IGFBP-3, a sensitive marker of physical training and overtraining

M Elloui, N El Elj, M Zaouali, F Maso, E Filaire, Z Tabka, G Lac

Objective: To investigate the response of the somatomedins (specifically, insulin-like growth factor-1 (IGF-1), insulin-like growth factor binding protein-3 (IGFBP-3)) to intense exercise in relation to tiredness.

Methods: The study involved 11 rugby players who completed a questionnaire intended to evaluate fitness or, conversely, overtraining and who agreed to plasma samples being taken before and after an international rugby match.

Results: The main finding of our study is that we observed strong negative correlations between IGF-1 (r = 0.652) and IGFBP-3 (r = 0.824) levels and the overtraining state estimated using the French Society of Sport Medicine questionnaire. In particular, there was a fall (of up to 25%) in IGFBP-3 levels after the match in the more fatigued subjects compared to an increase (of up to 40%) in fit subjects.

Conclusions: A fall in IGFBP-3 in response to an intense bout of exercise may represent an index of tiredness in highly trained sportsmen, as indicated by the scores obtained from the overtraining questionnaire.

Physical exercise is a powerful stimulus for growth hormone (GH) secretion, certain actions of which take place by way of growth factors called somatomedins, the principal one being somatomedin-C or insulin-like growth factor-1 (IGF-1). IGF-1 plays a role in many physiological processes, particularly in organism anabolism, related to bone and muscular growth. About 80% of IGF-1 occur in a ternary 150 kDa complex including insulin-like growth factor binding protein-3 (IGFBP-3) and a protein called acid-labile subunit; less than 1% of IGF-1 are free. The IGFBPs prolong the half-life of the IGFs, serve as IGF carriers in the circulation, and act as autocrine and/or paracrine regulators of their biological actions. IGFBP-3, which is synthesised in many tissues, is considered the major IGF-1 carrier. It is well documented that circulating levels of IGF-1 and IGFBP-3 are regulated by nutrition, aging, pregnancy, chronic diseases, insulin, and GH. A reduction in IGF-1 concentration is commonly associated with nutritional deficiency. Several studies have shown that intensive training stimulates both circulating IGF-1 and IGFBP-3, since positive significant correlations exist between these factors and physical fitness levels. In contrast, an associated fall in IGFBP-3 related to overtraining was observed. These correlations indicate that fitness in healthy subjects is related to increased activity of the IGF system, favouring an anabolic state. Thus, it can be confirmed that physical exercise affects tissue anabolism and may provide general health benefits. The evaluation of possible changes in concentrations of total IGF-1 and its binding proteins (mainly IGFBP-3) may be of interest because they are thought to affect performance, and probably reflect the physical overload state of athletes.

However, data reviewed in the literature concerning the variation of IGF-1 and IGFBP-3 after exercise, that is to say in a dynamic situation, present conflicting opinions, depending on the type of exercise and the degree of training. To our knowledge, no study to date has investigated the responses of these factors to exercise in relation to overtraining.

In this investigation, we report the concentrations of total IGF-1 and total IGFBP-3 in rugby players during a rest day and after an international rugby competition. Rugby is a physical activity characterised by mixed physiological demands, but essentially comprising of anaerobic lactic type physiological responses. At a high level, this sport requires intensive training (10 h per week), and during the championship season a match occurs typically every week. The duration of a rugby match (90 min including a 10 min half time) pushes players to exhaustion, particularly in an exercise situation of maximal activity levels as reflected during an international contest. Therefore, the aim of our study was to examine if changes in IGF-1 and IGFBP-3 were associated so that fitness or overtraining could be measured; overtraining was estimated by using the overtraining questionnaire of the French Society of Sport Medicine (SFMS). An English translation of this questionnaire is given in the appendix.

