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Helen Wills, for many the greatest female tennis player, gold medallist in singles and doubles at 1924 Paris Olympic Games.

THE EDITORIAL TEAM

 ISSN 2304–0904. Photo on the front cover: Helen Wills at Wimbledon, 1924. Popperfoto/Getty Images

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TARGETED TOPIC: SPORTS MEDICINE IN TENNIS

INTERVIEW

EMMA RADUCANU

"My off court team play a huge role. People often see players on the court and forget all the hard work that goes on behind the scenes with their teams, not just the coach, but physio, fitness trainer etc."

SPORTS MEDICINE IN TENNIS

284 INJURY TRENDS IN PROFESSIONAL TENNIS ACROSS DIFFERENT SURFACES
By Joani Essenmacher and Brianna Rosa

292 EXTENSOR CARPI ULNARIS INJURIES IN TENNIS
By Mike Hayton et al

298 PERSISTENT PAIN IN ELITE ATHLETES
ARE WE DOING OUR BEST?
By Polly Baker and Milena Mirkovic

PHYSIOTHERAPY IN TENNIS

308 UPDATED MUSCULOSKELETAL SCREENING RESULTS OF MALE PROFESSIONAL TENNIS PLAYERS
THE ATP PERFORMANCE AND INJURY PREVENTION PROGRAMME
By Todd Ellenbecker et al

316 REHABILITATION OF LUMBAR BONE STRESS INJURIES IN TENNIS PLAYERS
By Kevin Sims

324 MANAGING BREATHING PATTERN DISORDERS IN TENNIS PLAYERS
By Kris Bahadur et al

334 **THE WHEELCHAIR TENNIS ATHLETE**
Elevating Athlete Support in Wheelchair Tennis Through Comprehensive Screening
By Kirsty Elliott et al

340 Wheelchair Setup Considerations for Optimising Athlete Health in Wheelchair Tennis
By Samuel Williamson and Alex Cockram

348 **TENNIS SPORTS SCIENCE AND TECHNOLOGY**
High Performance Adolescent Tennis Player Longevity
Creating a robust training environment
By Fredrik Johansson

354 Change of Direction and Reactive Agility Tests in Tennis
By Dario Novak and Filip Sinkovic

358 The Use of Biomechanical Analysis to Help Reduce Serve Related Injuries
By Caroline Martin et al

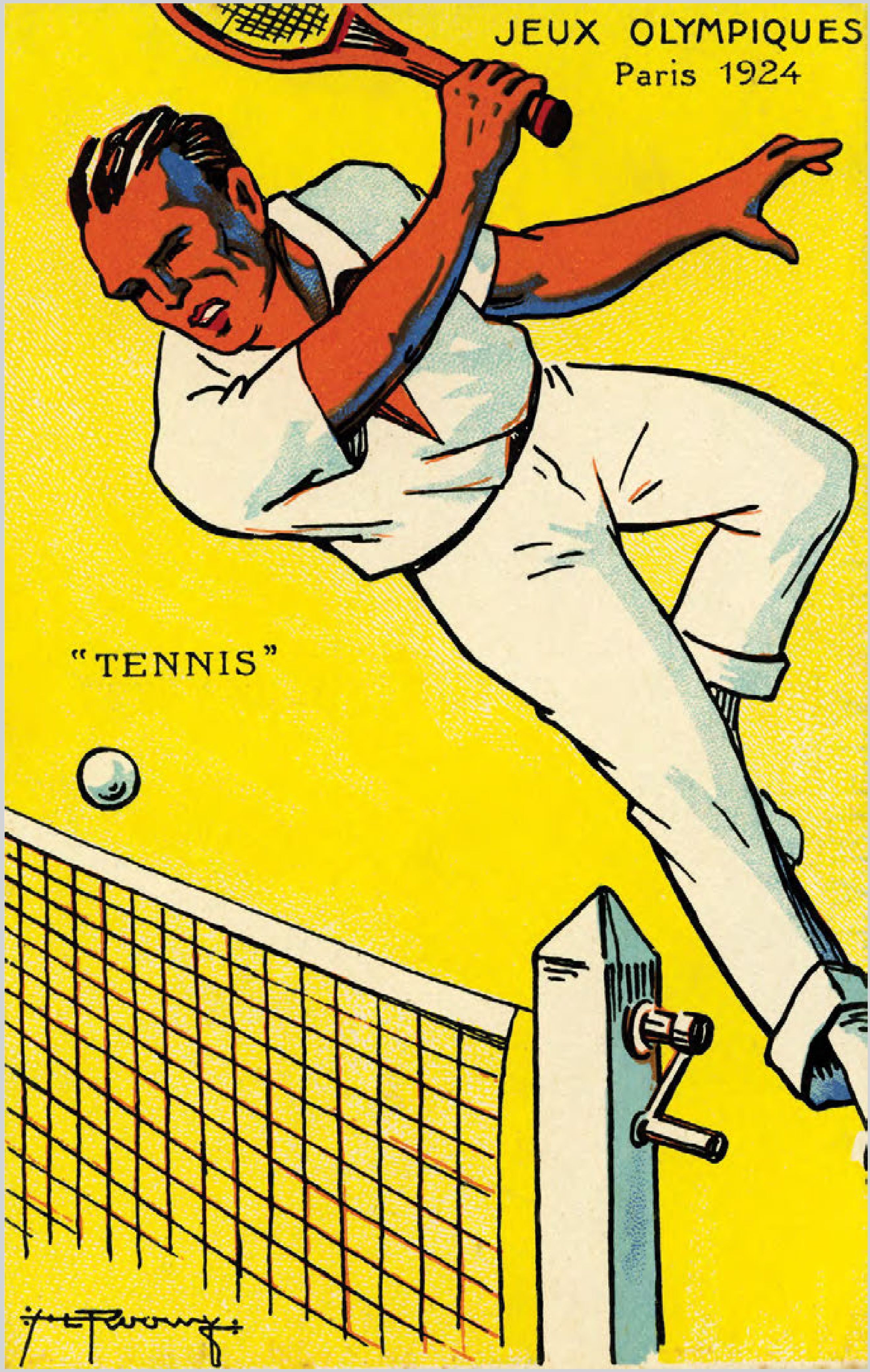
366 **EDITOR-IN-CHIEF'S SELECTION OF CLASSICS**
History of Sports Medicine in Tennis
By Per Renstrom

372 Understanding the Kinetic Chain
In tennis performance and injury
By Ben Kibler

378 Medical Issues Affecting Tennis Performance
By Babette Pluim

390 **ASPETAR UPDATES**
By Marco Cardinale

392 **INDUSTRY NEWS**
By Chris John Esh


JEUX OLYMPIQUES
Paris 1924
"TENNIS"

FROM OUR EDITOR

Prof Nebojsa Popovic MD PhD
Editor-in-Chief

Why Tennis?
Tennis is one of the world's most popular sports, enjoyed by elite athletes and millions of recreational players of all ages and abilities. It can be played by anyone who can hold a racquet. Tennis was part of the Olympic programme from the inaugural 1896 Summer Games in Athens until it was dropped after the 1924 Summer Olympics in Paris (because of a dispute between the International Lawn Tennis Federation and the International Olympic Committee over the definition of amateur players). Tennis returned to the Olympic programme at the 1988 Seoul Olympic Games. The tennis tournaments of the 2024 Summer Olympics in Paris are scheduled to run from July 27 to August 4 at the Roland Garros Stadium.

Why a Physiotherapist Guest Editor?
A decade ago, in 2014, we launched our first targeted topic issue: Sports Medicine in Tennis. Back then, as a young journal, we were honored to have Dr. Ben Kibler, a leading authority in the field, as guest editor. Dr. Kibler assembled a prestigious team of international experts he personally selected. This issue remains one of our most cited to this day, a testament to its lasting impact. Today, the Aspetar Journal is excited to celebrate our multi-disciplinary approach once again. We're thrilled to introduce Milena Mirkovic, a Senior Physiotherapist – highly specialised in Tennis, as our guest editor for this special Olympic issue. As a former tennis player, Milena completed her physiotherapy degree and Clinical Master's at La Trobe University in Melbourne, as well as the International Olympic Committee Diploma in Physical Therapy. For the past 14 years, she has worked at the Lawn Tennis Association in London, working full-time with elite British tennis players. Milena is the author of multiple publications on shoulder and tennis injuries. She is the founder of www.tennis-physio.com. Milena Mirkovic exemplifies the dynamic spirit of a young professional whose dedication and expertise promise to shape the future of physiotherapy.

Looking back over twenty years, physiotherapy has undergone a revolutionary transformation. No longer solely associated with massage and post-surgical rehabilitation, the profession now encompasses a diverse range of practices; from sports-specialised physiotherapy and neurological rehabilitation, to chronic pain management and preventative care. This evolution is directly linked to the explosion of knowledge within the field.

Gone are the days when physiotherapy education relied primarily on anecdotal evidence and tradition. Today, a robust body of research informs every aspect of practice. Sophisticated biomechanical analysis, advanced imaging techniques, and in-depth studies on movement patterns have provided a deeper understanding of the human body and its intricate workings. This knowledge empowers physiotherapists to develop targeted treatment plans, maximising patient outcomes and recovery rates.

Physiotherapists are now equipped with a wider range of skills, from manual therapy techniques to exercise prescription and patient education. This holistic approach empowers patients to take an active role in their recovery, fostering lasting improvements in their overall health and well-being.

This issue serves as a testament to the tremendous progress our field has made and a thrilling glimpse into the future. In addition to all these excellent papers, I would like to strongly recommend to readers an interview by our guest editor, with the young British women Tennis star Emma Raducanu. I would like to thank our guest editor, Milena Mirkovic for her excellent work, as well as all the authors for their generous contribution which have made this special Olympic issue possible.

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FROM OUR GUEST EDITOR

Milena Mirkovic PT(Hons), MPT(MSk), IOC Sports PT
Senior Physiotherapist

It's easy to fall in love with tennis, especially growing up in a grand slam city like Melbourne, where every January the city transforms into a tennis paradise to host the Australian Open. Watching tennis professionals compete live at Melbourne Park while making the game look easy inspired me to play. My dad would say: 'it can't be that hard - you just have to hit the yellow ball over the net, inside the baseline and away from the opponent'. And so my tennis journey began from a young age, taking me to international junior and challenger events, short lived due to a series of injuries, which eventually led me to study sports physiotherapy and work with professional tennis players.

Tennis is a sport that can be played by individuals of all ages, genders and abilities. Health benefits of regular participation in tennis are well established, from improved physical parameters, to positive cognitive and wellness benefits. This sport has seen a steady growth in participation over the years, and the International Tennis Federation (ITF) projects that 120 million people will be playing tennis by 2030.

As well as higher participation figures, at a professional level, players' competition seasons are becoming longer and more condensed to fit an increasing number of tournaments. Playing 20-30 tournaments and 100-120 singles matches in a 12-month period is not uncommon for a player who wants to climb up the ranks. Hence the training and competition loads are immense from an early age. The challenge to practitioners, especially to those working with adolescent players, is to not lose sight of the long-term player development plan. Careful load monitoring and adjustments are needed to help strike a healthy balance between competition schedules and additional physical development, to help develop players who are able to withstand the demands of professional tennis long term, in turn reducing injury risk.

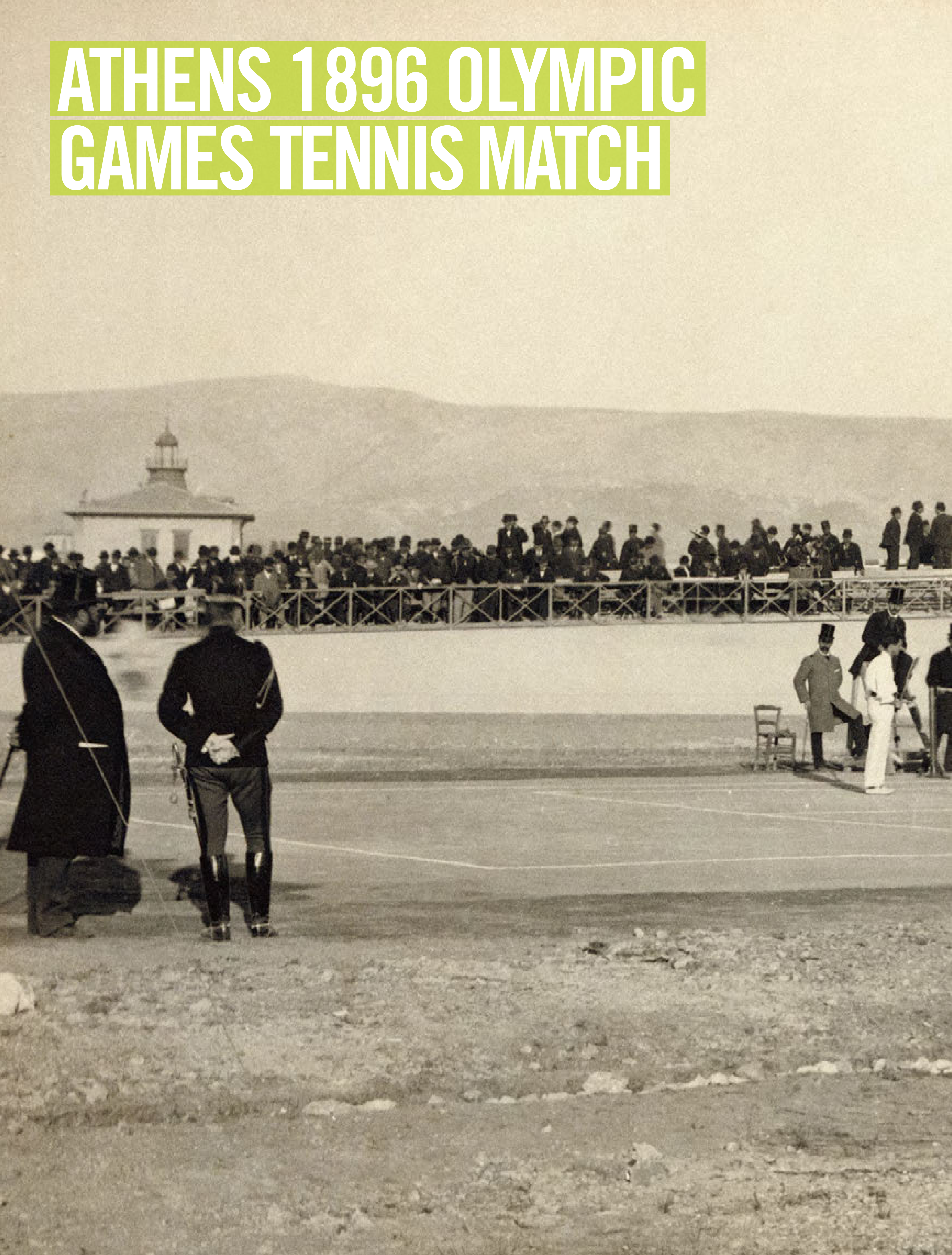
Tennis is played on multiple surfaces throughout the year, and specific injury trends have been observed on each surface. In fact, with the Paris Olympic Games scheduled this year, in July alone most top professional tennis players will compete on three different surfaces: hard, grass and clay courts. It isn't uncommon for a tennis player to continue competing despite experiencing a physical complaint, until it starts to significantly affect their performance, by which time multiple associated risk factors may play a role in persistent pain; from physical, to psychosocial, to biomechanical. As practitioners, we must think beyond pathology in players with persistent pain.

For those practitioners working (or planning to work) with wheelchair tennis players, an insight into comprehensive medical screening as well as wheelchair set up considerations, will provide a good understanding of this category of tennis.

We've had the pleasure of interviewing Emma Raducanu, a young professional tennis player and a grand slam winner, who sheds light into her journey of becoming a tennis professional, its rewards and challenges, and the importance of having a good sports science and medicine team supporting her.

It's an honour and a privilege to have contributed to putting together this special edition of Sports Medicine in Tennis, which will help upskill, or at least offer a check-and-challenge approach to those clinicians working with tennis players, as well as to other team members who are involved in the health, wellbeing and physical performance of players. Thank you to the authors for their time and expertise across different spheres of tennis medicine and science. A special thank you to Editor-in-Chief, Prof Popovic, and his team Ivan and Nasim for providing an opportunity to produce this targeted issue on tennis.

ATHENS 1896 OLYMPIC GAMES TENNIS MATCH



© Albert Meyer/The Calne Collection/Popperfoto/Getty Images – Athens 1896 Olympic Games. The final of the tennis doubles competition. John Boland and Friedrich Traun vs Dionysios Kasdaglis and Demetrios Petrokokkinos.

INJURY TRENDS IN PROFESSIONAL TENNIS ACROSS DIFFERENT SURFACES

– Written by Joani Essenmacher and Brianna Rosa, USA

INTRODUCTION

Tennis is a major global sport; 10.1 million viewers tuned in to watch the Australian Open in 2023[1] In the 2023 season, the Women's Tennis Association (WTA) reached a new global audience record of more than 1 billion[2]. The ATP Tour (ATP is the global governing body of men's professional tennis) has 71 events in 2024 on 5 different continents. The Hologic WTA Tour has over 70 WTA tournaments in 30 nations and regions, in addition to the four Grand Slam events. Every year, many ATP and WTA professionals will also play in the Olympics, the Billie Jean King Cup and Davis Cup. Events are played on different court surfaces, including clay-, grass- and hard courts. Each court surface contributes to different stresses on the musculoskeletal system, and hence distinct types of injuries, which can be debilitating for a professional athlete. The aim of this article is to review the influence of different playing surfaces on injuries in professional tennis, with objectives to: (i) provide an overview of injury data (and trends); (ii) compare acute versus chronic injuries; (iii) describe common body parts and pathologies for each of the three playing surfaces. Many injuries in professional tennis are non-time loss complaints which the players continue to manage while competing. We also describe the main injuries on each playing surface, and recommendations on how to mitigate these injuries during preparation for each surface, as well as during competition. Lastly, we present a sample of a player's daily schedule to illustrate a typical day in the competing WTA athlete with an injury.

COURT SURFACES

Depending on the tournament, tennis professionals play on different surfaces. The most common surfaces in tennis are hard, clay and grass courts. The change in court surfaces can affect the style of play, speed of play, ball response, and player biomechanics which in turn, contribute to different types of injuries or complaints for each surface.

The four Grand Slams are played on three different surfaces; the French Open on clay, the Wimbledon Championships on grass, while the US Open and Australian Open are both played on hard court. The most common surface on the ATP and WTA Tours is hard court, which is composed of acrylic surfaces over concrete or asphalt, and varies based on the paint (ratio of sand). It is rigid with reduced shock absorption, increased frictional resistance, and higher mean maximal force and peak pressure on the rearfoot. Clay court is made of crushed stone, gravel and bricks, and is considered the slowest of the three surfaces (using Court Pace Rating (CPR) ITF classification). Because pieces of the clay stick to the ball, the ball absorbs weight and moisture, becomes heavier, and looses speed. Effective (match) play time is 20-30% longer on clay courts than hard courts and requires a higher physiologic demand[3]. Clay courts have decreased frictional resistance and

Illustration

mean force in the foot is significantly lower on clay than hard courts[4]. Grass courts are natural grass on a sand-filled layer. It is considered the fastest surface with lower ball bounce and a shorter point duration. Players need to reach the ball more quickly on grass surfaces and the court may be slippery.

During the season, professional players switch between all three court surfaces within short time frames, which challenges their ability to adapt to the surface and perform without sustaining an injury.

INJURIES RELATED TO COURT SURFACE

Clay:

- Upper limb repetitive overuse injuries due to longer rallies and heavier balls
- Shoulder, wrist and elbow injuries develop from lack of endurance and strength/power of the scapular stabilizers
- For the same reasons, players may complain of mid- and low back tightness or pain
- Groin/adductor injuries are common due to overstretching with sliding, sudden stopping and change of direction

Grass:

- Gluteal, quadriceps and hamstring tightness or muscle strains are common from overstretching from slipping on the grass
- Athletes may experience low back injuries and tightness present due to reaching for the ball versus using hip and knee flexion
- Anterior knee pain (patellofemoral pain syndrome and patellar tendinopathy) related to sudden stopping and low bounce
- Achilles tendinopathy and posterior ankle injuries due to sliding and sudden stopping on the baseline
- Wrist injuries/pain because of the increased volume of volleying

Hard:

- Due to the compression and lack of shock absorption low back tightness and facet/muscle injuries
- Knee injuries/anterior knee pain
- Shin soreness (tibialis anterior, posterior tibialis)
- Hot-spots and blisters are common in the foot, as well as arch pain/tightness, plantar fasciopathy

INJURY EPIDEMIOLOGY RESEARCH IN TENNIS

Incidence & Definitions

Injury incidence reported in tennis ranges from 0.04 to 3.0 injuries per 1000 playing hours in players of all ages[5]. Several studies examined injuries in tennis and reported different incidence, nature and severity of the various injuries. Variations are mainly related to research methodologies and definitions of injury[6]. In a 2009 consensus statement Consensus on epidemiological studies of medical conditions in tennis, it was suggested that match exposure should be defined as actual match play and recorded as incidence (number of injuries/1000 player hours)[6]. The number of days lost is considered the overall severity of a condition and is grouped according to the duration of time loss (slight = 0), minimal (1-3days), mild (4-7 days), moderate (8-28 days) and severe (>28 days-6 months) and long-term (>6 months)[6]. New guidelines in 2021 provided updates to the 2009 Consensus statement, including recommendations to define risk as either number of injuries per 1000 hours or 1000 games played.[7] If this was not feasible, the authors recommended using injuries per 1000 sets or matches[7]. Acute-medical conditions are defined as resulting from a specific identifiable event (or a sudden onset of severe pain or disability). (e.g. ankle sprain, muscle tear) versus gradual-onset (non-acute) injuries, which are a medical condition that manifests with a gradual increase in the intensity of pain or disability, without a specific identifiable event (e.g. tendinopathy)[6].

Recreational

In recreational players, acute injuries, such as ankle sprains, are more common in the lower extremity, while chronic overuse injuries, such as lateral epicondylosis, are more frequent in the upper extremity[8]. In contrast, high-level players had a greater incidence of shoulder pain[8]. Notedly, professional players generally sustain medial epicondylosis, as lateral epicondylosis is usually related to poor technique.

According to a study of 3656 recreational members of the Royal Netherlands Lawn Tennis Association, there is no link between injury rates and court surfaces among players who typically play on one particular court surface[9]. However, players who switch between multiple surfaces have a higher risk of overuse injuries than those who play mainly on one surface. Switching between playing surfaces may also increase the risk of injury among elite players. For example, the French Open and the Wimbledon Championships are held only about a month apart; interestingly 61% of injuries during the Wimbledon Championships were initially sustained prior to the tournament[10].

Pro-circuits/juniors

In pro circuit events, women were more likely to experience an injury when playing on clay court surfaces, and they also experienced more injuries during the first half of the season. Injury rates for men often peaked during the qualifying months for Grand Slam competitions. Compared to women, men had a higher injury rate[11].

Professional (ATP, WTA)

There is a paucity of injury data in professional tennis. Using different models for exposure, injury data was compiled from the Australian Open, US Open, and Wimbledon. To date, there is no published data for the French Open (clay). Injury data was collected from the US Open from 1994 to 2009 and injury rate, classified by location and type of injury[12]. Injury rates (determined based on the exposure of an athlete to a match event) were calculated as the ratio of injuries per 1000 match exposures (MEs). During the study period, acute injuries occurred more frequently than gradual-onset injuries, as medical assistance was sought for 76.2±19.6 total injuries and 43.8±11.8 acute injuries per year[12]. The most common type of acute injury was muscle or tendon injuries. The rate of lower limb injuries was significantly higher than upper limb and trunk injuries ($p<0.01$). The most common sites of injury were the ankle, followed by the wrist, knee, foot/toe and shoulder/clavicle[12].

During the Australian Open from 2011-2016, epidemiological data was collected for sex, injury region, and type (and reported as frequencies per 10,000 game exposures)[13]. Muscle injuries were most frequent. High treatment frequencies were noted in both sexes for spine (including the cervical, thoracic and lumbar), trunk/abdominal, hip/groin and pelvis/gluteal areas. Female players experienced more injuries than male players (201.7 vs. 148.6)[13]. Shoulder, wrist, knee, and foot were the most prevalent injured areas among females, while in males thigh, knee, and ankle injuries were the most common. Notedly, over the 5-year period, stress fractures and treatment frequency for upper arm injuries increased more than twofold in both women and men.; as well as treatment frequency for upper arm injuries[13].

Medical staff performed a retrospective observational cohort injury study at the Wimbledon Championships over 10 years (2003-2012)[14]. Although less scientifically robust, it is arguably better for reporting injury rates in professional tennis. Data were collected per 1000 sets. The overall injury rate for all players over the 10-year period was 20.7 per 1000 sets played and 700 injuries were sustained. The spine and trunk accounted for (approximately) 25% of injuries, upper limb 28%, and lower limb 50%. Similar to the Australian Open study, injury rates were higher for females (23.4 per 1000) than males (17.7 per 1000). Lumbar spine, shoulder, and knee injuries were the most common in both genders. Men appeared to sustain more groin, hip, ankle and heel injuries, while women sustained more wrist and foot injuries. Most injuries over the time period were muscle tear or strain or tendinitis/bursitis/enthesopathy/apophysitis. Over 6-year period, 48% injuries were traumatic and 52% overuse. During this time, 39% injuries were acute new occurrences while 61% were sustained prior to arrival[14].

Using the official Association of Tennis Professionals (ATP) and Women's Tennis

"*During the season, professional players switch between all three court surfaces within short timeframes, which challenges their ability to adapt to the surface and perform without sustaining an injury.*"

Table 1

SURFACE	HARD	CLAY	GRASS
Characteristics	• Most rigid surface, decreased shock absorption • "Pounding" on the musculoskeletal system	• Slower court surface, with higher bounce • Balls pick up clay and become heavier • Longer rallies with more lateral movement at the baseline	• Particularly fast with low bounce • Lower bounce demands greater knee/hip flexion • Increased speed and explosive power needed to get to the ball faster
Strengthening Activities	• Low back/ core/ lumbopelvic region (abdomens and back extensors/multifidus)	• Light weight/high repetition exercises through full range-of-motion (ROM) to build endurance	• Quads, gluteus medius and maximus • Core stability/stability of trunk, gluteals • Shoulder stabilizers • Shoulder-resistance bands through mid and full ROM to prepare for the shorter strokes on grass
Stretching	• Focus on calf, gluteals, TFL/ ITB/fascial plane, piriformis, quadratus lumborum, latissimus dorsi • Consider adding Yoga poses	• Emphasize forearm, wrist, shoulder, hip adductor muscles	• Emphasis of TFL/ITB, quadriceps/hip flexors, calves, and hamstrings • Will assist in prevention of knee pain
Massage & Active Recovery	• Massage every other day, focusing on areas of stretching (calf, gluts, TFL/ITB/fascial plane, etc) • Active recovery-hydrotherapies to prevent post-match soreness; cool pools (12-15° C, epsom salt baths	• Massage as needed • Active recovery - hydrotherapies	• Regular daily to every other day massage through the grass court season • Active Recovery: hydrotherapy, epsom salt baths to prevent post-match muscle soreness (perform daily the first week on grass)
Training/Drills	• Cross-train-add variety to cardiovascular training as running contributes to additional pounding • Try biking/swimming • Visualization exercise themes: stay in the moment, focus in the now	• Change balls frequently during practice sessions • Specific footwork drills- to mimic court surface • Cardiovascular training (20 min or more), interval training mimicking clay court movements/rallies • Visualization exercise themes: perseverance, patience & endurance; prepare for longer rallies	• Focus on low lunges (ball rolling routine); • Add explosive action and sudden stopping with low bending to simulate low volley return • Extra volley drills to strengthen wrist and forearm mms • Visualization exercise themes: responsive & quick reactions, taking ball early; prepare for low bounces
Footcare & Footwear	• Blister prevention-wear 2 pairs of socks with wicking/change during match; use skin lube, padding or 2nd skin for "hot spots", shave callouses, make sure orthotics fit correctly and remove from shoes to dry after match and practice sessions • Footwear- A durable outsole with adequate midsole cushioning and a stable upper • Use an ankle lock lacing technique for added foot security	• Footwear-Herringbone (zigzag) grip pattern with adequate lateral stability to support movement along the baseline • Use an ankle lock lacing technique for added foot security	• Footwear: good grip with flatter outsole and nubs/pimple grip pattern

Table 1: Preparation for Court Surface Changes.

Association (WTA) web pages, Okholm Kryger[15] examined the reasons for retirements and withdrawals (excluding the 4 Grand Slams) from 2001-2012 on the ATP and WTA Tour. The main reasons for retirement(s) and withdrawal(s) were injuries. Women left primarily because of thigh injuries and were injured significantly more than men. Men left mainly because of back injuries. Women's injury withdrawals were affected by the round of tournament. Playing surface only had an influence on the risk of lower back injury.

In comparison with recording data at only a single event, Dakic et al[16] examined injury incidence rates in singles and doubles players during the 2015 WTA season. Thigh injuries were most common. While mild thigh injuries were frequent, when injury type and location data were combined, both abdominal and thigh muscle strains commonly resulted in loss of time from competition[16]. Okholm Kryger et al[15] also reported thigh injuries as the most frequently reported injury location for time loss from competition.

SUMMARY

Previous reviews on injury location have suggested that lower limb injuries are more prevalent (31–67%) than upper limb (20–49%) and trunk (3–21%) injuries across all levels of tennis[5,8]. Injuries sustained by the WTA Tour players are consistent with other studies that lower limb injuries are most common. Top injuries in the last year were thigh muscle strains, ankle sprains, trunk/abdominal strains, groin/hip strains, shoulder tendinopathy, wrist/ankle/knee tendinopathy, and foot blisters and lacerations. Although research has been conducted on injury incidence and prevalence in tennis, we do not have enough data to clearly correlate injury to surface type. A trend towards increased incidence of achilles tendonopathy, enthesopathy and plantar fasciitis has been observed on hard courts due to the decreased shock absorption, increased frictional resistance, and higher mean maximal force and peak pressure on the rearfoot as previously mentioned.

A wide range of injuries is evident from studies investigating injuries among professional athletes., likely as tennis players use most of their kinetic chain, characterised by intense movements with quick and repeated start/stops, lateral movements and directional changes during a match. Overall data suggest that male players in all studies had a lower injury rate; however, playing style and match duration are risk factors too. Indicative of the long season on different surfaces, many injuries occur prior to a tournament. For example, as mentioned earlier, at Wimbledon Championships, 61% of injuries were sustained prior to the event[14]. Interestingly, many injuries are non-time loss complaints, which the players continue to manage while they continue to compete[14]. This is consistent with our findings in the WTA training room; players may be managing injuries sustained at another event or managing overuse and chronic injuries (e.g. patellar tendinopathy). Analysing time-loss injuries alone in literature (which some studies have done) does not give a true representation of injuries on the tour. Like Dakic[16], we also find that abdominal and thigh muscle strains are common time-loss (from competition injuries).

Recent standardisation and consistency of injury and exposure data in tennis make future comparisons between studies more accurate. Some injuries are managed by the player's own team, which is a limitation of some studies in elite athletes. Overall, this review suggests that further research in this elite-level population is warranted for researchers and clinicians to identify risk factors and develop evidence-based injury prevention strategies.

Figure 1: Key complaints.

Preventative Strategies/Mitigation

Providing integrated care, the WTA Performance Health team uses a holistic injury management approach, that includes WTA Primary Health Care Providers (PHCPs), Mental Health Care Providers (MHCPs) and Massage Therapists. Medical advisors serve as consultants to athlete care and include the fields of cardiology, internal medicine, nutrition, orthopedics, podiatry, dermatology and psychology. Our sport sciences & medicine team blend "science and art"[5] to provide comprehensive quality care to all WTA Tour athletes, including manual therapy, individual exercise programs, biomechanical services (orthotics, OTSA, bra fitting), massage therapy, mental health care, women's health, health education, nutritional support and follow-up after or between events.

Skilled WTA Primary Health Care Providers (PHCPs) (with tennis-specific sports medicine and science knowledge and experience) provide day-to-day health care, on-court emergency care, and sport science services (e.g. biomechanical evaluations), while applying their knowledge of expectations and demands of an elite professional tennis player[5]. For example, if a WTA athlete has a shoulder injury, the complete kinetic chain is evaluated; besides the shoulder, the lumbopelvic region, lower extremity and foot/ankle complex will be examined. A key component of prevention and mitigation of injuries on different court surfaces is specificity of training and appropriate transition to a different surface. Given the athletes' demanding travel schedule, this can be difficult! To educate players, the WTA provides a Physically Speaking topic posted in training rooms and on the Player Zone "Preparation for Court Surfaces Changes." Table 1 summarizes strategies and education employed by the WTA Performance Health team.

Key Complaints: Hard, Clay, Grass

The WTA has developed several taping techniques to help prevent and manage injuries. Among these techniques is the unload tape, as shown in Figure 1. The unload tape is applied over the injured muscle by lifting and shortening the soft tissues towards the painful area, which helps minimize painful stretching during activity. Another common tape used is for hot spots or high friction areas. The WTA uses a combination of foam, gauze, and cover roll to reduce friction on these areas and prevent blisters from occurring.

TABLE 2

Sample Match Day Schedule of a Professional Tennis Player	
Pre-Practice Warm Up (90 minutes prior to match)	• *Evaluation of injury status* • *Manual therapy to enhance joint movement* • *Muscle activation exercises to reinforce proper movement patterns* • *Tape if necessary* • *Athlete notes MHCP is available and stops by for a brief touchpoint regarding match strategies* • *2-4 hours prior to match: carbohydrate-rich meal with low-fat protein and fluids*
Pre-Match (60 minutes prior to match)	• *Dynamic massage for soft tissue warm up & activation of nervous system* • *Tape if necessary* • *Provision of medication* • *Education for management of injury on-court* • *Education for nutrition/hydration on-court; 6-8 gulps of sports drink/water on every change of ends; use gels, sports chews/beans, fruit, pretzels for quick energy* • *30-60 min before play: snack of gels, chews or sports bar, sandwich, granola bar, pretzels/crackers, fruit, fruit smoothie, water, sport-drink, electrolyte drink*
Post-Match (Immediately to 3 hours after)	• *Active recovery and assisted stretching to cool-down* • *Recovery protein shake within 30 minutes; rehydrate with water/electrolytes* • *Re-evaluation* • *Recovery Pool and/or local ice to injured area* • *Recovery Massage* • *Treatment (Manual Therapy, Soft Tissue Release, Cupping, Dry Needling, etc.)* • *Therapeutic exercises and/or neuromuscular re-education* • *Post-match meal; include antioxidant rich foods* • *Athlete has appointment with WTA MHCP 3 hours after her match to discuss match performance and managing injury*

NOTE: All information in Table 2 adapted from Performance Health signs: "Performance Services", "Match Preparation", "Nutrition" signs which are posted in the Training Room.

Table 2: Sample Match Day Schedule of a Professional Tennis Player with an Injury.

Match Day Injury Management

Professional tennis players should find a balance between the demands of competition and the need to perform at their best while also staying healthy. To achieve this balance, it is important to manage any injury with a combination of physiotherapy, nutrition, hydration, massage therapy, and mental health and performance practices (as shown in Table 2). These different disciplines work together on-site to optimise physical readiness, mental resilience, and recovery strategies on match, practice, travel, and rest days. Table 2 demonstrates a sample match day schedule of a professional tennis player dealing with an injury during competition.

CONCLUSION

In this paper, we reviewed how the three different playing surfaces in tennis—grass, clay and hard court—influence injuries in professional tennis players. We emphasised comprehensive and integrated in-competition management strategies for the professional tennis player. More research is needed to allow researchers and clinicians to identify injury risk factors and develop better evidence-based injury prevention strategies.

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© George Rinhart/Corbis/Getty Images – Rene Lacoste in the final of the men's singles at Wimbledon, 1928.

EXTENSOR CARPI ULNARIS INJURIES IN TENNIS

– Written by Mike Hayton, Kevin Khoo, and Guy Evans, UK

INTRODUCTION

Tennis is a popular racquet sport which involves a combination of high intensity of running, agility, hand eye coordination and the use of both hands and wrists. Injuries to the wrist are therefore common and can be either a single acute traumatic event or more chronic secondary to the repetitive impact of the racquet and ball[1].

Ulnar sided wrist pain is common, where the high torque generated in the wrists of tennis players can lead to various injuries to the extensor carpi ulnaris (ECU) tendon such as a tendinopathy, instability of the tendon and ECU rupture[2]. It is thought that the repetitive forehand ground stroke with top spin is responsible for these different ECU pathologies however, such injuries have also been implicated by the double-handed backhand stroke where the ECU tendon is contracted eccentrically[3,4]. An understanding of the ulnar sided wrist anatomy can ensure a better understanding and management of ECU tendon injuries.

ECU ANATOMY

The ECU tendon is located along the dorso-ulnar aspect of the wrist and passes through the sixth extensor compartment of the wrist and inserts to the fifth metacarpal base. The extensor retinaculum acts as a pulley to guide the line of travel and prevent bowstringing of the ECU tendon. The extensor retinaculum inserts distally to the triquetrum and pisiform and not to the ulnar, to allow for pronosupination of the distal radioulnar joint (DRUJ)[2].

Beneath the extensor retinaculum, the ECU tendon is enclosed within a fibroosseous tunnel lined by the ulnar head and the ECU subsheath which holds the ECU tendon within a groove to the ulnar head[5,6]. The ECU subsheath is composed of the deep antebrachial fascia that inserts on the groove to the ulnar head and is reinforced at its ulnar insertion by the linea jugata to prevent volar subluxation of the ECU[2]. The function of the ECU subsheath itself is to provide a mechanical advantage to the ECU tendon and act as a pulley[6].

This subsheath is also a component of the triangular fibrocartilage complex (TFCC) which provides stability to the DRUJ. The ECU muscle is an important dynamic stabiliser to the DRUJ and contributes to wrist extension with wrist pronation, and flexion in wrist supination[4]. The relative stability of the ECU tendon in the ulnar groove also differs with wrist pronosupination whereby in full pronation the tendon is within its groove and in supination there is greater tension of the tendon against the subsheath, as demonstrated with clinical examination for ECU instability[7,8].

In addition to the anatomy, an understanding of the biomechanics of the wrist provides a better understanding to wrist injuries in tennis players.

BIOMECHANICS

When hitting a ball with a tennis racquet, the wrist is subject to both internal and external forces. Internal forces include muscle contractions and torque at the wrist to move to racquet towards the ball. The internal forces are dependent on the type of grip on the racquet, the tightness of the grip and the type of spin that is imparted to the ball[3,4,9,10]. Eccentric contraction of the wrist extensors with a one or two handed backhand stroke has been implicated to be a key mechanism of injury in the upper limb of tennis players[10].

External forces are resultant from the weight and size of the racquet, the position of the ball when it contacts the racquet and the tension of the strings of the racquet[3,4,9-11].

Figure 1: Note the picture of a professional tennis player with an eccentrically contracted ECU tendon shown by the arrow (printed with permission from the player).

Figure 2: The different types of grips to a tennis racquet is determined by the position of the index finger metacarpophalangeal joint and the volar surface of the wrist in relation to the base of the racquet handle. a) Western grip b) semi-western grip.

When there is an off-centre impact of the ball to the racquet, this causes the racquet to rotate which is compensated with an increase in grip strength to prevent an excessive rotation of the racquet[10]. The type of tennis ball and different playing conditions can also be considered as external forces affecting the tennis stroke, though these factors have not been reviewed previously.

