location were selected.

The three-axis accelerometer at the elbow enabled measurement of accelerations produced in the *x*-, *y*- and *z*-axes during any trial. Previous studies used only double axis accelerometers^{18,26} and single axis accelerometers¹¹ to measure accelerations at the elbow. At the elbow, it is difficult to place the accelerometer with its axis along the direction of vibration and maintain this position throughout the trial session. Even minimal rotation of the upper limb or movement of the elbow during recoil would direct the accelerometer in a different direction, thereby providing a reading that may not be representative of the true force in that trial. In the present study, the acceleration amplitudes in all three axes of the accelerometer at the elbow were summed up to provide the resultant acceleration at the elbow. Hence, even if the position of the accelerometer was altered minimally, the resultant acceleration would be representative of the force in each of the trials.

Any tennis racket gradually loses string-tension over time as a result of stress relaxation. Among the three rackets used in the present study, the racket with 245 N string-tension could have lost tension relatively quicker than the other two rackets. This would explain the narrow margin between the acceleration data of 222 N and 245 N rackets. This theory of unequal loss of string-tension among the three rackets could be tested if we could measure the actual string-tensions of these rackets; however, there appears to be no practical method of measuring the string-tension of a racket after it has been strung. Nevertheless, all three rackets were tested individually using a universal testing machine. Five equally spaced points were selected within the defined impact location (Figure 2). Three stiffness readings were taken using the universal testing machine at each of those points. The average stiffness was calculated from these values and the procedure was repeated with all three rackets (Table 3).

The stiffness testing confirms that the string-tensions of the rackets are sequential. However, the narrow spacing between the stiffness of 222 N racket and 245 N racket also suggests that the string-tension of the 245 N racket could have declined more quickly than the other racquets.

We standardized racket size to ensure minimal bias and maximization of consistent validated data. However, it is possible that, by standardizing racket size in this way, some subjects were required to use racket sizes to which they were not accustomed,

Table 3. Average stiffness of strings within impact location.

String tension (N)	Stiffness (kN m ⁻¹)
200	16.277
222	18.711
245	19.659

introducing bias in our data. The present study focussed on ensuring as robust and controlled an environment as possible, such that we could assess our controlled variable superior accuracy and consistency. Thus, we concluded that a uniform racket size would be an important factor in providing the optimal controlled environment that we required, accepting the risk of some participants having suboptimal racket sizes as a result.

Conclusions

Racket string-tension is one factor in several that influence force transmission to the elbow in tennis players. Excessive force transmitted to the elbow and the extensor origin at the lateral epicondyle is known to be a significant factor in the development of LE. Thus, variables such as racquet string-tension that could have a significant impact on this risk should be adjusted to minimize the force transmission to the elbow during tennis strokes, especially if they can be adjusted without significant impact on the in-game performance of a tennis player. A robust model was constructed to assess the effect of tennis racquet string-tension on force transmission to the wrist and elbow, where other variables could be controlled, enabling us to study the isolated role of string-tension.

We conclude that reduction of string-tension within the limits of the racket reduces force transmission to the elbow, and thus decreases elbow loading. This may be hypothesized to have beneficial effects in risk of development of LE. Future observational studies are required to assess string tension and subsequent development of tennis elbow. It is also important to consider other factors that have been shown to have significant impact on the risk of LE development that could lead to tennis elbow. A player with poor technique is still at significant risk of developing tennis elbow even when all other risk factors are minimized.

Summary

What is already known in this field

- LE is common in tennis players
- The development of LE is significantly influenced by forces transmitted at the elbow, which has been

hypothesized to be influenced significantly by string tension

What this study adds

- The present study determines a quantitative relationship between the amount of elbow loading and varying string-tensions, and illustrates, by using a practical, consistent and demonstrable model, that increasing string-tension increases elbow loading in one-handed backhand tennis strokes
- We demonstrate for the first time that lower string-tensions would reduce load on the elbow, and thus reduce the dynamic stresses that are a significant factor in the risk of development of LE
- In tennis players with a predilection for developing LE, reducing string-tension should be considered favourably to reduce the risk of developing LE.

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Ethical Review and Patient Consent

Ethical Approval was granted by the University Research Ethics Committee (UREC), Reference UREC 11106.

Level of Evidence

III

References

1. Morris M, Jobe FW, Perry J, Pink M and Healy BS. Electromyographic analysis of elbow function in tennis players. *Am J Sports Med* 1989; 17: 241–7.
2. Riek S, Chapman AE and Milner T. A simulation of muscle force and internal kinematics of extensor carpi radialis brevis during backhand tennis stroke: implications for injury. *Clin Biomech* 1999; 14: 477–83.
3. Verhaar JA. Tennis elbow: anatomical, epidemiological and therapeutic aspects. *Int Orthop* 1994; 18: 263–7.
4. Kraushaar BS and Nirschl RP. Tendinosis of elbow (tennis elbow). *J Bone Joint Surg Am* 1999; 81: 259–78.

