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# Injury trend analysis from the US Open Tennis Championships between 1994 and 2009

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## ABSTRACT

**Objective** Injuries can be a debilitating aspect of professional tennis. Injury rates and trends at the US Open Tennis Championships over multiple years are unknown. The purpose of this study was to examine injury trends in professional tennis players competing in a major professional tennis tournament between 1994 and 2009.

**Methods** From 1994 to 2009, injury data from the US Open Tennis Championships were recorded. Injuries were classified by location and type using terminology derived from a consensus statement developed specifically for tennis. Injury rates were determined based on the exposure of an athlete to a match event, and were calculated as the ratio of injuries per 1000 match exposures (MEs).

**Results** There was a statistically significant fluctuation in injuries across the timeframe analysed ($p<0.05$). There were $76.2\pm19.6$ total injuries and $43.8\pm11.8$ acute injuries per year seeking medical assistance. Muscle or tendon injuries were the most common type of acute injury. The rate of lower limb injuries was significantly higher than upper limb and trunk injuries ($p<0.01$). The ankle, followed by the wrist, knee, foot/toe and shoulder/clavicle were the most common injury sites.

**Conclusions** Acute injuries occurred more frequently than gradual-onset injuries, and most common injury types were similar to previously examined populations. However, there were differences in injury location trends compared to previous research, suggesting that further research in this elite-level population is warranted.

## INTRODUCTION

Injuries disrupt training and competition in professional tennis players.[1 2] Common injuries in tennis players include, but are not limited to, stress fractures, tendon injuries and muscle tears.[3–5] In non-junior, elite-level tennis players, the lower extremity[6 7] and upper extremity[8] have both been reported as the sites with the highest incidence of injury. However, injury prevalence and incidence vary considerably depending on the data source examined and the classification system adopted.[2]

Identifying areas of susceptibility to injury helps the medical community and allied health professionals develop preventative or prehabilitation programmes, as well as more effective postinjury interventions. While some research has been published on injury trends in elite-level tennis players, it has primarily consisted of short-term prospective and cross-sectional studies,[6 9] with one retrospective cohort study conducted over a 15-year follow-up in college students.[10] To the authors' knowledge minimal descriptive epidemiological studies have been conducted on elite-level, *professional* players. Furthermore, there has previously been a lack of procedural conformity concerning definitions for illnesses or injuries, severity of condition and additional information related to the nature of the condition.[2] In 2009, a consensus statement[1] was developed specifically for tennis to guide documentation and analysis of tennis injury-related data for research purposes. This consensus statement presented a classification system for reporting characteristics of a given injury, but is yet to be utilised to analyse injury patterns in elite-level tennis players.

Given the prestigious nature of the US Open Tennis Championships and the fact that it is held deep into the year-long professional tennis season, surveillance data collected during this tournament may provide valuable insight into longitudinal injury trends in professional tennis players. Therefore, the purpose of this study was to examine injury trends in tennis players during the US Open Tennis Championships over a 16-year period using the classification system outlined in the 2009 consensus statement.[1] The injury trends identified in this study will help highlight reoccurring and common areas of injury in elite-level tennis players. The study may help build on current knowledge and practice within physical conditioning and medical education programmes, and assist future research addressing sport-specific and population-specific risk factors and injury-related ramifications of playing professional tennis.[11 12]

## METHODS

The injury data were collected from the US Open Tennis Championships from 1994 to 2009. Any injury case included in the data analysis was defined as an injury that required a medical evaluation by a tournament physician during the US Open. Men and women competing in the qualifying and main draw tournaments (singles, doubles or mixed doubles) were included in this study. Junior US Open and wheelchair tournament players were excluded from this study. The injury classification system developed by Pluim *et al*[1] was used to categorise injury type and location, manner of onset (acute or gradual) and exposure (match or training).

Prior to data recording, each case was assigned an identification number, and all study data were recorded on a separate sheet from the original paperwork with the player name and identifying information removed. Cases were identifiable by their identification number only. Injuries were identified and documented by the medical staff affiliated with the US Open Tennis Championships (Chief Medical Officer and Director of Player Medical Services). Approval for this study was obtained from the

United States Tennis Association (USTA) Medical Office and the Hofstra University Institutional Review Board.

### Exposure and availability for match-play

Each medical report form also documented whether the injury occurred during match-play or training, and if the injury resulted in unavailability for match-play, withdrawal from match-play or retirement from the tournament. No further information describing the circumstances leading to the condition was included in the current analysis as this information was not always known to the player, coaching or medical staff, or was not documented on the original medical form. Since the data analysed in this study were limited to a physician evaluation at a tournament with limited follow-up information available for the tennis players, the approach suggested by Pluim *et al*[1] for reporting severity by duration of playing time lost was not possible for all cases. All matches were played on hard courts (DecoTurf with asphalt base).