Although present, it is not thought that the torque of the internal and external forces are great enough to cause injury from a single tennis groundstroke. Tennis players can perform more than 1100 ground strokes in one match, which suggests that wrist injuries are likely to be resultant of overuse[9]. This is in keeping with the chronic attritional findings of ECU tendinopathy, tears and subluxation, which can be found in tennis players who are asymptomatic[12].

Mechanism of injury

The ECU tendon is most vulnerable to injury with wrist in supination, flexion and ulnar deviation which increases the tension to the ulnar side of the ECU subsheath. This wrist position is seen commonly with the hand closest to the racquet in the double handed backhand stroke[2] (Figure 1). The same position of the wrist has been seen to cause ulnar sided wrist pains in other racquet and handle based sports such as golf. Interestingly, in professional tennis players, the hand furthest from the racquet tends to be more commonly affected with the double handed backhand in our experience.

It is believed by some authors that ulnar sided wrist pain in tennis players is due to poor technique with groundstrokes[4,13], although this is controversial in the proven elite athlete. Hand grip positions can affect both load transmission from the ball to racket to wrist as well as stroke biomechanics with single handed 'western or semi-western forehand grips' being attributed to ECU injuries [4,13] (Figure 2). This is thought to be due to the increased load through the ulnar side of the wrist during wrist extension, supination and ulnar deviation[9,13]. The clinician should always be mindful to a recent change in load (i.e. hitting time or intensity), change of grip, technique, equipment including the racquet, strings, balls and playing surface[1,4].

DIAGNOSIS AND IMAGING

Dorsoulnar wrist pain presents a diagnostic challenge due to the close proximity of a number of anatomical structures. The history provides an important clue to the diagnosis and injury sustained. This can either be an acute onset of pain, where the player recalls a pain following a single groundstroke or where there is an insidious onset of pain persisting for weeks when playing a certain shot. In both instances, the pain is localised to the dorsoulnar aspect of the wrist with associated swelling, reduction in grip strength and possibly, a snapping or flicking sensation over the dorsoulnar wrist with rotation at the wrist[14]. It is also important to identify those who have ECU subluxation secondary to tendon hypermobility which can be associated with connective tissue disorders and are more difficult to treat[15].

The examination occurs through the "look, feel, move" mantra with swelling and tenderness along the ECU tendon may be suggestive of a tenosynovitic picture. The range of motion at the wrist must be noted with particular attention to wrist extension, supination and ulnar deviation[16]. Provocative tests include the ECU synergy test which involves the patient resting their arm with the elbow flexed at 90° and forearm in full supination. On resisted radial abduction of the thumb, the ECU tendon synergistically contracts and can be palpated[17]. Bowstringing or pain palpated along the length of the ECU tendon can then be thought to be due to pathological extraarticular lesion to ECU or its subsheath[17] (Figure 3).

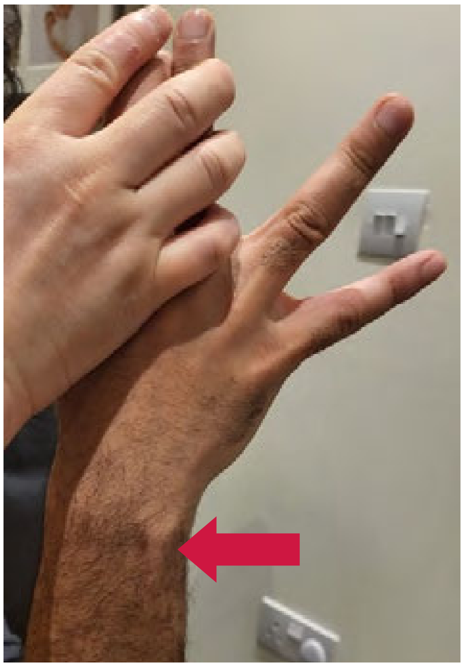

Figure 3: The ECU synergy test. With the elbow flexed to 90 degrees, the thumb is radially abducted against resistance to cause a synergistic contraction of the ECU tendon seen by the arrow.

For ECU tendon instability, one of the authors (MJH) has described a novel clinical test which simulates the action of 'scooping ice cream' with the hand[7]. The patient's wrist is initially positioned in full pronation, ulnar deviation and extension. The ulnar deviation is maintained and the wrist is supinated against resistance with palpation of the ECU tendon (Figure 4). Snapping of the tendon results in a positive test.

Subluxation of ECU on active supination with the wrist in resisted flexion and ulnar deviation is also indicative of instability, described as the Cobra test[5]. The ECU tendon is seen to reduce with active pronation of the wrist.

Imaging used for diagnosis include radiographs of the wrist, MRI scan and an ultrasound scan. A T1 weighted MRI scan with Gadolinium enhancement is thought to be most accurate in identifying ECU subsheath pathology[18]. Dynamic instabilities of the tendon relative to the ulnar groove can be identified with an ultrasound scan[19]. Each modality adds a further diagnostic layer to the presenting symptoms. The important questions to be answered on advanced imaging are:

- The depth of the ECU groove on the ulna
- ECU tendinosis with delamination
- ECU tendinopathy
- Subsheath pathology including tears or rupture
- 6th extensor compartment attenuation
- Ulna variance

ECU PATHOLOGY

ECU tendon pathology can range from chronic tendinopathies to more acute tendon ruptures and instability. The management of each condition differs but the pathophysiology all relates to the ECU tendon relationship with the ulnar head and the fibro-osseous subsheath.

Tendinopathy

ECU tendinopathy presents with a chronic history of pain following repetitive motion. The excessive friction between the tendon and its subsheath can cause degenerative changes to the ECU tendon. ECU tendinopathies have been classified as constrained and unconstrained tendinopathies with the integrity of the subsheath being the differentiating factor[6]. Constrained tendinopathies can further be subdivided to the common ECU tendinosis and a stenosing tendovaginitis.

ECU tendinosis is associated with an overuse pathology where repeatedly applied stress to the ECU tendon can cause the tendon to thicken, have disorganised matrix of collagen and are prone to areas of deterioration which histologically is referred to an angiofibrobalstic hyperplasia[6]. If left untreated, an advanced tendinosis can eventually lead to a complete rupture of the tendon[6]. A chronic systemic inflammatory condition (i.e. inflammatory arthropathy, gout) can also lead to the same histological findings with tendons however with less repeated stresses.

A more uncommon cause of ECU tendinopathy involves the thickening of the ECU subsheath which restricts the gliding of the ECU tendon through its tunnel, causing pain and inflammation. The pathophysiology of a stenosis

Figure 4: The 'Ice cream scoop test' a) The wrist is extended, fully pronated and is in ulnar deviation b) The ulnar deviation at the wrist is maintained and the wrist is brought into supination c) With the wrist in resisted full supination and ulnar deviation, the ECU tendon is palpated for snapping.

tendovaginitis is not completely known but it appears similar to that seen with trigger fingers and De Quervains Tenosynovitis[6,20].

ECU instability

Instability of the ECU tendon within its subsheath is an example of an unconstrained tendinopathy of ECU. Subsheath rupture is sustained with a sudden forceful contraction of the ECU with the wrist in ulnar deviation, supination and flexion[6,21,22]. The rupture will then allow for the volar subluxation or dislocation of the ECU tendon from its ulnar groove. Inoue and Tamara had described three different types of ECU dislocation, all with differing management strategies (Figure 5).

In tennis players, an isolated ECU instability is seldom found where most have an associated TFCC tears[6,23].

ECU tendon rupture

Complete tendon rupture is a very rare ECU pathology amongst tennis players but can be considered a career ending injury if not diagnosed promptly[2]. Tendon rupture can result from a chronic tendinopathy that leads to degenerative changes of the tendon[2,5,6]. Incomplete rehabilitation following an injury to the wrist can also rarely lead to a complete tendon rupture. A case report of an ice hockey player who had injured his wrist on hitting a goal post, but had continued to play the remainder of the season without rest[24]. Eight months after the injury it was noted that he had sustained a complete ECU tendon rupture[24].

Repeated corticosteroid injections into the subsheath can also cause a weakening of the ECU tendon and eventual rupture. Incidentally this treatment was also performed in the above case report and may have contributed to the tendon rupture[24].

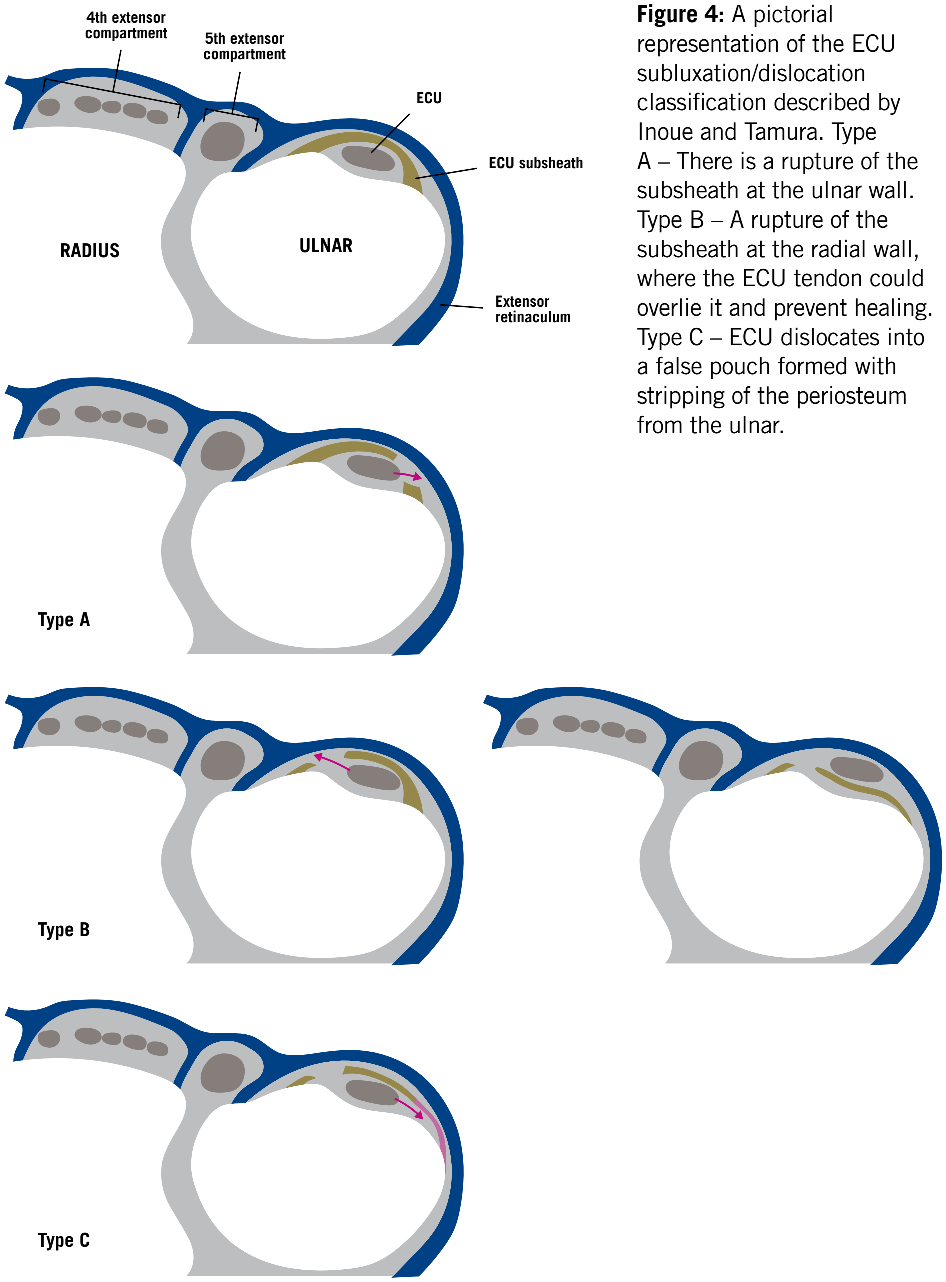

Figure 4: A pictorial representation of the ECU subluxation/dislocation classification described by Inoue and Tamura. Type A – There is a rupture of the subsheath at the ulnar wall. Type B – A rupture of the subsheath at the radial wall, where the ECU tendon could overlie it and prevent healing. Type C – ECU dislocates into a false pouch formed with stripping of the periosteum from the ulnar.

MANAGEMENT

Initial treatment in an elite athlete involves relief of pain and to prevent further degeneration of the ECU tendon. As such, the treatment regime needs to be tailored to each individual athlete from a shared decision-making process. Although rare, cases of ECU ruptures have presented in athletes with persistent ulnar sided wrist pains and alternating period of rest and play[2,24]. A realistic timeline of recovery should be shared with the athlete throughout the rehabilitation. An initial course of conservative management is usually recommended when treating ECU injuries.

Non operative management

Conservative management of ECU tendinopathies tend to be effective in the first instance with patient understanding of the condition being paramount to the rehabilitation process. Anti-inflammatory medication is effective to relieve pain and swelling, with some clinicians recommending short term splinting of the wrist in pronation, slight extension and radial deviation[6,25]. The key to successful treatment is early diagnosis which limits the degeneration of the tendon. If symptoms persist, then an ultrasound guided injection of corticosteroid within the ECU sheath may be beneficial but with the added risk of causing tendon weakness and rupture. A platelet rich plasma (PRP) injection is an alternative without the risk of tendon weakness[26]. The authors prefer PRP injections over coticosteroid injections around such an important tendon, that if ruptured, would be potentially career ending.

Different ECU tendon treatment protocols have been devised for treating the elite tennis players which are individualised for each patient. The Lawn Tennis Association (LTA) divides the protocol into preservation of tendon health, regain strength around the wrist, regain athleticism whilst reloading the wrist, increasing on-court tennis training and a return to full training and match practice. This is similar to a protocol devised by Graham, who divides the rehabilitation into an immobilisation, motion recovery, strength recovery and a sport-specific preparation phase [25]. The immobilisation phase involves splinting of the wrist to preserve tendon health and persists until the wrist is comfortable without the use of a brace followed by a gradual increase in intensity of range of motion exercises to the wrist with the ECU taped[25]. If the pain does not settle then an ultrasound guided PRP or corticosteroid injection to the sheath can be performed followed by splint immobilisation before resuming the motion recovery phase of rehabilitation. The strength recovery phase then follows with the ECU tendon taped both proximal and distal to the ulnar head to allow for free flexion and extension of the wrist and full ECU tendon excursion [25]. The strength recovery phase is continued until 75% of strength is regained in comparison to the contralateral wrist, before proceeding to the sport-specific preparation phase. This phase is conducted under the guidance of the tennis coaching team, which usually involves free swinging of a racquet before a gradual progression of groundstrokes with a tennis ball[25].

Similar ECU treatment protocols have also been used with acute subluxation/ dislocations of the ECU tendon but with a longer immobilisation period and full return to play after 5 to 6 months[2,6,18]. When there is a persistence of pain and discomfort which impairs competitive level activity, operative treatment can be considered.

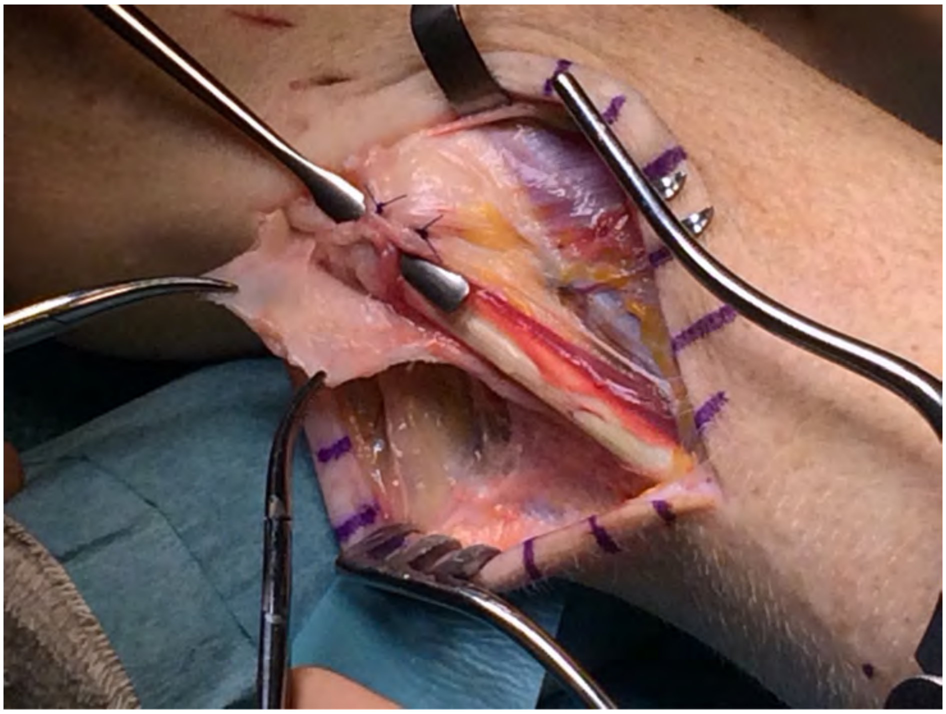

Figure 6: Direct anatomic repair of ECU subsheath. Photo Credit – Mike Hayton.

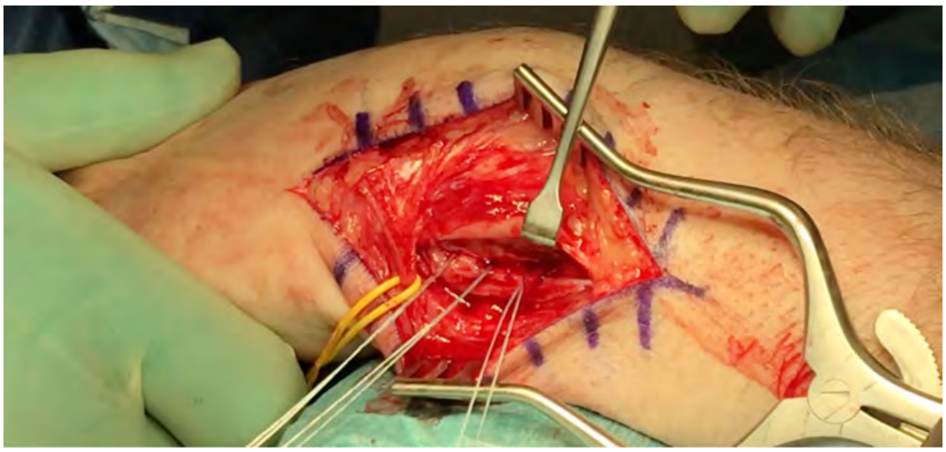

Figure 7: Row of soft anchors along the ulna ridge of the ECU groove. Photo Credit – Mike Hayton.

Operative management

The aim of surgery is to restore or reinforce the ECU subsheath and preventing the development of ECU instability and tendinopathy.

It has been suggested that chronic ECU subluxation/dislocations are not feasible for direct repair with high failure rates, especially when retraction and atrophy of the edges of the sheath are present however, a direct anatomic reconstruction can be considered[6]. Open reduction of the tendon and reconstruction of the sheath is recommended through a dorsoulnar approach to the wrist. Various techniques have been described, each with its own advantages and disadvantages. The use of the extensor retinaculum as a sling around the ECU tendon has shown success with return to previous sporting activities[6,14,22,23]. This technique has further been modified by many surgeons who favour a radially-based sling around the ECU tendon to ensure that the tendon is retained within the groove in full pronation of the wrist with a return to grip strength 9 months post-surgery[3,6,22]. The ulnar groove can also be inspected, where those with a shallow ulnar groove can be deepened with a burr although the authors have some concerns regarding this technique unless absolutely necessary[27]. Other techniques of reconstruction with the extensor retinaculum have also been described but all eventually lead to a limitation in pronosupination thought to be from adhesions[6,14,22]. A capsulotomy has been described for this complication, that describes lifting and ulnarly based capsuloperiosteal flap from the ulnar groove and relocation of the ECU tendon subperiosteally within the groove[6]. The radial edge of the capsuloperiosteal flap is then repaired to the radial side of the ulnar groove with suture anchors[6].

> *For an athlete to return to previous levels of tennis, a comprehensive rehabilitation period is likely to be required with both operative and non-operative management.*

Inoue and Tamura had described different operations based on the type of ECU subluxation/dislocation from their classification with type A and B injuries being repaired anatomically with a strip of fascia or direct repair respectively[6] (Figure 6). Type C injuries were repaired by reattaching the periosteum to the ulnar to reform the ECU subsheath[6]. All described techniques had anatomically restored the ECU subsheath with full pronosupination described with all patients[6,14].

The preferred method of type C injuries by the authors is to place a row of 1mm soft anchors along the ulna ridge of the ECU groove to close the "dead space" and prevent subluxation (Figure 7).

For all forms of surgical repair, a prolonged period of immobilisation from rotation is required for healing to occur, followed by rehabilitation due to the deconditioning of the wrist.

RETURN TO PLAY AND PREVENTATIVE MEASURES

For an athlete to return to previous levels of tennis, a comprehensive rehabilitation period is likely to be required with both operative and non-operative management.

Preventative measures include the appropriate technique and grips as the ECU are prone to injury with wrist position and certain groundstrokes as described earlier[2,4,9,13]. It is also thought that participation in tennis at an early age can also contribute to an increasing number of wrist injuries whereby the physically immature body cannot resist the increased repetitive load of competitive sport[9]. These factors would need to be considered by tennis coaching teams to ensure training loads are appropriate for age and stage in order to optimised performance and prevent injuries.

CONCLUSION

The ECU tendon is an important dynamic stabiliser of both the radiocarpal and midcarpal joint which is intimately attached to the other structures of the ulnar side of the wrist. The ECU and its subsheath can be injured in both an acute and chronic manner associated with an ulnar deviated, flexion and supination at the wrist which is a common movement for tennis players. Early diagnosis and treatment is paramount in order for successful treatment of these injuries and requires a high index of suspicion in order to prevent a potential career threatening consequence.

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PERSISTENT PAIN IN ELITE ATHLETES

ARE WE DOING OUR BEST?

– Written by Polly Baker and Milena Mirkovic, UK

INTRODUCTION

Although research and knowledge surrounding pain has grown exponentially over the past decade, its clinical application still lags behind[1]. It is now understood that pain can exist without tissue damage[2] and accounts for the updated definition of pain from the International Association for the Study of Pain – 'An unpleasant sensory and emotional experience, associated with, or resembling that associated with, actual or potential tissue damage'. Persistent pain is thought to be pain persisting after the natural tissue healing times[3], with the timings varying between different tissue types, and is illustrated by Figure 1.

It is proposed, therefore, that there are other factors that contribute, influence and drive the experience seen in persistent pain[4]. The possible mechanisms by which these drivers affect pain can be explained by an understanding of pain biology which, when relayed to the individual affected, helps rationalise a holistic approach to their pain. A knowledge of the possible pain drivers (see Table 1) can facilitate the clinician's identification of those relevant to their patient, which, in turn, promotes the use of appropriate interventions and formulation of a coherent, relevant management plan. The combination of and relative contribution of these factors will be unique to the individual experiencing pain and so, too, must be the management plan proposed to address them.

This article will address pain biology and how to apply this knowledge to treat an elite athlete with persistent pain. The key principles of a pain management plan will be outlined and then a real example of a professional tennis player with shoulder pain will be used to illustrate the process of elucidating drivers, treating, re-evaluating and ultimately returning the athlete to competitive play.

PAIN BIOLOGY

It is easiest to explain pain by thinking about an acute injury such as cutting your finger with a knife. As the process by which the tissue damage is conveyed to the brain, via the spinal cord, as pain is explained, let's elaborate on processes that can become involved when pain becomes persistent;

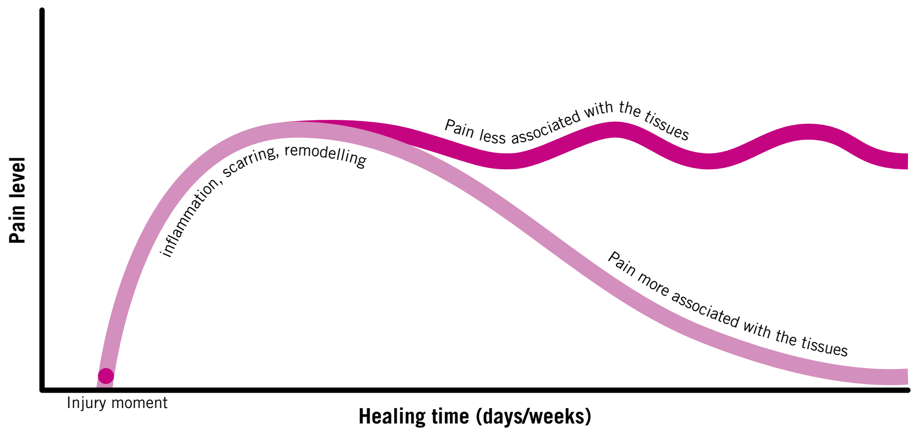
The tissue damage caused by the cut stimulates neurones called nociceptors. The primary function of these neurones is to detect danger and keep us safe. They do this by sampling the environment using sensors. These sensors, however, do not detect pain, and instead they respond to mechanical (e.g. pinch), chemical (e.g. stomach acid/ external allergens) and temperature stimuli (hot and cold). When these sensors are stimulated they will open, allowing ions to flow into the neurone. If enough ions enter the neurone it will reach its all or nothing point (Figure 2) and an impulse will be sent to the spinal cord. It is important to note that 'pain information' is not being transmitted at this point, but only that there has been a mechanical, chemical or temperature change to that tissue or that there is possible 'danger' present.

This is the first place where pain can be influenced. Processes such as activation of the sympathetic nervous system and adrenocortical axis can raise the excitability of the nociceptor. The neurone is brought closer to its 'all or nothing' threshold, allowing smaller stimuli to trigger an impulse. A number of pain drivers may affect these systems; for example lifestyle factors such as sleep deficit seen in jet lag.

The peripheral neurone meets the second order neurone in the dorsal root ganglion (DRG) found in the spinal column. This neurone is responsible for transmitting the information from the periphery to the brain and can be up or down regulated. As well as meeting the second order neurone, it meets peripheral neurones from surrounding tissues and the neurone coming down from the brain (Figure 3). At the point where the action potential reaches the second order neurone it releases neurotransmitters into the gap. These neurotransmitters have a specific configuration, represented in the diagram as a shape, and will only fit into its specific, same shape sensor using the lock and key principle. In doing so gates on the neurone travelling to the brain are opened or shut. If opened, more ions flow into the neurone making it more excitatory and likely to fire, and if shut the opposite occurs, making the neurone less excitatory and less likely to fire. Neurotransmitters therefore can be labelled as excitatory or inhibitory.

This is the second place where pain can be influenced. The information from the periphery, for example mechanical change detected, can be up or downregulated. It can even be stopped if enough inhibitory neurotransmitters are released from the neurone coming down from the brain; for example think of the rugby player with a severe injury that continues playing because they are caught up in the match.

If the danger message does get through to the brain, its 'information' is taken in context of all the other information being received, for example visual stimuli from the eyes, noxious stimuli from the nose and previous memories from hippocampus. Its job is to construct a story based on the information it is receiving. This concept is supported by research using PET scans on individuals in pain[5]. It shows not one but many areas of the brain lighting up during the pain experience. Each area is called an ignition node and is a congregation of a huge number of neurones (many more than at the DRG) with common locations being seen in areas of the brain such as the motor cortex, amygdala, hippocampus and sensory cortex. These nodes are linked both electrically and chemically; the pattern created during pain being called a neurotag (see Figure 4) and unique to each individual. Any one node can be stimulated, triggering the neurotag[6] and thus pain.



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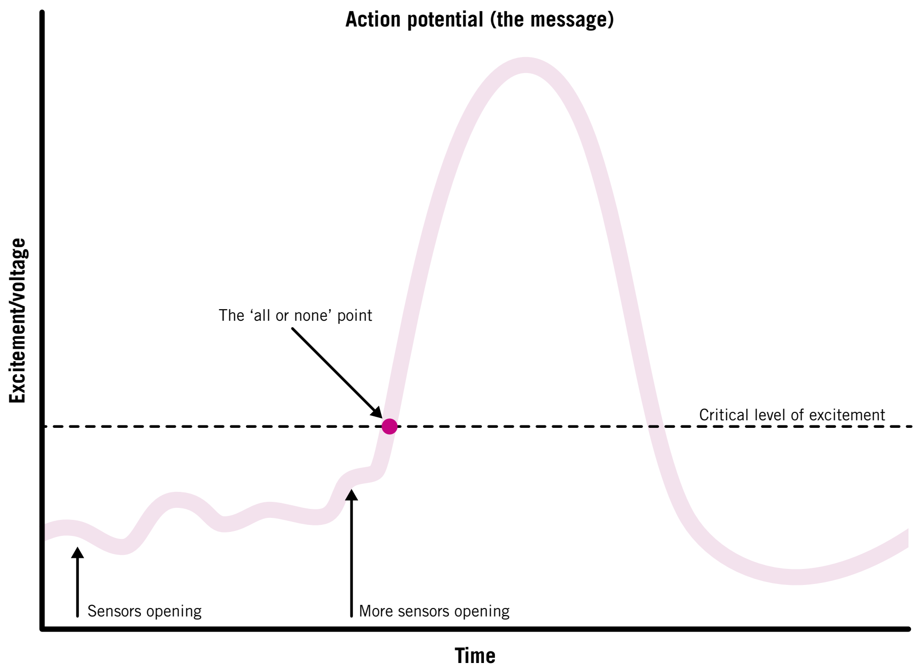

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This is where the information of change from the tissue is interpreted as pain and is the third, and final place where it can be influenced. It is where pain is most adapted, made unique and bespoke to the individual and is the target of many interventions. The multitude of ignition nodes in an individual's neurotag allows for different stimuli to activate pain and can explain the phenomenon of a soldier feeling pain in an old injury when revisiting a battleground. Here the stimuli maybe visual, auditory or even olfactory. The more the pain experience is felt, or neurotag triggered, the greater the reinforcement of the associated electrical and chemical pathways and the more easily the pain can be triggered again. This can be repeated again and again such that the patient's pain may be initiated by an ever decreasing stimuli. Think of a tennis player whose shoulder pain was initially felt towards the end of a match, who after developing chronicity feels it even when attempting a shadow serve off court.

MANAGEMENT

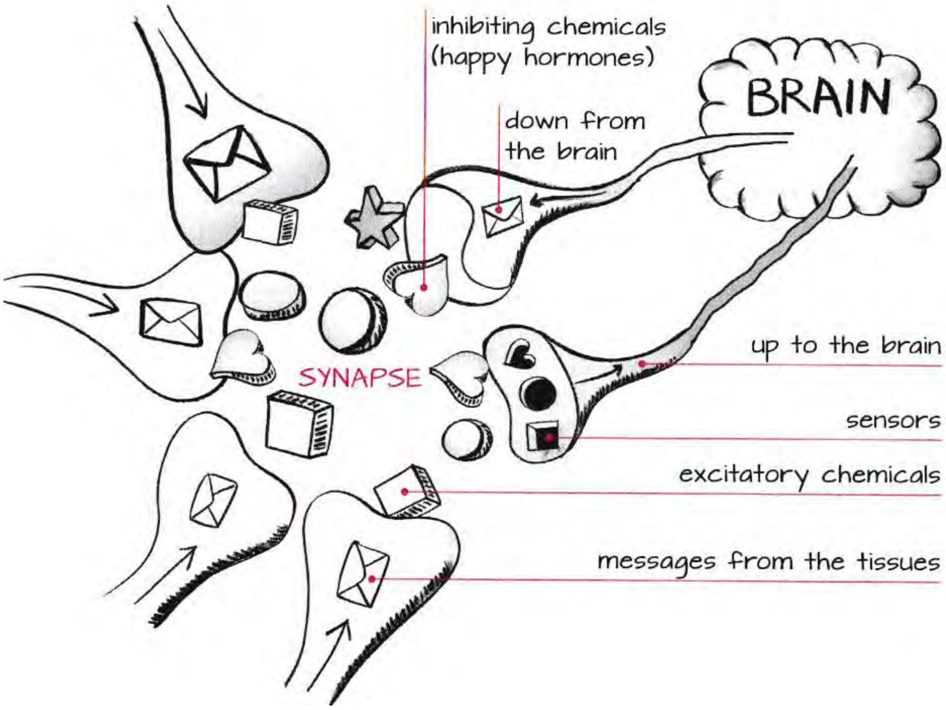
Recognition of persistent pain in the elite sport setting is fundamental. The culture within this environment promotes a strong belief that pain is related to injury and tissue damage. Clinicians need to be open to the concept that persistent pain can also exist in this population and address it accordingly. Management involves a thorough assessment and diagnostic work up to ensure the exclusion of 'red flag' pathology. In contrast to other settings, it is likely that the majority of persistent pain problems have started as an acute injury. Elements of the initial examination findings may still be present and are important to note so that aggravating movement/s can be reintroduced in a gradual manner. It maybe that there is still nociceptive input from the original injury, however other contributing factors (as described in Table 1) are likely to play a greater role and as a result this should be explored in detail in the assessment. The nuance to a pain management plan is to work out how much the other pain drivers are contributing and what interventions might be appropriate to address them. With this in mind, there are some key tools that can be universally applied:

1. Promotion of a strong therapeutic alliance

In simple terms getting the player to trust you. This has a number of effects; it allows them to feel safe, decreasing the sensitivity of danger system which has likely been upregulated since the onset of the injury including, but not limited to, the activation of the sympathetic nervous system and the adreno-cortical axis. In addition, if a player trusts you as a clinician, they are more likely to listen and take on board what you are recommending. This can include education around pain and injury but also suggested treatment. Management of persistent pain often asks the individual to step out of their comfort zone; for example, perform an activity they have been avoiding, and for that they need to trust the individual giving the advice.

How to build a strong therapeutic alliance is beyond the scope of this article but suffice to say communication is a vital component. This is not only important in delivering information to the patient, but also can help optimise the workings of an interdisciplinary team which are likely to be involved in managing an elite tennis player. Good communication within the team improves pain outcomes in two ways; firstly, the team understand the problem and how to manage it but also, and probably more importantly, each member of the team delivers the same message to the player. This in turn builds trust in their team and a positive feedback loop is set up where the player feels more safe, the danger system reduces further and the player is even more likely to continue down the recommended rehabilitation route.

One important component of managing persistent pain problems is the handing over of responsibility of management to the individual affected[7]. Better outcomes are seen when the individual learns to



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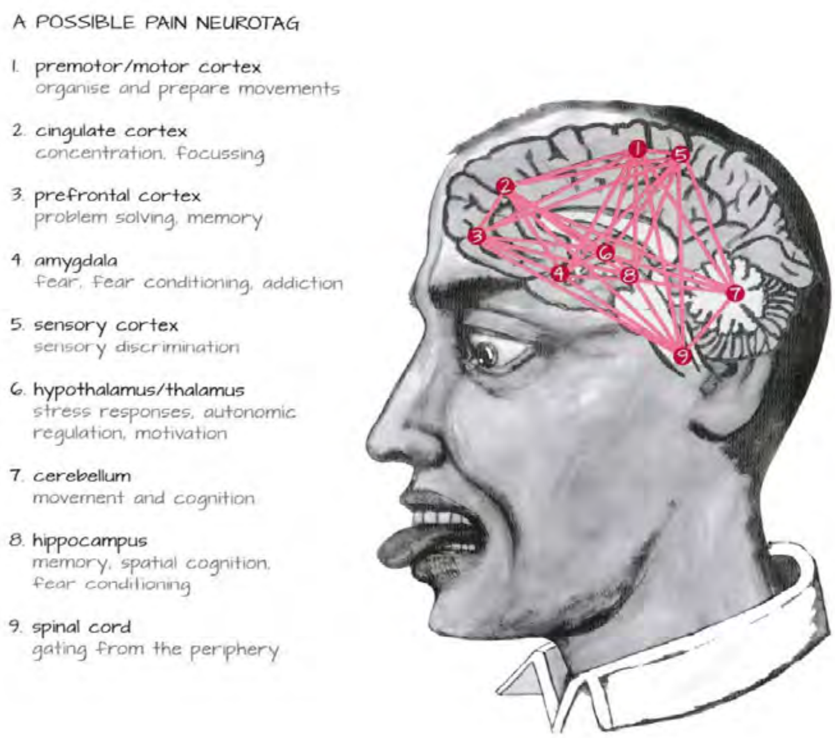

Figure 4: Reprinted with permission, Butler DS and Moseley GL: Explain Pain, 2nd Edition, Noigroup Publications, 2013.

Table 1

Contributing factors		Examples
Physical factors	*Extrinsic*	*Repetitive movements in sport e.g. tennis forehand*
	Intrinsic	*Changes to motor control e.g. holding back in extension in particular activities such as lifting*
Lifestyle factors		*Smoking, sedentary behaviour, sleep deficits*
Cognitive factors		*Fear of movement* *Belief that pain is all structural e.g. 'discs are crumbling'*
Emotional factors		*Stress, anger, anxiety and depression*
Social factors		*Work, family, coach expectations*
Genetic factors		*Pain is seen to be more prevalent in certain populations*
Individual factors		*Readiness to change, patient values, goals, acceptance.*

Table 1: Contributing factors to persistent pain[4] with examples.

self-manage, only using the clinician as a sounding board. It could be argued that this is more relevant to tennis players than other athletes, as they often spend time on the road without health care professionals and as a result have to self-manage niggles.

2. Education and knowledge acquisition
Education around pain and its management helps the patient in several ways. 'Deep learning', when information is retained and understood, allows incorporation into a person's attitudes and beliefs, which in turn promotes integration of behaviours into every-day life[8,9]. It helps the affected individual be independent and cope with similar situations in the future. The ability to self-manage improves outcomes, especially when they understand what they are doing and why.

Where education has been paired with movement approaches or an exercise programme it has been shown reduce pain further[13]. Additional benefits include an increase in strength and physical function and an improvement to quality of life [10–12]. Education is likely to reduce the threat of pain[13,14]. Understanding fundamental points, such as pain doesn't mean tissue damage, can allow patients to challenge unhelpful behaviours such as limping, or in the case of upper limb avoding simple tasks using the affected lilmb. This knowledge will reduce the activation of our protective systems such as sympathetic, immune, endocrine and motor which can directly feed back into the brain, reducing the sensitivity of the ignition nodes and potentially the perception of pain.

3. Movement and exercise
It is well recognised that exercise is an effective treatment to reduce pain and improve function in a number of pain conditions[16]. There are some uncertainties over the underlying mechanism, but it is thought to affect central processing by increasing the sensitivity of the descending inhibitory pathways and decreasing the sensitivity of the descending facilitatory pathways. It may be that this central processing change is initiated when the 'sweet spot' of exercise is achieved; just above the baseline.

The key with exercise prescription is that it stimulates and uses the affected tissues but at a level that does not cause a flare in pain. A small amount of pain is acceptable, but severe pain that takes days to settle is unhelpful as the individual will reduce their activity and decondition. In addition, it may prevent the individual participating in life, which may upregulate other inputs such as fear and anxiety. The first step, therefore, is to find the patient's baseline level. For example with persistent serve-related pain, shadowing a serve with no racket and no ball may be a good starting point (alongside the usual rehabilitation plan), or even in rare cases just going through the movement in their head.

The following case study aims to illustrate how to apply the knowledge of pain biology and its management to an injured elite tennis player with persistent shoulder pain. When formulating a treatment plan, aside from the usual criteria-based return to play plan, clinicians should consider what possible pain mechanisms could be at play and then tailor interventions to address them. As you can never be quite certain what mechanisms are involved or their relative contribution, it is important to reassess response to interventions regularly. The player knows their condition and themselves best, so involve them in the decision making as much as possible.