METHODS

This study was conducted in a realistic situation of international competitiveness. We followed 11 international rugby players who belonged to the national team of Tunisia. These 11 athletes gave their consent to participate in the study following an explanation of experimental procedures and purpose and agreed to be sampled on two occasions by sport physicians. The study was carried out in compliance with ethical rules currently applied in Tunisia. No subject was taking any drugs or medication or reported a history of endocrine disorders before or during any stage of the study. None of these 11 players was substituted during the match. The players, aged 26.6 (1.4) years, had all participated actively in rugby for 16.5 (1.3) years, and trained in their clubs 3–4 days a week (8–12 h/week) in addition to their weekly 1.5 h match.

Anthropometric measurements

Anthropometric measurements included height, body mass, body mass index (BMI: weight in kg/height in m2) and coefficient of variability; CV, coefficient of variability; G1, group 1; G2, group 2; GH, growth hormone; IGF-1, insulin-like growth factor-1; IGFBP-3, insulin-like growth factor binding protein-3; SD, standard deviation; SFMS, French Society of Sport Medicine

Abbreviations: AFC, after the competition; BMI, body mass index; CV, coefficient of variability; G1, group 1; G2, group 2; GH, growth hormone; IGF-1, insulin-like growth factor-1; IGFBP-3, insulin-like growth factor binding protein-3; SD, standard deviation; SFMS, French Society of Sport Medicine
percent body fat, estimated from skin fold thickness at the biceps, triceps, and subcapsular and subiliac sampling sites. Height was measured using a Harpenden anthropometer (Holtain, Crosswell, Pembrokeshire, UK) to the nearest 0.1 cm. Weight was recorded to the nearest 0.1 kg with a portable digital metric scale, which was calibrated prior to data collection using standard weights. Skin folds were measured on each subject with a Harpenden skin fold calliper (Holtain). All the data were collected by the authors who were experienced in taking skin fold thicknesses.

For the assessment of \( \text{VO}_{2\text{max}} \), subjects performed a continuous incremental test to exhaustion on an athletic track according to the protocol of Léger and Boucher.27

**Food intake**

To assess the adequacy of nutrient intake, a 7 day consecutive dietary record was completed. All players received a detailed verbal explanation and written instructions on data collection procedures. Subjects were asked to continue with their usual dietary habits during the period of diet recording, and to be as accurate as possible in recording the amount and type of food and fluid consumed. A list of common household measures, such as cups and tablespoons, and specific information about the quantity in each measurement (grams, etc) was given to each participant. Each individual’s diet was calculated using the Bilnut 4 software package (SCDA Nutrisoft, Cerelles, France), a computerised database that calculates food intake and composition from French standard references.

**Psychometric assessment**

The subjects were asked to complete a standardised overtraining questionnaire proposed by the French consensus group on overtraining (French Society for Sports Medicine, SFMS). This questionnaire was self-administered 48 h before the match. It allows the calculation of a score that helps to classify, on a clinical basis, the demands of sportsmen submitted to a heavy training program.25 This questionnaire consists of a list of 54 items requiring an answered response of “Yes” or “No” by the subject and selected from the reported clinical manifestations of the syndrome. The total of positive items (quoted “Yes”) is used as a score of overtraining (see appendix).

**Blood sampling and analytical methods**

Blood samples for each subject were collected from a forearm vein during a rest day, 48 h before the competition (Rest) and 5–15 min after the competition (AFC). Rest sampling was performed at 8 am after an overnight fast and 9 h of sleep. Sampling after the match occurred at 3 pm, 5 h after the last meal. Each subject was instructed to maintain a supine position on a clinical couch during blood collection. The blood was centrifuged and serum was stored immediately at –30˚C

**RESULTS**

All data are presented as results for the whole group (11 subjects) and for specific subjects presenting an increase (G1), or conversely, a decrease (G2), in IGFBP-3 levels. The subjects’ age and anthropometric characteristics are reported in table 1. Whatever the variable, there was no difference between G1 and G2.