### Injury classification

Multiple injury types and locations were grouped together under a single injury classification.[1] The type of injury was classified as (1) bone, (2) joint (non-bone) and ligament, (3) muscle and tendon, (4) skin, (5) central/peripheral nervous system or (6) other. The injury location was classified using the categories of (1) head and neck, (2) upper limbs, (3) trunk, (4) lower limbs and (5) other. Each injury was further subdivided under each type and location classification. For example, under the injury type grouping muscle and tendon, injuries were subdivided into (1) muscle rupture, tear, spasm or cramp (RTSC), or (2) tendon tear, tendinopathy or bursitis (TTB).

### Statistical analysis

Data were analysed using frequencies, linear regression and non-parametric cross-tabulation procedures ($\chi^2$ and Fisher's exact tests), using the PASW Statistics 17 software (SPSS Inc., Chicago, Illinois, USA), and rate ratios and CI using previously established methods.[13] For regression analysis, the year was considered the independent variable and the number of injuries was considered the dependent variable, which is an approach consistent with previous research exploring injury and illness trends in other sports.[4 14 15] Unless specified otherwise, $p<0.05$ was used as an acceptable level of significance for all analyses.

Injury rates were reported as injuries per 1000 match exposures (MEs). Tennis players are not required to train at the same facility during a tournament, and the data in this study were collected in this retrospective study by medical personnel in a clinical setting with the goal of evaluation and treatment of the athlete's presenting complaints. Therefore, although Pluim *et al*[1] recommend reporting incidence rates using playing hours, the calculation of incidence based upon a calculation of training versus competition hours was not possible in this study. Total ME during the US Open Tennis Championships, as opposed to playing hours, was used as an analysis tool to estimate injury rates. MEs were determined using two exposures for each singles match (two players per match), and four exposures for each doubles match (four players per match). The determination of injury rates per 1000 matches (vs playing hours) has been used in previous research.[9 16]

## RESULTS

During 1994–2009, there were 1219 documented injury reports involving the men's and women's qualifying and main draw players at the US Open Tennis Championships. Injury rates were higher during the qualifying tournament versus the main draw (58.5 vs 44.0 per 1000 MEs, rate ratio=1.33, 95% CI 1.18 to 1.49). The descriptive data for injuries and distribution of injury rates between 1994 and 2009 in men, women and overall are shown in table 1 and figure 1. There were significant trends in the injury rates for men ($p<0.05$), women ($p<0.05$) and overall ($p<0.05$) (figure 1).

### Exposure and availability for match-play

Acute injuries accounted for significantly more injury-related requests for medical assistance than gradual-onset or chronic injuries (27.65 vs 19.51 per 1000 MEs, rate ratio=1.42, 95% CI 1.12 to 1.59, $p<0.05$). A higher rate of injuries, acute or chronic, was attributed to ME as opposed to training (40.48 vs 5.13 per 1000 MEs, rate ratio=7.89, 95% CI 6.57 to 9.47) (tables 1 and 2). Minimal differences were shown between the percentages of acute and gradual-onset injury cases that were unavailable for play and withdraw from match-play (table 1).

**Table 1** Descriptive and incidence data for injury classification for men, women and overall at the US Open tournament between 1994 and 2009