CASE STUDY
A 25-year old right hand dominant professional tennis player presented to the team doctor with right shoulder pain. She was upset and asked for a 'scan to see what was going on'. Due to a drop of her ranking she was no longer receiving funding from the tennis governing body, which resulted in her not receiving input from the wider multi-disciplinary team, including physiotherapy, nutrition and psychology. She had been experiencing shoulder pain for a year, which had been getting progressively worse. She reported pain in the deltoid region on increasing serving load. When this occurred she would stop competing and serving and present to her external physiotherapist to receive treatment. She would then undergo a mini training block and re-enter competition. She would find on restarting serving she would have a return of pain. As this pattern repeated over the year she found the pain started to affect her serve as well as her forehand. She had a past medical history of an eating disorder and generalised hypermobility.

A joint assessment with the doctor and physiotherapist was performed. History and clinical examination was consistent with a presentation of multidirectional instability. Imaging confirmed no coexistent tendon tears and a thickened subacromial bursa.

It was decided due to ongoing pain that her bursa would be injected, but it was clearly explained to the player that this was only the starting point, and that a criteria-based return to play (RTP) plan was needed to prepare the whole shoulder complex (and the rest of the body) for competitive tennis. She was granted permission to complete the RTP plan 'inhouse' with the multidisciplinary team.

Table 2 summarises a five-staged RTP plan. Specifically to the shoulder: stage one focused on optimising recovery from the injection while restoring pain free range of motion below shoulder level; stage two on resuming upper body strengthening below shoulder level while optimising muscle control and reintroducing backhands on court; stage three on overhead strengthening and serve preparation drills while reintroducing forehands on court; stage four on rate of force development while reintroducing and building up serving volume and intensity and finally the fifth stage reintroduced match play in a controlled environment.

The pain biology behind the RTP plan:

1. Ultrasound guided injection; The doctor injected a 'structural cause of pain' and, on retesting the provocative shoulder movement after the injection, the pain was no longer present. Possible underlying mechanisms include anaesthetising of peripheral nociceptors and reduction of the threat response secondary to increased trust in the clinician and plan.
2. Education. At each stage of the RTP plan the reasoning behind exercises and interventions was explained to the player. Key points such as 'pain does not equal tissue damage' were emphasized, and that strengthening will improve tissue tolerance to be able to meet the demands of repetitive serving.

TABLE 2

	Stage 1 (of 5) *RECOVERY*	*Stage 2 (of 5)* *RELOADING*	*Stage 3 (of 5)* *RECONDITIONING*	*Stage 4 (of 5)* *RETURN TO SERVING*	*Stage 5 (of 5)* *PRE-COMPETITION*
PURPOSE	*Post-injection recovery & low tendon reload*	*Below shoulder strengthening & forehand (FH) preparation*	*Overhead shoulder strengthening & serve preparation*	*Serve reloading Increase on court tennis time*	*Return to match practice*
PHYSIO	*Manual therapy Compex disuse atrophy Basic cuff activation & scapula setting*	*Game Ready/cryotherapy (if required) Manual therapy RC NM drills into higher ranges and different planes*	*Manual therapy for maintenance Serve preparation program RC NM drills for warm up*	*Manual therapy for maintenance Independent shoulder warm up*	*Manual therapy for maintenance*
STRENGTH & CONDITIONING	*Left -sided UBWs only Core -avoid WB via upper limb (UL) Cardio (excluding heavy running/versa) LBWs without loading right arm*	*Reintroduce Push/pull exercises (excluding OH) Core (avoid WB via UL) Cardio (excluding versa) LBWs as per normal*	*Overhead UL strengthening focus Maintenance of body conditioning*	*Shoulder rate of force development training Maintenance of body conditioning*	*Maintenance of body conditioning*
TENNIS		*Backhands (BHs) only - time on court limited*	*Build up volume of FHs*	*Build up on-court training volume to normal Return to serve protocol (build up to 520)*	*Practice matches Normal serve intensity*
END STAGE CRITERIA	*PROM Horizontal Flexion at 35deg/+ Painfree AROM Flexn & Abdn to 90deg Thoracic rotation AROM at >40deg*	*Full and painfree AROM Flexion, Abduction & ER Passive TROM shoulder rotation within 10deg different Equal isometric shoulder strength @ 0-60deg elevation Dynamic rotary stability test (DRST) normal at 0-60deg Pain free shadow FHs x10*	*No scapula dyskinesis DRST normal at 90degrees Negative empty can test Complete serve prep drills comfortably Isometric ER:IR ratio of >0.75 @90/90*	*Eccentric ER:concentric IR ratio of 0.9-1.1 Eccentric ER/BW peak force @>25%BW*	*Play 10 practice sets in 4 days*

Table 2: Return to Play plan.

Legend: UBW=upper body weights; LBW=lower body weights; AROM=active range of motion; TROM=total range of motion; RC=rotator cuff; NM=neuromuscular.

Illustration

3. Promotion of a therapeutic alliance; The player was involved in the decision-making process. She had regular input from the same doctor and physiotherapist and was seen almost daily. Her concerns were addressed at every stage. In addition regular input from the psychologist helped reinforce the same message about the pain, as well as working through other concerns in day to day life.
4. Exercise prescription; At all points she was exercising. Not always the shoulder but her body. As well as staying conditioned it is likely this exercise helped modulate central processes of reducing pain.
5. Pacing and graded exposure; Each stage was challenging the shoulder more and more through progressive strengthening work as well as tennis-specific progressions, with a goal of no flare in pain at the end of each stage. In healthy tennis players the ratio of eccentric external rotation: isometric internal rotation at 90° of abduction and 90° of external rotation ranges from 0.8-1.2, and the average eccentric peak force is at 23% relative to body weight (BW)[17,18]. Her baseline shoulder strength markers were initially much lower than those, and so higher exit criteria targets were set. And specific to serving, stage 4 looked at increasing serving load through intensity and number of serves per session. Professional female players serve an average of 96 serves per match, and so the goal was to build up to at least 520 serves in a six-day training week, to prepare her for up to five singles matches during tournaments while lowering the risk of significant spikes in serving load.
6. Considering the context and the brain in pain; Stage 5 of the rehabilitation plan incorporated two three-set matches in a non-tournament setting. This emulation of the competitive environment, as well as the promotion of a therapeutic alliance and education to reduce the threat response, addresses several central mechanisms.
7. The player was treated holistically; She saw a psychologist and nutritionist to address her eating disorder. This condition may have put her in a pro-inflammatory state, making her nerves closer to the all or nothing threshold. By addressing her nutritional intake and the drivers contributing to her restriction her threshold will have been reduced.

Outcome: The player returned to competition after four months with no recurrence of shoulder injury.

SUMMARY

As clinicians working in the sports medicine field and particularly in the elite setting, we don't often consider the mechanisms at play behind the persistent pain an athlete experiences when injured, which in turn can affect their outcome. By understanding the biology behind pain clinicians can incorporate key principles into their management thus enabling more holistic and whole person care.

When formulating a treatment plan, aside from the usual criteria-based return to play plan, clinicians should consider what possible pain mechanisms could be at play and then tailor interventions to address them.

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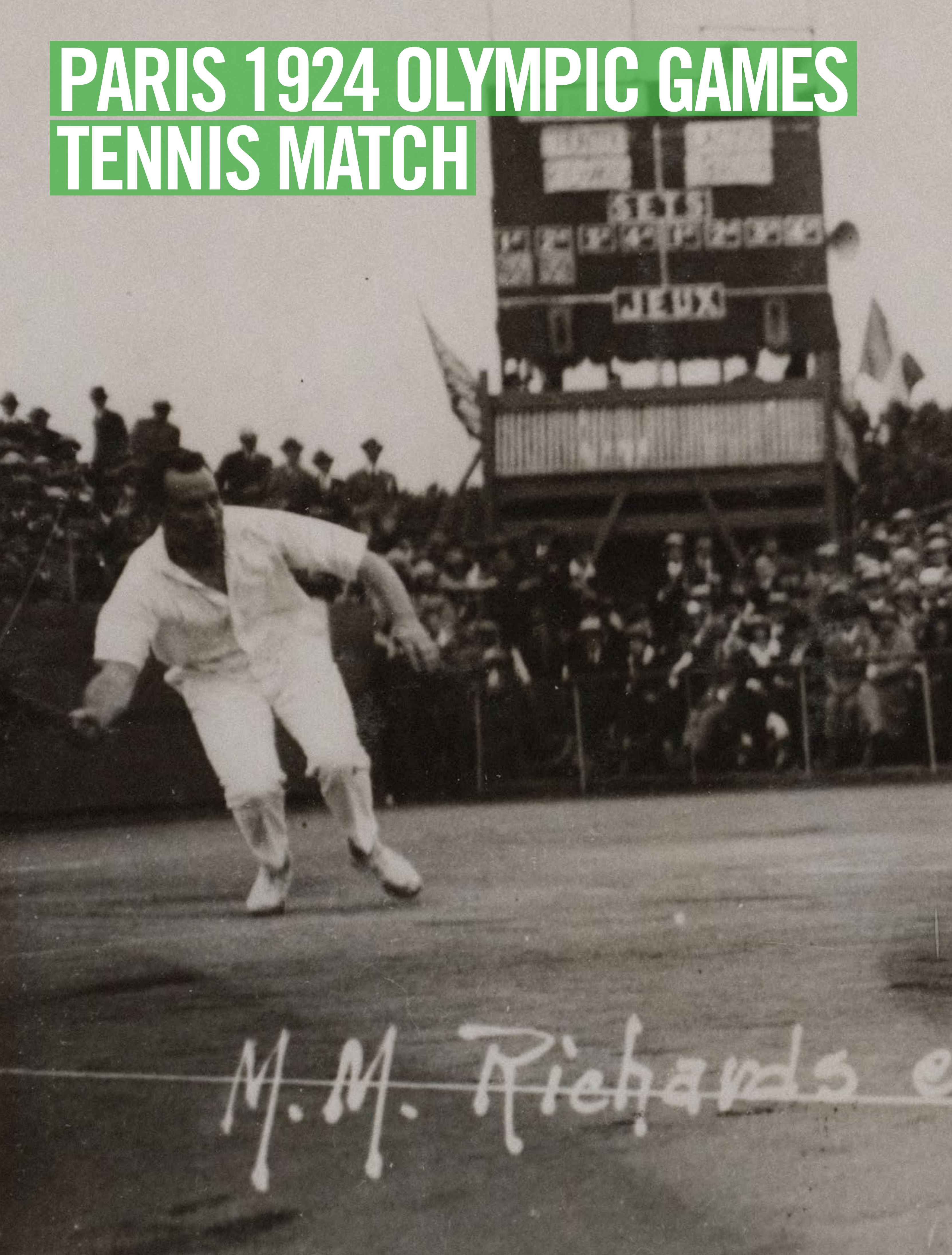
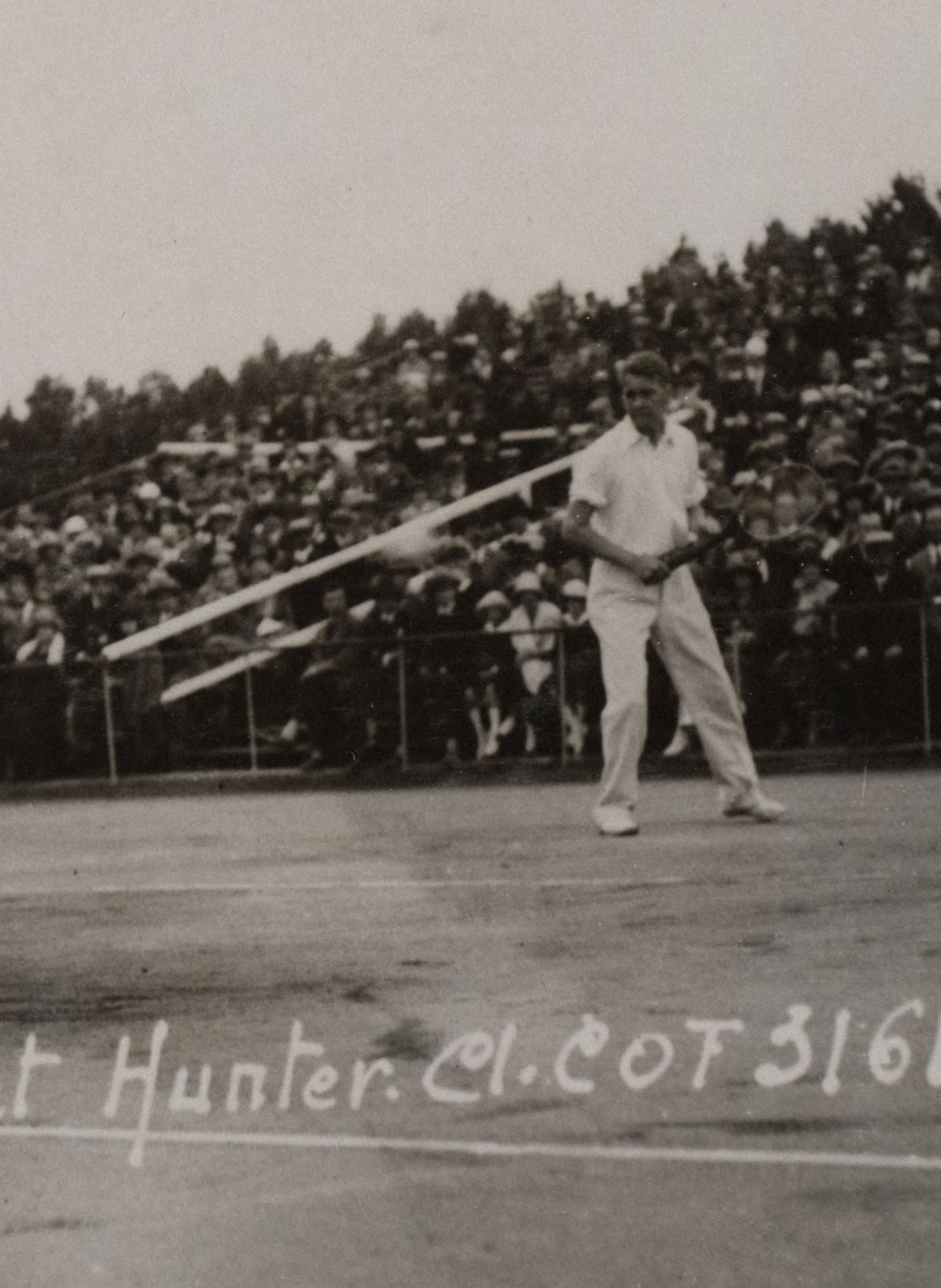
PARIS 1924 OLYMPIC GAMES TENNIS MATCH





© Archives CNOSF/AFP/Getty Images – Paris 1924 Olympic Games. Richards and Hunter vs Jean Borotra and René Lacoste in the semi-finals of the men's doubles tournament.

UPDATED MUSCULOSKELETAL SCREENING RESULTS OF MALE PROFESSIONAL TENNIS PLAYERS

THE ATP PERFORMANCE AND INJURY PREVENTION PROGRAMME

– *Written by Todd Ellenbecker, Gary Windler, David Dines, USA, Babette Pluim, The Netherlands, and Per Renstrom, Sweden*

INTRODUCTION

The use of a tennis specific musculoskeletal screening programme for elite level tennis players provides key information for both injury prevention and performance enhancement. Prior published reports[1,2] have outlined specific orthopaedic clinical tests applied for elite tennis players based on the understanding of the unique demands placed upon their musculoskeletal system[3].

The purpose of this updated article is to provide objective descriptive data highlighting the musculoskeletal adaptations and unique findings in male professional tennis players, obtained during the performance of screenings of 333 unique players over an 18 year period at ATP tournaments. The purpose of the ATP performance and injury prevention programme is to apply scientific and clinically valid and reliable screening tests to obtain objective descriptive information that can provide the framework for an exercise-based injury prevention programme. This programme targets areas of identified deficiency based on the descriptive data gathered during the screening session for the player. Not included in this report are findings from 245 follow-up screenings performed to provide longitudinal comparison and provide additional guidance beyond the initial screening session. To date, a total of over 600 tests have been performed on ATP players in this programme.

The sport of tennis produces significant repetitive demands on the entire body that can result in injury, primarily overuse, in the lower and upper body, as well as the trunk[4,5,6]. Table 1 outlines the clinical tests performed in the ATP Performance & Injury Prevention Programme. These

Table 1

Posture & Scapula:

Shoulder Height
Infraspinatus Atrophy Position (Hands on Hips View)
Kibler Scapular Dyskinesis Test

Shoulder:

Internal/External/Total Rotation ROM @ 90 Degrees Abduction
Horizontal Adduction (Cross ARM) ROM
Empty Can MMT with Hand Held Dynamometer (HHD)
Shoulder External Rotation at the side with HHD
Shoulder External Rotation with 90 degrees of Abduction with HHD

Elbow:

Elbow Extension ROM

Core Stability Tests:

Abdominal Bracing with Blood Pressure Cuff
Bridging with Unilateral Support
Ipsilateral Quadruped Test
One Leg Stability Test

Lower Extremity Flexibility Tests:

Straight Leg Raise ROM
Prone Knee Flexion ROM
Prone Hip Internal & External Rotation ROM
Thomas Test (Hip Flexors)
Dorsiflexion ROM (Knee straight/knee bent)

Table 1: Clinical Tests in the ATP Performance & Injury Prevention Programme.

Figure 1: Evaluation of shoulder height and visual observation of infraspinatus atrophy in the hands on hips resting position in an elite level tennis player.

specific tests measure range of motion, strength, and stability across the body, and are initially adapted and expanded from the USTA High Performance Profile (HPP)[3]. It is beyond the scope of this article to list in detail all tests and their diagnostic accuracy and methodology, however this can be found in prior published references[1,2]. The primary scope of this article is to present the latest clinical findings from the 333 musculoskeletal screenings. Additionally, it aims to summarize the significant and distinctive differences observed in male professional tennis players. The descriptive data provided in this article aims to aid sports medicine professionals in interpreting musculoskeletal testing results for the development of rehabilitation and injury prevention programs.

PLAYER DEMOGRAPHICS

Out of the 333 players in this sample, the majority were right-handed (85%) and predominantly used a two-handed backhand (76%). Additionally, 73% of players used a semi-western grip for their forehand. The players had an average age of 25.7±3.9 years and weighed 80.1±7.0 KG at the time of assessment.

POSTURE & SCAPULA

The typical shoulder posture observed in elite tennis players is characterised by the dominant shoulder being lower than the non-dominant shoulder[6]. This updated report confirms this observation, with 85% of players presenting with a lower dominant shoulder , while less than 5% presented with the non-dominant extremity lower. This suggests that a "lower" dominant shoulder, compared to bilateral height, is a normal finding in healthy uninjured players during clinical presentation. Infraspinatus atrophy, as agreed upon by two examiners based on significant concavity over the infraspinous fossa with visual observation, was detected in 73.5% of dominant shoulders and 6.16% of non-dominant shoulders (Figure 1). This finding aligns with a previous study by Ellenbecker et at[7], showing that infraspinatus atrophy correlated with external rotation weakness in professional tennis players. It indicates that dominant infraspinatus atrophy is prevalent in this population and may serve as an indicator of rotator cuff (external rotation) weakness requiring preventative intervention[1,7].

Figure 2: Measurement of shoulder internal rotation with scapular stabilization.

TABLE 2

Parameter	Dominant Arm	Non-Dominant Arm	Difference
Range of Motion (degrees)			
Shoulder ER	100.0+8.5	95.1+10.3	4.8+9.8
Shoulder IR	38.7+8.0	49.5+7.3	-10.8+9.1
Total Rotation	138.6+10.3	145.2+9.7	-6.6+8.9
X-arm Adduction	31.6+6.5	40.1+7.3	-8.3+6.9
Strength (KG/KG)			
Empty Can	13.4+3.3	14.1+2.90	-0.66+2.34
ER Neutral	16.9+3.64	18.8+2.94	-1.92+3.1
ER 90 ABD	18.7+3.7	17.6+3.7	0.93+2.63

Table 2: Shoulder ROM & strength data.

In this large study of male professional tennis players, the scapular dyskinesis test revealed observable scapular dysfunction, as per the classification and grading system of Kibler[8] in 54% of players on the dominant extremity and only 33% on the non-dominant extremity. These results underscore the necessity for preventative scapular stabilization exercises for a significant proportion of players in this population. During the test, a 2 kg ball was used in each hand to further provoke the scapular stabilizers during repeated arm elevation and controlled lowering. For players presenting with scapular dyskinesis, targeted scapular stabilization exercise focusing on the lower trapezius and serratus anterior force couple are advised and recommended.

SHOULDER

Testing shoulder range of motion (ROM) consisted of supine positioning with scapular stabilization as prior reported[1, 2,3] using a standard goniometer (Figure 2). Table 2 contains the mean±standard deviation of the dominant and non-dominant extremity as well as the average difference between extremities for the shoulder measurements from this study. The findings show 4.8±9.7 degrees greater external rotation ROM on the dominant extremity whilst internal rotation was 10.8±9.2 degrees less on the dominant extremity. This is consistent with many other reports on upper extremity overhead athletes[1,2,6,9].

Total rotation ROM which simply represents the summation of the external and internal rotation measurement was 6.6±8.9 degrees less on the dominant arm. This finding is clinically significant for interpretating shoulder rotational ROM in elite tennis players. It suggests that based on the descriptive data from this extensive population of professional males players, a loss of up to 6.6 degrees in total rotation ROM on the dominant arm is common. However, total rotation ROM losses exceeding 6-8 degrees indicate a pivotal threshold where interventions such as the sleeper and cross arm stretch are recommended and implemented to mitigate total rotation ROM loss on the dominant extremity[1,2,6,9].

Bilateral shoulder cross arm adduction ROM was assessed in a supine position, using scapular stabilization along the lateral scapular border with the examiners hand and an inclinometer (Figure 3). This test also measures posterior shoulder tightness in addition to the traditional measurement of internal rotation ROM at 90 degrees of shoulder abduction. The results indicate that the dominant extremity is 8.3±6.9 degrees tighter than the non-dominant extremity. This finding holds clinical relevance, emphasizing that approximately 8 degrees less horizontal adduction ROM is typically observed in the dominant extremity in the elite tennis player. When limitations exceed 8 degrees between extremities, it signals the need for posterior shoulder stretching performed on the dominant extremity both prior to and after tennis play to create a cross arm adduction profile with less than an 8-degree difference between extremities.

Results of shoulder strength testing are displayed in Table 2. The results of isometric strength data are presented in Kilograms (KG) of strength per KG of body weight (KG/KG) to allow for application of these ratios for clinical and performance cases. Tests were performed using a "make" test format to enhance reliability of the data acquisition. Normalization of strength data to body weight allows for application of descriptive

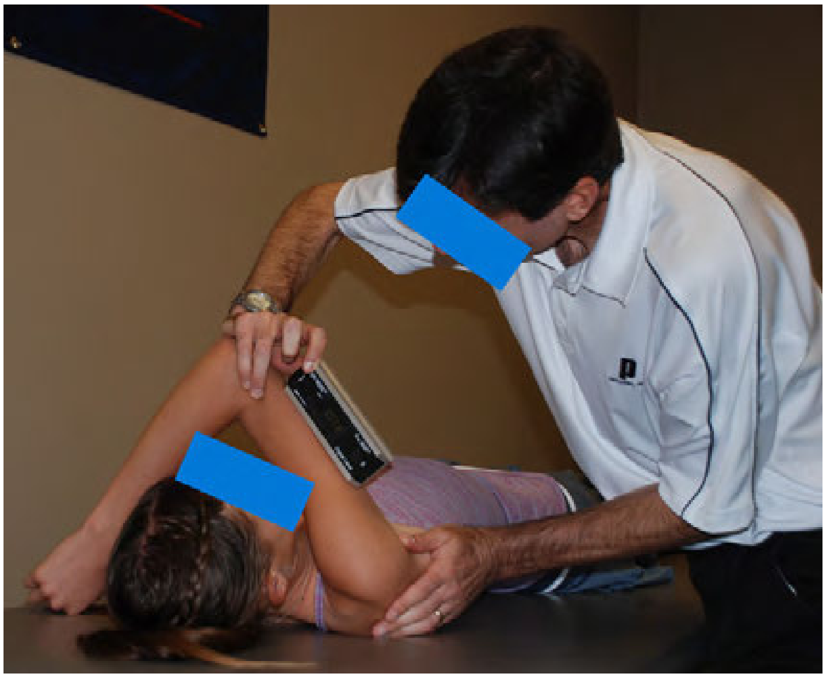


Figure 3: Measurement of shoulder horizontal adduction using an inclinometer with lateral scapular border stabilization.

Figure 4: Measurement of shoulder external rotation in 90 degrees of abduction in the seated position using a handheld dynamometer.

data profiles across players of various sizes and increases the utility of these measures.

The empty can test is used to best represent supraspinatus strength tested with a hand held dynamometer (HHD) in 90 degrees of elevation. Results of testing show the dominant extremity to be 0.66±2.34kg weaker than the non-dominant extremity. Concomitant testing of shoulder external rotation at the side, which primarily tests the infraspinatus, shows a mean deficit of 1.92±3.1 KG/KG on the dominant extremity in these players. Finally, testing the shoulder in 90 degrees of abduction for external rotation strength which primarily tests the teres minor and the infraspinatus secondarily showed 0.9±2.6 KG/KG greater strength on the dominant extremity compared to the non-dominant extremity (Figure 4). This creates a very abduction specific shoulder external rotation strength profile whereby external rotation strength measured at the side (infraspinatus) is slightly weaker on the dominant extremity whilst testing at 90 degrees of abduction (teres minor/infraspinatus) is actually stronger on the dominant extremity. Extensive support in the literature exists for the application of posterior rotator cuff strengthening using submaximal loading paradigms (low resistance, high repetition formatting) for both rehabilitation of shoulder pathology and injury prevention for overhead athletes[1,2,6]. These data can help guide clinicians evaluating high level tennis players with respect to normal shoulder strength characteristics based on this very large homogenous sample of male professional players.

ELBOW

The primary elbow test utilized was measuring elbow extension ROM with a standard goniometer in a seated position and 80-90 degrees of shoulder flexion and forearm supinated. Results of testing show a flexion contracture (loss of full elbow extension) of -2.7±6.7 degrees on the dominant arm with 4.6±6.4 degrees of hyperextension on the non-dominant extremity. This results in a bilateral difference of 7.1±6.2 degrees between extremities in elbow extension ROM. Players presenting with greater degrees of flexion contracture and bilateral difference may be candidates for interventions to improve elbow extension ROM through stretching and manual therapy/mobilization.

CORE STABILITY TESTING

Several tests are used to assess core stability in elite tennis players[1,2]. High levels of core muscle function are present during all tennis strokes and tennis specific functional movement patterns[4,10]. Loss of core muscle stabilization can increase spinal injury risk and inclusion of multiple tests of both anterior and posterior chain core muscle strength are important parts of a tennis specific musculoskeletal screening programme.

The abdominal bracing core stability test includes the use of a blood pressure cuff placed in the lumbar spine whilst alternatively lowering in a reciprocal fashion each lower extremity from a 90 degree hip and knee flexed starting position toward extension while maintaining a posterior pelvic tilt against the blood pressure cuff (Figure 5). An established requirement for passing this test is the ability to perform 10 repetitions with each lower extremity keeping an acceptable level of posteriorly directed pressure into the blood pressure cuff [1]. Achievement of 10 satisfactory repetitions was performed by 71% of the players tested in this investigation.

Concomitant bridging tests with alternating unilateral lower extremity support without rotational pelvic motion with arms crossed on the chest was achieved by 66% of the players in this study (ie 33% failed to perform the test correctly) (Figure 6). This pairing of abdominal bracing and posterior chain bridging is thought to encompass more of the core musculature in this population as compared to solely measuring the number of abdominal sit-ups in a designated time period[3].

Twenty-one% of players failed the ipsilateral quadruped test, also known as the rotatory stability test. They were unable to stabilize their core while moving the ipsilateral arm and leg pairings in the quadruped position. This is a more advanced core stability test requiring high levels of stabilization to allow ipsilateral extremity movements. The one leg stability test is used to assess both hip and core strength and stabilization[1]. The test is known to identify gluteus medius weakness through identification of contralateral hip drop (Trendelenburg Sign) during its execution, as well as excessive forward lean, and dynamic knee valgus[1] (Figure 7). In ATP players, 53% fail to perform the test without abnormal movement/substitution patterning (Trendelenburg Sign, Forward Lean or Dynamic Knee Valgus) on the dominant (same side as serving upper extremity) and a 48% failure rate was identified on the non-dominant lower extremity. Interventions to improve hip abduction strength and hip rotation (ER and IR) strength coupled with more traditional core stability exercises are given to players who fail these tests to address the insufficient core strength highlighted through failure of one or more of these core test procedures.

Figure 5: Abdominal bracing core stability test using a blood pressure cuff and reciprocal lower extremity lowering.

Figure 6: Bridging test with crossed arm to assess posterior chain core muscle function.

LOWER EXTREMITY FLEXIBILITY TESTS

Unlike the upper extremity (shoulder, elbow), where range of motion often reveals asymmetry, lower extremity flexibility tests consistently show bilateral symmetry. High levels of bilaterally symmetric hamstring (Straight leg raise) ROM were observed in these players (average 80 degrees), alongside comparable symmetry in prone knee flexion (quadriceps) flexibility (approximately 126-128 degrees). Prone hip rotation, measured with the hip in neutral 0 degrees of hip extension, displayed an average difference of approximately 1 degree bilaterally, showcasing remarkable consistency in hip rotational motion among these elite tennis players (Figure 8). This finding of bilateral symmetry in hip rotation ROM is consistent with a prior study of elite junior tennis players and professional baseball pitchers[11]. An average of 68 degrees of bilaterally symmetric total hip rotation ROM (adding hip ER and IR together) was measured.

However, one area of potential concern arises from the high failure rate of the hip flexor (Thomas) test, which stands at 59% for the dominant limb and 57% for the non-dominant limb. Tightness of the hip flexors can increase loading of the lumbar spine and limit hip extension range of motion required for optimal positioning during the cocking phase of the serve[10]. This loss of hip extension ROM can lead to compensation to achieve the extended position through lumbar spine hyperextension loading[12]. It is recommended to implement targeted exercises to improve hip flexor and rectus femoris flexibility after identifying a positive Thomas test result. This approach aims to improve hip extension range of motion.

Finally, distal ankle range of motion is measured in a non-weightbearing position, both with the knee extended (gastrocnemius) and knee flexed (soleus). The differences between the dominant and non-dominant lower extremity are negligible, aligning with the bilateral symmetry commonly observed in the lower extremities of tennis players (Table 3).

Figure 7: One leg stability test for hip and core stabilization.

Figure 8: Prone hip internal rotation measurement position and technique.

TABLE 3

Parameter	Dominant Arm	Non-Dominant Arm	Difference
Range of Motion (degrees)			
Straight Leg Raise	*80.2+8.5*	*80.6+8.6*	*-0.24+1.9*
Hip ER	*36.7+7.2*	*35.6+7.3*	*1.16+5.7*
Hip IR	*32.4+8.8*	*31.5+8.8*	*0.85+6.3*
Total Hip Rotation	*69.2+11.0*	*67.3+11.6*	*1.9+7.1*
Prone Knee Flexion	*127.5+5.9*	*125.8+6.0*	*2.1+3.9*
*Ankle Dorsiflexion **	*8.7+4.3*	*9.2+4.1*	*0.26+3.7*
*Ankle Dorsiflexion***	*14.7+4.8*	*13.3+4.4*	*1.3+3.9*

*Measured in knee extension; **Measured in knee flexion

Table 3: Lower extremity flexibility in professional male tennis players (degrees).

SUMMARY & CONCLUSION

The findings derived from the ATP performance and injury prevention programme provide objective descriptive data highlighting the musculoskeletal adaptations occurring in professional male tennis players due to repetitive elite play. This data set consistently highlights unique upper extremity range of motion characteristics, including reduced shoulder internal rotation, total shoulder rotation, cross arm adduction, and elbow extension ROM on the dominant extremity compared to the non-dominant extremity. Moreover, common findings of infraspinatus atrophy in the dominant arm, lower dominant shoulder posture, and scapular dyskinesis are indicative of postural variations among elite tennis players. Knowledge of these prevalent musculoskeletal findings is crucial for accurately interpreting clinical measurements in elite male professional tennis players. Regarding the lower body, symmetry in range of motion is notable, alongside robust core muscle function. However, frequent failures in the Thomas test and one leg stability test underscore areas of concern. These findings serve as valuable guidance for the designing and implementing both rehabilitation and prevention programs for elite tennis players.

LIMITATIONS

Data from the ATP performance and injury prevention programme is collected from ATP players during ATP tournaments. Due to the tournament setting, players may exhibit varying levels of fatigue, and additionally we have no control over pre-measurement activity or rest. To minimise measurement variation, all measurements were conducted by a single physiotherapist. The programme aims to provide crucial information for players, coaches, physiotherapists, and doctors involved in player care, enabling the development of evidence-based preventive exercise programmes. To enhance compliance, players are equipped with portable exercise equipment (such as elastic bands, weighted balls, and balance platforms) and provided with written and video-based exercise descriptions. This support is essential given the extensive world-wide travel and time spent away from facility-based gyms by professional tennis players.

Knowledge of these prevalent musculoskeletal findings is crucial for accurately interpreting clinical measurements in elite male professional tennis players.

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REHABILITATION OF LUMBAR BONE STRESS INJURIES IN TENNIS PLAYERS

– *Written by Kevin Sims, Australia*

INTRODUCTION

The lumbar spine is the most commonly injured region in elite adolescent tennis players[1] and it is estimated that 60% of tennis players aged between 11-19 with low back pain have a symptomatic pars interarticularis abnormality[2]. The pars interarticularis is typically at risk in sports such as tennis due to repetitive axial loading, twisting and extension of the trunk in end range positions[3]. A pars interarticularis abnormality of a fracture or cortical defect has been traditionally described as spondylolysis[4], however more recently lumbar bone stress injury (LBSI) has become the preferred term because it encompasses the broader continuum ranging from bone oedema on MRI (bone stress) at the lower end to cortical breach (stress fracture). LBSI also implies that the pars abnormality is symptomatic, a relevant distinction as pars abnormalities have been observed in over one third of asymptomatic adolescent tennis players[2].

Management

When managing a LBSI the clinician has two broad approaches to choose. One is to use a functional approach which is guided by symptoms and recovery of function but where bone healing, although desired, is not a priority[5]. This approach allows a more rapid return to activity (approximately 2-3 months) but the longer term recurrence rates are not clear. The other is to follow a "structural" approach[6] where a healed fracture is a very important criteria for return to sport. The time frames for return to sport using this approach are longer (typically 5-6 months) but experiences from other sports (particularly cricket fast bowling) has suggested that fracture healing following a LBSI correlates well with greater long term resilience in elite sport[6] and is the approach advocated by this author.

Use of imaging

MRI scans are the modality of choice when assessing LBSI as they are sensitive to active bone stress as well as being able to visualise fracture morphology[7]. This provides the clinician with a tool to do the following:

- Diagnose a LBSI and stage the point on the bone stress injury continuum (stress reaction or stress fracture)
- Assess the potential to heal (active stress fracture or chronic united defect)
- Assess bone healing over time.

Staging where the athlete is on the bone stress continuum is key; an early diagnosis without the presence of significant cortical breach is associated with excellent bone healing (taking approximately 2.5 months), whereas when the cortical breach is bigger it takes longer to heal (3-5 months), and

Table 1

Phase 1 (0-6 weeks)					
Lumbo-pelvic control examples	*Mobility*	*Aerobic activity*	*Tennis specific*	*Avoid*	*Criteria to progress*
Modified dead bugs-leg lower/lift variation includng SLR and hip abduction *4 point kneel hip extension variations* *Bridging* *DL squat* *Lunge* *DL RDL* *Lateral plank*	*HS stretch* *Hip flexor stretch* *Supported Tx rotation*	*0-2 weeks: Walking alternate days* *2-6 weeks: Stationary bike (lumbar spine neutral)*	*Nil*	*Extension* *Rotation/LF* *Jumping/landing* *Provocative activity* *Swimming*	*Absence of clinical findings (no pain in ADL, no pain on previous positive clinical testing eg: quadrant)* *Performing exercises with good control and technique (clinician's subjective interpretation)* *MRI at 6 weeks showing reduced BMO and a healing fracture*

Table 1: Summary of phase 1 management.

approximately 20% of the cases do not heal[8]. Getting a fracture to heal first time is preferable as recurrent fractures may take 2-3 times longer and be more prone to recurrence[9].

Other factors

It is important to consider other contributing factors in the development of the bone stress injury that may require input from other health professionals. In particular, relative energy deficiency in sport (RED-S) is a syndrome associated with inadequate fuelling for athletic demands and is a risk factor for bone stress injury[10]. Therefore, both sports dieticians and sports physicians play an important role in diagnosis, management, and education of the athlete. Optimal nutrition during the recovery process will also facilitate healing of the fracture.

Manual therapy

Although a graduated exercise program is the cornerstone of the rehabilitation process, manual therapy is a useful adjunct to address some of the potential underlying factors in the development of a LBSI. Commonly, there may be a loss of thoraco-lumbar rotation, an essential element for tennis ground strokes[11] and serving[3], which may lead to increased load on the lumbar spine[12]. Also, a loss of hip extension range due to a hip flexor restriction may contribute to either an increased lumbar lordotic position, or a compensatory lumbar extension, either of which may overload the pars interarticularis. Similarly hamstring tightness has been linked with an increased risk of LBSI in soccer players[13]. Therefore, manual therapy and exercise interventions to address these deficits may be an important aspect of the conservative management throughout the rehab process.

Phases of rehabilitation

Three main phases of rehabilitation when managing a LBSI have been proposed[14] and are outlined below with approximate time-frames. In an elite sports environment tracking bone healing with MRI forms an important part of the decision-making process with respect to when the athlete is able to progress to higher level activity. There is no strong evidence to support any particular exercise approach, with published reports being based on clinical experience, and the following is based on our clinical experience. It should also be emphasised that the time frames are a guide, and individual cases will vary when clinical, functional, technical, maturational, and radiological variables are taken into consideration. The case study presented later in this article provides an example of this.

Phase 1- Fracture protection (0-6 weeks)

During this early phase (see Table 1) the emphasis is on protecting the fracture to facilitate healing. The use of bracing in this phase is often advocated but to date the evidence does not provide strong support for this approach[15]. In a tennis player where the causative factor is a specific sporting movement (e.g.: serving) which is not replicated in normal activities of daily living then bracing is not usually required. However, bracing may be appropriate if:

1. There is a bilateral acute LBSI
2. There is a near full or full unilateral fracture
3. The pain is of high intensity

Although a brace may not be necessary, instructions to the athlete to avoid lumbar extension, rotation, axial loading (and tennis) need to be adhered to.

During this phase the player is able to do lumbo-pelvic control exercises provided they are able to maintain a neutral lumbar spine when under load. Aerobic activity is initially limited to walking (when pain-free) and progressed to stationary bike (low to moderate intensity remaining seated with a neutral spine). Swimming is best avoided in phase 1 while the clinician is trying to limit lumbar extension and rotation.

Fundamental movements (e.g.: squat, lunge, hip hinge) can be introduced with body weight resistance and emphasis on performing the movement with good technique. Resistance can then be added to these movements at an appropriate time later in the rehabilitation.