5. Groppel JL and Nirschl RP. A mechanical and electromyographical analysis of the effects of various joint counterforce braces on the tennis player. *Am J Sports Med* 1986; 14: 195–200.
6. Runge F. Zur Genese und Behandlung des Schreibekrampfes. *Berlin Klin Wochenschr* 1873; 21: 245–8.
7. Brody H. Vibration damping of tennis rackets. *Int J Sport Biomech* 1989; 5: 451–6.
8. Hatch GF, Pink MM, Mohr KJ, Sethi PM and Jobe FW. The effect of tennis grip size on forearm muscle firing patterns. *Am J Sports Med* 2006; 34: 1977–83.
9. Hatze H. The effectiveness of grip bands in reducing racket vibration transfer and slipping. *Med Sci Sports Exerc* 1992; 24: 226–30.
10. Hennig EM, Rosenbaum D and Milani TL. Transfer of tennis racket vibrations onto the human forearm. *Med Sci Sports Exerc* 1992; 24: 1134–40.
11. Li FX, Fewtrell D and Jenkins M. String vibration dampers do not reduce racket frame vibration transfer to the forearm. *J Sports Sci* 2004; 22: 1041–52.
12. Nesbit SM, Elzinga M, Herchenroder C and Serrano M. The effects of racket inertia tensor on elbow loadings and racket behavior for central and eccentric impacts. *Journal of Sports Science and Medicine* 2006; 5: 304–17.
13. Wu SW, Gross MT, Prentice WE and Bing Y. Comparison of ball-and-racquet impact force between two tennis backhand stroke techniques. *J Orthop Sports Phys Ther* 2001; 31: 247–54.
14. Casolo F and Ruggieri G. Dynamic analysis of the ball-racket impact in the game of tennis. *Meccanica* 1991; 26: 67–73.
15. De Smedt T, de Jong A, Van Leemput W, Lieven D and Van Glabbeek F. Lateral epicondylitis in tennis: update on aetiology, biomechanics and treatment. *Br J Sports Med* 2007; 41: 816–9.
16. Bauer JA and Murray RD. Electromyographic patterns of individuals suffering from lateral tennis elbow. *J Electromyogr Kinesiol* 1999; 9: 245–52.
17. Kawazoe Y, Tomosue R, Yoshinari K and Casolo F. Prediction of the shock vibrations at the wrist joint with the new large ball compared to the conventional ball during the forehand stroke. In: Miller S (ed.) *Tennis science & technology*. London: ITF Licensing Ltd, 2003, pp.105–12.
18. Wei SH, Chiang JY, Shiang TY and Chang HY. Comparison of shock transmission and forearm electromyography between experienced and recreational tennis players during backhand strokes. *Clin J Sport Med* 2006; 16: 129–35.
19. Li L, Yang SH, Hwang CS and Kim YS. Effects of string tension and impact location on tennis playing. *J Mech Sci Technol* 2009; 23: 2990–7.
20. Giangarra CE, Conroy B, Jobe FW, Pink M and Perry J. Electromyographic and cinematographic analysis of elbow function in tennis players using single- and double-handed backhand strokes. *Am J Sports Med* 1993; 21: 394–9.
21. Glynn JA, King MA and Mitchell SR. A computer simulation of one-handed backhand strokes to investigate elbow joint loading. In: Miller S and Capel Davies J (eds), *Tennis science and technology*. Vol. 3, London: ITF Licensing Ltd, 2007chapter 1: 105–12.
22. Glynn JA, King MA and Mitchell SR. A computer simulation model of tennis racket/ball impacts. *Sports Eng* 2011; 13: 65–72.
23. Bower R and Sinclair P. Tennis racket stiffness and string tension effects on rebound velocity and angle for an oblique impact. *J Hum Mov Stud* 1999; 37: 271–86.
24. Bower R and Cross R. String tension effects on tennis ball rebound speed and accuracy during playing conditions. *J Sports Sci* 2005; 23: 765–71.
25. Kelley JD, Lombardo SJ, Pink M, Perry J and Giangarra CE. Electromyographic and cinematographic analysis of elbow function in tennis players with lateral epicondylitis. *Am J Sports Med* 1994; 22: 359–63.
26. Walther M, Kirschner S, Koenig A, Barthel T and Gohlke F. Biomechanical evaluation of braces used for the treatment of epicondylitis. *J Shoulder Elbow Surg* 2002; 11: 265–70.