| | Women (n=515) | | | Men (n=704) | | | Overall (n=1219) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total cases | Injury rate per 1000 MEs | 95% CI | Total cases | Injury rate per 1000 MEs | 95% CI | Total cases | Injury rate per 1000 MEs | 95% CI |
| Average per year | 32.19±14.73 | 40.64 | 26.64 to 54.64 | 44.00±7.55 | 55.56 | 39.14 to 71.98 | 76.2±19.6 | 48.10 | 37.31 to 58.89 |
| Exposure | | | | | | | | | |
| Match | 447 | 35.27 | 32.00 to 38.54 | 580 | 45.77 | 42.05 to 49.49 | 1026 | 40.48 | 38.00 to 42.96 |
| Training | 42 | 3.31 | 2.31 to 4.31 | 88 | 6.94 | 5.49 to 8.45 | 130 | 5.13 | 4.24 to 6.01 |
| Unknown | 26 | 2.05 | 1.26 to 2.84 | 36 | 2.84 | 1.91 to 3.77 | 63 | 2.49 | 1.88 to 3.10 |
| Availability for match-play | | | | | | | | | |
| Yes | 432 | 34.09 | 30.88 to 37.30 | 579 | 45.69 | 41.97, 49.41 | 1011 | 39.89 | 37.43 to 42.35 |
| No | 82 | 6.47 | 5.07 to 7.87 | 124 | 9.79 | 8.07 to 11.51 | 206 | 8.13 | 7.02 to 9.24 |
| Unknown | 1 | 0.08 | −0.07 to 0.23 | 1 | 0.08 | −0.07 to 0.23 | 2 | 0.08 | −0.03 to 0.19 |
| Withdrawal from match-play | | | | | | | | | |
| Yes | 75 | 5.92 | 4.58 to 7.26 | 88 | 6.94 | 5.49 to 8.45 | 163 | 6.43 | 5.44 to 7.42 |
| No | 440 | 34.72 | 31.48 to 37.96 | 616 | 48.61 | 44.77 to 52.45 | 1056 | 41.67 | 40.39 to 42.95 |
| Retired from tournament | | | | | | | | | |
| Yes | 19 | 1.50 | 083 to 2.17 | 49 | 3.87 | 2.79 to 4.95 | 68 | 2.68 | 2.04 to 3.32 |
| No | 496 | 39.14 | 35.70 to 42.58 | 655 | 51.69 | 47.73 to 55.65 | 1151 | 45.42 | 42.79 to 48.04 |

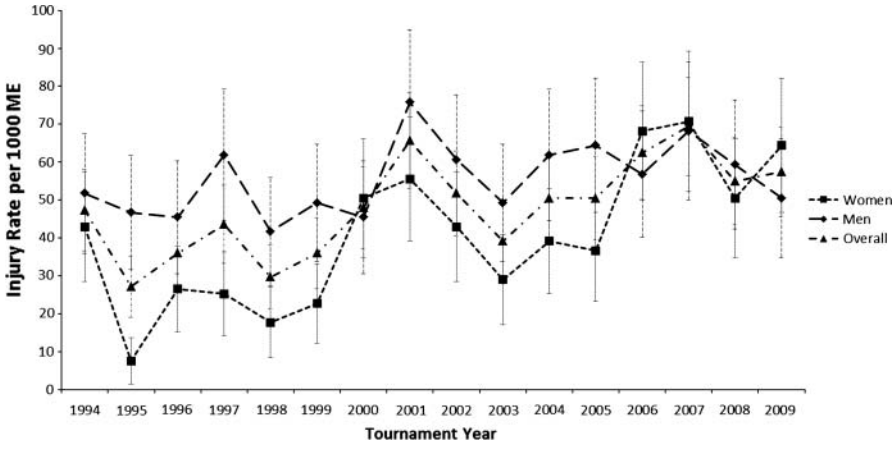


**Figure 1** Injury rates for men, women and overall in players at the US Open tournament between 1994 and 2009.

Only 6 of the 163 cases that involved an injury necessitating withdrawal from immediate match-play also resulted in retirement from the tournament (possibly due to lack of ongoing involvement in another event).

### Injury type

Muscle or tendon injuries accounted for a significant majority of all injuries seeking medical assistance (40.56 vs 7.54 per 1000 MEs, rate ratio=7.54, 95% CI 6.43 to 8.80, p<0.05) (tables 2 and 3). This finding was consistent across both acute and gradual-onset injuries (table 2). Muscle and tendon injuries were significantly higher in men than in women (47.74 vs 33.38 per 1000 MEs, rate ratio=1.43, 95% CI 1.26 to 1.62), and men were three times as likely to experience a nervous system-related injury (0.71 vs 0.24 per 1000 MEs, rate ratio=3.00, 95% CI 0.83 to 11.38).

**Table 2** Descriptive data for acute and gradual-onset injuries in tennis players at the US Open tournament between 1994 and 2009