Upper body loading, particularly maintaining shoulder and scapular muscle function can be done provided the lumbar spine remains in a neutral position and is symptom free. Depending on the specific clinical situation, care may be needed with overhead loading, and this is often best left until phase 2 when the clinician is more confident that bone healing is progressing as expected.

Phase 2- Protected reloading (6-12 weeks)
In this phase the rehab approach shifts from a "support and control" focus to gradually increasing resistance load, running with transition to on-court movement, spinal mobility, and shadow hitting. Resistance loading with a high rate and strain magnitude is a potential osteogenic stimulus[16], which may improve fracture healing in the remodelling phase[17].

The time frames in Table 2 are a guide and each case may be slightly different depending on the size of the fracture, the stage of healing, whether the fracture is new or recurrent and the symptomatic status. The return to running program is based on a previously described program for runners[18] initially but after 2-3 weeks can become more tennis specific movement on court.

If there is a technical aspect to the injury (e.g. serve or ground strokes) then this phase of the rehabilitation is an opportunity for the coach to begin some basic technical correction with shadow hitting and for the on-court movement sessions to incorporate any specific factors that may need to be addressed with respect to footwork.

TABLE 2

Phase 2 (6-12 weeks)					
Lumbo-pelvic control examples	*Mobility*	*Aerobic activity*	*Tennis specific*	*Avoid*	*Criteria to progress*
Dead bugs-contra-lateral arm and leg together Prone plank +/- hip extension Loaded hip thrust Paloff press Banded rotation in lunge Medicine ball pass and catch into rotation Add DB load to DL squat/RDL/Lunge	*Add Tx rotation in half kneel Introduce lumbar rotation stretch (approx week 8)*	*Progressive running program alternate days Progressive swimming*	*8-9 weeks: Begin on court tennis specific movements Shadow FH/BH 10-11 weeks: Shadow serves 12 weeks: Med ball slams Med ball catches into lumbar extension*	*Heavy axial load Repetitive end range extension/ rotation*	*Continued absence of clinical findings Consistent strength program with quality movement patterns and tolerating progressive resistance Demonstrating progressive on court tennis specific movement intensity Ideally MRI at 12 weeks shows healed or advanced healing of fracture*

Table 2: Summary of phase 2 management.

TABLE 3

Return to serving guidelines			
Volume	*Intensity*	*Frequency*	*Periodisation*
Keep volumes around 40-60 serves per day initially while intensity is progressed Aim for blocks of 10-15 consecutive serves (serving is spread over the session) Once player is comfortable serving at good intensity (approx 3-4 weeks) look to add volume Aim is to build toward 400-500 serves per week Allow 6-8 weeks to reach ths goal Serve reload therefore taking approx 3 months	*Start from service line Progress to base line over 3-4 sessions Walk through serves initially Flat serve before progressing to kick serve Monitor intensity with radar or inertial sensors Allow 3-4 weeks to build to full intensity*	*Alternate days serving for first 4 weeks Gradually add consecutive days over the 2nd 4 weeks*	*When player is serving at normal training intensity begin increasing volume with fluctuating loads over a week Low serve day = 40-60 serves Moderate serve day = 60-80 serves High serve day = 80-120 serves Higher volume serving can be spread over two sessions in the day*

Table 3: Return to serving guinelines.

Phase 3-Return to sport (12-24 weeks)
In an ideal situation there is radiologically confirmed healing of the fracture at the beginning of this phase. Therefore, off court, the rehab process can be a more normal training program, which gradually progresses the existing work that has been done during phase 2. Woodchop and med ball throw variations can load the spine into rotation manner which is relevant to building resilience to tennis. In addition, heavier lifts using squat or dead lift variations may be appropriate provided they are done with good technique. As mentioned previously, this type of loading may provide the necessary osteogenic stimulus, as evidence from cricket fast bowlers suggests that lumbar bone mineral density may take up to a year to return to pre-injury levels following a LBSI[19]. This aspect of this approach (the "structural" management approach), is the primary negative aspect as longer time is needed to demonstrate fracture healing, which in turn requires a longer time to reload the bone back to pre-injury levels.

The tennis reload requires close collaboration with the physical performance trainer and coach to gradually increase on-court time. A typical approach would be to limit sessions to inner range movement early (1-2 steps), progressing to mid range (3-4 steps) and outer range (single line to single line) over 3-4 weeks. Also allowing adequate recovery time between sessions is important for bone adaptation, which would typically mean hitting on alternate days for 3-4 weeks.

If the serve is the provocative factor in the development of the LBSI then the serve reload should be well planned with a gradual increase in volume initially and then subsequently in intensity. It is recommended to keep serving to blocks of 10-15 initially and spread over the course of a session to give bone within-session recovery time. Table 3 provides some guidelines for a return to serve program.

In an elite environment, the use of GPS trackers with inertial sensors (e.g. Catapult units) is recommended as an easy way to track actual volumes of serving and ground strokes during training, as well as giving an indication of movement intensity.

Case study
Presentation: An elite 18-year-old tennis player presents with R side low back pain

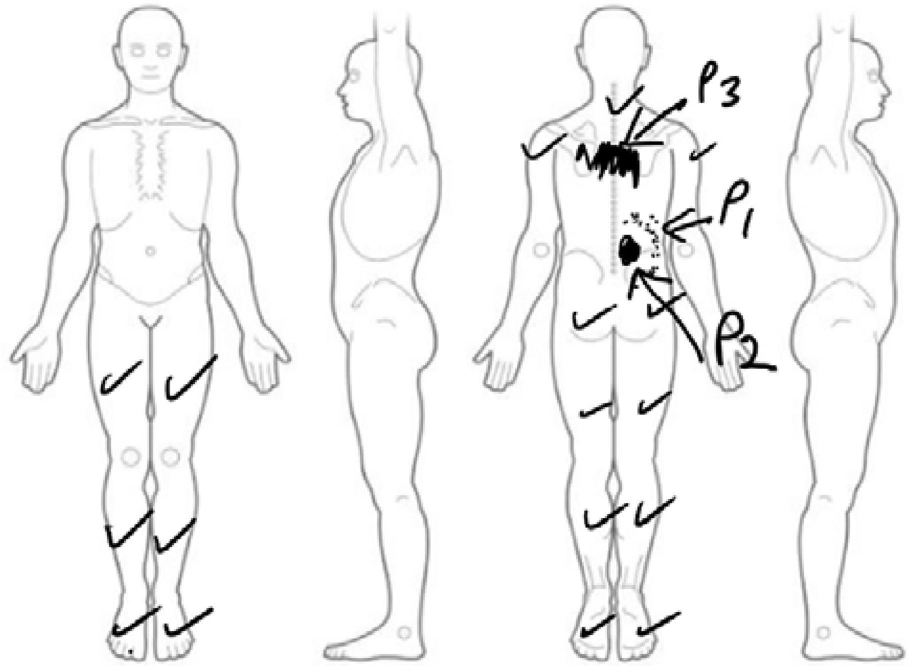


Figure 1: Body Chart of player's pain pattern.

(see Figure 1)

- P1= constant low-grade ache (1/10 Visual analogue scale (VAS)) on court with small warm up effect
- P2= sharp pain with closed stance backhand (BH) and kick serve. The quality of his kick serve and BH is becoming more limited by P2
- P3= thoracic spine stiffness

History:

- Pain has gradually increased over the past month but was pain free prior to this.
- In the past month, training has changed from predominantly hard to clay courts. There is a higher bounce on the clay surface and has had to rotate his trunk more to the right to control his BH because of this. Has also been hitting his kick serve more to take advantage of the higher bounce.
- Has been training with a top 100 male professional (including practice matches) at a higher intensity than normal with less rest and harder ball striking.

Past History:

- Stress fracture low back aged 13-no past scans available, thinks it was right side
- He rested from tennis for 6 months and has not had any issues since then
- Pain in the sternocostal joints approximately 6 months ago which was helped with thoracic spine mobility treatment.

Growth and Maturation: 3 years post peak height velocity, height and weight stable for the past 9 months

Patient Goals: Tournament in 7 weeks' time (junior grand slam).

Physical Examination:

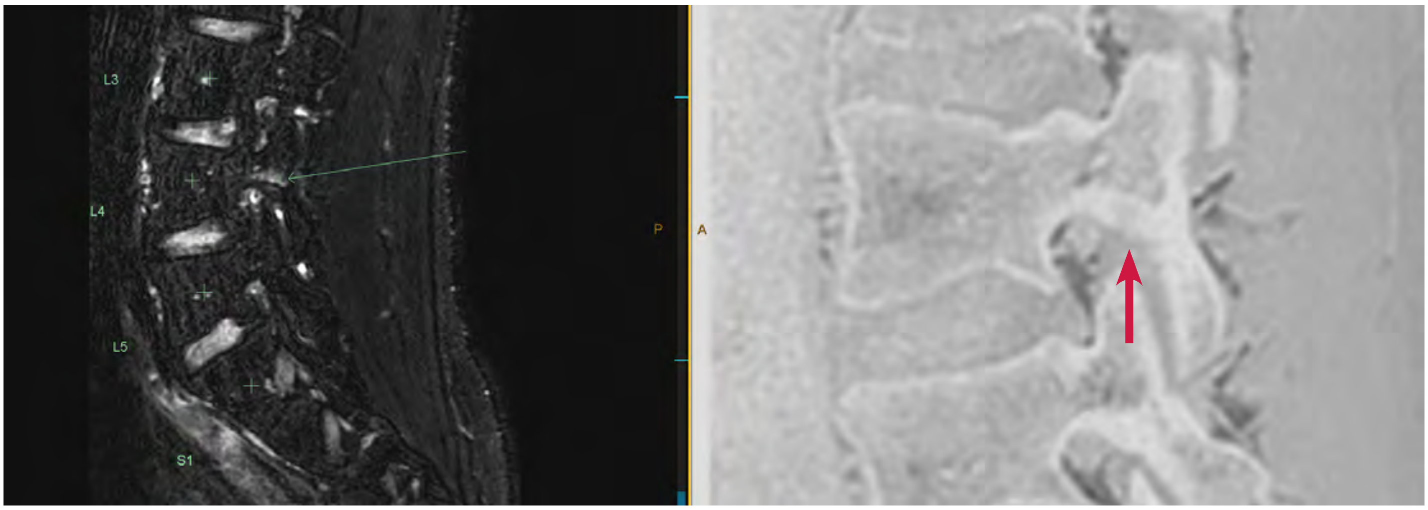
Key outcome measures	
1. Thoracic rotation range of movement in sitting	Right lumbar pain reproduced at end of range to right (Limited range (40° bilaterally))
2. Lumbar quadrant	To the right side reproduces right side lumbar pain
3. Lumbar palpation	Reactive to unilateral pressure right side at L4-5 and L5-S1
4. Hip extension range of movement	10° deficit on left and right modified Thomas test

Imaging (see Figure 2): MRI showed LBSI right L4 pars interarticularis: bone marrow oedema with a ratio of signal intensity from the pars relative to vertebral body of 3.6[20]. Possible cortical anomaly (minor) at L4 pars but no obvious fracture.

Interpretation
Pars interarticularis lesions are common in adolescent tennis players[2] and likely contributors to this injury were:

- Younger age
- Higher intensity of practice/play
- Higher volume of kick serves (self-reported)-kick serve puts higher forces on lumbar spine[21]
- Change in loading on closed stance backhand due to higher bounce on clay-lumbar rotation loads the contralateral (and ipsilateral) pars[22]
- Reduced thoracic rotation range = lumbar spine closer to end range during backhand
- Past history of lumbar spine stress fracture

Management
This situation required careful consultation, management and planning to accommodate the players desire to play in two junior grand slams. Returning to play at week 7 represented a risk as LBSI injuries may take up to 16 weeks to heal[9]. However, in favour of a possible early return was the lack of cortical breach and the BMO although intense (ratio of 3.6) was quite localised. A plan was agreed between sports science and sports medicine staff, player, and coach, giving the maximum amount of deload



Bone marrow oedema (BMO) ratio = 3.6
Ratio = pars interarticularis signal/vertebral body signal

No fracture but slight cortical anomaly

Figure 2: MRI at diagnosis.

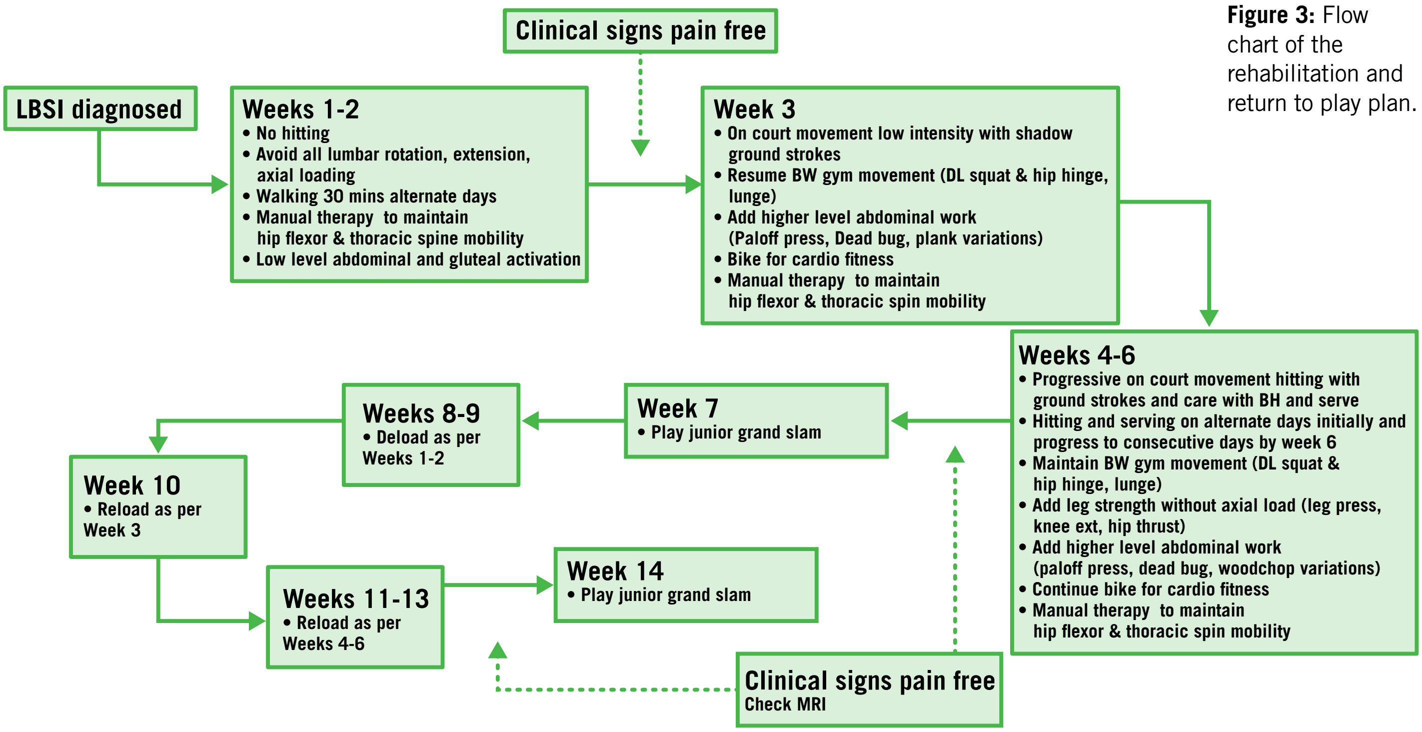


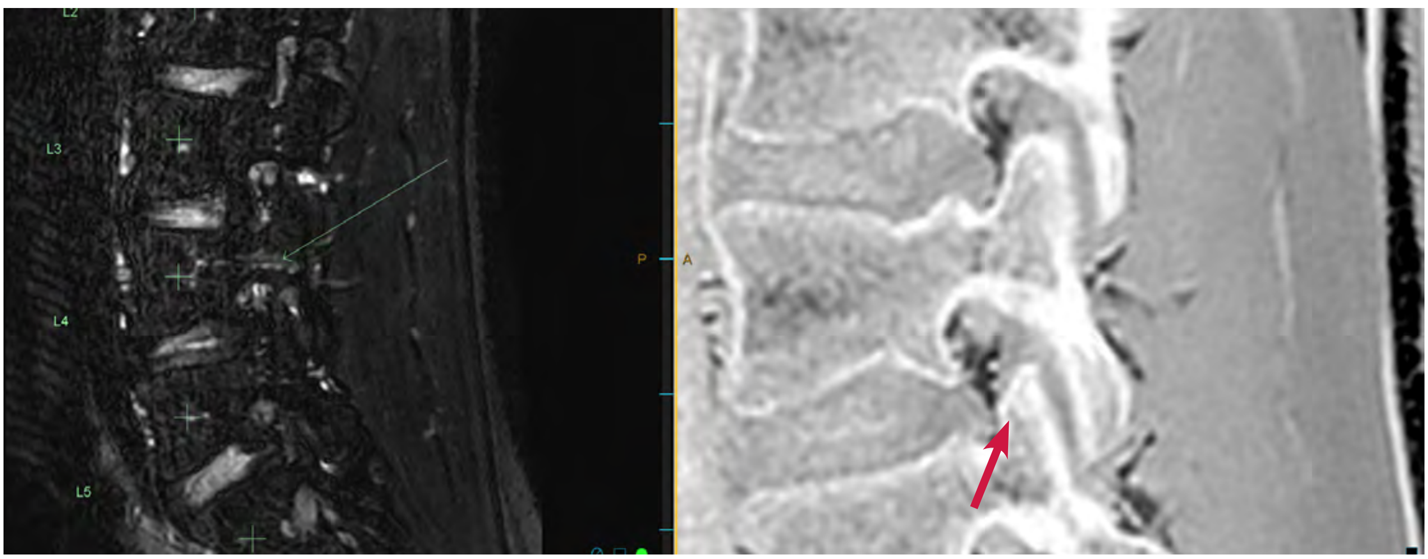
Figure 3: Flow chart of the rehabilitation and return to play plan.

possible (2 weeks) to allow some healing but still have sufficient time to prepare for a tournament. The potential risks of pushing to play were clearly outlined to all parties before a final decision was made. The player's consistent tennis load over the previous year provided some confidence that he could return to play on a limited preparation.

Figure 3 summarises the rehabilitation and return to play plan. Weeks 1-2 consisted of manual therapy including mobilisation of the thoracic spine with posterior-to-anterior glides over the zygapophyseal and costotransverse joints, and a therapist assisted thoracic rotation movement in controlled range to avoid lumbar rotation (see Figure 4). The hip flexors were treated with soft tissue massage and controlled stretching (avoiding lumbar extension). The rationale for both was to improve movement in the adjacent regions to potentially reduce load on the lumbar spine. At the end of the second week the goal was for the clinical outcome measures to be pain-free, and this was achieved.

Week 3-6 involved a tennis reload starting with tennis specific movements on court but with shadow hitting only. Over the next 4 weeks tennis work including hitting was reintroduced on alternate days initially, as bone responds well to bouts of loading and recovery time[23]. In the final week before competition consecutive days of hitting were reintroduced.

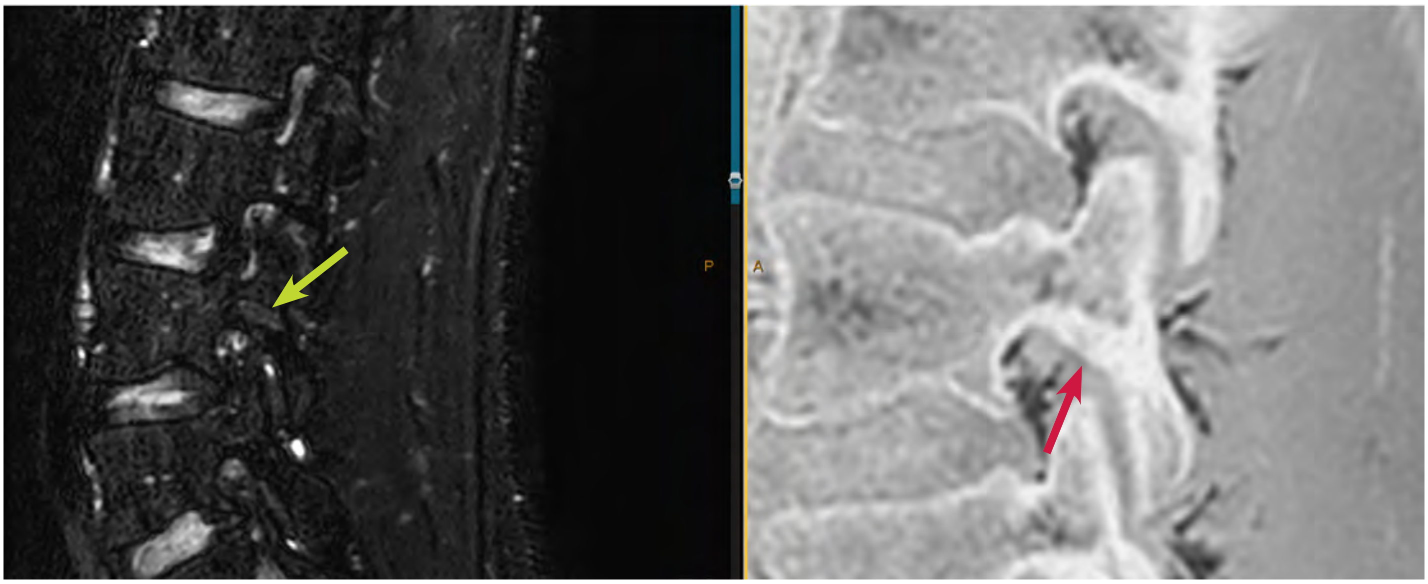
Figure 4: Therapist assisted thoracic rotation in controlled range avoiding lumbar rotation.



Bone marrow oedema (BMO) ratio = 1.6

No fracture but cortical anomaly more apparent

Figure 5: MRI at 6 weeks



Bone marrow oedema (BMO) ratio = 1.1

No fracture, cortical anomaly much improved

Figure 6: MRI at 12 weeks.

An MRI was performed prior to leaving for the tournament which showed a marked reduction in BMO but the cortical bone anomaly at L4 was a little more obvious (Figure 5). The radiologist did not think it represented a fracture but there was some concern about potential resorption of bone at that site (known to occur as part of fracture healing)[24].

The player was able to play the first junior grand slam with no issue and clinical outcome measures remained negative. The loading strategy was then repeated to prepare for the next grand slam. Clinical outcome measures remained negative, and a repeat MRI (at 12 weeks post diagnosis) showed resolution of bone marrow oedema and an improvement in the cortical anomaly (Figure 6). He was able to play the second grand slam and has since made a full recovery.

Considerations

This case study shows the value of an early diagnosis, the ability to be flexible on time frames provided clinical and radiological factors are considered and the importance of a well communicated return to play plan with buy in from all stakeholders. A concern was a possible cortical defect developing on the week 6 scan but the resolution of bone marrow oedema, the absence of clinical signs and the radiologist's interpretation gave confidence to continue as planned.

Other factors that contributed to a good outcome included regular treatment and carefully controlled gym work which improved the range of thoracic rotation and hip extension, which both potentially reduced load on the lumbar spine. The coach and player were also comfortable with the plan to train on alternate days initially, which was a shift in their normal training philosophy, but likely a very important factor in the successful return to play.

SUMMARY

A successful recovery from a LBSI in a tennis player requires an understanding of the underlying healing process of bone. The time frames to achieve bone healing are long and must be respected to get a good long-term outcome. During the healing process rehabilitation can be undertaken to improve muscle support and flexibility initially, and to drive bony adaptation later in the process. There is however some flexibility in the process depending on each individual case, with factors such as the nature of the LBSI, the maturation status of the player, the technical efficiency (or inefficiency) and the athletic development all contributing to the decision-making process. A good starting point is to allow 6 months from the point of stopping tennis to returning to play.

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Available at www.aspetar.com/journal

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MANAGING BREATHING PATTERN DISORDERS IN TENNIS PLAYERS

– Written by Kris Bahadur, Clare-Louise Chadwick, John Dickinson, Ian Horsley, Juliette Lloyd, Victoria McIntyre, Robin McNelis, Julie Moore, Suzanne Scott, and Gwynn Wallace, UK

Tennis players' capacity to appropriately ventilate their lungs is fundamental to their physical fitness and movement efficiency during training and matches. Like many athletes, when compared to the general population, tennis players are more likely to experience exercise respiratory symptoms (e.g. shortness of breath, chest tightness, cough, wheeze, difficulty in breathing) and airway dysfunction (e.g. exercise induced bronchoconstriction [EIB])[1]. Although EIB may explain the presence of these exercise respiratory symptoms in some tennis players, the symptoms may also be caused by other conditions, such as breathing pattern disorders (BPD), exercise induced laryngeal obstruction (EILO) or upper airway obstruction/rhinitis. This review article will explain what a BPD is, highlight considerations for management of BPD in tennis players, and briefly present potential future BPD management strategies.

TABLE 1

Respiratory Symptoms	*Non-Respiratory Symptoms*
Shortness of breath (dyspnoea)	*Persistent muscle tightness in back, shoulders and/or neck*
Not able to take a satisfying breath	*Early onset of fatigue*
Dry, persistent cough	*Prolonged time to recover from high intensity exercise*
Wheeze when breathing in	*Lightheaded during or immediately after exercise*
Difficulty in breathing through nose	*Fainting*
Tightness around chest when breathing in	

Table 1: BPD symptoms.

What is a breathing pattern disorder (BPD)?
BPD is a pattern of breathing characterised by inefficient movement of the rib cage and abdomen and can lead to respiratory and/or non-respiratory symptoms (Table 1).

In most cases of BPD in tennis players, the player experiences disproportionate breathlessness and an inability to sustain high intensity (HI) performance, or to recover from HI training efforts. BPDs can present in many forms. A pattern commonly presenting in tennis players with BPD is excessive breathing relative to the physiological demands of the match activity. This can be observed as prolonged, elevated breathing rates, during recovery windows between points and sets, and is a typical characteristic of a BPD. Players may have a BPD in isolation, but it can also present in conjunction with other respiratory conditions such as EIB, EILO, or rhinitis.

Not all athletes have the same form of BPD, but a BPD usually incorporates one or more of the following (see Figure 1).

Tennis players with BPD could typically experience any of these different patterns

Figure 1: Categories of breathing pattern disorders.

***

- Apical breathing can lead to shoulder injuries
- Overactive abdominals and over bracing can lead to pelvic floor dysfunction
- Inspiratory breath hold can lead to tight sternocleidomastoid, scalene and pectoral muscles

during HI phases of their training sessions or matches. The symptoms usually last between 1-5 minutes, and occur once the tennis player slows or stops activity; however, despite resolution of symptoms, the episode may have impacted the quality of the training session, or their ability to recover between points during a match. In terms of chronic symptoms, players with BPD may report a persistent, dry cough that can last up to 24 hours post-training, and frequent, recurring tightness in their back or shoulders. BPD may not be consistent, occurring only at certain times, for example, during/after particularly hard training sessions, HI and/or high-stakes matches, and under specific environmental conditions (E.g. wind, cold).

Prevalence and diagnosis of BPD in tennis players

Prevalence of BPD in tennis players is unknown, due to the lack of gold-standard methodologies to diagnose athlete BPD however, BPD is reported to occur in approximately 20% of elite UK based athletes[2]. The recognition of a BPD symptoms (see Table 1) may be identified by any member of the athlete's support team. Observations should be discussed within the athlete's multidisciplinary review meetings which may then instigate further assessment with the wider team. It is important that other cardiopulmonary conditions are excluded. Differential diagnosis may include cardiovascular and/or haematological conditions (E.g. anaemia), asthma, rhinitis, EIB, EILO, psychological aspects or a combination of these conditions.

When considering diagnosis of BPD, it is advisable to incorporate a systematic respiratory assessment, so the practitioner can consider whether upper and lower airway conditions are present, which may contribute to the development of the respiratory symptoms reported by the player.[1] Assessment methods for BPD include, evaluating breathing during cardiopulmonary exercise tests (CPET) or other respiratory evaluations, such as, Fractional Expired Nitric Oxide (FeNO) Spirometry and a Eucapnic Voluntary Hyperpnoea (EVH) challenge. A combination of symptom questionnaires, visual and manual assessment of the breathing pattern will support the diagnosis. Consideration must be given to the psychological factors (such as stress, performance anxiety) that may contribute to the development of or sustain a BPD.

A cardiopulmonary exercise test (CPET) can be used to identify a potential BPD, by observing the volume and breathing frequency output during the test. A normal response to the increased levels of work load during a CPET is an increase in minute ventilation throughout the test. Increase in minute ventilation achieved by predominantly increases in volume during the early exercise stages of the CPET. When volume comes towards a plateau there is an increase in breathing frequency to continue to increase minute ventilation through to the termination of the CPET. A player with BPD may show an erratic combination of

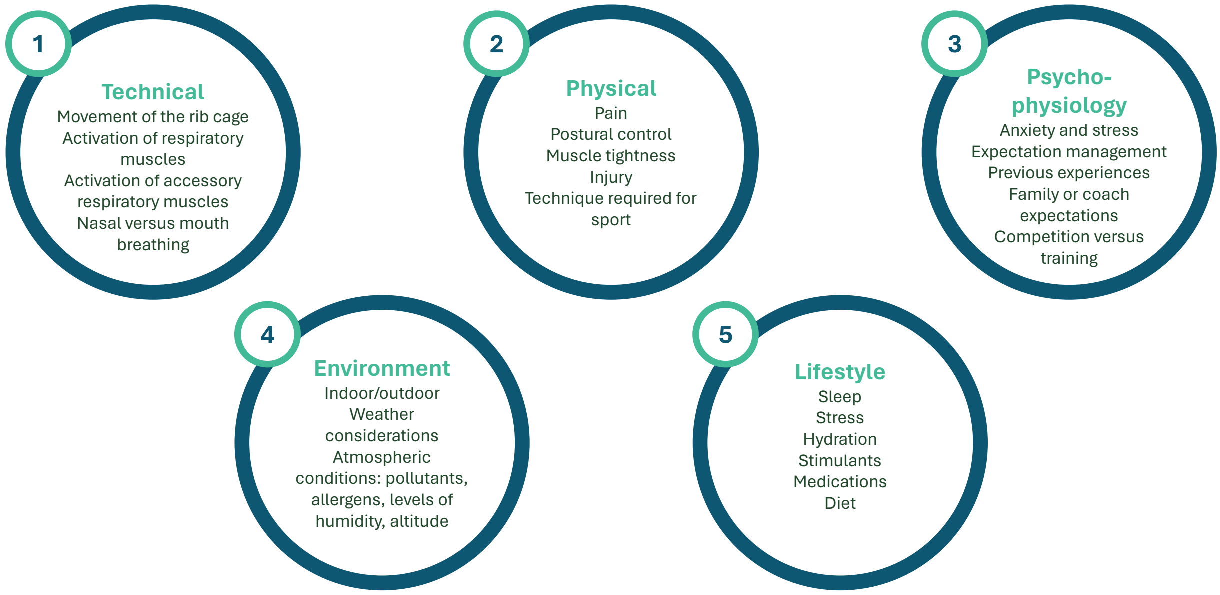

Figure 2: Areas of consideration for the management of BPD in tennis players.

volumes and breathing frequency through out the test.

To better understand what form of BPD the player has (Figure 1), we advise observing the player's breathing pattern during and directly after a high intensity phase of exercise that triggers the player's respiratory symptoms. The can be a live observation but can also be a taken as a video, which can be helpful to show the player their breathing. Breathing pattern should be observed from the front, side on view and from behind the athlete. Assessment of the thoracic complex and posture are important components.

Screening tools, like the breathing pattern assessment tool (BPAT)[3] is conducted with the athlete seated and at rest. A score ≥ 4 is thought to be suggestive of BPD.[3] In addition to the BPAT, the breathing assessment involves asking the player questions related to the respiratory symptoms they are experiencing, whilst listening to the responses the practitioner is also noting signs of a breathing pattern disorder. The Nijmegen questionnaire can be used for assessing hyperventilation symptoms. The Nijmegen questionnaire has 16 items (related to symptoms of hyperventilation syndrome) to be answered on a 5-point scale ranging from 'never' (0) to 'very often' (4). A total score of more than 23 out of 64 points suggests hyperventilation. Additionally, the exercise-induced laryngeal obstruction - dyspnoea index[4] (EILO-DI) questionnaire offers insights during exercise, aiding in identifying individuals with EILO and BPD.

Figure 3: Athlete practising rested breathing to promote diaphragm movement: hand on upper abdomen moves, with little movement of hand on upper ribcage.

Figure 4: Athlete practising optimised breathing pattern, initiating breathing in with lower rib cage movement, so the lower rib cage expands into the band.

Emerging techniques, such as opto-electronic plethysmography that uses 3D motion capture has been shown to detect differences between healthy and disordered breathing patterns[2] .

Management of BPD in tennis players
Management of BPD in tennis players should always take the individual into consideration and examine possible factors implicated in BPD development. Figure 2 presents five areas that should be considered when dealing with breathing pattern disorder: Technical, Physical, Psycho-physiological, Environmental and Lifestyle. The subsequent sections of this review discuss methods to support tennis players by optimising each of these five aspects of breathing, with the aim of helping them overcome BPD and to enhance their performance.

Optimising the technical aspects of breathing
A healthy breathing pattern at rest is different from breathing during exercise. At rest, breathing should be quiet, in and out through the nose, small volume (approximately 500mls per breath), accompanied by a slight descending movement of the diaphragm, and expiration via passive recoil. The athlete can check this by themselves using this online tool: (https://www.physiotherapyforbpd.org.uk/test-your-breathing/).

When the athlete starts to move, characteristics such as breathing rate and volume change in response to activity demand, a process initiated by movement in the lower rib cage between the 10th and 12th pairs of ribs. Initially, lower ribcage movement is lateral and, as exercise demand increases, the ribcage also moves forwards, backwards and upwards to accommodate larger volumes (deeper breaths), and there is an increase in breathing rate and tidal volume, according to ventilatory demand for oxygen and carbon dioxide exchange[2].

Figure 5: Athlete practising expanding lower rib cage, whilst performing a core stability exercise.

Using our understanding of a healthy breath, tennis players with BPD should be educated in optimal movement of the chest and diaphragm during breathing. Exercises which encourage breathing optimally both at rest and to ensure lateral movement of the lower rib cage, as the body starts to move (Figures 3 and 4) can then be prescribed for the tennis player.[5] These exercises are typically performed initially in a stationary position, usually standing or sitting, before progressing to functionally more complex movement, to help the tennis player adopt the optimised breathing pattern whilst in a sport-specific position.

Once the player is competent at taking optimal breaths at rest and during sport-specific actions, breathing intensities can be modified to start to mimic those the player may reach during HI phases of training or match play (Figure 5). Players may also consider using respiratory muscle training (RMT), with a focus on adopting an optimised breathing pattern and with the aim of transferring this to practice and match play.

Optimising the physical aspects of breathing
A comprehensive examination of physical factors contributing to BPD ensures consideration beyond addressing movements of the rib cage. Tennis

> **When considering diagnosis of BPD, it is advisable to incorporate a systematic respiratory assessment, so the practitioner can consider whether upper and lower airway conditions are present, which may contribute to the development of the respiratory symptoms reported by the player.**

players may present with respiratory and musculoskeletal adaptations and experience muscular imbalances, alterations in motor control, and physiological adaptations that influence breathing pattern and movement dynamics[5].

Tennis players with BPD may present with shortening of the upper, middle and lower trapezius and the levator scapulae posteriorly, and shortening of the pectoralis major and minor, and weakness of the deep cervical flexors, anteriorly. These structural adaptations are accompanied by a change in posture, commonly characterised by forward head posture, increased cervical lordosis and thoracic kyphosis, an elevated and protracted shoulder girdle, and abduction and internal rotation of the scapulae. This presentation is typical of the hypothesised 'upper crossed syndrome', as described by Janda[7] however, the proposal that upper crossed syndrome leads to musculoskeletal injury has not been substantiated by rigorous scientific study[8]. Adaptations in posture can influence economy of breathing patterns, leading to accessory respiratory muscles working excessively at rest. This can result in myofascial changes, which in turn may detrimentally effect shoulder girdle movement and increase pain[9].

Considerations in management of physical aspects of BPD/breathing dysfunction include assessing for weakness or tightness in muscle groups identified above, evaluating head posture and neck posture, and encouraging players to avoid holding postural tension in respiratory and accessory respiratory muscles. In support of this approach, diaphragmatic muscle training has been shown to be effective in improving shoulder pain and mobility[10].

Optimising the psycho-physiological aspects of breathing

From a psycho-physiological perspective, breathing is a unique behaviour, being a vital function that is both autonomic and subconscious and able to be unconsciously and consciously controlled. Although the respiratory system is tightly and continually regulated, to maintain homeostasis via the respiratory centre, we can consciously control our breathing for short periods of time when awake. Considering this, breathing presents a unique set of challenges, as well as opportunities, for the athlete.

Challenges include the conscious brain interfering with autonomic regulation of body systems, as well as autonomic system regulation being misunderstood/misinterpreted by the brain, leading to breathing dysregulation/disorder. For example, those with anxiety about their performance may overstimulate the sympathetic nervous system, provoking an exaggerated 'fight or flight' response, which can be detrimental to performance. In addition, negative emotions and unhelpful thoughts can activate the amygdala region of the brain leading to air hunger, and creating a physiologically stronger than necessary desire to breathe, causing a cycle of hyperventilation and an associated drop in performance.

Opportunities include educating athletes about the bi-directional relationship between mind and body, and the key roles the autonomic and sympathetic nervous systems play during performance, which can directly benefit the athlete, as they learn how to work with these systems, and use them to their advantage. For example, athletes who experience hyperventilation at high intensity, and during high stakes performances, may welcome guidance on understanding how they can control their breathing rate and prevent the detrimental effects of over-breathing. In addition, learning how to calm the sympathetic nervous system by adopting slow or slower breathing pre-, during and post-performance, is speculated to yield performance benefits, although evidence into the effectiveness of this strategy in athletes is still lacking'.

Optimising environmental responses

Environments that are cold and of low humidity will increase the prevalence of airway dysfunction. However, there is limited evidence for how environmental factors, such as air temperature, humidity, and wind speed, impact a tennis players' breathing pattern. Anecdotal subjective evidence, gathered from consultations with players, suggests that uncomfortable environments increase the likelihood of respiratory symptoms and BPD occurrence, indicating that research into the impact of the environment and how it may promote BPD development is needed. Furthermore, uncomfortable environments may cause athletes to alter posture and affect upper respiratory muscle tension, which may also contribute to athlete BPD.

When athletes encounter environments that are uncomfortable, they should be encouraged to relax their breathing and maintain good sporting posture, and to avoid forcing their breathing pattern and holding a rigid posture. In cold conditions, athletes may also consider wearing face coverings, which have been shown to be beneficial in reducing airway dysfunction in athletes exercising at lower temperatures.

"Athletes who experience hyperventilation at high intensity, and during high stakes performances, may welcome guidance on understanding how they can control their breathing rate and prevent the detrimental effects of over-breathing."

