Upper Extremity Angular Kinematics of the One-Handed Backhand Drive in Tennis Players With and Without Tennis Elbow

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Wrist and elbow angular kinematics and racket acceleration at impact were measured in the tennis one-handed backhand drive for three groups of players: Professionals with no history of tennis elbow (PRO), intermediates with no history of tennis elbow (–TE), and intermediates with a history of tennis elbow (+TE). Electrogoniometer, strain gauge, and accelerometer signals were sampled for thirty strokes at 1000 Hz. The first ten strokes with central impacts were analyzed. Angular kinematics and racket acceleration at impact were analyzed with planned comparisons ANOVA. A significant ($p < 0.05$) difference in mean wrist angular velocity after impact was observed between the PRO group (–4.04 rad/s of extension) and the +TE group (0.42 rad/s of flexion). No significant differences were observed in impact acceleration or elbow angular kinematics. Eccentric wrist extensor muscular actions through impact may be an important area of study for one-handed backhands and TE.

Key words: Tennis elbow, backhand, eccentric, wrist, muscle

Introduction

Tennis elbow (TE) is an umbrella term describing medial and lateral elbow pain from a variety of activities. This paper will use the term TE to refer to lateral epicondylitis, which in tennis is most frequently identified as an overuse injury of the extensor carpi radialis brevis (11, 13, 18, 25, 26, 30). The terms tendinitis or tendinosis more precisely describe the pathological changes near the lateral epicondyle in TE (26). Up to 50% of tennis players develop TE (11), and there is clinical and epidemiological evidence of a link between the tennis one-handed backhand and TE (7, 24, 29).

Many studies have attempted to identify factors in the one-handed backhand that may be related to TE (2, 6, 9, 10, 12, 14, 21). A recent goniometric and EMG study of wrist function has identified eccentric wrist extensor muscle actions prior to and after impact in the one-handed backhand drives of novice tennis players (3). This is an important line of research since eccentric muscle actions have been associated with large muscle forces and injuries to the musculotendinous unit (1, 4, 8, 19, 20, 23, 32, 33).

The angular kinematics of both the wrist and elbow during the tennis one-handed backhand are needed because the wrist extensors cross the wrist and elbow joint. Angular kinematic data would also provide evidence of the muscular actions of the wrist extensors that are injured in TE. Unfortunately, ball impact gives these signals high frequency components requiring high sampling rates. Measurement of wrist and elbow angular motions with the light-weight and flexible Penny & Giles electrogoniometers would provide an analog signal, that may be free of post-impact artifact observed with rigid goniometers (3). Penny and Giles electrogoniometers have been used to study a variety of human movements (16, 27, 31). The purpose of this study was to examine wrist and elbow angular kinematics and impact acceleration of the racket during the tennis one-handed backhand for players with various skill levels and histories of TE. This would provide further data on the hypothesis that eccentric muscle actions of the wrist extensors may be associated with TE.

Material and Methods

Subjects

Sixteen male volunteers with a mean (SD) age and mass of 35 (11) years and 78.9 (11.3) kg gave informed consent to participate in the study. The study was approved by the Baylor University Committee for the Protection of Human Subjects in Research. The subjects were right-handed and normally used a one-handed backhand. Subjects were selected into one of three groups: tennis professionals (n = 5) with no history of TE (PRO), intermediates (n = 6, National Tennis Rating Program 3.5 to 4.5) with no history of TE (–TE), or intermediates with a medically confirmed history of TE (n = 5) that are now pain-free (+TE). All +TE subjects received conservative treatment for their lateral epicondylitis. Selected descriptive data are presented in Table **1**.

Table 1 Medical history of subjects with lateral epicondylitis

Subject	1	2	3	4	5
Age (years)	52	45	36	48	50
Tennis Experience (years)	38	6	20	20	26
Time since Injury (years)	2	1	2	6	4
Recovery Time (months)	4	3	10	6	6
Technique Change Pescribed	No	Yes	No	No	Yes
Grip Strength (kgf)	49.9	52.2	72.6	55.3	44.0

The mean grip strength of these subjects 54.8 ± 10.8 kgf was not significantly different from the mean strength of the – TE (57.2 ± 7.5) or the PRO subjects (64.2 ± 15.2) (mean ± SD).