| | Injury cases (n=1219)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Acute injuries: 1994–2009 (n=701) | | | | Gradual-Onset Injuries: 1994–2009 (n=495) | | | |
| | Cases | Percentage of injuries | Injury rate per 1000 MEs | 95% CI | Cases | Percentage of Injuries | Injury rate per 1000 MEs | 95% CI |
| Average per year | 43.8±11.8 | 57.48 | 27.65 | 19.46 to 35.84 | 30.9±10.0 | 40.55 | 19.51 | 12.63 to 26.39 |
| Exposure | | | | | | | | |
| Match | 607 | 86.5 | 23.95 | 22.04 to 25.86 | 414 | 83.6 | 16.34 | 14.77 to 17.91 |
| Training | 71 | 10.1 | 2.80 | 2.15 to 3.45 | 59 | 11.9 | 2.33 | 1.74 to 2.92 |
| Unknown | 24 | 3.4 | 0.95 | 0.57 to 1.33 | 22 | 4.5 | 0.87 | 0.68 to 1.06 |
| Availability for match-play | | | | | | | | |
| Yes | 575 | 82.1 | 22.69 | 20.84 to 24.54 | 416 | 84.0 | 16.41 | 14.83 to 17.99 |
| No | 125 | 17.8 | 4.93 | 4.07 to 5.79 | 79 | 16.0 | 3.12 | 2.43 to 3.81 |
| Unknown | 1 | 0.1 | 0.04 | −0.03 to 0.12 | 0 | 0 | 0 | 0 |
| Withdrawal from match-play | | | | | | | | |
| Yes | 94 | 13.4 | 3.71 | 2.96 to 4.46 | 69 | 13.9 | 2.72 | 2.08 to 3.36 |
| No | 607 | 86.6 | 23.95 | 22.04 to 25.86 | 426 | 86.1 | 16.81 | 15.21 to 18.41 |
| Retired from tournament | | | | | | | | |
| Yes | 50 | 7.1 | 1.97 | 1.42 to 2.52 | 17 | 3.4 | 0.67 | 0.35 to 0.99 |
| No | 651 | 92.9 | 25.69 | 23.72 to 27.66 | 478 | 96.6 | 18.86 | 17.17 to 20.55 |
| Type of injury | | | | | | | | |
| Bone | 18 | 2.6 | 0.71 | 0.38 to 1.04 | 7 | 1.4 | 0.28 | 0.08 to 0.48 |
| Joint/ligament | 24 | 3.4 | 0.95 | 0.57 to 1.33 | 32 | 6.5 | 1.26 | 0.82 to 1.70 |
| Muscle/tendon | 589 | 84.0 | 23.24 | 21.36 to 25.12 | 434 | 87.7 | 17.12 | 15.51 to 18.73 |
| Skin | 42 | 6.0 | 1.66 | 1.16 to 2.16 | 10 | 2.0 | 0.39 | 0.15 to 0.63 |
| Nervous system | 10 | 1.4 | 0.39 | 0.15 to 0.63 | 2 | 0.2 | 0.08 | −0.03 to 0.19 |
| Unspecified/other† | 18 | 2.6 | 0.71 | 0.38 to 1.04 | 10 | 2.0 | 0.39 | 0.15 to 0.63 |
| Location of injury | | | | | | | | |
| Head/neck | 12 | 1.7 | 0.47 | 0.20 to 0.74 | 3 | 0.6 | 0.12 | −0.01 to 0.25 |
| Upper limbs | 238 | 34.0 | 9.39 | 8.20 to 10.58 | 208 | 42.0 | 8.21 | 7.06 to 9.33 |
| Trunk | 105 | 15.0 | 4.14 | 3.35 to 4.93 | 48 | 9.7 | 1.89 | 1.35 to 2.43 |
| Lower limbs | 343 | 48.9 | 13.53 | 12.10 to 14.96 | 236 | 47.7 | 9.31 | 8.12 to 10.50 |
| Unspecified | 3 | 0.4 | 0.12 | −0.01 to 0.25 | 0 | 0 | 0 | 0 |

*Including 23 cases for which the onset was unknown.
†Unspecified/other=visceral, dental and undiagnosed injuries.

**Table 3** Descriptive and incidence data for injury type and location for men, women and overall at the US Open tournament between 1994 and 2009