Optimising lifestyle

In managing BPD in tennis players, we also have the opportunity to consider the individual from a holistic perspective and recognise the importance of taking time to uncover and understand lifestyle factors that may be exacerbating the breathing pattern disorder. Many things influence the way we breathe, as a starting point we would encourage assessment of:

- Sleep hygiene (e.g. encourage nose breathing)
- Stress awareness and the impact it has on breathing pattern (increases apical breathing and breathing rate)
- Ensuring good hydration (the lungs are approximately 90% water)
- Awareness of the effects of stimulants on breathing (e.g. caffeine promotes sympathetic NS activity, which can increase apical breathing and breathing rate)
- Awareness of medications and their effects on breathing (e.g. overuse of asthma therapy, such as inhaled salbutamol, will increase heart rate and heighten sympathetic NS activity)
- Optimal diet to promote stable blood sugar, as this can also influence breathing rate and pattern during performance

Future advances in management of BPD

Breathing pattern training should be a holistic and multi-dimensional intervention that is individualised and athlete specific. Interventions focussing on optimising respiratory rate, depth of breathing, chest wall movement and synchrony are frequently used. These components rely on active participation for effective rehabilitation. Innovative techniques and technologies are being developed to engage both clinicians and end users to further improve breathing patterns and outcomes. An avenue of emerging research targeting rehabilitation involves gathering real-time data to analyse breathing patterns and physiological parameters; examples of this approach include use of biofeedback, virtual reality (VR) training, and digital breathing coaches incorporating smart phone technology (SPT), together with the increased use of respiratory muscle training (RMT) and optoelectronic plethysmography (OEP). Figure 6 illustrates proposed benefits of future therapies.

Biofeedback can include visual, auditory, or haptic options, which widens its potential use. VR programmes to simulate training environments, and SPT to support home use, could provide tailored protocols and position the user at the core of the rehabilitation process. RMT, used within health and sport disciplines for a considerable time, has demonstrated secondary improvements in breathing pattern, for example, an increase in inspiratory flow, volume, and power, together with changes in respiratory timing and should be further explored. 3-D motion OEP is another non-invasive method of objectively measuring chest wall movement and breathing pattern characteristics that holds promise. Dysfunctional breathing patterns can be acutely improved with real-time OEP phase angle feedback, which highlights the potential of this method and suggests that this, alongside other interventions highlighted, could be valuable additions to current interventional approaches.

Practical tips for tennis players

Try these between points and games:

- Reset posture in breaks – relax shoulders, adopt good posture
- Focus on 3-5 good quality lower rib cage breaths in-between points
- Relax and let the breath out
- When comfortable, breathe in through the nose
- Post-match reset breathing, relax shoulders and calm the breath
- Remember: good tennis form promotes good breathing patterns.

Points to remember when considering BPD (see Figure 7 on the next page)

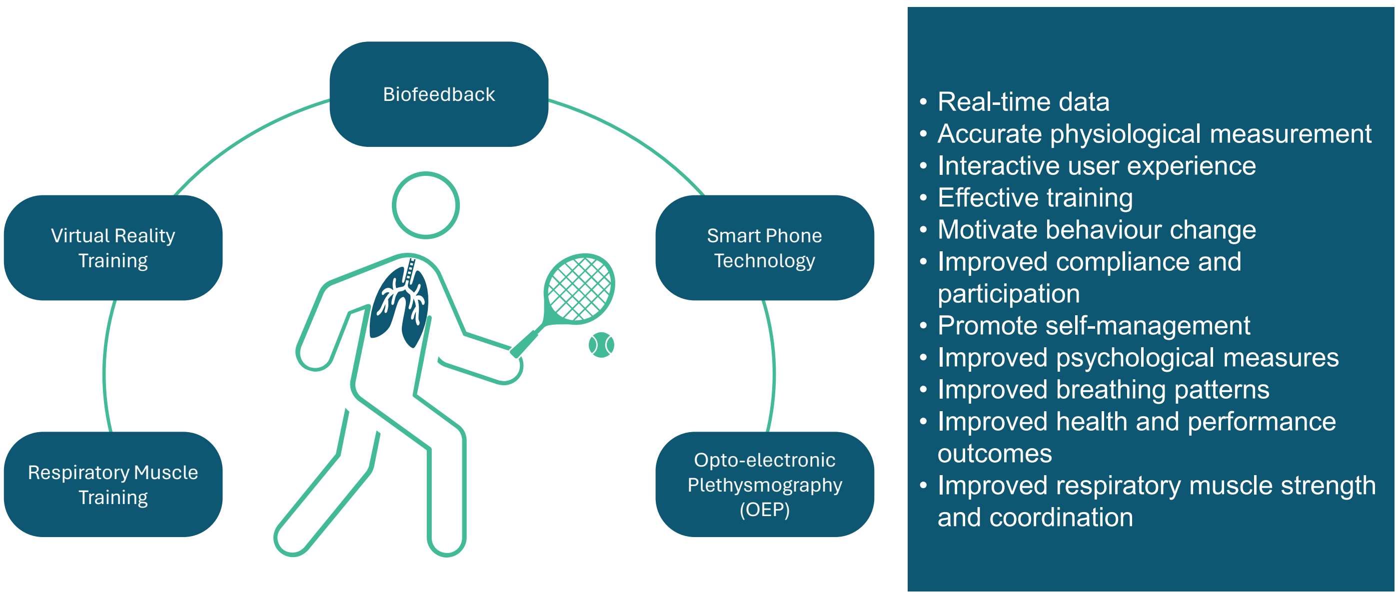

Figure 6: Proposed benefits for future therapies.

Muscle imbalance	**S**tress factors
Accessory muscle use	**E**xpectations
Tightness and injury	**R**ib cage movement
Cough and wheeze	**V**entilation rate
Head position and posture	**E**nvironment

Figure 7: Points to remember when considering BPD.

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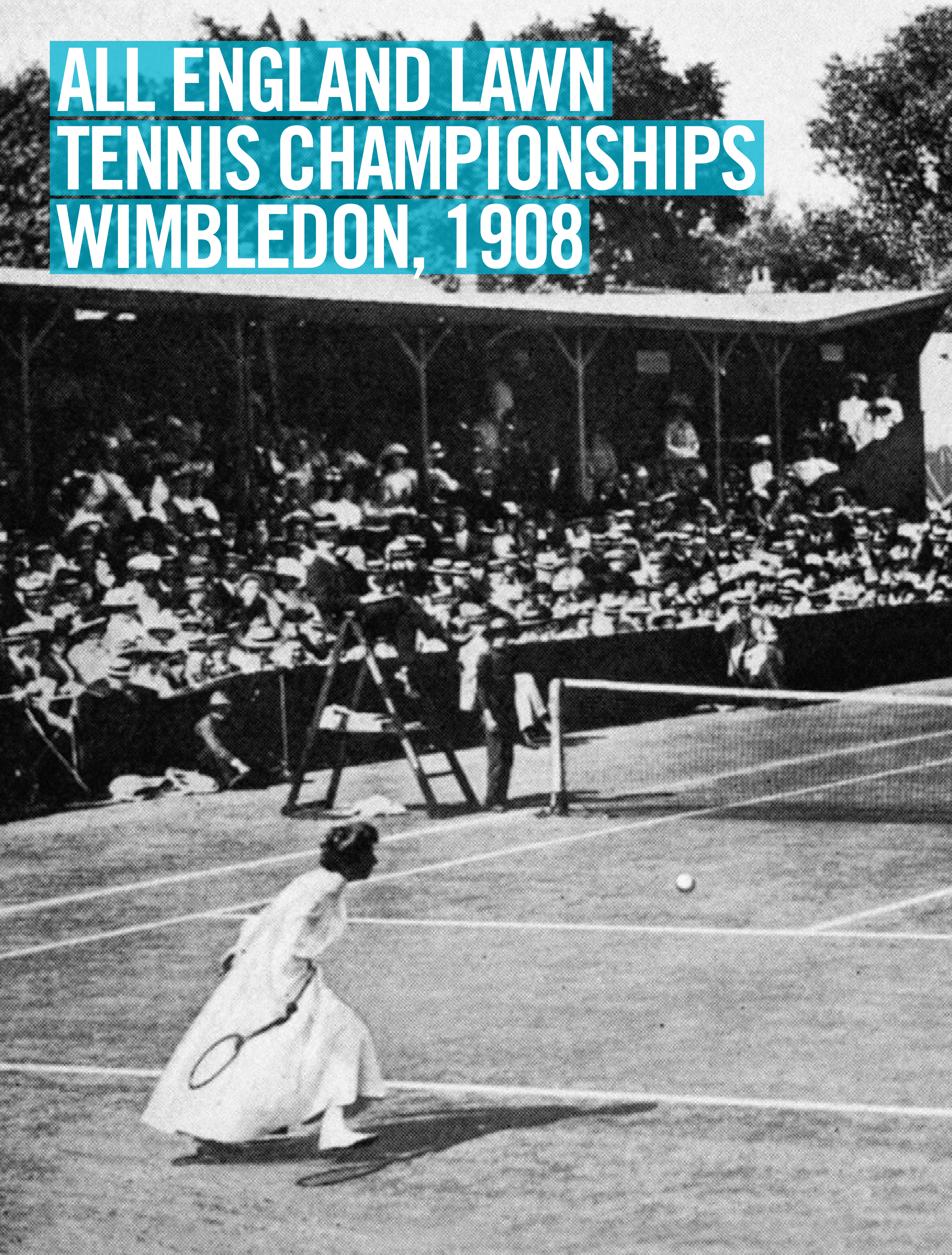
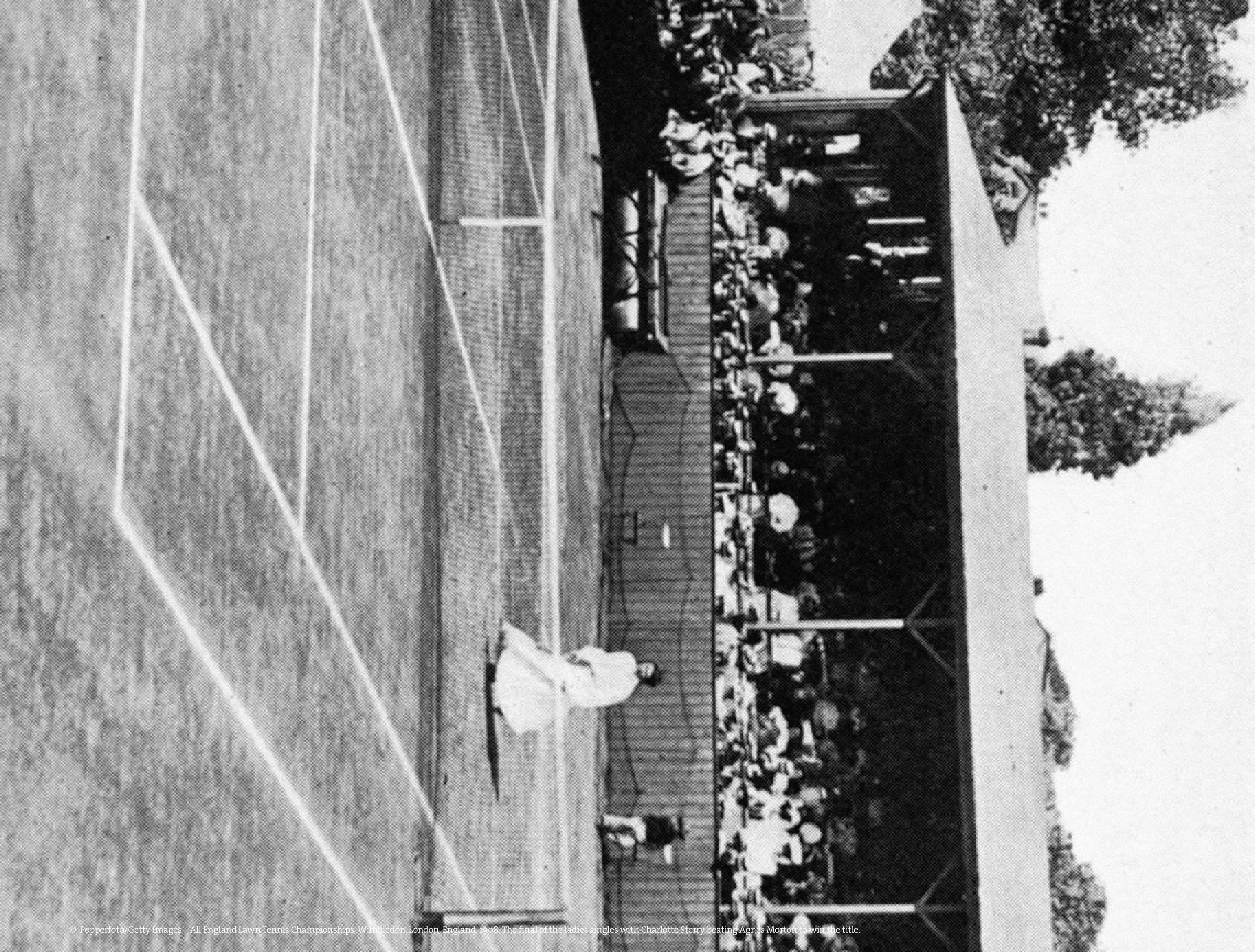
ALL ENGLAND LAWN TENNIS CHAMPIONSHIPS WIMBLEDON, 1908





© Popperfoto/Getty Images – All England Lawn Tennis Championships, Wimbledon, London, England, 1908. The final of the ladies singles with Charlotte Sterry beating Agnes Morton to win the title.

ELEVATING ATHLETE SUPPORT IN WHEELCHAIR TENNIS THROUGH COMPREHENSIVE SCREENING

– Written by Kirsty Elliott, Dina (Christa) Janse van Rensburg, South Africa, and Babette Pluim, The Netherlands

In the dynamic world of wheelchair tennis, where risk and performance are ever evolving, the need for comprehensive athlete screening has never been more crucial. Understanding the intricate balance between health, performance, and readiness is essential for players aiming to excel on the court. Understanding the measurement frequency of periodic screening and high frequency monitoring sets the stage for a nuanced understanding of the athlete's journey. Like a compass guiding through uncharted waters, screening offers periodic glimpses into the athlete's inner workings, identifying potential pitfalls and opportunities for growth. Meanwhile, monitoring serves as a constant beacon, shedding light on the ever-changing landscape of adaptation and recovery[1]. Together, these approaches form the cornerstone of athlete support, navigating the twists and turns of athletic endeavour with precision and purpose.

WHEELCHAIR TENNIS DEMANDS

Wheelchair tennis presents unique challenges for players, on and off the court. On-court demands require players to master the physical and technical aspects of the game, including stroke technique, court movement, and shot selection. Adaptation to the specific challenges of playing in a wheelchair is crucial, involving manoeuvring the chair, hitting shots from various positions, and reacting swiftly to opponents' moves. Furthermore, movement demands such as agility, speed, and balance are essential for effective on-court performance[2]. Off-court demands encompass training, recovery, travel, and managing daily life activities.

Beyond the physical realm, wheelchair tennis players face psychological and physiological hurdles. Psychological stressors like performance pressure, injury management, and competition anxiety and depression can impact players' mental well-being. Physiological challenges include regulating body temperature, managing pain, and combating fatigue, which is especially relevant for those with spinal cord-related disorders.

Weight management poses a common hurdle, particularly for players with spinal cord-related disorders, who may contend with reduced mobility and metabolic changes. Moreover, the diverse

Image: © Getty Images for LTA. Printed with permission.

range of physical impairments among players necessitates tailored training programs and injury prevention strategies. Daily physical demands, for example, transferring in and out of the chair and navigating between venues, contribute to players' overall load, underscoring the importance of rest periods and training volume adjustments.

Despite their challenges, wheelchair tennis players often exhibit remarkable strength, attributed to the need to manoeuvre their body weight, and adapt to various assistive devices. It is common to find areas of great strength contrasted with inactive, very weak musculoskeletal systems, highlighting the importance of addressing muscular imbalances to mitigate injury risks. Additionally, players who start wheelchair tennis later in life may have a low training age despite their chronological age, necessitating tailored physical program prescriptions suitable for beginners.

Understanding the specific impairments faced by wheelchair tennis players allows for targeted interventions to address their unique needs and challenges, ultimately enhancing their participation and enjoyment of the sport.

Mason et al.[3] conducted a comprehensive study on the demands of elite wheelchair tennis, revealing intriguing insights into players' activity profiles and performance dynamics in different divisions. The study highlighted that activity profile variations were linked to individual players' absolute physical capacity, with internal workload and technical performance levels remaining similar across divisions. Interestingly, the research emphasized that technical proficiency often outweighed physical prowess across all divisions, underscoring the importance of skill and strategy in wheelchair tennis.

Key findings from the study shed light on specific gameplay dynamics within the men's elite division. Only 10% of balls were struck on the second bounce, indicating the fast-paced nature of matches. Men also exhibited a higher frequency of volleys than female or quad divisions, suggesting differences in playing style and strategy. Moreover, the study noted that matches where players lost sets were characterized by more high-speed accelerations, indicating moments of decreased control and increased effort in chasing down balls.

Rotational velocity during turning emerged as a crucial factor in predicting tennis performance in wheelchair players, emphasizing the significance of rotational movement ability in gameplay. Furthermore, a specific analysis of backhand strokes[5] revealed notable changes in trunk rotation and shoulder dynamics between wheelchair and standing conditions. In the wheelchair condition, players demonstrated greater angular excursion, velocity, and acceleration during shoulder flexion, as well as higher values for shoulder abduction and adduction. Interestingly, lower racket vibration was observed in the wheelchair condition, suggesting potential differences in stroke mechanics or equipment interaction.

An in-depth understanding of the sport provides valuable insights into the nuanced demands and performance characteristics of elite wheelchair tennis, highlighting the intricate interplay between physical capacity, technical proficiency, and gameplay dynamics. These findings underscore the importance of tailored training and screening protocols to optimize player performance and enhance their competitive edge in the sport.

Screening is therefore necessary to ensure safety and well-being during sports participation, offering a vital opportunity to assess players' health status, detect underlying conditions, and monitor changes over time. This comprehensive approach is particularly crucial in elite wheelchair tennis, where the effects of aging and prolonged athletic activity can impact players' health and performance over the span of their careers.

SCREENING OF WHEELCHAIR TENNIS PLAYERS: WHAT IS IT?

An organization, coach, or player typically requests screening for the following purposes:

- Injury and disease prevention
- Health and well-being monitoring
- Early disease detection/injury prevention
- Performance optimization
- Compliance and safety
- Educational opportunities

The process can further be categorised into medical screening and performance monitoring. Both involve assessing individuals' health status but differ in focus, objectives, and methods. A multi-layered approach to screening should be adopted, incorporating a team of inter-disciplinary professionals to gain objective, global insight into the player. Through comprehensive screening processes and prioritizing player screening, we can ensure wheelchair tennis players receive the support they need to excel in their sport while safeguarding their overall well-being.

Every tennis player presents a unique set of abilities, and the Individualisation principle is important for all players, but within a wheelchair tennis context, this tops the priority list. These players present unique mechanical, physiological, and psychological abilities to the extent that there may not be anything in common between two players competing in this sport. This takes the individualized approach to another level. The general guidelines for screening, treating, or training non-disabled athletes are often not sufficient for wheelchair tennis players, and a think-out-of-the-box approach is required.

Wheelchair tennis is organized into two main divisions: the Open division, featuring separate draws for men and women, and the Quad division, which includes a mixed draw. Diagnostic groups are divided into two primary categories to effectively assess and classify players, following recommendations from the Para sport translation of the IOC consensus on recording and reporting data for injury and illness[4].

The first category comprises neurological impairments, which encompass a range of conditions affecting the nervous system. Neurological conditions found among wheelchair tennis players can be further divided into brain disorders, spinal cord-related disorders and neuromuscular disorders. Neuromuscular disorders are stable or progressive, and screening health care professionals must remember this. Stable disorders could include post-polio or peripheral nerve impairments. Progressive conditions include motor neuron disease, muscular dystrophy or myopathy, which are degenerative by nature and need monitoring over time.

The second category involves musculoskeletal impairments, which affect the structure and function of the musculoskeletal system. This category includes conditions like limb deficiency, where a player may have limb impairment, short stature, leg length differences, and impaired passive range of motion in joints. These musculoskeletal impairments can significantly impact a player's mobility, strength, and coordination, affecting their performance on the tennis court.

WHAT SHOULD BE SCREENED AND HOW?

A few factors will influence the best screening protocol for the individual player.

- The nature of the player's physical impairment
- The interdisciplinary team that is consistently available to that player
- Budget
- Competitive level of the player
- Validity and sensitivity of tests used.

> ***Through comprehensive screening processes and prioritizing player screening, we can ensure wheelchair tennis players receive the support they need to excel in their sport while safeguarding their overall well-being.***

Table 1

Medical Doctor	*Trainer / Strength & Conditioning practitioner / Sport Scientist*	*Physiotherapist*	*Psychologist*
	Screening/ monitoring role in the team		
• *Cardiovascular assessment (ECG, and echocardiogram if indicated)* • *Medical and injury history (questionnaire)* • *General medical and musculoskeletal examination* • *Laboratory testing (blood markers)* • *Sleep quantity and quality* • *Lifestyle habits* • *Vaccinations*	• *Performance marker testing (serve velocity, speed, endurance capacity)* • *Biomechanical movement efficiency* • *Acute and chronic training load* • *Growth and maturation influences* • *Scheduling of travel, training, competition, follow up assessments, interdisciplinary engagements* • *Nutrition*	• *Functional tests such as joint range of movement, proprioception, balance, and some strength tests) ("Aspetar - Athletes Screening Article")*	• *Well-being status* • *Goal setting* • *Life demands* • *Game readiness*
	Recommended frequency of the screen		
Annually	***Daily - Quarterly***	***Bi-annually***	***Weekly - Monthly***

Legends: ECG = Electrocardiogram

Table 1: Example of the screening and monitoring roles of an interdisciplinary team.

The screening process in wheelchair tennis encompasses a thorough examination of both physical and psychological aspects, recognizing their interconnectedness and profound influence on a player's performance. By identifying and addressing any barriers or limitations in these domains, coaches and practitioners can develop more effective training and strategic plans tailored to each player's unique needs. Understanding the physical impairment of the player, including endurance capacity, strength, power, speed, flexibility, and mobility, is crucial for optimizing technical skills and executing tactical manoeuvres on the court. Simultaneously, delving into the psychological realm, such as assessing mindset, confidence levels, and coping mechanisms, can uncover hidden obstacles that may hinder performance. By zooming in on these key areas during screening, coaches, and support staff can gain invaluable insights into the holistic development of the player, fostering a comprehensive approach to tennis planning strategy that maximizes potential and enhances overall success.

Building the screening plan, an interdisciplinary team should assess the following areas (see Table 1): health, well-being, injury history, physical capacities, lifestyle, life demands, training details and schedules, competition schedules and player goals. One should liken this to an artist painting a picture. Only once they have layered the different painting techniques and covered the whole canvas can you interpret the meaning of the piece.

Medical Screening

A Periodic Health Evaluation (PHE) conducted by a medical doctor is recommended for players regularly. This PHE includes basic medical screening as well as special investigation(s).

The basic medical screen encompasses:

1. a thorough evaluation of personal and medical histories,
2. a history on sleep, nutritional and lifestyle habits of the player, and
3. a physical examination which includes a systematic evaluation of all the organ systems (cardiovascular, respiratory, nervous, skin, musculoskeletal, digestive, endocrine, urinary and reproductive).

Special investigations, including essential non-invasive tests [e.g., electrocardiograms (ECGs)], which provide insights into the heart's electrical activity and spirometry, assessing lung function and capacity, are suggested. Additional diagnostic measures, such as echocardiography and exercise tests, may be employed based on clinical necessity. Blood samples can be used to screen for disease prevention, check for haematological conditions, or as a monitoring tool.

Neurological assessments, including evaluations of sensation, reflexes, and motor function, are essential for detecting or managing any neurological impairments. Many reliable functional screening tests are available to screen players for neuromuscular function, soft tissue health and overall movement competency, which inform muscle contraction and/or joint biomechanics. This usually depends on the player's choice of practitioner to perform the tests and the background of that practitioner, but it is commonly performed by a medical doctor or physiotherapist[6,7]. Urological screening, specifically for players with spinal cord-related disorders is a crucial step that can often be overlooked.

Limb deficiency is another common physical impairment seen in wheelchair tennis. A comprehensive examination of musculoskeletal and dermatological health and function needs to be conducted on these players to ensure their functioning limbs can cope with their altered movement mechanics and that the skin-prosthesis interface is well-fitted and maintained. It is worth considering the individual's day to day locomotion as some players may only use a wheelchair while playing tennis. Musculoskeletal radiology services, including X-rays, ultrasound scans can be utilized if indicated, and magnetic resonance imaging (MRI), ensuring a thorough and tailored approach to screening.

A truly holistic screen should also incorporate an interdisciplinary approach to assess the player's visual, dental, psychological, and nutritional health.

Psychological Screen

A player's psychological state plays a pivotal role in their overall readiness and performance, often serving as the linchpin that can either enhance or hinder their physical and mental capabilities. While screening for health, wellness, and readiness covers important aspects of a player's preparation, overlooking their psychological well-being can undermine all other efforts. A player may possess optimal physical fitness, technical skills, and tactical knowledge, but if their psychological state is compromised, it can neutralize these advantages instantly.

Psychological factors such as confidence, focus, motivation, resilience, and emotional stability profoundly impact a player's ability to perform under pressure, adapt to challenges, and sustain long-term success. Issues such as performance anxiety, lack of self-belief, stress, or burnout can manifest unexpectedly, significantly impacting performance outcomes and overall well-being.

Therefore, comprehensive screening should encompass psychological assessments and interventions to identify and address underlying issues that impede a player's mental readiness. This may involve cognitive-behavioural interventions, mindfulness practices, goal-setting strategies, and stress management techniques tailored to the individual player's needs.

By recognizing the pivotal role of psychological factors in athletic performance and incorporating psychological screening into player assessments, coaches and practitioners can better support players in achieving holistic readiness and peak performance.

Performance Monitoring

Implementing a dual strategy that combines daily monitoring of relevant biomarkers and performance metrics with periodic health assessments can offer comprehensive insight into the player's well-being and readiness to perform. In optimizing the timing and execution of these strategies, it's crucial to have a deep understanding of the player's training and competition schedule[1], which can be obtained through regular interactions with the coach and sports scientist. While a snapshot of markers collected during a medical screening may provide some value, continuous player monitoring can provide the context needed to derive the greatest insights from the medical screening process.

The comprehensive evaluation of a player's readiness to perform in wheelchair tennis encompasses different tests and assessments to gauge various aspects of physical fitness and performance. Utilizing tools such as using speed gates or IMUs

(Inertial Measurement Units) to assess speed and manoeuvrability[8], along with the 30-15 intermittent fitness test for court sports, provides reliable tools for monitoring a player's readiness to perform in wheelchair tennis. These tests offer insights into a player's aerobic fitness levels and anaerobic explosiveness, which are crucial for maintaining peak performance amidst the travel demands and competition schedules inherent in tennis. Additionally, the Wingate arm ergometer test and supine or seated overhead medicine ball throw test[6] are valuable indicators of power, freshness, and readiness to compete for both non-disabled and wheelchair tennis players. Grip strength using an isometric dynamometer can also be used as a quick and reliable measure of the ability to produce maximal force and is a tool that players can travel with and use as an objective measure of preparedness[6]. While measuring serve velocity with radar guns or video methods may be less feasible for lower-level players, it remains a pivotal predictor of tennis performance, particularly in junior players. Thus, incorporating these monitoring tools into screening processes enables coaches and practitioners to make informed decisions about a player's readiness to compete and tailor training programs accordingly.

CONCLUSION

A comprehensive screening approach in wheelchair tennis is not merely a routine task but a fundamental aspect of player management, essential for safeguarding health, enhancing performance, and promoting overall well-being. The timing of the screening and thorough understanding of the unique demands of wheelchair tennis and the individual need to be tailored to the player's impairment, which is key to making this process valuable. Medical doctors and performance support staff can be pivotal in optimizing player readiness and success. Adopting a multi-layered approach to screening and incorporating an interdisciplinary team of professionals ensures a holistic understanding of the player, safeguarding that players receive the comprehensive support they need to excel in their sport while prioritizing their health and safety, on and off the court. It is beyond the scope of this article to delve into the detail of every possible scenario that wheelchair tennis players could present, as each player will require a detailed understanding of their unique impairments and the appropriate net of screening tools specific to the individual, the options given above should provoke further investigation into the most suitable practitioner to provide a thorough screening network for the player.

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WHEELCHAIR SETUP CONSIDERATIONS FOR OPTIMISING ATHLETE HEALTH IN WHEELCHAIR TENNIS

– Written by Samuel Williamson and Alex Cockram, UK

INTRODUCTION

Wheelchair Tennis is a global para-sport and the world leading version of disability tennis. It is played by approximately 8,000 people around the world, spanning 80 countries and provides sporting opportunity for those with a physical disability from grassroots level to the Paralympic Games and all four tennis Grand Slams.

The court, balls, rackets and rules used in Wheelchair Tennis are largely the same as in standing tennis. However, there are two main changes to the rules;

1. The ball is allowed to bounce twice before players play a shot
2. Players play matches seated in a sports wheelchair

Whilst the wheelchair used in competition is subject to rules and certain specifications[1], there are many customisable aspects that can be tailored to suit the needs of individual athletes. Much like other equipment used in tennis (footwear, racket, string) the wheelchair has many parameters that can be changed in order to aid performance. For example larger wheels make it easier to keep momentum whilst moving and make covering the court easier, and changes to seat height can affect reach meaning an athlete can get to more shots. However, the impact of chair set up on preserving athlete health should not be overlooked and is a key factor for players both recreationally and professionally.

This article will discuss various chair set up considerations which, in the experience of the authors, can impact a player's health, as well as discuss case studies in which both large and small alterations to a player's chair has resolved or prevented health complications.

WHAT SHOULD A CHAIR PROVIDE?

Broadly speaking, the physical demands of wheelchair tennis, as with its standing counterpart, can be split in to two groups:

- Movement around the court
- Shot making

A recent systematic review[2] found that athletes cover an average of almost 4km per match with an average rally duration of around 6 seconds. Mason et al[3] also found that players made 12-13 turns per minute depending on the division. Williamson et al[2] also found that athletes made an average 366 shots per match.

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Therefore, the tennis wheelchair must help the athlete achieve both the movement and shot making demands of the game. It should allow athletes to cover the court in the most efficient way possible as well as provide a stable base from which athletes can effectively generate force to strike the ball.

It is the authors experience that setting up the wheelchair to optimise efficiency of movement around the court as well as for shot making, has not only performance benefits, but can have a significant effect on reducing health issues. Given the repeated effort nature of the sport, efficiency is key in reducing unnecessary joint and soft tissue loading, leading to less health complaints.

A BALANCING ACT

In an ideal situation, any change to chair set up would improve both the efficiency of movement and shot making. However, as with many decisions surrounding sporting equipment, changes to any aspect of wheelchair setup are rarely a cure-all and are more commonly a process of weighing up the positives and negatives for the athlete. This is especially true in a sport such as wheelchair tennis, where athletes may present with a wide range of health conditions and impairment types.

Considering the aim of achieving efficiency in movement and stability for effective force transfer for shot making, most choices will be based on two underlying questions:

1. How does the change impact stability and support provided by the chair versus range of movement of the athlete's body segments?
2. How does this change impact the stability of the chair for shot making versus the efficiency of the chair for movement?

Given the goal of improving movement and ball striking efficiency to reduce excess loading of athletes, and with the above-mentioned balancing act in mind, we will now discuss some of the common chair setup parameters, and how a change to these might impact efficiency, loading and health.

THE WHEEL

Wheel size:

Typically, wheel size ranges from 24" for junior athletes to 26" or 27" for senior athletes. Research has shown that larger wheels provide less rolling resistance than smaller wheels during maximal and sub-maximal efforts[4,5]. This leads to reduced physiological demands, less overall effort and therefore lower levels of fatigue when using larger wheels, compared to smaller wheels. Given the repetitive demands of wheelchair tennis, reduced local and global fatigue can play a vital role in reducing injury risk in athletes.

This research also showed that larger wheels were no worse at acceleration from a stationary start than smaller wheels. However, Mason et al[6] found that athletes from both wheelchair tennis and wheelchair basketball (where chair set up is similar to wheelchair tennis), reported that smaller wheels feel easier to accelerate and require less force from a stationary start. Observationally and subjectively according to athletes, smaller wheels are easier to accelerate and require a smaller peak effort when athletes start pushing.

The physical profile of an athlete also plays a part in selection of wheel size. Athletes who may struggle to generate higher peak forces when pushing may benefit from smaller wheels, as there is less effort required to get the chair moving. Typically, this may be athletes who are smaller in stature, have significantly impaired trunk function, or upper limb weakness.

Athletes who are larger in stature, have good trunk function and no upper limb impairment are likely to be able to produce the required forces to accelerate the chair, Therefore, they may benefit from the overall efficiency and reduced loading that larger wheels offer, both physically and physiologically, leading to a reduced risk of upper limb musculoskeletal injury and lower systemic demand.

Camber Angle:

As previously mentioned, a key wheelchair tennis movement characteristic to consider when looking at chair design is the multidirectional nature of the sport, with an emphasis on turning efficiency[3]. Shot making should also be considered, where the setup facilitates rotation and stability during execution of the various strokes, and this is where camber comes into play.

Camber has been defined as the angle of the main wheels in relation to the vertical[7], with an increased camber angle leading to a wider base of support, and therefore greater levels of stability when turning and shot making. It has also been shown that mechanical efficiency at sub-maximal speeds improves with a larger camber angle, without significantly impacting trunk or wrist motion[7]. This is reassuring considering the injury risks associated with greater peak extension values of the wrist within the wheelchair user population[8].

Athletes engaged in court-based sports typically select chairs with a camber angle of 15-24 degrees[9], however 22 degrees is the common choice within wheelchair tennis. Ultimately, this could help to minimise upper limb and trunk load by increasing the stability of the chair and reducing the need to grip or handle the push rim when turning and rotating.

THE SEAT

Size:

Size and fit of the sports wheelchair seat in relation to the athlete is key in preventing health related issues. Efficient transfer of energy between the player and the chair is best achieved when the chair is well fitted, leaving little-to-no room for the athlete to move around in the chair. As the athlete turns, a good connection between the pelvis / upper legs and the chair will allow the athlete to rotate the chair more easily and effectively. Optimising this energy transfer reduces the loading on the upper limbs when propelling the chair, and on the spine and pelvis when turning the chair, reducing the risk of musculoskeletal injury.

Wheelchair athletes, especially those who cannot ambulate at all, are at greater risk of skin health issues than their non-disabled counterparts[10]. A well fitted seat is a key factor in reducing both direct pressure and shearing forces on the skin, which will protect against skin breakdown.

Seat angle:

The inclination of the seat in a tennis chair is often based on the previously mentioned balance between the need for stability and the need for range of movement. Athletes with impaired trunk function will often require more stability from the seat set up, to allow them to be stable in chair propulsion and shot making. This can be achieved by increasing the inclination angle of the seat (raising the front of the seat in relation to the back of the seat) to position the knees higher than the hips. The added stability supports the athlete's spine and again, improves efficiency of energy transfer when the trunk is not able to provide it.

Athletes with good trunk function will be able to create their own stability through the trunk, and therefore do not need as much help from the chair. For these athletes, lowering the inclination angle to raise the hips higher than the knees may be more appropriate. Placing the hips in a relatively more extended position facilitates better use of the hip musculature, pelvic and spinal mobility. The result of this is increased use of the kinetic chain for force generation and dissipation, consequently reducing the risk of musculoskeletal overload along the kinetic chain.

Backrest height:

Like seat angle, backrest height is a component of chair setup which affects stability and range of movement available to the athlete. A higher backrest supplies the athlete with greater stability, but reduces the ability to extend, side-flex, or rotate the trunk during shot making. A lower backrest allows the athlete to have more spinal mobility but requires greater trunk strength to create stability. Backrest height should be determined by considering the individual's function, their need for stability verses movement and the health risks associated with this.

It is important to note that with a lower seat angle and backrest height, the demand

> ***The tennis wheelchair must help the athlete achieve both the movement and shot making demands of the game. It should allow athletes to cover the court in the most efficient way possible as well as provide a stable base from which athletes can effectively generate force to strike the ball.***

on the athlete's trunk and spine increases. Therefore, in athletes with no underlying trunk impairment, there is still a high need for trunk and spinal column strength in all directions, as well as good technical ability. To prevent back injury, caution is advised with aggressively reducing the support from the chair in novice or junior athletes with lower training history whilst they develop the physical capacities required.

THE SEAT-FRAME CONNECTION

Fore-aft position:

The position of the seat in the horizontal plane in relation to the camber bar is known as the fore-aft position. Seat positioning can have a big impact on a players' ability to manoeuvre the chair and the physical exertion associated with court coverage. A seat position which is further back will increase rotational sensitivity of the chair, which can help to reduce the energy cost plus upper limb and trunk load when turning. Consequently, this can have a negative impact on forward propulsion and acceleration, requiring greater levels of trunk flexion/extension to achieve the desired push length. A compromise could be achieved by bringing the seat position forward slightly, however the preference in favour of turning efficiency is seen in athletes set up across the board.

Figure 1: Comparison of non-customised and customised chairs.

Seat Height:

Seat height is linked with the seat angle and therefore hip position. A higher seat can give the athlete an enhanced view of the court and improve overhead reach, whilst helping to lower the relative height of shots to potentially reduce overhead loading of the shoulders. This will reduce the risk of shoulder pain, which is highly prevalent in the wheelchair tennis population.

However, if the seat height is too high then propulsion becomes an issue. The athlete feels unstable when turning, leading to unnecessary stress through the spine. A lower seat position might be more suitable for someone with a shorter stature, relatively shorter upper limb length or limited to no trunk function.

Figure 1 shows a side-by-side comparison of two tennis chairs. The left-hand chair is an adjustable mid-range chair, whilst they right hand chair is a professional chair that has been tailored to suit the needs of the individual using it. Note the difference in seat angle, seat shape and fit, seat fore-aft position, as well as placement of staps and presence of shin guards.

OTHER CONSIDERATIONS

There are many more factors that can impact the efficiency of pushing and shot making which can help reduce tissue overload;

Padding – connection with the seat can be improved in some cases by appropriate padding or other material. The aim is to create a better fit with the seat for efficient energy transfer. However, padding can also play a key role protecting skin, soft tissue and joints that may be vulnerable depending on an athlete's disability (e.g. limb dysmelia, amputation stumps, muscle contractures).

Seat material – there are various seat materials available. Key considerations for this will be based upon the athletes' need for support versus range of movement. Another key consideration here is maintenance of seat material. Wear and tear of material can lead to a change in lumbar spine support, as well as expose the skin to higher risk of pressure areas.

Straps or other restraints – shin guards, hip straps, and trunk straps can all be utilised as a simple, easily applied method to improved player stability and connection with the chair. Similar to padding, these are often easily adaptable or customisable to allow for an athlete's disability and can also be used to support an athlete when returning to play from injury, or a change in condition, without needing a completely new chair.

Chair maintenance – a simple but often overlooked method of reducing rolling resistance and therefore reducing overall effort and load experienced by an athlete is to be proactive with chair maintenance. Tyre pressure should be monitored and corrected frequently, with consideration given to changing tyre pressure for different court surfaces. It the authors' experience, correcting tyre pressure can significantly reduce athlete reported wrist, shoulder and lumbar spine pain. Casters and bearings should be cleaned and replaced when showing wear. Caster height and size may also need to be changed to optimise the efficiency of the chair across different surfaces. Table 1 outlines two example chair setups for athletes with different physical profiles.

CASE STUDY

Outlined below is a recent example of the journey an Open division wheelchair athlete went through when selecting and modifying a chair to find their desired setup based on their health and physical needs.