Table 2 shows the data for \( \text{VO}_{2\text{max}} \) results, overtraining score, and food intake. There was no difference in \( \text{VO}_{2\text{max}} \) between G1 and G2. The mean overtraining score was 15.3 for the whole group. This score was higher (p<0.01) in G2 (21) than in G1 (10.5).

Nutritional assessment showed similar values for G1 and G2 for mean food intake. This intake is lower (~6%) than recommended (3373 kcal) for subjects with corresponding

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>Whole group (n = 11)</th>
<th>G1 (n = 6)</th>
<th>G2 (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{VO}_{2\text{max}} ) ml/min per kg</td>
<td>58.4 (0.9)</td>
<td>56.9 (1.1)</td>
<td>60.1 (1.2)</td>
</tr>
<tr>
<td>Overtraining score</td>
<td>15.3 (2.3)</td>
<td>10.5 (0.6)</td>
<td>21.0 (3.5)**</td>
</tr>
<tr>
<td>Food intake</td>
<td>3148 (56)</td>
<td>3174 (66)</td>
<td>3116 (130)</td>
</tr>
<tr>
<td>kcal</td>
<td>13.16 (0.24)</td>
<td>13.27 (0.28)</td>
<td>13.03 (0.54)</td>
</tr>
<tr>
<td>Protein intake, g/kg per day</td>
<td>1.27 (0.04)</td>
<td>1.31 (0.03)</td>
<td>1.23 (0.09)</td>
</tr>
</tbody>
</table>

Data are means (SE).

**IGFBP-3**

Serum concentrations of total IGFBP-3 were estimated using the Non-Extraction Insulin-Like Growth Factor-Binding Protein-3 (IGFBP-3) Immunoradiometric Assay Kit (Diagnostic Systems Laboratories, Webster, TX, USA). The minimum detection limit was 2 SD from the mean of 22 replicates of the 0 ng/ml IGFBP-3 standard, is approximately 0.5 ng/ml. The intra-assay CVs were 1.8 and 3.9, respectively, for the mean concentrations 82.72 and 7.35 ng/ml. The inter-assay CVs were 1.9 and 0.6, respectively, for the mean concentrations 76.9 and 8.03 ng/ml.

**Subjects analysis**

Subjects were divided a posteriori into group G1 (n = 6) and group G2 (n = 5) following the response (positive or negative) of IGFBP-3 to the match.

Results are expressed as means (SE). The non-parametric Mann-Whitney test was used to test differences between variables within groups G1 and G2. Wilcoxon’s test was used to test differences between variables within subjects (Rest v AFC). Simple correlations were performed to analyse relationships between biological, physical, and psychological variables. Analysis was performed using StatView software and the significance threshold was set at p<0.05.

**IGF-1**

Serum concentrations of total IGF-1 were estimated using the Non-Extraction Insulin-Like Growth Factor-I IRMA Kit (Diagnostic Systems Laboratories, Webster, TX, USA). The theoretical sensibility, or minimum detection limit, calculated by interpolation of the mean plus 2 SD of 20 replicates of the 0 ng/ml IGF-1 standard, is 2 ng/ml. The inter-assay coefficients of variability (CVs) were 7.4 and 4.2, respectively, for the concentrations 32.54 and 383.86 ng/ml. The intra-assay CVs were 7 and 3.9, respectively, for the mean concentrations 34.03 and 373.86 ng/ml.