| | Women (n=515) | | | Men (n=704) | | | Overall (n=1219) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cases | Injury rate per 1000 MEs | 95% CI | Cases | Injury rate per 1000 MEs | 95% CI | Cases | Injury rate per 1000 MEs | 95% CI |
| Injury type | | | | | | | | | |
| Bone | 13 | 1.03 | 0.47 to 1.59 | 12 | 0.95 | 0.41 to 1.49 | 25 | 0.99 | 0.60 to 1.38 |
| Joint/ligament | 28 | 2.21 | 1.39 to 3.03 | 29 | 2.29 | 1.46 to 3.12 | 57 | 2.25 | 1.67 to 2.83 |
| Muscle/tendon | 423 | 33.38 | 30.20 to 36.56 | 605* | 47.74 | 43.94 to 51.54 | 1028 | 40.56 | 38.08 to 43.04 |
| Skin | 27 | 2.13 | 1.33 to 2.93 | 26 | 2.05 | 1.26 to 2.84 | 53 | 2.09 | 1.53 to 2.65 |
| Nervous system | 3 | 0.24 | −0.03 to 0.51 | 9* | 0.71 | 0.25 to 1.17 | 12 | 0.47 | 0.20 to 0.74 |
| Unspecified/other† | 39‡ | 3.08 | 2.11 to 4.05 | 5 | 0.39 | 0.04 to 0.74 | 44 | 1.74 | 1.23 to 2.25 |
| Injury location | | | | | | | | | |
| Head/neck | 7 | 0.55 | 0.14 to 0.96 | 9 | 0.71 | 0.25 to 1.17 | 16 | 0.63 | 0.32 to 0.94 |
| Head/face | 0 | 0 | 0 | 3 | 0.24 | −0.03 to 0.51 | 3 | 0.12 | −0.01 to 0.25 |
| Neck/C-Spine | 7 | 0.55 | 0.14 to 0.96 | 6 | 0.47 | 0.09 to 0.85 | 13 | 0.51 | 0.23 to 0.79 |
| Upper limbs | 193 | 15.23 | 13.08 to 17.38 | 255 | 20.12 | 17.65 to 22.59 | 448 | 17.68 | 16.04 to 19.32 |
| Shoulder/clavicle | 61 | 4.81 | 3.60 to 6.02 | 93* | 7.34 | 5.85 to 8.83 | 154 | 6.08 | 5.12 to 7.04 |
| Upper arm | 4 | 0.32 | 0.01 to 0.63 | 12* | 0.95 | 0.41 to 1.49 | 16 | 0.63 | 0.32 to 0.94 |
| Elbow | 25 | 1.97 | 1.20 to 2.74 | 49* | 3.87 | 2.79 to 4.95 | 74 | 2.92 | 2.25 to 3.59 |
| Forearm | 8 | 0.63 | 0.19 to 1.02 | 4 | 0.32 | 0.01 to 0.63 | 12 | 0.47 | 0.20 to 0.74 |
| Wrist | 70 | 5.52 | 4.23 to 6.81 | 74 | 5.84 | 4.51 to 7.17 | 144 | 5.68 | 4.75 to 6.61 |
| H/F/T | 25 | 1.97 | 1.20 to 2.74 | 23 | 1.82 | 1.08 to 2.56 | 48 | 1.89 | 1.35 to 2.43 |
| Trunk | 60 | 4.73 | 3.53 to 5.93 | 95 | 7.50 | 5.99 to 9.01 | 155 | 6.12 | 5.16 to 7.08 |
| Sternum/ribs/UB§ | 22 | 1.74 | 1.01 to 2.47 | 29* | 2.29 | 1.45 to 3.12 | 51 | 2.01 | 1.46 to 2.56 |
| Abdomen | 13 | 1.03 | 0.47 to 1.59 | 33* | 2.60 | 1.71 to 3.49 | 46 | 1.82 | 1.30 to 2.34 |
| LB/pelvis/sacrum | 25 | 1.97 | 1.20 to 2.74 | 33 | 2.60 | 1.71 to 3.49 | 58 | 2.29 | 1.70 to 2.88 |
| Lower limbs | 246 | 19.41 | 16.98 to 21.84 | 337 | 26.59 | 23.75 to 29.43 | 583 | 23.00 | 21.13 to 24.87 |
| Hip/groin¶ | 24 | 1.89 | 1.13 to 2.65 | 48* | 3.79 | 2.72 to 4.86 | 72 | 2.84 | 2.18 to 3.50 |
| Thigh | 24 | 1.89 | 1.13 to 2.65 | 50* | 3.95 | 2.86 to 5.04 | 74 | 2.92 | 2.25 to 3.59 |
| Knee | 70 | 5.52 | 4.23 to 6.81 | 96 | 7.58 | 6.06 to 9.10 | 166 | 6.55 | 5.55 to 7.55 |
| Lower leg/AT | 14 | 1.10 | 0.52 to 1.68 | 16 | 1.26 | 0.64 to 1.88 | 30 | 1.18 | 0.76 to 1.60 |
| Ankle | 52 | 4.10 | 2.98 to 5.22 | 65 | 5.13 | 3.88 to 6.38 | 117 | 4.62 | 3.78 to 5.46 |
| Foot/toe | 62 | 4.89 | 3.67 to 6.11 | 62 | 4.89 | 3.67 to 6.11 | 124 | 4.89 | 4.03 to 5.75 |
| Unspecified | 9 | 0.71 | 0.25 to 1.17 | 8 | 0.63 | 0.19 to 1.07 | 17 | 0.67 | 0.35 to 0.99 |
| Overall | 515 | 40.64 | 37.13 to 44.15 | 704* | 55.56 | 51.46 to 59.66 | 1219 | 48.10 | 45.40 to 50.80 |

*Statistically higher than women ($p<0.05$).
†Unspecified/other=visceral, dental and undiagnosed injuries.
‡Statistically higher than men ($p<0.05$).
§Including injuries to the mid-back or thoracic region.
¶Including injuries to the gluteal muscles.
AT, Achilles tendon; C-Spine, cervical spine; H/F/T, hand/finger/thumb; LB, lower back; UB, upper back.