The athlete presented with hamstring contractures leading to extreme fixed flexion deformity at both knees as well as fixed inversion and flexion of both ankles and feet. Figure 2 shows her seated position in a mid-range adjustable chair. Whilst this chair does have certain parameters that can be altered, the unique presentation of this athlete meant she was unable to achieve a leg position that allowed a good connection with the seat. This led to compromised pelvic, spinal and shoulder positions for effective propulsion. In addition, due to the position of the athlete's legs in this chair, there were several areas where her skin health was at risk, including contact between the moving wheels and her legs.

Figure 3 shows our modifications to the original setup to help improve her positioning and interaction with the seat, by increasing the seat bucket and removing the cushion to make room for her legs, as well as turning the backrest bar around to create a new platform to sit on. These changes led to a more level pelvic and open hip position, which in turn improved her spinal position and ability to push the chair more effectively.

Whilst this was an improvement on her initial setup, the padding and depth of the new platform seat wasn't sufficient, leading to discomfort and potential pressure sores, and the material supporting her legs was too abrasive, putting her skin health at risk. At this point it became evident that a bespoke fitted chair with a similar design concept was required, so the necessary measurements were taken to ensure a suitable final product was made. In preparation for the arrival of this chair, we designed a strength programme to prepare her trunk and upper limb muscles for the demands of pushing and to help minimise the injury risk. Figure 4 shows her in the new bespoke chair, where she is suitably supported by the seat and in a more optimal position for pushing.

	5'3" C6 Spinal cord injured athlete. • *High level of trunk impairment* • *Reduced upper limb strength.*	*6'2" athlete with single below knee amputation.* • *Full trunk function* • *No upper limb impairment*
Wheel size	*Smaller*	*Larger*
Camber angle	*22 o*	*22 o*
Seat angle	*Bucketed – hips lower than knees*	*Level or slight forward tilt – hips higher than knees*
Backrest height	*Raised to provide adequate support*	*Reduced to allow range of motion*
Seat fore-aft position	*Less rearward to balance turning efficiency and propulsion*	*Further rearward to assist turning efficiency*
Seat height	*Lower*	*Higher*
Straps	*Likely shin, lap and possibly trunk strap*	*Shin and or lap strap. No trunk strap*

Table 1: FExample chair setups for athletes with different physical profiles.

Figure 2: Player in non-customised chair.

Figure 3: Player in chair with temporary modifications.

CONCLUSION

As with any sporting equipment, optimisation and customisation of the tennis wheelchair can have a significant impact on athlete health and performance. The parameters discussed in this article, whilst not exhaustive, should all be considered with regards to the health of the athlete, when selecting or adjusting a chair for wheelchair tennis participation. Key underpinning principles of efficiency of energy transfer, and balancing stability and range of movement should be considered for each decision.

Figure 4: Player in customised chair.

Key points:

- Chair set up is key for managing health risk in wheelchair tennis athletes, including musculoskeletal, skin health, and fatigue factors.
- There is no perfect chair. What is right for one athlete, may not work another.
- Efficiency, stability and range of movement are all important outcomes of changes to chair set up when considering athlete health.
- Do not forget basic chair maintenance – it is simple and can significantly reduce unnecessary tissue loading for athletes.

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ROLAND GARROS 2005

© CHRISTOPHE SIMON/AFP/Getty Images – Rafael Nadal won his first French Open in 2005. Roland Garros, Paris, France.

HIGH PERFORMANCE ADOLESCENT TENNIS PLAYER LONGEVITY

CREATING A ROBUST TRAINING ENVIRONMENT

– Written by Fredrik Johansson, Sweden

There are different roads to a successful performance, however including both evidence from research and on court experience is most likely a very smart move to make, no matter what road you choose to travel on. However, to be able to take that integrated approach, the team working with the player needs to be well-informed, open-minded and be ready to adjust daily to the changes that take place in the environment. In view of the adolescent player even more things come into play such as growth, maturation, and mental abilities, all taking their individual road of development. Therefore, to create a sustainable road with the adolescent player is in many ways a more complex task than developing and managing the adult professional player.

In this article the primary aim is to present an overview of long-term player development using a practical and sustainable approach, with special emphasis on the high-performance player.

WHAT DOES SCIENCE TELL US ABOUT LONG-TERM ATHLETE DEVELOPMENT?

In view of high-performance and adolescents we need to remind us daily that adolescents are not fully grown professionals and therefore we cannot perform a scaled down copy-paste strategy from the professionals' training regime. However, we also need to remind us that although on one hand we have a lot of time with an adolescent player, we cannot postpone training, be unprepared nor be without a clear mindset of what we want them to achieve.

Long-Term Athlete Development models

There are different models of long-term athlete development presented in literature[1]. One of the first youth athlete development models was described in 1999 by Cote, based on a small sample of athletes and interviews. It was a good initiative, but to provide a more solid base, a more comprehensive approach was needed. In 2004, Balyi and colleagues presented the nowadays established long-term athlete development model (LTAD) which is based on biological growth and development by using peak height velocity (PHV) to determine readiness for each training stage. Also, in the LTAD model sensitive periods or "windows of opportunity" are something that has gotten a lot of attention. Although it may hold true, in a real world setting we need to be careful, so players and coaches do not misunderstand and think that if they miss a "window of opportunity" that the chance of developing a specific skill is lost forever. Lastly, in 2012, the youth physical

Image: © Vegafoto. Reproduced with permission from Vegafoto and the player.

development (YPD) model proposed by Lloyd and Oliver also emphasized a development-based over aged-based approach. However, compared with the LTAD model, YPD provides a more detailed scheme of what type of training should be emphasized during each developmental stage, also with regards to male and female athletes.

These models have on one hand revolutionized the approach of the young athlete and how we approach long-term development. On the other hand, some sports (including tennis) require a lot of skill training at an early age due to the complex technical demands of the sport. Therefore, it takes a lot of patience and knowledge to follow these models, and it may need some modification due to the specific demands of tennis such as the competition schedule.

Competition schedule and its effects on long-term player development

Tennis at a professional level is one of the most challenging sports in view of prevention and performance due to a variety of factors. First, the competition schedule is very intense throughout the calendar year with very few periods of long-term recovery. Second, the system within itself encourages players to compete almost every week in pursuit of ranking points to reach the next level. Lastly, due to the above, the timeframe for working on prevention and performance is narrow and therefore the knowledge, planning and structuring of sessions become crucial to stay healthy, and free from injury.

Although the adolescent player is not a professional player and potentially could take time off in the competition schedule, it is less likely to happen because the system is based on the professional tour level; the ITF junior system operates by ranking points across different levels of tournaments, with more points awarded at higher grade tournaments and thus Grand Slam Junior events being the most prestigious.

Therefore, intense travel, playing between 20-30 tournaments and 100-120 singles matches in a 12-month period is not uncommon, and most likely needed if the player wants to increase the ranking. With those numbers the training and competition load is immense from an early age on, and the long-term health of the adolescent player may be de-prioritized and the injury risk enhanced[2].

Early specialization in tennis

Early specialization does not necessarily need to be all bad, but to be sustainable it needs an environment that is very player-centered and possess a high degree of knowledge within the team around the player. In a setting with early specialization the risk of burn-out and/or injury is higher, especially during periods of intense growth, which may reduce the possibility of long-term success[3].

To be proactive with the adolescent player choosing early specialization, a sound model of load management is helpful. Such a model has been presented, dividing the players into load sensitive, naive, and tolerant athletes[4]. This approach gives a broader view of growth and maturation and if used wisely it may reduce the risk of injury from a long-term perspective. The high weekly training load that is needed in tennis is not within itself a risk factor, but the challenge is to get there safely. Previous studies have highlighted the risk of injury by stating the "too much, too soon" concept[2], therefore we need to start building the players early, and year by year increase training and competition load in a controlled manner. That road is not an easy one and all players have their individual rate of growth and maturation. To support decisions along that road bio-banding has been successful in some other sports and may be helpful also in tennis to keep players in the safe zone with relation to overuse injuries[5].

In addition, the understanding of early versus late entry into puberty is helpful in the long-term development of the tennis player. It has been shown in ice-hockey that the late maturer to a greater extent reached the highest level[6].

LOAD MONITORING IN ADOLESCENT TENNIS PLAYERS

The foundation of training monitoring is to evaluate intensity, duration, frequency, and sport specific activities. Monitoring of training load has become more and more common, and there is growing research in the field and its association with injury risk[7]. Furthermore, tennis players' optimal training progression can be supported by reliable and valid monitoring tools such as GPS, heart rate monitoring watches and/or other devices[8].

Training load is most often defined as either internal load which refers to measures like session RPE, heart rate, and blood markers such as lactate, creatin kinase, and cortisol[9]. Another possible option for internal load measurement that has strong evidence, would be represented through heart rate variability (HRV), which is a measurement of the variation in time between consecutive heartbeats. This method can provide more insights into the athlete's recovery status and intensity of the training.

External load refers to the actual load on the athlete such as kilogram lifted in one session per muscle group, meters covered in a training session, and/or number of directional changes[9].

Wearable technology

A valuable support to provide specific measurements for coaches and/or players in their strive for optimal performance is to use wearable technology[8]. In tennis, it is of high importance for example to understand how much load has been put on the player in the on-court setting in terms of distance, change of direction and number of shots being performed. Also, the intensity of the on-court sessions is of great importance to be able to plan the off-court sessions in an optimal way.

In summary, there are many advantages to using wearable technology, but to be able to maximize the information from the wearables, knowing how to interpret information relative to tennis is a crucial factor, and not all teams have this option available.

However, for those unfamiliar to load monitoring, or those not having access to wearable technology or other devices, a practical and cost-efficient method in the field mainly with adolescent players is to use a 3-step load monitoring model including volume, intensity, and arbitrary units (AU).

Volume

Of all the different ways of load monitoring, registering training volume in hours is the most basic step. Although it takes a lot more than just keeping track of hours to able to draw any major conclusions, it could be a first step to bring the player and the coach on board. Furthermore, it can be useful to monitor quantity since many sports (including tennis) demand a relatively high training load from an early age on. A tennis player trying to reach high levels of competition is expected to practice 15-20 hours of tennis per week plus strength and conditioning training. Therefore, monitoring total hours of weekly training is needed as the basic first step.

Intensity

To complement volume, the next step is intensity, to understand how much the sessions "cost" in terms of metabolic demands. The easiest way to monitor intensity would be to use the session Rate of Perceived Exertion (RPE) number between 1-10[10]. It is important that to assess the RPE 30 minutes post practice, otherwise the rating may be biased by the last exercise performed in the session. Furthermore, the RPE rating of 1-10 is an understandable and easy assessment for most adolescent players, and over time they become self-educated, more precise, and honest in their rating.

Arbitrary units (AU)

A session's training load can be expressed by multiplying training volume and intensity, to provide a total score in arbitrary units (AU). For example a 90min tennis traning session with a recorded RPE of 7 gives you a training load score of 630 AU. That number does not say much if you estimate one session, but over time and if continuously registered it becomes a training tool that is very helpful. For example, either in terms of designing intense periods of training, trying to adjust the load, or if injury occurs as a guide in return to play.

With adolescent players and coaches, these 3 steps can be sufficient to help monitor training load. And like all monitoring, if you do not analyze and work with the numbers, the monitoring becomes unnecessary information.

TRAINING VOLUME – PREVENTION AND INJURIES

For many decades the discussion about training volume and its relation to injuries has been debated by the scientific and medical team in search of finding the optimal load. Of all things that can happen on the negative side, long-term injury is one of the most challenging ones. On one hand, prevention is getting more and more attention in the total training plan. On the other hand, coaches and players are less willing to perform prevention training, instead wanting to push the boundaries and practice more intensely, in the chase for improved tennis specific skills and winning titles. The truth is most likely found somewhere in between and very dependent on the individual athlete and the resilience from the athlete both physically and mentally.

SUDDEN CHANGES IN TRAINING – SPIKES AND OVERUSE INJURIES

Increasing the training volume is an easy intervention and can be performed by anyone, and its short-term result is often very positive. However, to build sustainability and long-term performance in a player other aspects need to be considered, such as evidence-based knowledge, experience and integrated on-court sessions.

Rapid changes in training volume have been investigated in different sports to a relatively great extent and although methods do vary between articles, a consensus is so far that these rapid changes may be a potential risk for injury. In tennis there have been fewer articles, but the result is in line with previous literature, highlighting an increased risk for injury if rapid spikes occur within the weekly training load[9]. The interpretation of these articles to a practical setting is that the load should be consistent from week to week, and slowly increase over time to build a robust player. However, increasing training load gradually is needed for development. Based on author's experience a 10-15% increase from year to year in volume is probably a safe recommendation in the 12-19 year old age groups.

LTAD and injuries

One topic that is not as clearly addressed as others in the LTAD concepts is injury and how we either prevent or manage injury in the adolescent athlete, and how that subsequently affects their long-term development. The LTAD model presupposes that you progress from one developing phase to another, outlining a best-case scenario. However, very often adolescent players are not on track due to many different reasons such as injuries, mental health challenges, growth, maturation, and other challenges.

It could be a minor injury that requires short term leave, but it could be several minor injuries that in the end add up to a quite long time of absence. On the other hand, it could also be a major injury such as a stress-fracture that needs longer periods of rest and recovery. In both cases the LTAD model (and its different phases) is to a minor or major extent disrupted, meaning that the player and coach need to adjust the arrival date of the destination. An adjustment not only including taking load off the player but also considering that the development of different skills most likely will be delayed, and therefore demanding a lot of patience from the team around the player.

BIOMECHANICS, MOVEMENTS, AND STRENGTH FROM A PREVENTION AND PERFORMANCE PERSPECTIVE.

In terms of prevention and or performance in tennis, the discussion about technical proficiency is not getting enough attention. In a sport like tennis, repetition on-court is the key, and if the movement pattern is not functioning almost to a perfect standard the structures of the body will need to compensate. In addition, the strokes are performed at high speeds, generating forces in all planes of movement. Therefore, if the technique is poor and inefficient, the different structures of the body such as the tendons, muscles and bones may be overloaded, which could lead to injury.

To better understand how much repetition takes place, we used GPS-tracking with a Catapult device (Tennis module) to quantify the load of two high-performance female players during a 2 hour-session on clay, mostly performing different drills from the baseline. The session was repeated 3 times the same week and the numbers were on average 900 groundstrokes per 2-hour session. Extrapolated into one year of tennis in an adolescent 15-year-old player being on-court ±15 hours we end up at 300 000 plus strokes per year. That gives us an idea of how important the mechanics are both from a prevention and performance perspective.

With such a high volume of tennis stroke repetitions it will be an almost impossible task to balance that in the gym with prevention exercises. However, one solution is to work closely together on court targeting specific biomechanical aspects of the different strokes. As presented in literature by Kovacs and Ellenbecker in the 8-stage serve model[12], the player could benefit a lot from a team of competences when evaluating the serve biomechanics.

Image: Illustration of the serve – reproduced with permission.

For example, how the loading phase of the serve not only build power and speed but also by using the kinetic chain from legs up actually take load off on the upper extremities such as the shoulder, elbow and wrist[13].

Strength

One big challenge in tennis is the performance of strength training. We know from studies that strength in general has a positive effect on health parameters. In addition, the consensus statement from the national strength association highlights the fact that strength is supportive in the learning process of different motor skills. Furthermore, tennis players are not an exception, meaning that if we prescribe strength training, they will respond in a positive way.

In a LTAD setting we know there are evidence-based guidelines outlining the path in view of how we can or should load young players. Integrating the tennis competition schedule into that model is a challenge, since competition starts at an early age and continues to be relatively frequent throughout adolescence. To be able to protect the body and build resilience, the tennis player should also start earlier with general strength training to improve tissue tolerance to load, possibly preventing potential overuse injuries. Figure 1 demonstrates a way of integrating tennis volume and strength training during a 13-week period.

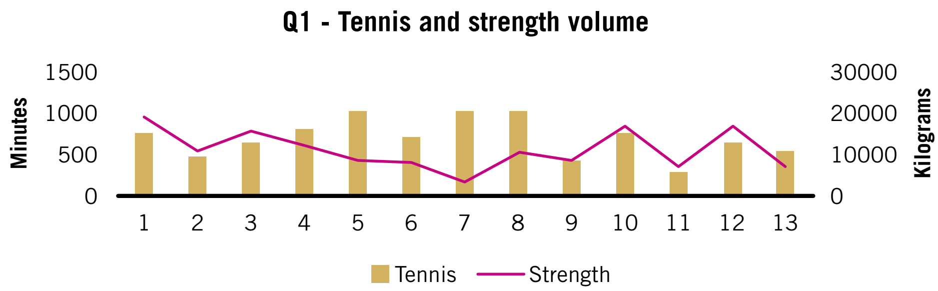

Figure 1: The interaction between tennis volume and strength during one quarter (13 weeks). When the tennis load (in hours) is high, the load in strength (kilograms lifted) is less and vice versa. In some weeks tennis and strength are almost equal in load (week 9) and the differences between the weeks is a good base for discussion within the team.

THE SHOULDER PERSPECTIVE – A LOCAL PARAMETER OF STRENGTH

In view of the shoulder there are many considerations to discuss such as local strength and flexibility mainly in the rotator cuff and biceps, as well as global strength including the legs and core, and the ability to generate force using the kinetic chain[13].

Shoulder strength - How strong do you need to be?

The shoulder strength has been evaluated extensively, mainly by isokinetic assessments first, and later by hand-held dynamometry[14]. In general, the shoulder as a local contributor to efficient mechanics needs to be highlighted. Furthermore, the shoulder is one of the most affected body parts in tennis, especially vulnerable in the high-speed forehand and service motion. Despite all the assessments the question seems to remain, how strong is strong enough?

As presented in the study by Johansson et al[15], percentiles were used to divide players in different groups which may be a more clinical approach than just one number answering the question if you are strong enough. Also, when normalized to body mass, the study by Johansson et al shows sex differences such as the strength values of the female players are leveling out comparing the age group 14 years and under with the age group 15 years plus, whilst male players still increase their relative strength throughout adolescence. Furthermore, although you may be strong in external rotation (1.5-1.8N Normalized to Body Weight) and internal rotation (2.3-2.6N Normalized to body weight) based on the Johansson et al study, we must also include general strength to get the full picture of shoulder robustness. Based on unpublished data on tennis players and experience a value in shoulder press would range from 0.4 to 0.75 and 0.4 to 0.6 of bodyweight for 1 RM for male and female players respectively during the ages of 14-19 years of age.

In summary

Natural physical characteristics for a player are advantageous but establishing a robust training environment where players train to be able to train, then train to be able to compete, will be a smart journey to travel on.

HOW TO GET GOING WITH A LONG-TERM DEVELOPMENT PLAN?

- Integrate research with on-court experience for optimal development
- Have a clear long-term goal within the team
- Balance training and competition schedules effectively to maximize long term development
- Load management is key, use the 'load sensitive, naive and tolerant' model
- Monitor volume, intensity, and arbitrary units as a basic first step
- Build chronic workload over time and avoid rapid changes (spikes)
- Be patient and adjust if injury occurs
- Use biomechanics to your advantage
- Prioritize strength, build globally (legs, core), protect locally (shoulder)
- Train to be able to train, then train to be able to compete.

Training Load and Shoulder Injuries in Competitive Adolescent Tennis Players: The SMASH Cohort Study. Sports Health. 2022 Jan-Feb;14(1):103-110.

To be able to protect the body and build resilience, the tennis player should also start earlier with general strength training to improve tissue tolerance to load, possibly preventing potential overuse injuries.

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CHANGE OF DIRECTION AND REACTIVE AGILITY TESTS IN TENNIS

– Written by Dario Novak and Filip Sinkovic, Croatia

INTRODUCTION

Agility is considered one of the most significant abilities for success in many sports, including tennis. It is defined as the ability to quickly and efficiently change direction and/or movement[1]. There are two relatively independent manifest forms of agility: non-reactive or pre-planned change of direction speed (CODS - Change of Direction Speed) and reactive or non-planned agility (RAG - Reactive Agility)[1]. Agility training in tennis often focuses on developing both CODS and RAG abilities, as they are essential for quick and precise movement on the court. Effective agility drills and exercises help tennis players enhance their ability to react swiftly to unpredictable situations, such as opponent shots or changes in game dynamics, ultimately improving their overall performance on the court[2]. Additionally, the development, construction, and modification of new and existing CODS and RAG tests are becoming increasingly popular topics in research circles. Therefore, the aim of this paper is to emphasize the practical application and difference in terminology between these two concepts and provide some of the tests used to measure them. These findings will provide valuable information for coaches to advance existing training procedures and design a variety of tennis-specific exercises aimed at improving performance, particularly in terms of players' neuromuscular fitness.

CHANGE OF DIRECTION SPEED (CODS) PERFORMANCE IN SPORTS

Due to frequent changes in direction in many sports, including tennis, CODS and RAG are considered highly important motor abilities[3]. CODS involves a rapid change of direction that is pre-planned and known in advance, and players do not need to react to a specific stimulus[3]. In CODS tests, decision-making factors are not present, making participants less susceptible to errors during execution[3]. When evaluating the evidence relating to the importance of physical factors for CODS in different sports, a major difficulty is the huge variety of CODS tests. This is expected because different sports require different ranges of movement patterns. In other words, CODS is determined by technical factors and physical elements such as straight sprinting speed[4]. Additionally, an example of a CODS activity in sports is base-running in baseball or softball, where the batter runs a predetermined distance before changing direction at a different angle. Some sports involve lateral shuffling, such as basketball, while others, such as rugby, commonly require side-stepping movements. One element common to all of these tests is that the athlete is required to complete a preplanned task defined by obstacles, such as cones, in the shortest possible time, usually assessed with an electronic timing system[4]. CODS tests also vary greatly due to differences in the angle and the number of changes of direction, but there is no "gold-standard" generic CODS test that can be used for all sports.

REACTIVE AGILITY (RAG) PERFORMANCE IN SPORTS

Unlike CODS, RAG involves a cognitive component, including perception and decision-making factors[5]. Therefore, it can be concluded that RAG manifests in situations where an athlete needs to perform an agile movement but must react to a stimulus. In the context of sports, RAG typically involves a visual stimulus, as athletes base their agile movements on their visual perception of either the opponent's movements or the trajectory of an incoming ball[5]. Due to the higher demand for reaction speed, tests of RAG are considered more complex and challenging to execute, resulting in slightly lower performance compared to the CODS[6]. Based on all the aforementioned, it is evident that RAG is influenced not only by motor abilities but also by various cognitive factors such as perception, anticipation, and decision-making speed in response to a stimulus[5]. In different sports, whether attacking or defending, agility skill requires the ability to perceive relevant information about opponents' movements and react quickly and accurately[6]. Therefore, reactive agility performance is considered one of the most important motor abilities for achieving success in sports.

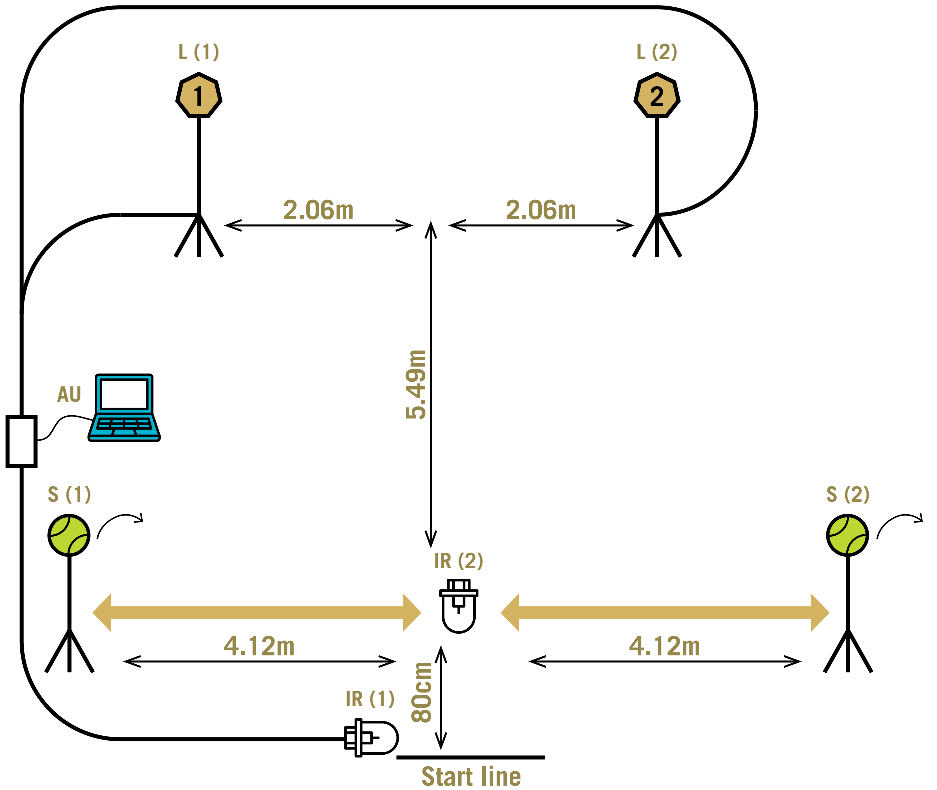

Figure 1: The interaction between tennis volume and strength during one quarter (13 weeks). When the tennis load (in hours) is high, the load in strength (kilograms lifted) is less and vice versa. In some weeks tennis and strength are almost equal in load (week 9) and the differences between the weeks is a good base for discussion within the team.

DEVELOPMENT OF NEW SPECIFIC CODS AND RAG TESTS IN TENNIS

According to the existing literature, a solid number of agility tests with various levels of specificity have been developed and used in tennis over the years, but the majority of the used tests were primarily change of direction (CODS) tests[7,8,9,10]. Those tests did not really consider the cognitive aspect of agility, the "reaction to a stimulus," which would be a much better representation of the kind of agility performance needed in a real tennis match rally situation. Despite the importance of reactive agility in tennis, there is a very limited number of scientific studies that have addressed this motor dimension, particularly under specific conditions. More specifically, a comprehensive systematic literature search yielded that there are only a few tennis-specific reactive agility tests, including a response to a stimulus, showing reliable and valid results[4,12,13].

EXAMPLES OF NEWLY CONSTRUCTED RAG TESTS IN TENNIS

One of the rare tennis-specific reactive agility tests (TAT) for monitoring tennis players has been designed in the research by Jansen et al[11]. The TAT consists of four movements on stimulus at the back of the court around the baseline and one drop shot. According to established criteria, the TAT showed moderate relative reliability with an ICC of 0.74 (95% CI 0.34-0.92; $p < 0.01$). A significant positive moderate correlation of 0.70 ($p < 0.01$) was found between the TAT and the Spider Drill test. In conclusion, the test has shown solid test-retest reliability and concurrent validity in relation to a popular generic Spider Drill agility test. However, although the TAT test has been designed to be used in a practical setting by sports scientists and coaches, the test still requires some technical equipment and settings to be arranged (cones and light positions, etc.) for it to be successfully conducted. In addition to the mentioned research, Munivrana et al[12] designed a tennis-specific reactive agility test (TS-RAN) with a movement pattern that simulates the actual situation in the game, with participants not knowing the direction of movement in advance. They performed two strokes (forehand or backhand) on the baseline and two strokes (forehand or backhand) on the service line. The newly constructed tennis-specific reactive agility test (TS-RAN) showed to be on the margin between moderate and good reliability, with an ICC of 0.74 (95% CI 0.48–0.92; $p < 0.01$). Another similar study was conducted by Sinkovic et al[4], where they designed a new sport-specific TENRAG test (ICC = 0.72 – 0.74) in a way that participants imitated specific movements in tennis (Figure 1)[4]. In detail, participants start from a predetermined starting line, and the timing begins when the infrared signal (IR1) next to the starting line is interrupted by the "split step". At this point, one of the two lights (L1 or L2) illuminates, and the participant must identify which light is lit, perform a run with overstepping and a lateral side-to-side technique to reach a stand with a ball (S1 or S2), and hit the ball with a forehand or backhand stroke in front of their body with sufficient force for the ball to hit the ground. After playing the shot, the player should quickly return to the device in front of the starting line, interrupting the infrared signal (IR2), which stops the measurement. In the TENCODS test, participants are aware in advance of which light will illuminate, allowing them to plan their running and

Illustration

shot execution. The test was performed nine times, with a 60-second break between measurement repetitions, and the mean value of the measurements was used for further analysis[4].

PRACTICAL APPLICATION OF CODS AND RAG IN TENNIS

Athletes and their coaches are always seeking new ways to improve their motor abilities in order to achieve better results in their sports. Sport-specific tests provide more detailed information about the actual state of the attributes and abilities that ultimately ensure a player's success at an elite competitive level. These tests better describe a player's motor abilities associated with technical performance compared to general tests. Moreover, these tests enable coaches and sports scientists to track athletes' progress over time, providing valuable insights into how their motor abilities develop with training and experience. In summary, in order to understand and enhance CODS and RAG in tennis, it is necessary to develop and validate specific tests that provide relevant information about these motor abilities. This would enable a better understanding and improvement of players' performance. To conclude, the application and development of specific CODS and RAG tests can contribute to:

1. Diagnostic tools: They allow coaches to analyze athletes' sports performance in detail, providing deeper insights into their abilities for changing direction and rapid acceleration and deceleration.
2. Injury prevention: By identifying weaknesses in CODS and RAG, coaches can shape workouts that strengthen the muscles needed to stabilize during rapid changes in direction, reducing the risk of injuries such as knee or ankle injuries.
3. Rehabilitation programs: Using specific tests during rehabilitation enables monitoring of patients' progress in returning to full functionality after injuries, such as knee or ankle injuries.
4. Personalized training regimens: They allow coaches to tailor workouts to the individual needs of each player, focusing on improving specific aspects of speed and agility.
5. Enhanced tactical planning: Coaches can use information obtained from tests to better understand the strengths and weaknesses of each player and develop a tactical plan that maximizes their performance on the court.
6. Mental preparation: Increasing players' self-confidence through improving speed and agility can positively impact their mental preparation for matches, increasing their ability to adapt to dynamic situations on the court.

In order to understand and enhance Change of Direction Speed (CODS) and Reactive Agility (RAG) in tennis, it is necessary to develop and validate specific tests that provide relevant information about these motor abilities.

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THE USE OF BIOMECHANICAL ANALYSIS TO HELP REDUCE SERVE RELATED INJURIES

– Written by Caroline Martin, Pierre Touzard, and Loïc Fourel, France

INTRODUCTION

Over the last thirty years the serve has become the most important stroke for tennis performance. Directionality, accuracy and speed are key elements of a successful serve, putting the opponent under time pressure and hampering their return. However, the serve is also the most difficult, complex and physically demanding stroke in tennis, with high muscular activity and joint loads in the trunk, the lower back, the shoulder and the elbow that can cause injuries[1].

Epidemiological data generally shows a preponderance of acute injuries to the lower limbs while chronic injuries mainly affect the upper limbs[2]. Specifically, the serve has been associated with muscular strains to the abdominal muscles and with overuse injuries to the lower back, the shoulder and the elbow[3,4]. In US national collegiate male tennis players[4], the serve is the most traumatic shot. It is involved in twice as many injuries as the forehand and backhand. Injuries in tennis can result from a complex interaction between various risk factors such as skill level, age, previous injury, muscle weakness and imbalance, racket properties, number of repetitions during trainings and competitions or biomechanical factors[5].

BIOMECHANICS OF THE TENNIS SERVE

The tennis serve biomechanics are described as the coordination of body segments in a specific and difficult sequence to master, called the kinetic chain[1]. It initiates from the lower limbs, storing energy from the ground and later transferring it to the hips, the trunk and the serving arm to produce optimal racquet trajectory and velocity upon impact with the ball. In biomechanics, the serve is divided into five phases in order to better understand this kinematic chain and its influence on injury risk; the preparation phase between the start of the serve and the ball toss, the cocking phase between the ball toss and the maximum external shoulder rotation, the acceleration phase between the maximum external shoulder rotation and the ball-impact, the deceleration phase between ball impact and the maximum internal shoulder rotation, and the follow-through phase between the maximum internal shoulder rotation and the end of the serve. Figure 1 illustrates the 5 phases of serving.

In the preparation phase, the player's activity can be summed up as controlled muscular work, during which most joints perform movements with amplitudes that can be described as "normal or physiological", since they are not extreme. As a result, the risk of injury is very low.

The other phases of the tennis serve have a more ballistic nature due to the higher joint velocities involved. As a result, they are potentially traumatic.

During the cocking phase, players move the racquet away from the body to generate speed and power by combining abduction with external rotation of the shoulder and lumbar spine hyperextension[3]. At the

Figure 1: The different phases of the serve.

end of the cocking phase, the abdominal muscles are maximally stretched, storing elastic energy. The lumbar region sustains substantial loads, including lateral flexion forces approximately 8 times those experienced during running[6]. Moreover, the anterior capsule and ligaments of the glenohumeral joint, as well as those of the elbow joint, are stretched close to their physiological limits: the shoulder joint is externally rotated around 172°, abducted around 90 - 100° and horizontally adducted around 7°[7]. Theoretically, this arm position optimizes congruence of articular and bony surfaces and therefore confers maximum stability to the shoulder joint in static position. However, the dynamic nature of the tennis serve compromises the joint stability at the end of the cocking phase and considerably increases the risk of injury. Then, the acceleration phase marks the release of mechanical energy towards the racket, accelerating the rotations of the trunk and the upper limb segments and joints. As a result, professional tennis players experience particularly high joint loads (forces and torques) in the shoulder and elbow during the cocking and acceleration phases of the tennis serve[8]. Finally, the deceleration phase also presents a high risk of injury, as mechanical energy needs to be absorbed and segments and joints need to slow down on a very short timescale.

PATHOMECHANICAL FACTORS RELATED TO THE TENNIS SERVE

The use of inefficient serve techniques is an additional risk factor for injury. Any technical element that significantly increases the constraints (forces and moments) at the joints without increasing ball speed is considered "pathomechanical"[9]. For example, a deficit in leg action (flexion and extension) can significantly reduce ball speed[10], induce abdominal overwork[11] and increase maximum joint loads at the shoulder and elbow (+15% for internal rotation torque at the shoulder and +18% for varus torque at the elbow)[12]. Additionally, when tennis players horizontally abduct their arm for too long during the shoulder external rotation phase[9], shoulder loads increase and ball velocity decreases. This pathomechanical motion can cause rotator cuff impingement, as it can lead to translation of the humeral head in relation to the glenoidal cavity. Finally, increased wrist extension and reduced shoulder abduction during the late cocking phase can induce what is commonly known as the waiter's serve position (i.e racket face parallel to the ground during the backswing), which results in increased shoulder and elbow maximal joint loads[13].

BIOMECHANICAL ANALYSIS AND INJURY PREVENTION

While musculoskeletal screening may be a useful baseline test to help identify potential problems, there is also a need for more functional testing such as 3D kinematic analysis[14]. For example the 2022 Bern consensus statement on shoulder injury, prevention and rehabilitation[15] encourages identification of inadequate movement strategies wherever they occur along the length of the kinetic chain to improve sport-specific biomechanics/technique, but also to better prevent injury or improve the quality of rehabilitation. Biomechanical analysis can be used to estimate joint loads and identify pathomechanical factors. Consequently, it is used by scientists to better understand the etiology of serve-related tennis injuries. Increasingly, tennis players and their teams are turning to biomechanical analysis for individual screening, to help optimize performance as well as reduce injury risk.

As a result, top-level tennis players, national tennis federations and tennis academies are increasingly turning to biomechanical evaluation tests (such as those carried out by the M2S laboratory in Rennes 2 University) to optimize their serve motion through individualized analysis. Based on our last 10 years of research on tennis biomechanics we have gained a better understanding of the determinants of performance and injury risk factors, and most of the injuries we meet are shoulder and elbow tendinopathies, muscular strains in the abdominal area, and lower back injuries.

BIOMECHANICAL ANALYSIS OF SERVE USING A CASE STUDY

A 16-year-old female, right-handed competitive tennis player, usually practicing tennis five times per week, suffered from a stress response in the right L5 pars, confirmed by an MRI exam. Two years earlier, she already had a history of a stress fracture in the right L5 pars region. After diagnosis, her medical team prescribed six weeks of rest which resolved the pain. She then resumed low-intensity physical activity (walking, cycling, pilates) and followed a graduated muscle strengthening program with a fitness coach to improve her core strength. Twelve weeks after the injury, she made a staged return to tennis, without hitting a single serve. She was then allowed to serve again at progressively increasing

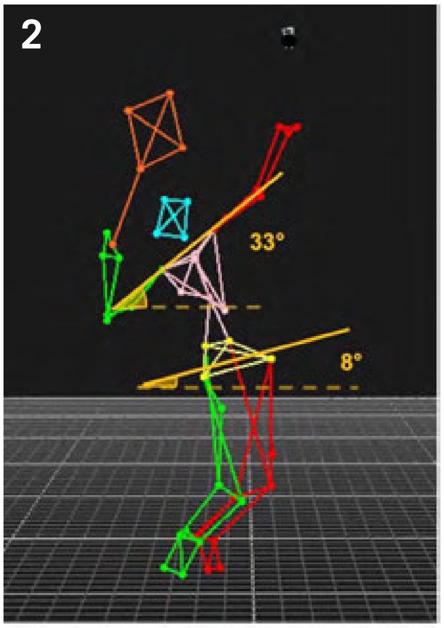


Figure 2: Angles of upper trunk and pelvis lateral flexion during the cocking phase at the instant of trophy position.

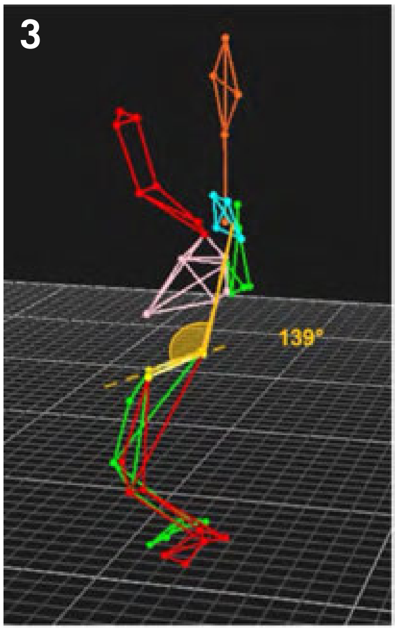


Figure 3: Trunk extension angle during the cocking phase.

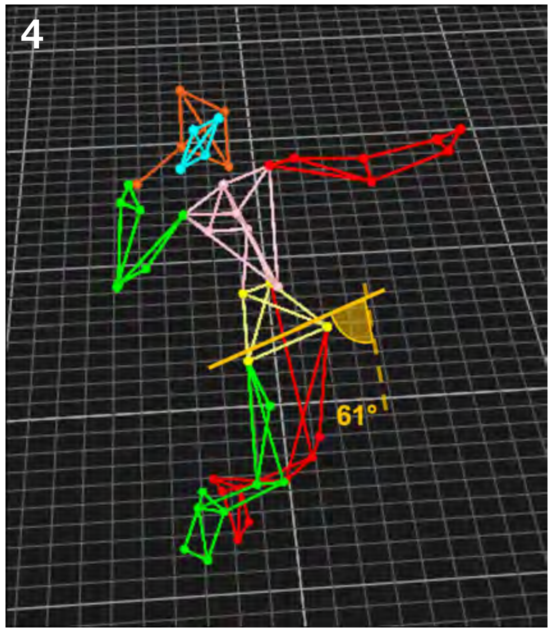


Figure 4: Angle between the pelvis and the baseline in the transverse plane during the cocking phase.

intensity. Unfortunately, the pain in her right lower back returned with serving. Her team thought that her lower back problems might be linked to incorrect tennis serve biomechanics. As a consequence, they scheduled a biomechanical analysis test of her serve.