Instrumentation

A midsized composite racket was strung with nylon at 267 N (60 lbs) of tension. The racket weighed 362 g and was instrumented with four strain gauges in a full-bridge configuration to transduce torsional strain (15). The torsion created by off-center impacts has been related to the large variability of post-impact force loading (17,28). A Dytran low-mass triaxial accelerometer (3016A) was bolted to the throat of the racket and wired to Dytran 4113 power supply. Strain gauge signals were amplified by a Micromeasurements 2100 amplifier. Two Penny & Giles electrogoniometers (M180 and M110) were taped to the wrist and elbow of the subjects. For the wrist flexion/extension angle the M110 goniometer was placed across the transverse joint axis with the dorsal side of the hand and forearm, aligned with the longitudinal axis of the third metacarpal and the longitudinal axis of the forearm. For elbow flexion/extension the M180 goniometer was placed across the transverse joint axis on the lateral side of the arm, oriented along the longitudinal axis of the forearm and upper arm.

One channel of these goniometers was connected to a K100 Penny and Giles amplifier. Strain gauge, electrogoniometer, and accelerometer signals were monitored by A/D conversion and AXOTAPE 2.0 software. Data were stored on magnetic tape through the use of a pulse code modulator recording adapter (Vetter 3000A) at 10,000 Hz. Stored data were then sampled at 1000 Hz per channel by the analog sampling module of the Peak Performance Technologies software.

Protocol

Prior to data collection subjects gave informed consent, answered demographic questions, and performed maximal grip strength tests on a hand dynamometer (Table **1**). Pain-free grip strength has been shown to be a good measure of recovery from tennis elbow (34). Subjects were instructed to perform their best flat one-handed backhand down the center of a court that was laid out in a gymnasium. The subjects warmed up and practiced the strokes before data were collected. The goniometers were attached to the subject's racket arm, and Electrogoniometer data were collected with the subject holding maximal flexion and extension of the wrist and elbow. New tennis balls were projected from a Match Mate ball machine at a frequency and ball speed similar to a baseline rally. A minimum of thirty strokes were sampled and stored on tape.

Analysis

Data were analyzed with Peak Performance software. The first ten trials with central impacts (minimal strain gauge output) were selected for analysis. The impulse of impact was calculated by integrating the rectified acceleration normal to the racket face for the 100 m after impact (10) because signals in the other directions were negligible. Joint angular positions and velocities before and after impact were calculated. The velocities were determined by finite differences between ±22 ms to ±2 ms relative to impact because of the quality of the analog signals. Statistical analyses were made with Planned Comparisons ANOVA to maximize statistical power with the small samples of subjects. Comparisons were planned between the + TE group and professional group, and between the + TE group and the – TE group to examine players with and without TE. Statistical significance was accepted at $p < 0.05$, and data are reported as mean and standard deviation (SD).

Results

ANOVA analysis demonstrated no significant differences for any angular kinematic variable prior to impact (Table **2**). All subjects used correct one-handed backhand technique with the elbow almost completely extended during the stroke.

Table 2 Angular kinematics before impact.

Group	Elbow θ	Elbow ϖ	Wrist θ	Wrist ϖ
+ TE	2.65 (0.22)	0.60 (1.99)	– 0.53 (0.19)	0.10 (2.05)
– TE	2.73 (0.17)	1.88 (2.79)	– 0.28 (0.32)	– 1.30 (1.03)
PRO	2.78 (0.17)	0.18 (0.94)	– 0.27 (0.35)	– 2.50 (2.75)

Data are reported as mean and (sd) in radians and radians per second, with elbow extension and wrist flexion positive. θ = joint angle, ϖ 0 joint angular velocity, + TE are intermediate subjects with previous tennis elbow, – TE are intermediate subjects without tennis elbow, and PRO are tennis professionals without tennis elbow.

The mean impulse after impact was not significantly different for the three groups. There was no significant difference between mean elbow angular position or velocity after impact. There was a significant ($F_{(1,13)} = 4.90$, $p < 0.05$) difference in wrist angular velocity after impact between the + TE group and the professional group (Table **3**). The mean (– 4.40 rad/s) wrist extension velocity after impact in the PRO group was significantly different from the 0.42 rad/s of wrist flexion in the + TE group. The – TE group had a mean wrist extension angular velocity after impact of – 1.3 rad/s, but this was not significantly different from the + TE group.