The number of cases of RTSC-related injuries was significantly higher than TTB-related injuries (13.02 vs 10.22 per 1000 MEs, rate ratio=1.27, 95% CI 1.08 to 1.49, $p<0.05$), although minimal differences were observed overall (20.71 vs 19.85 per 1000 MEs, rate ratio=1.04, 95% CI 0.92 to 1.18). The highest number of acute RTSC-related injuries occurred in the abdomen, thigh and shoulder region, whereas the majority of the TTB injuries occurred in the ankle, wrist and knee (figure 2). Statistical analyses revealed a significant difference in RTSC across the 16-year timeframe ($p<0.05$), but no significant trend for TTB injuries ($p>0.05$).

### Injury location

Overall, injuries to the lower limbs were over three times more likely than injuries to the trunk (23.00 vs 6.12 per 1000 MEs, rate ratio=3.75, 95% CI 3.14 to 4.48), and 1.3 times more likely than injuries to the upper limbs (23.00 vs 17.68 per 1000 MEs, rate ratio=1.32, 95% CI 1.17 to 1.49) (table 3). This trend was also consistent for men and women (table 3). Men were 1.29 (95% CI 0.48 to 3.46), 1.32 (95% CI 1.09 to 1.59), 1.37 (95% CI 1.16 to 1.61) and 1.59 (95% CI 1.15 to 2.20) times more likely to sustain a head/neck, upper limb, lower limb or trunk injury, respectively, compared to women. The highest acute injury rate by location was in the ankle, followed by the wrist, knee, foot/toe and shoulder/clavicle. Overall (acute and gradual-onset; table 3) the highest rate was observed in knee, shoulder/clavicle, wrist and foot/toe. The wrist and knee, followed by the foot/toe were the highest for women, whereas the knee and shoulder/clavicle were the highest for men (table 3). Overall, men were more than twice as likely to sustain an upper arm (0.95 vs 0.32 per 1000 MEs, rate ratio=2.94, 95% CI 0.95 to 9.12), abdominal (2.60 vs 1.03 per 1000 MEs, rate ratio=2.50, 95% CI 1.32 to 4.75), hip/groin (3.79 vs 1.89 per 1000 MEs, rate ratio=2.00, 95% CI 1.22 to 3.25) and thigh (3.95 vs 1.89 per 1000 MEs, rate ratio=2.07, 95% CI 1.27 to 3.37) injury than women. Men also had a significantly higher likelihood of shoulder/clavicle (7.34 vs 4.81 per 1000 MEs, rate ratio=1.52, 95% CI 1.10 to 2.09), and elbow (3.87 vs 1.97 per 1000 MEs, rate ratio=1.95, 95% CI 1.20 to 3.16) injuries relative to women. Significant fluctuations in injury location between 1994 and

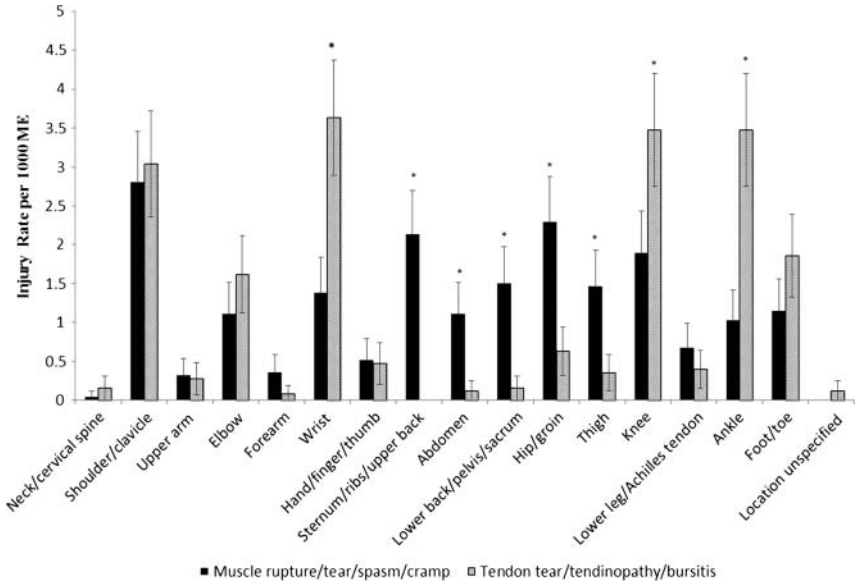


**Figure 2** Muscle-related and tendon-related injuries by location in players at the US Open Tennis tournament between 1994 and 2009. *Significantly different at the $p>0.05$ level.