**Statistical analysis**

Food intake of the subjects

Table 2 shows the aerobic capacity, overtraining score, and mean food intake of the subjects.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Whole group (n = 11)</th>
<th>G1 (n = 6)</th>
<th>G2 (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, year</td>
<td>26.6 (1.4)</td>
<td>28.3 (2.0)</td>
<td>24.6 (1.6)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>91.1 (3.5)</td>
<td>93.5 (5.6)</td>
<td>88.2 (3.8)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>180.9 (1.6)</td>
<td>179.7 (1.8)</td>
<td>182.4 (2.8)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.56 (1.0)</td>
<td>28.42 (1.5)</td>
<td>26.5 (1.2)</td>
</tr>
<tr>
<td>% Fat mass</td>
<td>19.5 (1.0)</td>
<td>20.5 (1.6)</td>
<td>18.2 (1.2)</td>
</tr>
<tr>
<td>Lean mass, kg</td>
<td>72.4 (2.4)</td>
<td>72.8 (4.0)</td>
<td>72.0 (2.7)</td>
</tr>
</tbody>
</table>

Data are means (SE)
been well documented, but other pituitary hormones may also respond to the imposed stress, in particular GH. This hormone is important in relation to metabolic supply when energetic demand is increased, as in sports performance. GH secretion is characterised by pulses and by a short half life (½ h), so that a single dosage is of little significance. For that reason, it is better to assay IGF-1 which is a hepatic relay of GH action (agreed that it may originate from other places) having a linear production and a longer half life (6 h), representing an integration of the changes in GH levels. In plasma, IGF-1 is linked to carrier proteins (IGFBP-1 to IGFBP-6). The biologically active fraction is the free fraction; thus, the level of free plasmatic IGF-1 depends not only on GH production, but also on the degree of linking to its carrier proteins, particularly to IGFBP-3 which has been shown to demonstrate some changes in response to exercise.

It was reported that stress related cortisol secretion is associated with low IGF-1 and that total IGF-1 does not present a circadian rhythm. Therefore, we determined resting values from morning samples collected 48 h before the match in order to avoid the precompetitive stress due to cognitive anticipation leading to increased cortisol levels. Similarily, the SFMS questionnaire was self administered 48 h before the match, since it aims to evaluate a general state of tiredness and not reaction to the competition. The score of 20 is only suggestive and not absolutely indicative of overtraining, like many other indexes (comportmental or biological), when taken alone.

Although not significantly different, G1 and G2 were not perfectly matched: G1 was a little bit older and heavier than G2; the difference in body weight was accounted for by a higher percentage of fat mass in G1. Effectively, the two groups had very similar lean body masses. As they also had very similar food intakes, this difference in fat mass may be related to a natural trend linked to age. Whatever the cause, this did not seem to introduce a bias in the general conclusions.
IGFBP-3, a sensitive marker of physical training and overtraining

The main finding of our study is that we observed strong correlations between IGF-1, IGFBP-3, and the overtraining state as estimated by the scores of the SFMS questionnaire completed at the same time, and more particularly, that the more tired subjects presented a fall in IGFBP-3 after the match compared to resting values.

Participation in regular physical exercise generally increases serum concentrations of IGF-1.11–13 Conversely, it has been observed that high intensity training or prolonged endurance activities provoke a long term decrease in IGF-1 levels.9 10 17 18 It has also been established that reduced energy intake, or, more generally, when the energetic cost exceeds energy consumption, a fall in free IGF-1 levels occurs.21 22

We observed similar results since, in all subjects, both at rest and after the match, the total IGF-1 levels were lower (range: 100–310 ng/ml) than adult norms. This may be related to the food intake of these sportsmen which was lower (6%) than recommended.29 Similar observations are frequently reported in sportsmen who probably limit their food intake to avoid overweight.29 More particularly, the mean protein intake (1.27 (SE 0.04) g/kg per day) was lower (6%) than recommended.29 30 31 32 33 The total IGF-1 values recorded immediately after competition were significantly higher than baseline. This increase in free IGF-1 levels may be explained by the very different exercise protocols examined and by variation in individual subject profiles. Results from Nguyen et al29 further illustrate the variability in IGF-1 response after exercise, as they reported a 12% increase, a 15% decrease, and no change in an incremental ergometer cycling exercise, in a long distance Nordic ski race, and in a treadmill simulated soccer game, respectively.