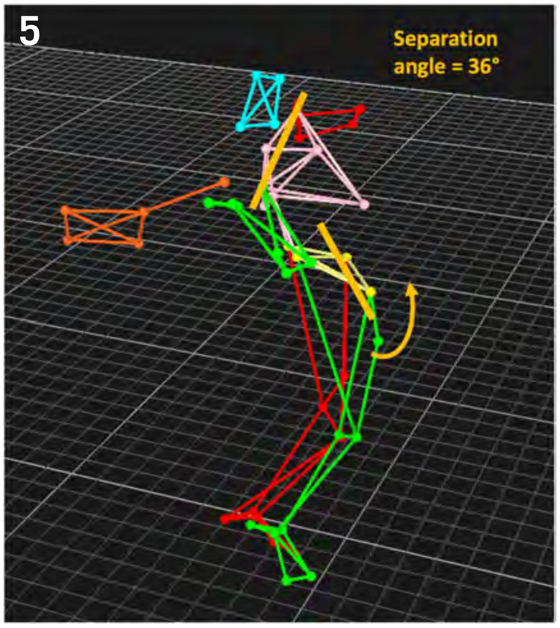
TESTING PROCEDURE

The test took place on an indoor tennis court. The player was equipped with 38 retroreflective markers placed on anatomical landmarks determined in agreement with previously published data[9]. Five additional landmarks were positioned on her racket. She wore a bra and a tight shorts to limit movement of the markers. She used her own racket during motion capture to ensure she felt as comfortable as possible during her serves. Before the test, she had as much time as needed to familiarize herself with the testing environment and the landmarks set. After a warm-up of 20 min (stretching and low intensity serves), she performed five successful "flat" serves from the right service court to a 1m x 1.50-m target area bordering the T of the "deuce" service box. She was asked to serve with her usual foot-up stance technique, bringing the back foot close to the front foot before pushing against the ground. A 30-s rest period was allowed between serve trials. A motion capture system with 23 cameras sampling at 300 Hz (Oqus, Qualisys AB., Göteborg, Sweden) was used to record the trajectories of the three-dimensional anatomical landmarks. Postimpact ball speed was measured for each trial by use of a radar (Stalker Professional Sports Radar) fixed on a 2.5-m height tripod placed 2 m behind the player in the direction of the serve.

BIOMECHANICAL VARIABLES MEASURED

According to scientific literature two main mechanisms are considered as risk factors for pars stress fracture injuries in tennis[16]: compression forces related to excessive trunk rotations or traction forces exerted by lumbar muscles to compensate for an inefficient leg action. When the lumbar spine extends, tilts and rotates longitudinally during the serve, the inferior articular process of the cranial vertebra may impact the pars interarticularis of the caudal vertebra, a compressive mechanism known as "nutcracker". These repetitive compressive impacts can produce a stress or fatigue fracture of the pars interarticularis. The second mechanism is that the pars interarticularis fails in tension through a traction mechanism caused by the contraction of the muscles[16]. To differentiate from these two potential mechanisms given the serve technique of this player and her injury, we measured various kinematic parameters that have been previously linked to lower back injuries during the serve:

- the angles of upper trunk and pelvis lateral flexion during the cocking phase at the instant of trophy position (Figure 2). For right-handed players, excessive lateral trunk tilt to the right during the trophy position of the tennis serve can cause compressive load in the right lumbar region[6].
- the maximal angle of trunk extension during the cocking phase (Figure 3). Trunk hyperextension during the tennis serve is associated with a high rate of lower back radiological abnormalities in tennis players[17].
- the angle between the pelvis and the baseline in the transverse plane during the cocking phase (Figure 4). Campbell et al. (2014) showed that players with lower back pain demonstrated more pelvis rotation towards the net in the horizontal plane than players without lower back pain during the tennis serve[6]. Moreover, players with lumbar spine abnormalities tended to initiate their pelvis rotation towards the net earlier than players without spine abnormalities during the serve[18].
- the maximal separation angle between the shoulders and the hips in the transverse plane during the cocking phase (Figure 5). This angle between



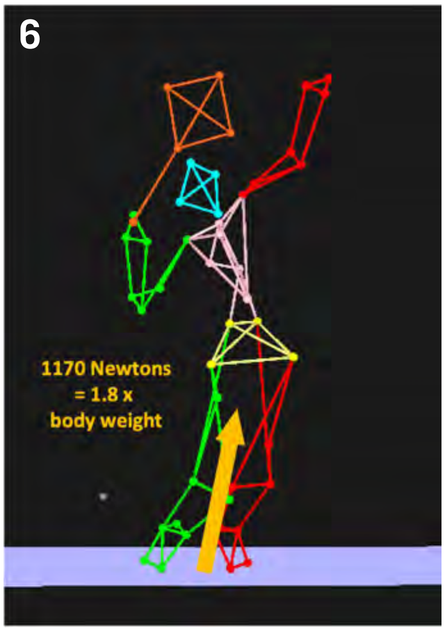


Figure 5: Maximal separation angle between the shoulders and the hips during the cocking phase.

Figure 6: Maximal ground reaction forces produced during the leg drive.

the shoulders and the hips can predict and/or differentiate between players with and without a history of lower back pain in other sporting populations, including cricket fast bowlers[19].

- the maximal vertical ground reaction forces (GRF) and power produced by the leg drive (Figure 6). According to Kibler[20], an inefficient leg drive characterized by a low value of maximal vertical GRF during the serve would force the player to produce a "pull" mechanism, in which the trunk and arm muscles, respectively, tow and pull the lower back and the back hip upwards and the dominant arm and the racket towards the hitting zone. On the contrary, a "push" serve mechanism is characterized by high maximal vertical GRF and a powerful leg extension enabling the player to lift off well above the ground to hit the ball as high as possible, while limiting the pulling actions on the lower back, the back hip, the trunk and the arm.

BIOMECHANICAL RESULTS AND RECOMMENDATIONS

Concerning performance indicators, the player hit the ball at mean speed of 129.4 km/h at a height corresponding to 1.46 x her body height. We analyzed the player's biomechanical data and compared it with a data base including female players at the same level of skills, in the same age category (under 18 – U18) and with no previous lower back injuries. The results (table 1) show that the lateral flexion angles of the player's upper trunk and pelvis in trophy position were within the range of our reference data, and therefore did not appear to be associated with a risk of injury in the lumbar region. In the same way, the player's maximal trunk extension was similar to what we usually observed in our reference values. Consequently, the player's trunk extension did not seem to be responsible for her injury.

On the contrary, she demonstrated:

- a low angle between the pelvis and the baseline in the transverse plane at the beginning of the cocking phase showing a premature opening of the hips towards the net
- a high maximal hips/shoulders separation angle during the cocking phase. It is likely that the lumbar spine is exposed to a significant torque due to the counter-rotation, or "closing", of the shoulder line away from the baseline and the rotation, or "opening", of the hip line towards the baseline during the cocking phase.
- low values of maximal vertical GRF and power during the leg drive. In this player's case, the results show that the leg drive appears inefficient, theoretically forcing her to use a "pull" serve technique that may over-stress her lumbar muscles and increased tension loads on her lower back.

Based on our team experience, technical instructions were given to the player in order to modify the biomechanical elements potentially involved in the onset of her injury[21]. Figure 7 demonstrates a comparison between the player's usual technique and the post-intervention (new) technique; we asked her to change her stance technique from foot-up (FU) to a foot-back (FB) stance, where the feet do not move during the wind-up and the cocking phase, in order to:

1. delay the rotation of the hips towards the net
2. limit the maximal hips/shoulder separation angle during the cocking phase
3. facilitate a "push" serve mechanism in order to reduce the traction mechanism on the right region of her lumbar spine.

After a period of familiarization with this modified technique during the test, we recorded new serve trials. She managed to modify her technique quite easily and all the parameters of interest in relation to her injury improved by the end of the test (Table 1). Concerning performance parameters, her mean ball speed increased by 8.4 km/h to reach 137.8 km/h and her impact height remained relatively similar (1.47 x body height) with the new FB technique. As a result, the technical change seems to have optimized her serve kinetic chain since all biomechanical variables related to lower-back injury improved (except the vertical GRF and power) and the performance factors increased.

A few days after the test, a full biomechanical report including injury risk

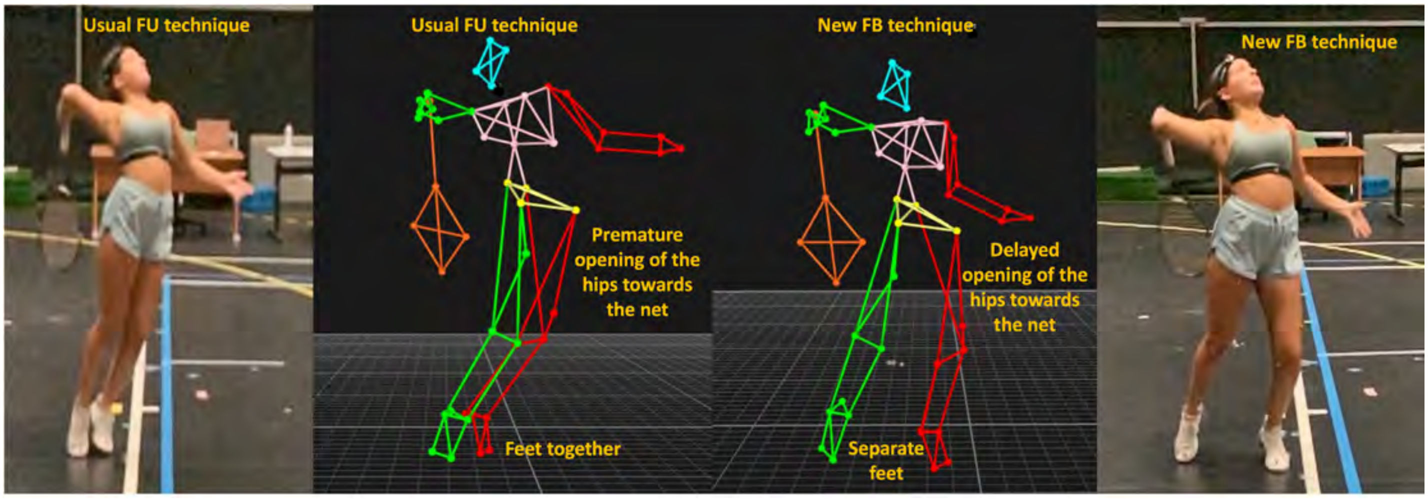


Figure 7: Comparison between the player's usual and the new techniques.

Table 1

	Player – usual FU technique (mean value)	*Player – new FB technique (mean value)*	*Data base U18 (mean ± SD)*
Angle of upper trunk lateral flexion at time of trophy position	*33°*	*33°*	*31 ± 9°*
Angle of pelvis lateral flexion at time of trophy position	*8°*	*10°*	*5 ± 5°*
Maximal angle of trunk extension during the cocking phase	*139°*	*138°*	*135 ± 9°*
Angle between the pelvis and the baseline in the transverse plane at the beginning of the cocking phase	*61°*	*76°*	*75 ± 13°*
Maximal hips/shoulders separation angle during the cocking phase	*36°*	*28°*	*30 ± 7°*
Maximal vertical GRF during the leg drive	*1.8 (BW)*	*1.8 (BW)*	*2.1 ± 0.4 (BW)*
Maximal vertical power during the leg drive	*21.0 W/kg*	*21.0 W/kg*	*21.6 ± 5.9 W/kg*

Table 1: Biomechanical parameters for the player and our U18 data base. FU=foot-up technique, FB=foot-back technique, SD=standard deviation, W=watts, kg=kilograms, BW=bodyweight.

factors and serve performance data was sent to the player and her team. One month after the test, a video debriefing was held with the player, her parents, her physiotherapist and her tennis coach to review the technical modifications made. We have suggested to the player's staff (coach, physical trainer, doctor, and physiotherapist) a corrective program based on our particular observations. Subsequently in the few months following implementation of new serving technique, the player was able to return to competition pain free, with no injury recurrence.

CONCLUSION

When it comes to serve-related persistent or recurrent injuries, biomechanical evaluation constitutes an interesting solution in a complex system approach. Of course, biomechanical assessment alone is not sufficient, and must be coupled with other methods of athlete management (physical conditioning, musculoskeletal screening, training load considerations, medical care, equipment, etc.). The success of the biomechanical assessment obviously depends on the involvement and commitment of the player and coach. Our work also highlights the need for awareness by medical staff of the importance of biomechanical analysis in reducing the risk of injury in tennis players.

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EDITOR-IN-CHIEF'S SELECTION OF CLASSICS

© Simon Bruty /Sports Illustrated/Getty Images – Novak Djokovic winning his first Wimbledon title in 2011. London, England.

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HISTORY OF SPORTS MEDICINE IN TENNIS

– *Written by Per Renstrom, Sweden*

The history of sports medicine in tennis follows the development of tennis as a sport. In the early days of tennis, the heavy wooden racquet, clothing and technique affected a player's performance and power. Therefore any reason for contact with any medical personal was due to common overuse injuries related to the equipment and poor technique, such as 'tennis elbow' or 'tennis toe'. Since the 1980s, tennis as a sport has undergone a revolution in many ways, not least of which is the role of sports medicine in the game.

HISTORY OF TENNIS AS A GAME

Most historians credit the first origins of the game to 12th century French monks who began playing a court game where the ball was struck with the hand against their monastery walls or over a rope strung across a courtyard. The monks soon added the first version of a racquet, which was probably made of wood and leather. The first ball was wooden but soon evolved into a leather surface filled with a fatty substance. The French royal families adopted the game early. The Hampton Court in the UK was built in 1625 and is still used today[1].

The real breakthrough in popularity came in 1874 when Londoner Walter Clopton Wingfield patented the equipment and rules for a game fairly similar to modern tennis. In 1877, the All England Club held the first Wimbledon tournament and its tournament committee came up with a set of rules that are essentially the game we know today. The US National Men's Singles Championship, now the US Open, was first held in 1881 at Newport, Rhode Island. The US National Women's Singles Championships were first held in 1887. The French Open was introduced in 1891 and Australian Open in 1905. Tennis was part of the Summer Olympic Games programme at the inaugural 1896 Games, but was dropped in 1924. It returned as a full medal sport in 1988. The rules of today are largely from 1924, with the one major change being the addition of the tie-break system designed by James Van Alen around 1970.

EARLY SPORTS MEDICINE IN TENNIS

For a long time, tennis medicine was synonymous with tennis elbow, which is an overuse injury related to tennis, first described by Runge in 1873[2]. It is called lateral epicondylitis, but is really a degenerative process characterised by large populations of fibroblasts, disorganised collagen and vascular hyperplasia. This injury has been described in over 1600 scientific articles since 1928. During the 1940s, quite a few articles emerged describing what was called 'tennis leg', which was defined as a partial tear of the gastrocnemius muscle often associated with the landing after

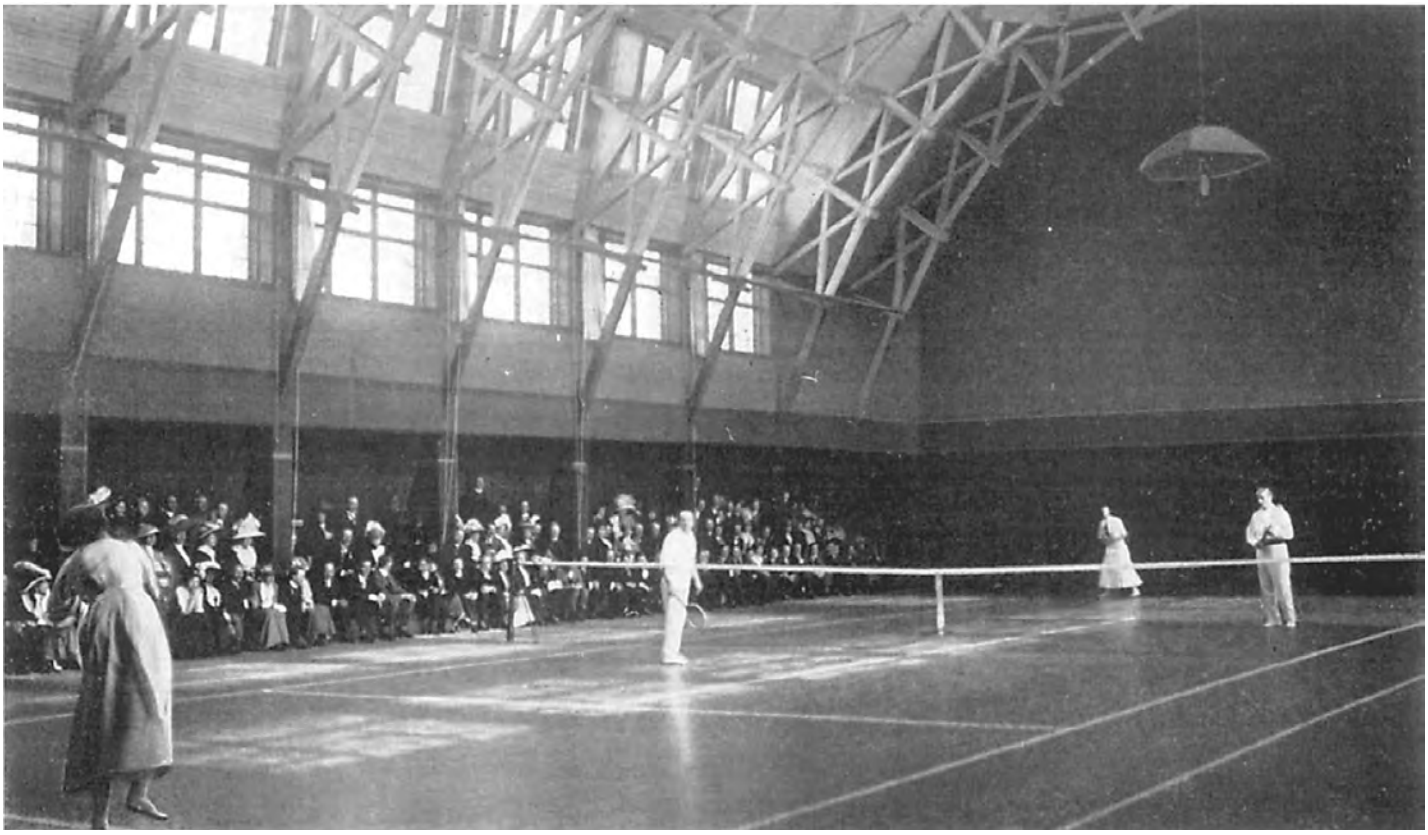

Figure 1: Tennis (lawn tennis) was played at the Stockholm Olympic Games in 1912. Image shows mixed finals.

serving. Articles on 'tennis toe' (subungual haematoma) caused by jammed shoes showed up during the 1970s.

The history of tennis sports medicine can thereafter largely be defined by some important developments.

An understanding of biomechanics from a sports medicine perspective is a key area in player development because all strokes have a fundamental mechanical structure and sports injuries primarily have a mechanical cause[3]. The concept of the kinetic chain was introduced in tennis in the 1990s by Dr Ben Kibler, adapted from a concept created by Dr Jack Groppel. The kinetic chain allows generation and transfer of forces from the leg to the hand. Of the total kinetic energy and forces of the serve, 50% are developed in the legs, hip and trunk and then the shoulder, elbow and wrist function as power transmitters of this[4]. If any part of this link is not functioning optimally, it can lead to a high risk of injury.

An injury definition in tennis was worked out in 2009 by the International Tennis Federation (ITF)[5]. This was the first article to discuss the definition of injury in an individual sport. The true incidence of tennis injury is, however, still elusive. Injury rates in the general tennis population are low and estimated to be one to three injuries per 1000 hours of play per year[6]. Most tennis injuries occur in the lower extremity (31 to 67%), upper extremity (20 to 49%) and trunk (3 to 21%)[7].

The shoulder is increasingly exposed in elite tennis players, especially due to the increasing role of the serve, which is now the dominant type of stroke – 45% of the strokes at the French Open and 60% in Wimbledon are serves[8]. Shoulder disorders have gradually increased over time and now account for up to 50% of tennis injuries, commonly due to repetitive use and related to scapular dyskinesis, rotator cuff pathology or glenohumeral internal rotation deficit, which results in internal impingement and/or labral pathology. Maladaptation exists in 60 to 86% of all tennis players[4]. In the dominant shoulder there may be increased external rotation and decreased internal rotation. A future problem may be injuries in young tennis players as, for example, back problems increase in incidence.

The average number of illness cases at the US Open over a 16-year period analysed was 58.19 ± 12.02 per year (36.74 per 1000 match exposures) requiring assistance by the medical staff. Risk factors may include extensive international travel and new milieus[9].

Meticulous injury and illness registration is vital to establish risk factors associated with tennis, using the results to implement policies and develop strategies to minimise these i.e. prevention. The tennis medical services of ITF, ATP (Association of Tennis Professionals) and WTA (Women's Tennis Association) have for the last 10 years worked together with medical technology specialists to produce a system called the Athlete Health Management System (AHMS®) which is a comprehensive web-based, electronic health record system focusing on the diagnosis, treatment and rehabilitation of injuries and illnesses suffered by tennis players in the course of the players' competition and training. The system is also used by NHL and enables information received to be captured onto a single, secure electronic health record that follows the player for the duration of his/her career.

TENNIS EQUIPMENT – THE EFFECT ON THE NATURE OF THE GAME AND RISK OF INJURY

The wooden racquet dominated the game into the 1980s as it gave a 'good feel' for the game. Modern composite materials racquets have facilitated a change in playing style from one of technique to one characterised by power and spin[10]. The combination of the increased stiffness of modern racquets and the tendency for tennis balls to have become harder has led to an increased shock transmission from the racquet to the player. Today's game is very different to the one played 25 years ago. Besides changes in equipment materials etc the players are much better trained and prepared and they have taken in modern sports science thinking, which helps for quicker recovery. The player today is a well-rounded athlete. The ITF is increasingly active in evaluating and regulating tennis equipment and surfaces within its Science and Technical Department.

THE PERIOD OF INDIVIDUAL SPORT PHYSICIANS AND PHYSIOTHERAPISTS (ATHLETIC TRAINERS)

Before the 1980s, sports medicine in tennis was dependent on a few individuals who were interested in the game. Very little was organised or well-managed. In this context, there are a few people of note who stood out in that early era.

Dr Irving V. Glick was the tournament physician for the US Open Tennis Championships for over 25 years. When in 1978 the United States Tennis Association (USTA) moved the US Open to USTA Billie Jean King National Tennis Center in New York City, Glick established a medical department that became the model of medical care at tennis tournaments throughout the world. Glick founded and chaired the USTA Sports Medicine Advisory Committee in 1980 and was a member of the ITF Medical Commission. He was instrumental in developing the Tennis Anti-Doping Programme and a founding member of the ITF Wheelchair Tennis Medical Committee. In 2000 he was the first recipient of the annual award named in his honour, the WTA Irving Glick Award.

Legendary ATP trainer Bill Norris was another person truly dedicated to tennis medicine and started to administer the men's professional tennis tour in 1973. He is a founding father of the ATP Medical Services Committee and served as its chair for some years. Bill was awarded the 2013 Samuel Hardy and Tennis Educational Merit awards by the International Tennis Hall of Fame.

Figure 2: ATP World Tour physiotherapist legend Bill Norris in action on court treating Goran Ivanisevic.

Figure 3: An ATP World Tour physiotherapist manages groin pain on court.

SPORTS MEDICINE AND SCIENCE GET ORGANISED

National tennis associations

As a general rule, many of the top tennis nations have, with time, developed centralised medical clinics, often at the headquarters of the national association, to provide year-round medical care by experts in sports medicine in tennis.

The USTA Sport Medicine Committee was founded in 1980 and in 1986 renamed the Sports Science Committee to signify a new emphasis on research, fitness evaluations and injury treatment.

The French Tennis Federation has long had a very active medical and science committee with a medical clinic at Roland Garros. Players have annual tests and screenings with specialists in orthopaedics, ophthalmology, dentistry, nutrition, podiatry etc. Many other successful tennis countries such as Germany, Spain, Holland,

Figure 4: An ATP World Tour physiotherapist treating player Andy Roddick on court.

Japan, Brazil and Argentina formed early national Medical Committees of good quality. In Sweden, a Medical Committee was formed in 1984, when there was a tennis boom in the country.

THE ITF

Founded in 1913, the ITF is the world governing body of tennis and is the guardian of the rules of the game. The ITF Medical Commission focused for a long time almost exclusively on anti-doping matters. When the ITF became a signatory to the World Anti-Doping Agency (WADA) in 2000, the name of the Medical Commission was changed to the Sports Science & Medicine Commission (SSMC), which included sports science and sports medicine. A separate Anti-Doping Working Group including representatives from the ATP and WTA was formed, which functions separately.

Commission members analyse and discuss the areas of sports science relevant to tennis, including physiology, psychology, nutrition, biomechanics, motor learning and sports medicine. The focus is on the provision of sports science and medicine to national associations, in particular those developing tennis nations that have little or no such expertise. The ITF SSMC is comprised of a group of sports scientists, physicians and tennis administrators from different parts of the world, including representatives from the ITF, the ATP and WTA Tours.

WORLDWIDE MEDICAL SERVICES IN TENNIS

The ATP World Tour Medical Services

The ATP was formed in 1972 and the ATP Tour was born in 1990. Today it is called ATP World Tour and represents over 60 tournaments played in 31 different countries over the course of a 10.5-month season.

The ATP Medical Services were reorganised in 1994 under the leadership of David Altcheck and Hartmut Krahl to take primary responsibility of the healthcare for all ATP players at the Grand Slams and ATP Tour events. The ATP Medical Services Department today includes six full-time and five part-time sports medicine physiotherapists. They travel to all ATP Tour and Grand Slam events, where they provide athletic training and physiotherapy services to the players. They also co-ordinate the on-site management of injuries and illnesses that require a physician's care. Currently, the ATP Medical Services Committee is comprised of three orthopaedic sports medicine specialists who serve as medical directors in an advisory capacity to the chief of the committee. In addition to this committee, the ATP Medical Services could not function without the dedication and expertise of its more than 100 tournament physicians from around the world providing on-site medical coverage for the players at all ATP World Tour events.

Extra medical services provided in the ATP are dermatology, nutrition, orthotics and podiatry consultation. Off-season performance and injury prevention screenings including assessment of muscular strength and muscle balance, upper and lower body flexibility, core and scapular stability are offered at a couple of tournaments. These testing sessions have made it possible to construct injury prevention and performance enhancement programmes given to the players on an individual level. Further studies will show the effectiveness of these prevention programmes. The fact that the players meet the same medical providers the whole time is a base for the success of the programme. The medical services offered for top tennis players during these worldwide tournaments are considered one of the best medical services available in sport[11].

The ATP World Tour has a significantly longer season and a more extensive travelling schedule than most other sports. The ATP World Tour therefore decided in 2012 to shorten the season by 2 weeks, thus lengthening the off-season to 7 weeks, in the hope of aiding injury prevention. The challenge now is to make this longer off-season effective. The WTA Tour has ruled that the female players take a 3 weeks break in the summer after Wimbledon and an 8-week end of year off-season.

The WTA Tour Sports Science and Medical Services

The vision of the WTA Tour is to make tennis the leading global sport for women. It was founded in 1973 and organises the Women's Tour with 63 tournaments in 35 countries. The WTA Tour is the largest premier professional sport for women worldwide. The founding women understood the valuable relationship of health and performance.

In 1990, the WTA health services were reorganised. The Sport Sciences and Medicine Department is based on the six disciplines of sports sciences: sports medicine, sports nutrition and biomechanics, motor learning, exercise physiology and sports psychology. The team is comprised of highly specialised professionals with formal university degrees in both physical therapy and athletic training and are referred to as Primary Health Care Providers (PHCP). The team is comprised of seven full-time and 11 part-time PHCPs, and seven massage therapists. The Sport Sciences and Medicine Department provide comprehensive medical care of the highest standard, inherently treating the whole person and not just the athlete. This involves the player's ability to read herself physically, emotionally, mentally and spiritually. This holistic approach may help the player to reach her goals. The PHCPs are supported by the medical advisors and tournament physicians.

SOCIETY FOR TENNIS MEDICINE AND SCIENCE

During the late 1980s it was evident that there was a need to improve the support for both research and medical services in tennis. A well-prepared organisational meeting was therefore held in New York at the US Open in September 1990 which led to the formation of the Society for Tennis Medicine and Science (STMS). The STMS was officially incorporated in February 1991. Several actions came out of this meeting:

- The name was chosen to reflect the mission of emphasising treatment of injuries and conducting research into the basic science of the injuries.
- Dr Ben Kibler was elected President and charged to develop the charter and bylaws.
- Prof Per Renström was elected Vice President and charged to develop the first scientific meeting of STMS.
- STMS would develop partnerships with other tennis organisations regarding all aspects of tennis science and medicine.

Yale University agreed to host the first scientific meeting and many great tennis personalities soon became very involved. The first STMS conference was held 15-18 August 1991, in New Haven, Connecticut. About 90 attendees from around the world were present. It was decided to rotate the international meetings every other year among the regional groups and to hold regional meetings on the alternative years.

The Second International meeting was hosted in Essen, Germany, in 1994. An educational grant was secured, resulting in the publication Tennis: Sports Medicine and Science, edited by Krahl, Kibler, Renström and Pieper. Subsequent meetings have been hosted in countries such USA, England, Sweden, Belgium, Japan Spain and Argentina. The next international STMS will be in Rome, Italy in 2015. Regional groups have continued to have meetings in alternative years, especially in the USA and Europe.

The journal Medicine and Science in Tennis and the STMS website, along with the meetings, are forums and disseminators of tennis-related information and catalysts for advancement in tennis sports medicine and science. In 1995 financial backing for the journal was secured, allowing an expansion of focus and an increase in issue frequency. The development of a website (www.stms-web.org) further enabled the society to grow and reach interested readers.

STMS has been successful in developing close relationships with the major international organisations within the

Figure 5: Measurement of shoulder internal rotation range of motion is an integral part of the performance and injury prevention screenings performed since 2006 on the ATP World Tour.

Figure 6: WTA Primary Health Care Provider treating player Steffi Graf on court.

tennis world such as the ATP, WTA and ITF as well as with national associations such as the USTA, Lawn Tennis Association, Tennis Australia, the German, Flemish, French, Spanish, Italian, Japanese, Swedish Tennis Associations etc to promote medicine and science in tennis. The recent board of the STMS includes many young upcoming tennis medicine specialists and scientists.

WORLD MEDICAL TENNIS SOCIETY

In 1971, Dr Stanley R. McCampbell of Oklahoma City, conceived the idea for an international medical tennis organisation. The goal was to conduct regular international medical conventions with a scientific programme at which tennis competitions for players of all levels could be offered to the delegates and their spouses. Besides international friendships, the series of annual meetings has produced patient referrals and sharing of medical research and techniques across national and ideological boundaries.

FINAL WORDS

Tennis is a demanding sport physically, mentally and emotionally. We do know quite a bit about the inherent demands in tennis in terms of forces and velocities as well about ranges of motion and amount of tennis play and the musculoskeletal adaptations. However there is much still to learn about the stress of playing all year round, the true incidence of injuries and illnesses and prevention. This will hopefully improve with the new registry systems.

We know that tennis players must stay as healthy as possible. Over the years, comprehensive healthcare that treats the 'whole person' has developed and is today a very popular service that most players have come to take for granted. The ATP World Tour, WTA and ITF and its members are of the opinion that overall, well-educated and experienced physiotherapists and physicians are key for successful management of top level tennis player health problems.

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UNDERSTANDING THE KINETIC CHAIN

IN TENNIS PERFORMANCE AND INJURY

– Written by Ben Kibler, USA

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:

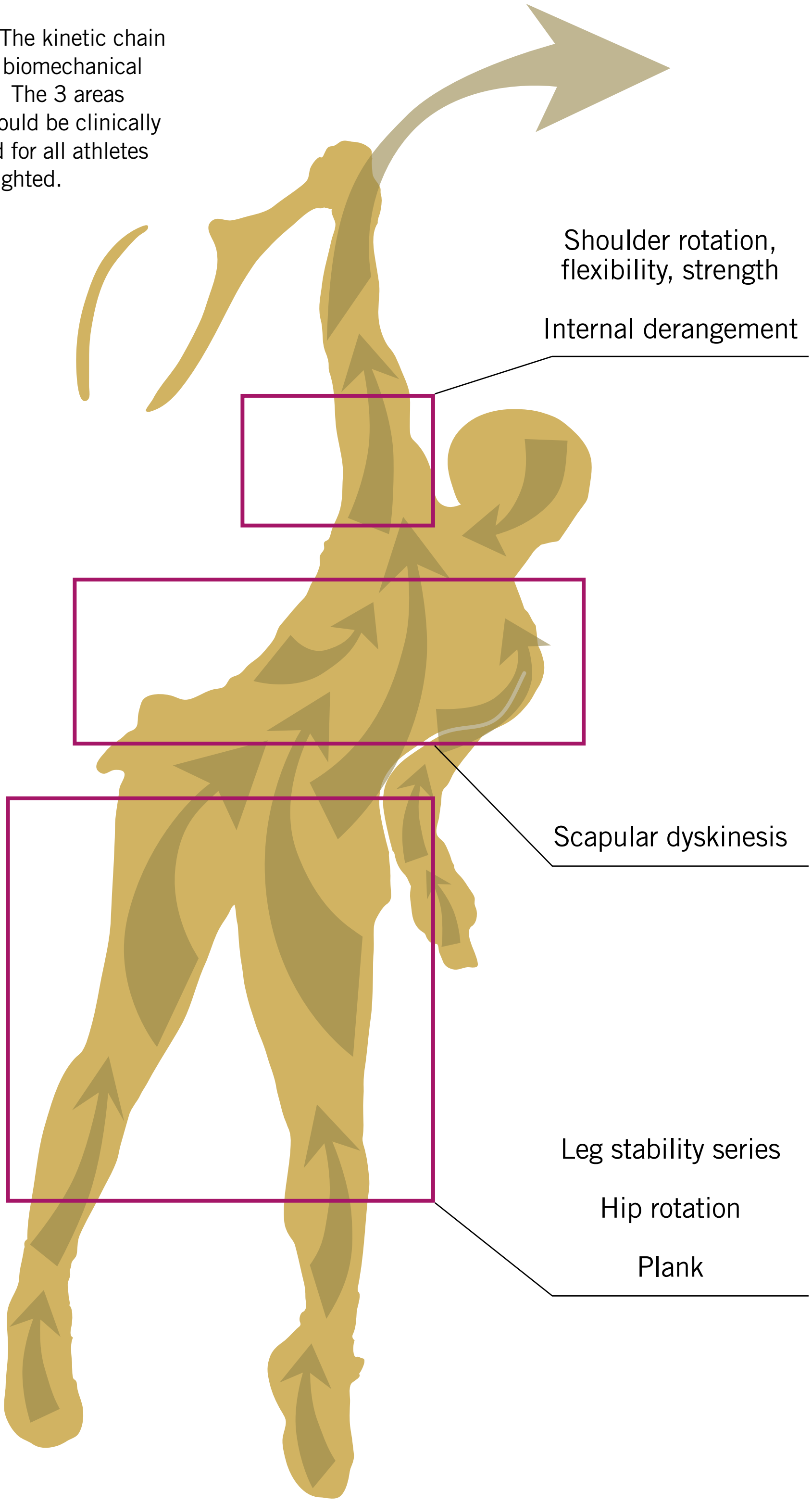
- Using integrated programmes of muscle activation to temporarily link multiple body segments into one functional segment (e.g. the back leg in cocking and push-off, the arm in long axis rotation prior to ball impact) to decrease the degrees of freedom in the entire motion[2].
- Providing a stable proximal 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.

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MEDICAL ISSUES AFFECTING TENNIS PERFORMANCE

– Written by Babette Pluim, The Netherlands

The focus of most epidemiological studies in tennis has been on injuries[1,2], but it is increasingly being recognised that illnesses form a significant burden of disease as well. Sell et al[3] recently reported on the incidence of illness over a 16-year period during the US Open Tennis Championships (1994 to 2009). They found that the number of illness cases requiring assistance by medical staff was 58.2±12.0 per year and 36.7 per 1000 match exposures, compared to 76.2±19.6 injuries per year and 48.1 per 1000 match exposures[4]. The most commonly reported types of illness for both men and women were conditions of the upper respiratory tract (ear, nose, throat) and the skin.

In a recent study, 73 junior tennis players in the Netherlands were monitored over a 32-week period using a weekly online questionnaire on injuries and illnesses. The average weekly prevalence of injuries was 7.6% (95% CI:6.9-8.3%) and illnesses 5.8% (95% CI: 4.6-6.9%). The incidence of acute injuries was 1.2/1000 hours of tennis play (95% CI: 0.7-1.7). On average, 12.1% of players reported some form of overuse problem at any given time (95% CI: 10.9-13.3%) and 3.4% reported substantial overuse problems (95% CI:2.3-4.4). The most commonly reported illnesses were upper respiratory tract infections (61%), followed by gastro-intestinal infections (9.4%).

This review describes the most common medical conditions that affect performance in tennis players and how to treat them[5].

UPPER RESPIRATORY TRACT INFECTIONS

The most common illness affecting tennis players are viral upper respiratory tract infections[3]. Most colds primarily affect the nose and throat, although the same viruses can cause bronchitis and laryngitis. More serious bacterial infections of the throat, ears and lungs can follow a viral cold.

Colds are spread by direct contact with infected secretions (shaking hands, kissing) or indirect inhalation of the virus in the air. Contrary to common belief, exposure to cold temperatures, damp environments or draughts do not seem to enhance vulnerability. However, a long, strenuous practice day, an exhausting tennis match or persistent over-training or stress can increase the susceptibility to and severity of upper respiratory and other viral infections. Strenuous exercise has a depressant effect on the immune system that can persist for a week or more.

Symptoms of a viral upper respiratory tract infection can range from a runny nose, sneezing and congestion to sore throat, hoarseness and a non-productive cough. Players often feel weak and occasionally have sore muscles, despite little or low-grade fever. Infections can greatly affect tennis performance. Exercise during the

early acute phase of some infections may worsen or prolong the illness. Therefore, if signs and symptoms indicate that viral infection is impending, the player should greatly reduce volume and intensity of heavy training for 1 to 2 days and take more rest. He should abstain from heavy practice or matches with a temperature of over 38°C (100.4°F). This is because a serious virus infection may also produce inflammation of the heart muscle, which is a potentially serious disease with an increased risk of acute arrhythmias leading to sudden death during exercise[6]. A cold usually lasts 3 to 4 days but can persist up to 10 to 14 days.

Treatment consists of non-prescription cold remedies, decongestants, cough syrups, cough drops and gargling with warm salty water for symptom relief as well as getting some rest. Antibiotics are only needed if a bacterial infection develops on top of the viral infection, but are not useful in the early stages of a viral infection.

TRAVELLER'S DIARRHOEA

'Traveller's diarrhoea' is the most common disease affecting travellers. Players travelling to tournaments in developing countries in Latin America, Africa, and Asia are at highest risk[7]. The primary source of infection is ingestion of faecally contaminated food or water.

The onset of traveller's diarrhoea usually occurs during the first week of a stay, but may occur any time, even after returning home. Illness usually begins suddenly and typically includes four to five loose or watery bowel movements each day. The player may also experience abdominal cramps, nausea, vomiting, bloating, fever, urgency and malaise. Most cases are benign and resolve in 1 to 2 days and 90% resolve within a week, but optimal tennis performance may not be regained for a week or so.