Discussion

Previous studies of tennis players have hypothesized that errors in one-handed backhand technique (leading elbow) may contribute to the development of TE (2,3,5,12,24,25,30). Since this was a retrospective study, is not known how the present + TE subjects developed TE but they currently had correct back-

Table 3 Angular velocity after impact.

Group	Elbow	Wrist
+ TE	1.74 (1.45)	*0.42 (3.88)
– TE	0.10 (5.88)	– 1.30 (1.05)
PRO	1.22 (0.63)	*– 4.04 (2.16)

Data are reported as mean and (sd) in radians per second with elbow extension and wrist flexion positive.
*$p < 0.05$

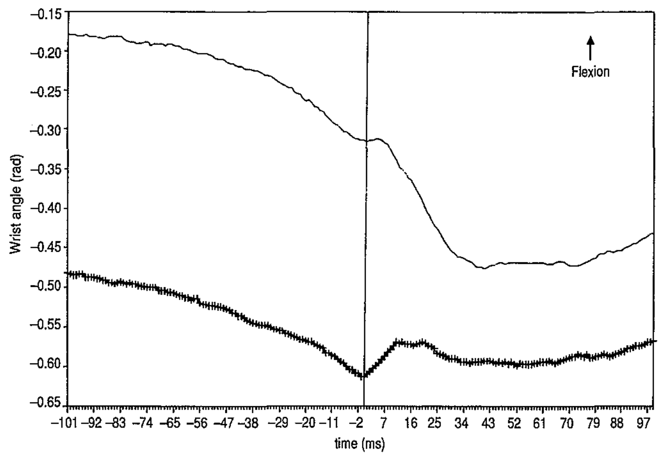

Fig. 1 Typical wrist angular position data of the one-handed backhand for a professional (-----) and an intermediate player with a history of tennis elbow (+++++). At impact (t = 0) the wrist of the + TE subject is forced into wrist flexion, while the PRO subject is able to maintain concentric action of the wrist extensors.

hand technique at the elbow. The elbow goniometer data demonstrated that the intermediate level subjects in this study were skilled enough not to use the leading elbow technique common in novices.

The mean hyperextended wrist position before impact for the subjects in the present study (– 0.36 rad) was similar to the mean wrist angle (0.4 rad) previously reported for expert players (3). The mean wrist extension velocity prior to impact for expert players (– 1.7 rad/s) reported in Blackwell and Cole (3) was also similar to the mean observed for the professional group (– 2.5 rad/s). There was a nonsignificant trend of – TE subjects to have less wrist extension prior to impact (– 1.3 rad/s), while the + TE subjects had a mean wrist flexion velocity (0.1 rad/s) prior to impact. The wrist angular kinematics for representative trials from a professional and a + TE subject are illustrated in Fig. **1**.

Since EMG studies have shown strong activation of wrist extensors before and after impact in tennis one-handed backhands (3,5,12,21,22), wrist angular velocity after impact would give an indication of the kind of muscle action of the wrist extensors. All the professional subjects were extending their wrists after impact and had a mean angular velocity of – 4.04 (2.16) rad/s. This was significantly ($p < 0.05$) different from a mean wrist flexion velocity of the + TE group of 0.43 (3.88). This mean difference had an effect size of 1.27, showing the importance of this difference between professional and + TE subjects. PRO and – TE subjects were able to maintain concentric action of the wrist extensor muscles after impact in tennis one-handed backhands, while the + TE subjects tended to have eccentric muscle actions of the wrist extensors after impact. It is unknown if this wrist extension velocity was due to wrist extensor strength or other factors.

The greater muscle stress in repeated eccentric muscle actions of the wrist extensors may be an important factor in developing TE. This hypothesis is supported by a previous study finding greater EMG activity in the wrist extensors during and after impact in subjects with TE compared to subjects without TE (12). The study of eccentric muscular overload of the wrist extensor muscles in one-handed backhands may be an important area of TE research. The combination of EMG and light-weight goniometers may provide important information in understanding wrist muscle actions in tennis. Future studies of TE and one-handed backhands should focus on muscle actions, wrist extensor strength, and the wrist angular velocity after impact.

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