2009 were observed for upper limb, trunk and lower limb injuries ($p<0.05$) (figure 3).

## DISCUSSION

This study is the first that has examined injury trends over a 16-year period in a professional tennis competition. It is also the first study to use the injury classification methodology outlined in the *Consensus statement on epidemiological studies of medical conditions in tennis*.[1] The main findings of the current study were a statistically significant fluctuation in injuries in tennis players competing at the US Open Tennis Championships over a 16-year period, a significantly higher injury rate in men, and the emergence of the lower extremity (specifically the ankle) as the most common site of injury.

The current study found that the lower limbs, followed by the upper limbs and the trunk, were the most frequently injured regions of the body. Pluim and colleagues[2] found that epidemiological studies, case reports, cross-sectional and prospective studies on elite-level tennis players have shown equivocal results concerning predominance of injury location. Several studies have suggested that the upper extremity had the highest incidence of injury,[9 17] whereas others suggested the lower extremity was most common.[6 7 10] However, when all tennis player populations (recreational, youth, elite) were grouped together, this review of over 100 studies found that the lower extremity, followed by the upper extremity and trunk, were the most common injury sites for tennis players.[2]

Compared to previous research, there is some discrepancy regarding the most common injury location. The current study suggested that the ankle was the most commonly acutely injured site, followed by the wrist, knee, foot and shoulder. An injury trend analysis conducted over 4 years in young adult elite-level tennis players revealed a higher prevalence of injury in the lower extremities, with the ankle documented as the most frequently injured site.[7] However, other studies on elite-level tennis players have documented the most common sites of injury as the shoulder, back and ankle,[6 9] which agrees partially with the trends in overall injuries in the current study. In a recent survey of 861 competitive junior players, the back, shoulder, ankle, knee and wrist were the most common locations for injury.[18] Back injuries, followed by thigh, shoulder and ankle injuries, have been previously reported as common injury sites in junior players at the USTA boys championship tournament.[14] Subtle differences in injury location were observed between men and women in the current study, a trend that has been observed in previous research in elite young players[7] but not college-level[10] or elite adult players. This study further highlights the potential differences in injury location across

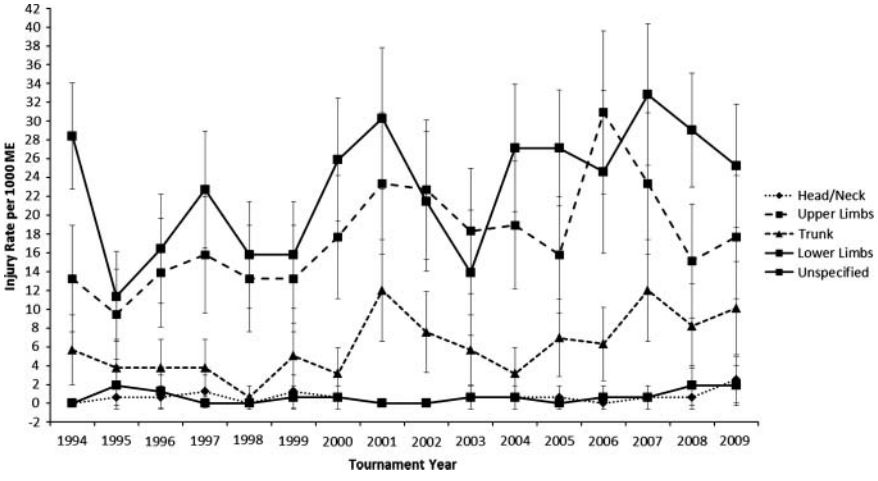


**Figure 3** Injury classification by body region in players at the US Open Tennis tournament between 1994 and 2009.

tennis playing populations and levels suggested in previous research.[2]

The US Open Tennis Championships is operated during the latter part of August and early September, towards the end of the tennis season. Prior to the US Open tournament players have most likely been competing and/or preparing on hard court surfaces for 2–6 weeks. Professional tennis players experience repetitive physiological stress and overload on various anatomical structures during high-intensity practice and regular competitive play. The combination of playing volume throughout the year, and the physiological impact of playing on hard courts compared to clay or grass (eg, higher ground reaction forces, greater load transfer through kinetic chain, force absorption through lower limbs[19 20]) may contribute to higher rates of injury, especially through the lower extremity.[21]

Players who would typically not play a smaller tournament with minor injuries may make an effort to play through a pre-existing injury due to the high-profile status of the US Open Tennis Championships and the need to accumulate or defend ranking points, in addition to the greater financial benefits of playing in one of the four major tournaments of the year. Unfortunately, the relationship between court surface, playing volume and injury rate has not been widely studied and is not well understood,[7 16] especially in adult elite tennis players. The trends in injury type and location observed in the current study supports the need for further research in this area.