Prevention is therefore important and includes the avoidance of tap water, iced beverages, food from street vendors and fresh leafy greens and fruit that cannot be peeled before eating. Hot tea or coffee, boiled water, soup, bread, butter, bottled carbonated beverages, fruit that requires peeling and food that is well-cooked and immediately consumed are safe.

The most important treatment for diarrhoea is to replace the fluids, including salts and sugars, which the body loses through watery bowel movements. Fluid and electrolyte balance can be maintained by purified water, potable fruit juices, broth, caffeine-free soft drinks and oral re-hydration salts. When feeling better, gradually introduce small amounts of bland, easily-digested food (bananas, salted crackers, carrots, rice). Dairy products aggravate diarrhoea in some people and should be avoided.

Anti-motility drugs, such as loperamide, may be used if rapid relief of symptoms is desired e.g. when a player has a match coming up, but only in the absence of fever or bloody stools. Anti-microbial therapy may be used if it is important to shorten the course of the disease or to decrease the severity. A physician should be consulted if the player has a high fever, is severely dehydrated or has bloody stools.

GLANDULAR FEVER

Glandular fever (infectious mononucleosis) has a bad name among tennis players after several of the top players, including Roger Federer, Andy Roddick, Robin Soderling, Mario Ancic and John Isner revealed they had suffered from this illness and that it had drained their energy for months.

Glandular fever is a result of an infection with the Epstein-Barr virus and the incidence is highest among 15 to 30-year-olds. It is therefore not surprising that we see it a lot among young male and female tennis players on the tour who fall into this age group. Infectious saliva is the cause of the spreading (which is why it is known as 'kissing disease').

Symptoms include fatigue, fever, sore throat, headache and nausea. Clinical examination may reveal a throat infection, swollen lymph nodes and enlargement of the spleen. The illness lasts between 5 to 15 days, but it may take several months before the fatigue and weakness entirely disappear. This is why many players fear this illness, but there is no solution other than to take the time to recover.

A player suffering from glandular fever should take a break from tennis until all acute symptoms have disappeared. In some cases the liver of the patient can be affected (hepatitis). If this is the case, a low-fat diet should be followed. Resumption of training may be allowed as soon as blood tests show improved liver function.

Training should be resumed gradually, first increasing duration and then intensity, with adequate periods of rest. It may help to regularly monitor heart rate to determine intensity of play.

CHRONIC MEDICAL CONDITIONS

For optimal tennis performance it is important that players control chronic medical conditions, such as diabetes and asthma.

Diabetes mellitus

Diabetes mellitus is a group of metabolic diseases characterised by high glucose levels of the blood, due to deficiency or diminished effectiveness of insulin. In diabetes mellitus type 1, most common in those aged below 30, the body fails to produce the hormone insulin. In diabetes mellitus type 2, occurring mainly in the middle-aged and elderly, there is a depressed sensitivity to insulin at the cellular level. This high blood sugar may cause symptoms such as frequent urination, thirst, weight loss and tiredness. Serious long-term complications of diabetes include heart disease, kidney failure and damage to the eyes. Famous tennis players with diabetes include Arthur Ashe and Billy Jean King (both type 2).

Tennis players with diabetes mellitus type 1 must receive insulin, which can only be administered by injections. They therefore need to apply for a Therapeutic Use Exemption (TUE), since insulin is on the prohibited substance list and the administration of injections is normally not allowed during match play[8]. Type 2 diabetes is treated with diet and medications with or without insulin. Exercise has a beneficial effect on diabetes mellitus type 2, because it increases insulin sensitivity. In diabetes mellitus type 1, exercise does not improve the control of the glucose levels and careful monitoring of blood glucose levels is required, but regular exercise is associated with long-term positive changes. An adjustment of insulin dosage is important in reducing the risk of low glucose levels during or after exercise.

At the first indication of a low blood glucose level (sweating, nervousness, tremor), the player should ingest carbohydrate in solid or liquid form. A semiconscious or unconscious diabetic patient requires intravenous glucose administration. Players should be alerted to the possibility of delayed exercise-induced low blood glucose levels several hours after completion of exercise. A player should abstain from exercise when glucose levels are very high and there is insulin deficiency at the beginning of exercise. The glucose cannot be utilised, leading to increasingly higher levels and the burning of fat in the absence of glucose will lead to the production of acetone, recognisable by its foul smell.

Practical tips for diabetes sufferers

- *Monitor blood glucose level before, during and after play to establish the player's response pattern.*
- *Adjust carbohydrate intake and insulin dosages according to the duration and intensity of the player's practice (approximately 15 to 30 g of carbohydrates per 30 minutes of exercise).*
- *If the training will last more than 45 to 60 minutes, the insulin dose may be reduced.*
- *The player should abstain from play if their blood glucose level is above 16 mmol per litre because a further rise may be expected.*
- *Respect the doping regulations. Diabetics with a valid TUE are allowed to use a device off-court to check blood glucose and administer subcutaneous injections of insulin if necessary.*

Exercise-induced asthma

Exercise-induced asthma is asthma that is triggered by vigorous or prolonged exercise. It is quite common in young players, with a 10 to 15% incidence in adolescent athletes, including tennis players. Groups at high risk are those with asthma (70 to 80%) and allergic rhinitis (40%).

Symptoms include wheezing, tightness of the chest, shortness of breath, unusual fatigue and coughing. These symptoms usually begin within 5 to 20 minutes after the start of exercise or 5 to 10 minutes after brief exercise has stopped.

The strongest trigger for an attack is cold, dry air. Rapid breathing during exercise tends to cool and dry the airways and the muscle bands around the airways react by contracting.

Regular medication helps diminish lung hyperactivity, reducing the risk of asthma attacks and generally include corticosteroids and bronchodilators. Any nasal obstructions should be treated because congestion in the upper airways may decrease nasal filtration, heating and humidification.

Make sure to check the list of prohibited substances. Nasal and inhaled corticosteroids are allowed and so are salbutamol, formeterol and salmeterol in therapeutic dosages, but terbutaline, for example, requires a TUE.

Heat illness

Tennis is frequently played in very hot environmental conditions, such as during the US Open and the Australian Open, resulting in an increased risk of heat-related illnesses, including cramps, heat exhaustion and heat stroke.

Heat cramps are painful, involuntary muscle spasms of skeletal muscle and, although they may also occur during normal ambient temperatures, they are more often seen in the heat. In tennis players, the calf and thigh muscles are affected most often. The exact cause of muscle cramps is unknown, but suggested causes include dehydration and electrolyte imbalance and altered neuromuscular control[9]. Treatment of cramps consists of gentle stretching of the affected muscle and oral fluids containing sugar and salt.

Heat exhaustion is caused by the circulatory strain induced by dehydration, resulting in a lower circulatory fluid volume. Symptoms are physical exhaustion, a fast, weak pulse, clammy skin, low blood pressure, headache, dizziness and nausea. The player may even faint, due to a fall in blood pressure. Laying down improves the blood flow to the heart and brain and the person will quickly regain consciousness. Treatment consists of cooling the body, taking oral fluids and cessation of play.

If the player continues to play without taking any extra measures, the body may react by reducing blood flow to the skin, reducing heat loss from the surface, which may lead to a further rise in core body temperature and could potentially lead to heat stroke[10].

Heat stroke is a life-threatening illness, characterised by a hot, dry skin, rapid pulse and a high body temperature, which may rise over 41°C (106°F). The player may display irrational behaviour due to disturbances of the central nervous system and the high body temperatures can lead to irreversible damage of the internal organs and even death. The body should be cooled as quickly as possible and the players should be re-hydrated with oral or intravenous fluids. Immediate transfer to a hospital should be arranged.

Tennis players can maintain their core body temperature at a safe level across a wide range of environmental conditions; core body temperature is determined mainly by the intensity of the exercise and the resulting metabolic rate[11]. When the cooling mechanisms of the body (sweating and vasodilation in the skin) work normally, thermal equilibrium is reached and maintained during tennis match play[11]. However, in adverse environmental conditions (e.g. high air temperature, high humidity, solar radiation and no wind), core body temperature is determined not only by the metabolic rate, but also by the environmental heat load.

It has been shown that when thermal discomfort increases, players slow down in the heat, which reduces their metabolic heat production[12].

In hot environmental conditions, players can take additional measures to cool their bodies during the changeover and may use ventilators, fans, parasols, ice vests, ice towels and cold water. The water and electrolytes lost through sweat must be replaced to avoid dehydration and the most effective way is by consuming sports drinks (beverages containing salt and electrolytes) before, during and after play. Finally, fit and acclimatised players will be less affected by the heat than players who are unfit and not acclimatised.

DIET

Since Novak Djokovic published his book 'Serve to win: the 14-day gluten-free plan for physical and mental excellence', many tennis players have followed his example and sworn off gluten, dairy and tomatoes and have turned to nuts, seeds, vegetables, fish, chicken and quinoa. However, only those with coeliac disease need to eliminate gluten from their diet and what works for Djokovic may not work for everyone.

Players should eat a healthy and balanced diet – what is good for health is generally also good for tennis. This diet should provide all the necessary macronutrients (carbohydrates, fats, proteins, fibre, water) and micronutrients (vitamins and minerals) that are needed for growth and development and that will provide enough energy during training and competition.

Players are advised to consume a healthy low fat diet with 5 to 7 g of carbohydrates per kg and no more than 25 to 30% fat, preferably polyunsaturated fats. Carbohydrates remain an important fuel when playing tennis and protein should be added to enhance recovery. Extra carbohydrates should be consumed prior to and during play on heavy training or competition days, preferably complex carbohydrates (starches). Protein is important for the strengthening and restoration of muscles after a workout and players are recommended to consume about 1.2 g/kg body weight daily. After a strenuous training session or match, players are recommended to consume 1.5 g carbohydrates per kg body weight and

Practical tips for asthma sufferers

- *A thorough warm-up is advised because a gradual, lengthy warm-up prior to more strenuous exercises has been shown to make the airway more resistant to irritants and to decrease the incidence of bronchospasms.*
- *A high fitness level will help to reduce the frequency and intensity of the attacks. A good way to build up stamina is by interval training, as this type of training has been shown to provoke fewer attacks.*
- *Tobacco smoke and other obvious forms of air-pollution should be avoided.*
- *Infections can cause asthma (colds, flu, sinusitis), so exercise should be restricted when the athlete is ill.*

> ***Vitamin, mineral and antioxidant supplementation to a player on a well-balanced diet has not been shown to improve performance and is generally unnecessary***

about 20 g protein within an hour after exercise to speed up recovery[13].

Vitamin, mineral and antioxidant supplementation to a player on a well-balanced diet has not been shown to improve performance and is generally unnecessary. If vitamin and mineral intake is inadequate, it is at least as important to change nutritional habits toward nutrient rich foods as it is to take supplements. If a player does take dietary supplements (including vitamins, minerals, protein shakes, amino acids, herbal and 'natural' products) he needs to be sure they are guaranteed free from contamination with prohibited substances, to avoid an inadvertent doping offence. And it is NOT sufficient to just check the label, they may contain undeclared substances. Regulations for dietary supplements are less strict than for medications, so they need to be truly tested and guaranteed doping free.

CONCLUSION

In summary, there are no medical conditions that prevent an individual from playing tennis and there are widely published studies that outline the health benefits of tennis. As with any vigorous physical exercise, participants must be guided by their own general practitioner or specialist if they are on regular medication or suffering from a chronic medical disorder (e.g. cancer, cardiovascular disease).

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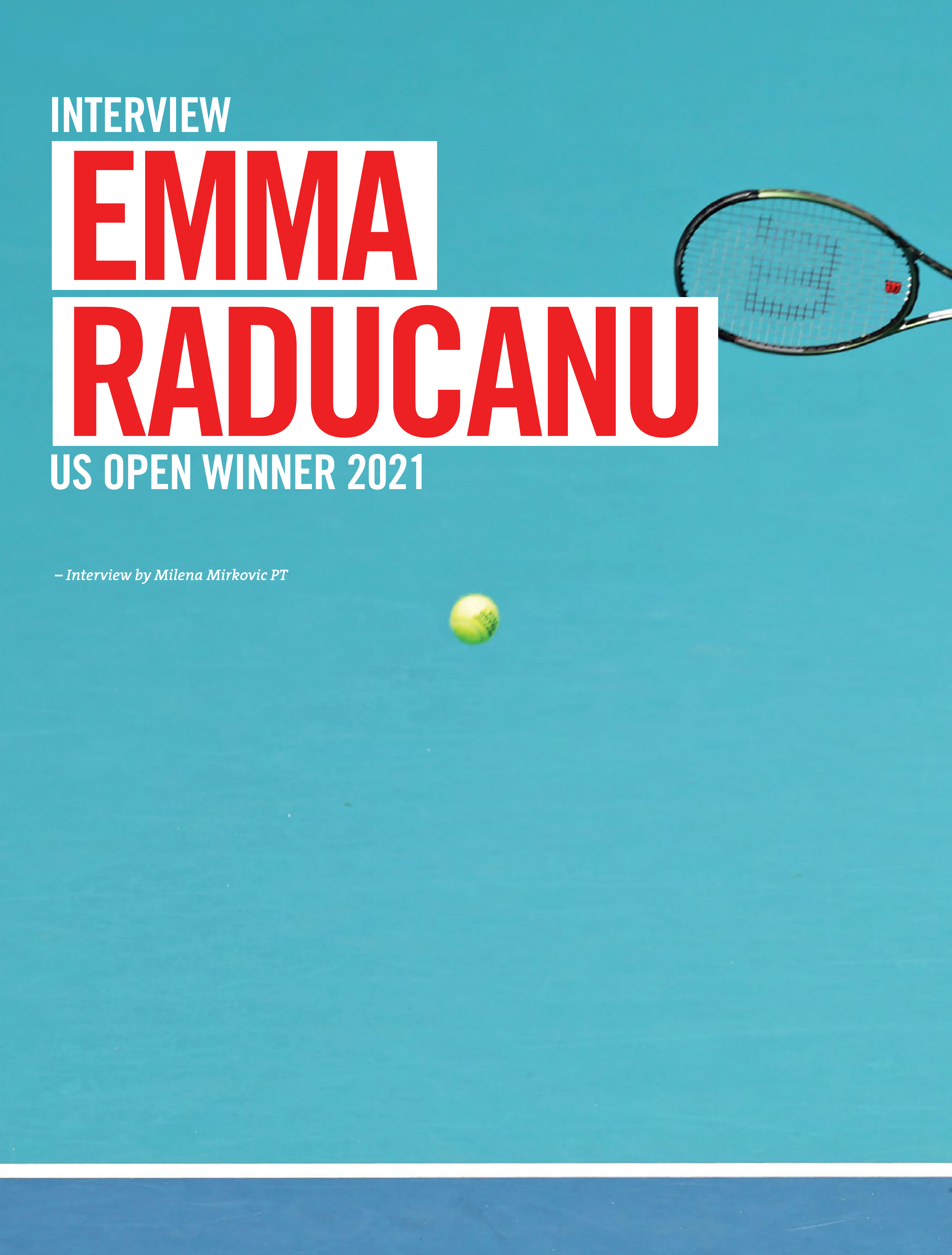
INTERVIEW

EMMA RADUCANU

US OPEN WINNER 2021

– Interview by Milena Mirkovic PT



EMMA RADUCANU

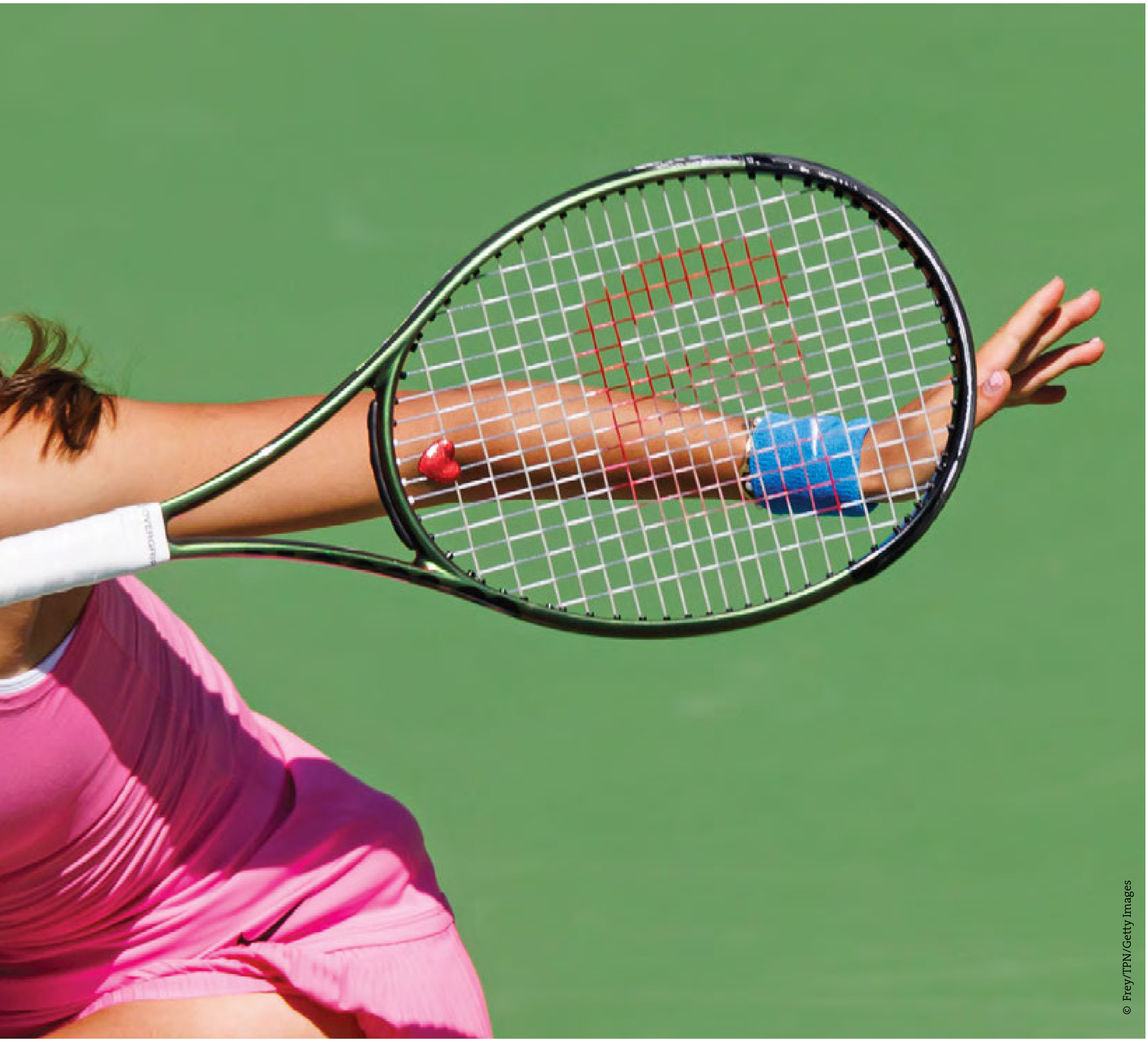
At the age of 18 Raducanu become the youngest British woman to win a Grand Slam.

Prior to her triumph at the USA Open 2021 Raducanu was ranked outside the top 300 in the world.Her stunning performance in the tournament propelled her to newfound fame and skyrocketed her ranking to the top 25. Alongside her tennis career Raducanu is also academically accomplished,showing her dedication and determination both on and off the court. Raducanu has earned plaudits for her grace and sportsmanship on and off the court. Her positive attitude and respectful demeanor make her a role model for young athletes worldwide.

She shared her story with our Guest Editor Milena Mirkovic.

What is tennis for you?
I think from the outside, the life of a professional tennis player can be viewed as very glamorous, but the reality is quite different. Yes, you're travelling the world, playing in some of the best venues and cities, following the sun, etc., however I think it is one of the loneliest and most emotionally challenging of sports. I think a lot of players would say the same thing. That all said, it's the sport I love and one that builds character and discipline unlike many others.

When did you start playing tennis?
I was five years old, I remember starting out when my dad would take me to the local park and the Bromley Tennis Centre in London.



How did you get involved in sports?
My dad threw me into every sport possible as he believed they would all help my athletic ability. So from the age of five to eight I was doing horse riding, swimming, tap dancing, basketball, skiing, golf, and go karting!

Did you play other sports during your childhood?
Yes, all of the ones above, and I loved them all, and took lots different learnings from each one, but then tennis took so much time I had to stop most.

When did you start with your specialization in tennis?
I'd say around eight years old. As I said, playing lots of sports was great for me and it helped me gain a diverse skill set ... but as I started winning in tennis, the tournaments would take up the weekend, so these other activities couldn't happen anymore and tennis took over.

Let's talk about your opinion on early specialization in tennis. So many tennis academies for young talents are opening up globally. Do you see this as an advantage for the future stars of the new generation?
Of course more specialized tennis facilities around the world is a good thing for future generations who want to pursue tennis as a career path, which is ultimately good for the sport. I would also still advocate though that it's a good thing kids not going too

Image left: Emma Raducanu at the 2023 Australian in Melbourne, Australia, January 2023.

Image below: Raducanu during her first-round match of the 2023 BNP Paribas. Indian Wells, California, March 2023.

Image right: Emma at Madrid Open on April 24, 2024 in Madrid, Spain.

Image right below: Emma Raducanu after she was made a Member of the Order of the British Empire (MBE) by King Charles III in November 2022. Windsor, England.

specific into tennis straight away, and actually benefiting from playing and being exposed to different sports from a young age. I think acquiring skills in multiple sports helps develop creativity and equips people better to handle fresh challenges later in their sporting life.

You've recently helped team GB qualify into the Billie Jean King Cup Finals. How would you compare your preparation for a singles tournament as an individual player versus preparing for a BJKC tie?

It's not too different to be honest, I think every player has their pre match prep routines, and once you get used to a new environment, conditions, you just try and follow the process that you and your team have in place.

Is it tough to be an elite tennis player today?

Yes, I spoke about it above. It has its challenges just like any elite sport does, but with tennis specifically, so long as you're ok with the travel, being good in your own company and being resilient, it's manageable and every week you have an opportunity to prove yourself.

What is your advice to young people who would like to become high level tennis players?

It's an amazing sport for young people to be involved in and I think has a lot of positives attached to it both on one's physical and mental wellbeing, but the most important thing I'd say when you're starting out is to just have fun with it!

What do you think is the profile of a 21st century tennis player?
The physical side to tennis both in the men's and women's game has become a hugely significant part of the sport. However, the mental component is just as important if not more due to the nature of tennis, the quick momentum shifts, losing every week in front of yourself and also the public who comment without knowing the facts of what really goes on behind the scenes, it requires resilience to deal with.

How important is your medical team to you?
My off court team play a huge role. People often see players on the court and forget all the hard work that goes on behind the scenes with their teams, not just the coach, but physio, fitness trainer etc. It's a major investment but a very important one, and all in a bid to make our general 'health' and physical/ mental levels improve.

In your opinion, what is the ideal profile and a set of qualities that a Sports Medicine Physician should have?
I think being a good team player is a very important one, certainly for me. Someone I can trust. Also have an in-depth understanding of the specific sport they're working in, as well as wider sports culture and practices.

There is a big focus on injury prevention in sport. Do you follow any injury prevention programs?
Of course, me and my team are always thinking and practicing about how I can not only be best prepared to be match ready, but also how my body can sustain the relentless nature of the tennis calendar which is 'always on'!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What advice would you give to young people who dream of becoming top-level athletes?
My tips for anyone starting is at the beginning, just like everything – you may feel it's hard and like giving up but don't get discouraged. If you have a dream, go after it! And don't let anything get in the way of that.

Milena Mirkovic PT

ASPETAR RESEARCH UPDATES

– Moderated by Marco Cardinale Ph.D.
Qatar

Shared decision-making with athletes: a survey study of healthcare professionals' perspectives

Shared decision-making (SDM) is a trending topic in athlete health care; however, little is known about its use in a sports context. This study aimed to measure knowledge and self-perceived practice of SDM among healthcare professionals working with athletes. This study evaluated SDM attitudes and preferences and explored how healthcare professionals perceived the factors influencing SDM. The data collection was conducted with A web-based cross-sectional survey with open-ended and closed-ended questions.

The survey was completed by 131 healthcare professionals. The majority (63.6%) reported to prefer SDM and to be confident in their SDM skills (81.1%). Despite this inclination and confidence, only one in four clinicians reported consistent practice of SDM when feasible. Additionally, most clinicians lacked SDM knowledge. The barriers perceived by healthcare professionals included time constraints (17.6%), limited patient knowledge (17.6%), limited patient motivation (13.5%) and language barriers (16.2%). Importantly, two-thirds of the participants believed that SDM in athlete health care differs from SDM in non-athletes due to the high-pressure environment, the tension between performance and health, and the involvement of multiple stakeholders with potentially conflicting interests.

Although healthcare professionals preferred SDM, they did not fully understand nor routinely practice it. Most healthcare professionals perceive SDM in athlete health care to differ from SDM in the general population. Therefore, to inform the implementation of SDM in athlete health care, future research is crucial to understand better what makes practicing SDM unique in this setting.

Nelis S, Dijkstra HP, Damman OC, Farooq A, Verhagen E. Shared decision-making with athletes: a survey study of healthcare professionals' perspectives. BMJ Open Sport Exerc Med. 2024 Apr 30;10(2):e001913. doi: 10.1136/bmjsem-2024-001913. PMID: 38736642; PMCID: PMC11086382.

DYNEELAX Robotic Arthrometer Reliability and Feasibility on Healthy and Anterior Cruciate Ligament Injured/Reconstructed Persons

Anterior cruciate ligament (ACL) injuries are commonly assessed using clinical examination and magnetic resonance imaging, but these methods have limitations in reproducibility and quantification. Instrumented laxity measurements using devices, like the DYNEELAX®, offer an alternative approach. However, to date, there is no human data on the DYNEELAX® and the reliability of these devices remains a subject of debate, and there is no consensus on appropriate knee tightening levels for testing. We hypothesized that the DYNEELAX®, with standardized knee tightening, would provide reliable measurements of knee laxity in adult volunteers.

This prospective cohort study involved 48 pain-free adult volunteers. Laxity measurements were taken using a robotic-type motorized instrument (DYNEELAX®) on two separate occasions, at least 1 h and no more than 8 h apart, with knee tightening forces of 90 N ± 5 N. Metrics of anterior tibial translation and internal/external tibial axial rotations were recorded. The device displayed excellent intrarater reliability for all the metrics, with intraclass correlation coefficients ranging from 0.91 to 0.96. Anterior translation exhibited the highest reliability (intraclass correlation coefficient = 0.96), with a minimum detectable change of 0.83 mm.

DYNEELAX® is reliable in measuring knee laxity in adult volunteers when using standardized stabilizing knee tightening forces of 90 ± 5 N. The most sensitive measurement parameters (in terms of minimum detectable change as a proportion of the observed range) were anterior translation (in mm) at 150 N and secondary compliance.

Nascimento N, Kotsifaki R, Papakostas E, Zikria BA, Alkhelaifi K, Hagert E, Olory B, D'Hooghe P, Whiteley R. DYNEELAX Robotic Arthrometer Reliability and Feasibility on Healthy and Anterior Cruciate Ligament Injured/Reconstructed Persons. Transl Sports Med. 2024 Apr 15;2024:3413466. doi: 10.1155/2024/3413466. PMID: 38654720; PMCID: PMC11023723.

Acute clinical evaluation for the diagnosis of lateral ankle ligament injuries is useful: A comparison between the acute and delayed settings

The purpose of this study was to determine the diagnostic value of seven injury history variables, nine clinical tests (including the combination thereof) and overall clinical suspicion for complete discontinuity of the lateral ankle ligaments in the acute (0-2 days post-injury) and delayed setting (5-8 days post-injury).

All acute ankle injuries in adult athletes (≥18 years) presenting up to 2 days post-injury were assessed for eligibility. Athletes were excluded if imaging studies demonstrated a frank fracture or 3 T MRI could not be acquired within 10 days post-injury. Using standardized history variables and clinical tests, acute clinical evaluation was performed within 2 days post-injury. Delayed clinical evaluation was performed 5-8 days post-injury. Overall, clinical suspicion was recorded after clinical evaluation. MRI was used as the reference standard.

Between February 2018 and February 2020, a total of 117 acute ankle injuries were screened for eligibility, of which 43 were included in this study. Complete discontinuity of lateral ankle ligaments was observed in 23 (53%) acute ankle injuries. In the acute setting, lateral swelling had 100% (95% confidence interval [CI]: 82-100) sensitivity, haematoma had 85% (95% CI: 61-96) specificity and the anterior drawer test had 100% (95% CI: 77-100) specificity. In the delayed setting, sensitivity for the presence of haematoma improved from 43% (95% CI: 24-65) to 91% (95% CI: 70-98; $p < 0.01$) and the sensitivity of the anterior drawer test improved from 21% (95% CI: 7-46) to 61% (95% CI: 39-80; $p = 0.02$). Clinical suspicion had a positive likelihood ratio (LR) of 4.35 (95% CI: 0.55-34.17) in the acute setting and a positive LR of 6.09 (95% CI: 1.57-23.60) in the delayed setting.

In the acute setting, clinical evaluation can exclude complete discontinuity (e.g., absent lateral swelling) and identify athletes with a high probability of complete discontinuity (e.g., positive anterior drawer test) of the lateral ankle ligaments. In the delayed setting, the sensitivity of common clinical findings increases resulting in an improved diagnostic accuracy. In clinical practice, this study underlines the importance of meticulous clinical evaluation in the acute setting.

Baltes TPA, Geertsema C, Geertsema L, Holtzhausen L, Arnáiz J, Al-Naimi MR, Al-Sayrafi O, Whiteley R, Slim M, D'Hooghe P, Kerkhoffs GMMJ, Tol JL. Acute clinical evaluation for the diagnosis of lateral ankle ligament injuries is useful: A comparison between the acute and delayed settings. Knee Surg Sports Traumatol Arthrosc. 2024 Mar;32(3):550-561. doi: 10.1002/ksa.12079. Epub 2024 Feb 22. PMID: 38385771.

Baseline clinical and MRI risk factors for hamstring reinjury showing the value of performing baseline MRI and delaying return to play

This project was funded by a grant from the International Olympic Committee and was a collaboration between the IOC Centres of Aspetar and Amsterdam.

Studies identifying clinical and MRI reinjury risk factors are limited by relatively small sample sizes. This study aimed to examine the association between baseline clinical and MRI findings with the incidence of hamstring reinjuries using a large multicentre dataset.

We merged data from four prospective studies (three randomised controlled trials and one ongoing prospective case series) from Qatar and the Netherlands. Inclusion criteria included patients with MRI-confirmed acute hamstring injuries (<7 days). We performed multivariable modified Poisson regression analysis to assess the association of baseline clinical and MRI data with hamstring reinjury incidence within 2 months and 12 months of follow-up.

330 and 308 patients were included in 2 months (31 (9%) reinjuries) and 12 months (52 (17%) reinjuries) analyses, respectively. In the 2-month analysis, the presence of discomfort during the active knee extension test was associated with reinjury risk (adjusted risk ratio (ARR) 3.38; 95% CI 1.19 to 9.64). In the 12 months analysis, the time to return to play (RTP) (ARR 0.99; 95% CI 0.97 to 1.00), straight leg raise angle on the injured leg (ARR 0.98; 95% CI 0.96 to 1.00), the presence of discomfort during active knee extension test (ARR 2.52; 95% CI 1.10 to 5.78), the extent of oedema anteroposterior on MRI (ARR 0.74; 95% CI 0.57 to 0.96) and myotendinous junction (MTJ) involvement on MRI (ARR 3.10; 95% CI 1.39 to 6.93) were independently associated with hamstring reinjury.

Two clinical findings (the presence of discomfort during active knee extension test, lower straight leg raise angle on the injured leg), two MRI findings (less anteroposterior oedema, MTJ involvement) and shorter time to RTP were independently associated with increased hamstring reinjury risk. These findings may assist the clinician to identify patients at increased reinjury risk following acute hamstring injury.

Zein MI, Mokkenstorm MJK, Cardinale M, Holtzhausen L, Whiteley R, Moen MH, Reurink G, Tol JL; Qatari and Dutch Hamstring Study Group. Baseline clinical and MRI risk factors for hamstring reinjury showing the value of performing baseline MRI and delaying return to play: a multicentre, prospective cohort of 330 acute hamstring injuries. Br J Sports Med. 2024 May 10:bjsports-2023-107878. doi: 10.1136/bjsports-2023-107878. Epub ahead of print. PMID: 38729628.

INDUSTRY NEWS

– Written by Chris John Esh, Qatar

Physical fitness and performance: what separates the elite players from the rest?

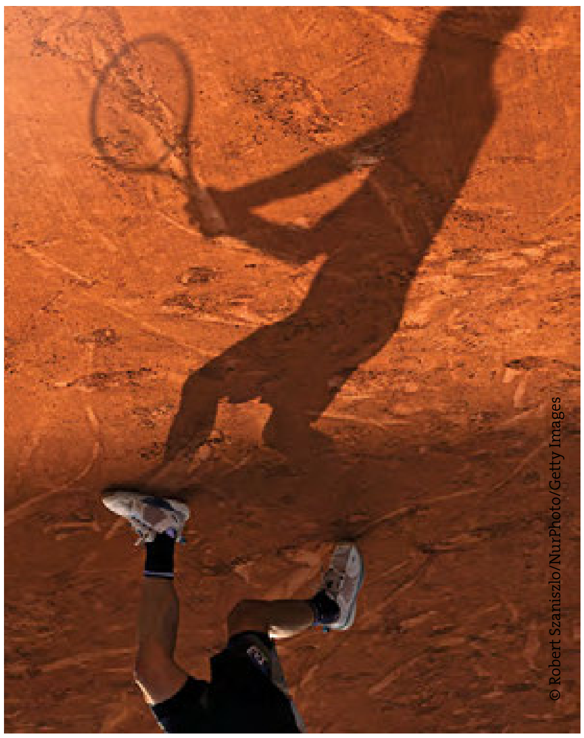
Sports Science

Tennis match play requires a variety of physical attributes inclusive of speed (e.g., ~8-15 m sprints), agility (e.g., frequent and rapid changes of direction), strength/power (e.g., stroke performance) and endurance (e.g., match durations of 3 to 5 hours). While elite tennis players have been shown to have higher physical fitness and greater stroke performance, until a recent systematic review and meta-analyses it was not clear which physical attributes may/may not determine performance differences between the elite players and the rest. Evidence that may allow aspiring tennis players to address components of fitness/performance to be able to reach the elite level. From this review the largest differences in physical fitness were for lower extremity muscle power, endurance and agility with elite players excelling in all these facets. Furthermore, greater fitness within these areas was correlated with improved stroke performance (determined by stroke velocity). Within the elite and non-elite players those who had greater fitness values within these areas had greater stroke performance. While there are considerably more factors that contribute to elite level tennis match play this data suggests that improving lower extremity muscle power, endurance and agility may have the greatest impact on stroke performance.

Does court surface impact the physical demands of tennis?

Sports Science

Tennis is played across three court surfaces: i) hard court; ii) grass court and, iii) clay court all of which place different physical demands on the players. A recent systematic review with meta-analyses examined the impact of court surface on the physical demands of tennis. Mean match duration across all surfaces was 89.7 minutes for male and 88.0 minutes for female players. Insufficient data was available to determine the mean durations of matches between surfaces. Mean rally duration was highest on clay surfaces for males: 7.1 seconds (grass: 4.3, hard: 5.6) and females: 8.8 seconds (grass: 5.7, hard: 6.4). mean number of strokes per rally was 4.1 across all surfaces for males (clay: 4.8, hard: 4.2) and 3.9 for females but insufficient data to determine court surfaces differences in female matches. Work to rest ratios were variable depending on court surface, for males (hard: 1:3.5 to 1:5.6; clay:1:2.0 to 1:3.5; grass: 1:3.7 to 1:5.0) and females (hard: 1:3.4 to 1:4.5; clay: 1:2.1 to 1:2.4; grass: 1:3.2). While this data provides some insight into the physical demands of tennis further data is required to provide a comprehensive overview of how playing surface impacts the physical demands of tennis match play. Recommendations are for players to train (i.e., aerobic fitness/capacity and strength and conditioning work) in a manner that simulates tennis match play (e.g., high intensity work with work to rest ratios of 1:2 to 1:4) to optimally prepare for competition.



Epidemiology of injury

Sports Medicine

Limited epidemiological injury data exists from elite tennis players on the Association of Tennis Professionals (ATP) and the Women's Tennis Association (WTA) Tour however, one research group investigated injury incidence and prevalence on the National Collegiate Athletic Association (NCAA) tennis circuit between 2014 and 2019 in both male and female players. Within the NCAA there are three divisions (I, II and III) and injury rated were compared between the divisions. Across the period 2014 to 2019 an injury was recorded when a player required medical attention from an athletic trainer or physician during scheduled training and NCAA competition, irrespective of whether the player was able to return to play immediately and/or without any time loss from training and competition or missed training and/or competition to allow for recovery/rehabilitation. The findings for male and female players are subsequently outlined.

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Male players

From 2014 to 2019 a total of 56,895 athletic events (i.e., training session or competition) were recorded with 251 injuries reported. A rate of 4.41 injuries per 1000 athletic events. Injuries occurred in competition (6.69 injuries per 1000 athletics events) more often than in training (3.72 injuries per 1000 athletic events). Injury rates were higher in Division I (4.96) compared to Division II (4.20) and III (3.57) and similar rates of injury were seen during training between the divisions (I = 3.80; II = 3.96; III = 3.32). During competition however, injury rates were significantly higher in Division I (8.61) than Division II (4.94) and III (4.48). Overall 34.3% of these injuries required players to miss at least one day of training/competition (Division I: 34%; Division II: 23% and, Division III: 48%). The most common injuries were to the Trunk (15.1%) and shoulder (13.2%) with the most common type of injury being a muscle strain (27.9%) followed by tissue inflammation (22.7%) and sprains (11.6%) with the most commonly reported injuries being ankle ligament tears (8.4%). The majority of injuries occurred during general play (45%).

Female players

In female players a total of 72,671 athletic events were recorded with 302 injuries being reported. An injury rate of 4.16 per 1000 athletic events. Injuries occurred in competition (6.62) more often than in training (2.82). Overall injury rates were higher in Division I (5.32) compared to Division II (2.99) and III (3.08) and similarly during training (Division I = 4.18; II = 2.48; III = 2.61) and competition (Division I = 9.07); II = 4.44; III = 4.48). Overall 32.1% of these injuries required players to miss at least one day of training/competition (Division I: 33.3%; Division II: 18.2% and, Division III: 37.7%). A shoulder injury (15.2%) was the most commonly reported injury, while the most common types of injuries were tissue inflammation (27.5%), muscle strain (20.9%) and sprain (11.3%). The majority of injuries occurred during general play (48%).

Injury rates and types of injuries sustained appear to be similar between male and female players, with the higher ranked players (i.e., Division I players) being more likely to suffer an injury. Research is required on the ATP and WTA tours to determine how this data translates to elite tennis players.

DID YOU KNOW?

- **The fastest serves recorded in tennis are 263 km/h (163 mph) in the male game (Samuel Groth, May 2012) and 211 km/h (131 mph) in the female game (Sabine Lisicki, July 2014).**
- **In the open era of tennis (since 1968) 8 males and 10 females have completed the singles career grand slam by winning all of the major championships (Australian Open, French Open, Wimbledon and the US Open).**

NEXT ISSUE – TARGETED TOPIC:
Sports Medicine in Handball

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