In the current study, the number of injuries in the trunk, and upper and lower extremities fluctuated significantly. In a 4-year study of elite tennis players between 1982 and 1985, the overall number of injuries in the lower extremity, trunk and upper extremity increased from 1982 to 1984, and then decreased substantially in 1985.[7] In the current study, the minimal change (average annual change: 2.00%) in lower limb injuries (even with the larger increase in overall injuries) over the 16-year period documented may be the result of improvements in sport-specific conditioning and prehabilitative programmes, especially given the growth in research and understanding of the force generation patterns through the kinetic chain during tennis-related activities[7 22] However, the fluctuation and overall increase in trunk and upper extremity injuries may be explained by changes in equipment use (eg, racket weights and sizes, grips, string composition), balls or court surface composition. In addition, changes in structure and volume of medical staff (eg, increases in athletic trainers and medical professionals) able to assist and fully document cases involving medical assistance, and improvements in injury documentation, may have impacted injury documentation trends.

The fluctuations in both RTSC and TTB injuries may also have been influenced by changes in equipment, medical services, conditioning practices or playing conditions (structural or environmental). Given that these changes have occurred consistently for both men and women, similar trends concerning injury type are not surprising. The high prevalence of RTSC and TTB injuries in the current study agrees with prior injury research in tennis players, and injury prevalence reported in overhead striking and racket sports. Muscular contractures and other musculoskeletal injuries (eg, strains, sprains, cramps) are the most commonly reported type of injury in junior tennis players[7 14 23] and adults.[4 9 16] A comprehensive discussion of the pathophysiology and mechanism of musculoskeletal injuries is beyond the scope of this article, but is discussed elsewhere.[4 5 24 25] The diversity of regions within the body exhibiting RTSC and TTB injuries in the current study (figure 2) is also supported in previous research.[4]

The current study found that injury rates were higher during competition compared to training or practice, which is consistent with previous longitudinal and single competition research in other sports, such as beach volleyball,[26] basketball[27] and soccer.[8] The current study also agrees with trends in other sports, suggesting that the majority of injuries experienced by professional athletes are acute in nature.[8]

As with any injury surveillance study, several limitations may have influenced the study outcomes. Many players travel with their own entourage, which typically includes a coach and a physiotherapist. Although rare, players may travel with their own physician or obtain medical consultation from a private medical specialist not located at the tournament. In these instances, if players required medical evaluation for an injury that did not occur during match play, they may not seek assistance from the US Open medical staff and the injury would subsequently not be included in this study. Injury rates were determined using MEs as opposed to athlete exposure hours or total games or sets played that would have increased the total ME, thus increasing the denominator in each rate calculation. Collectively, these factors may have contributed to higher injury rates than previously reported. Epidemiological studies utilising information gathered during a tournament have an inherent selection bias towards the acuity of injuries, increasing sensitivity to incidence of injury. However, these approaches may also underestimate injury rates by unintentionally excluding players who have current injuries inhibiting participation entirely. Medical staff working with tennis players should be encouraged to use a form of data documentation that is consistent with the aforementioned consensus statement to allow future researchers to conduct research in a manner that fosters generalisation and comparison across studies.

This study adds to the current research by providing an extended injury trend analysis in *elite, professional* tennis players during competition. Changes in racket technology, court surface composition, competitive playing schedule and conditioning practices within tennis over the last two decades, coupled with the biomechanical and physiological demands of tennis, may have impacted injury patterns. However, future research is needed to examine the population-specific risk factors for the observed injuries, and the impact of targeted strategies, and injury prevention and educational programmes for decreasing injury risk in the future. This study may help medical staff, therapists, athletic trainers, coaches, and strength and conditioning professionals by building on current epidemiological knowledge in related populations, and the consequent enhancement of population-specific performance and injury prevention programmes.

### What this study adds

- This is the first study to examine injury trends over a 16-year period in professional tennis players, and to use the injury classification methodology outlined in the *Consensus statement on epidemiological studies of medical conditions in tennis* by Pluim *et al*[1]
- This study adds to the current research by providing an extended trend analysis of injury trends in *elite, professional* tennis players during a Grand Slam tournament.

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