Free IGF-1 may be affected by the decrease in IGFBP-3 level, which is a compensatory mechanism allowing an increase in free IGF-1. It has been proposed that exercise induced IGFBP-3 proteolysis contributes significantly to the anabolic effects of exercise.15 It has been documented that there was no change in IGFBP-3 after short (4–5 min) intense exercise,3 but a decrease in IGFBP-3 was found after longer exercise.15 21

These low levels of IGFBP-3 seem to indicate excess training, suggesting a risk of overtraining. Some studies found a decrease in IGFBP-3 after 1 year of gymnastic training10 14 and negative correlations were found between IGFBP-3 and overtraining states in high level soccer and volleyball players, suggesting that a lowered IGFBP-3 level may reflect a reversal of the neuroendocrine adaptation to training.15 This is in agreement with the results from this study since we also found a strong negative correlation between the overtraining score and the serum levels of IGFBP-3 recorded just after the match. These low levels of IGFBP-3 may exert a protective mechanism against catabolism through an increase in the free IGF-1 fraction. Effectively, it was suggested that a high IGF-1 to IGFBP-3 ratio, as was the case in G2 after the competition, leads to a greater disponibility of IGF-1.43

![Figure 4](link)

**Figure 4** Relationships between the overtraining score and the resting serum total IGF-1 level.

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![Figure 5](link)

**Figure 5** Relationships between the overtraining score and the after competition serum total IGFBP-3 level.

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![Figure 6](link)

**Figure 6** Relationships between the overtraining score and IGFBP-3 level changes from baseline to after competition.
The more salient finding of the present study was that the IGFBP-3 levels increased in six rugby players and decreased in the five others after the match. This led us to classify our subjects into two subgroups. The first group (G1) included the six subjects who presented both elevated serum IGF-1 and elevated IGFBP-3; these subjects exhibited low scores of overtraining (mean 10.5). The second group (G2) included the subjects whose IGFBP-3 levels decreased and who presented high scores (mean 21). Another approach was to consider the subjects whose score was >20 (overtrained subjects according to the SFMS guideline) and to examine the corresponding values of IGF-1, IGFBP-3, and AIGFBP-3 from baseline for after competition values. From this, it follows that AIGFBP-3 is a very reliable index of overtraining. Moreover, considering that the overtrained subgroup is rather small (only three subjects), it is not possible to calculate a reliable sensitivity. In spite of this, we strongly suggest the use of this index in further surveys to confirm our finding.

Thus, the results of our study suggest that low levels of IGFBP-3 are linked to a state of tiredness. Moreover, in a dynamic situation such as a rugby match, IGFBP-3 level decreases in the more fatigued subjects. Therefore, we conclude that a fall of IGFBP-3 in response to an intense bout of exercise may represent an index of tiredness in highly trained sportmen, as indicated by the scores obtained from the overtraining questionnaire.

Acknowledgments

The authors wish to thank Dr. E. Filaire for the technical assistance with the hormone assays. They also would like to thank Drs. M. Donat, G. Hainque, and M. Vacher for their help in the selection of the subjects.

Keywords

- Overtraining
- Rugby players
- Salivary cortisol
- Salivary IGF-I
- IGFBP-3

References

English translation of the SFMS questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>M</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is your profession?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>How many hours do you practise per week?</td>
<td>6–8</td>
<td>8–10</td>
</tr>
<tr>
<td>What is your main sport or game?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If you play other sports or games, write them:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>This month, has there been any significant event which may have disturbed your private or professional life?</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

This month

1–My level of sports performance/my general form has decreased          | Yes | No  |
2–I am not as attentive as before                                       | Yes | No  |
3–My close friends think that my behaviour has changed                | Yes | No  |
4–I have a sensation of pressure in my chest                           | Yes | No  |
5–My heart seems to beat faster                                        | Yes | No  |
6–I have a lump in my throat                                          | Yes | No  |
7–I have less appetite than before                                     | Yes | No  |
8–I eat more                                                           | Yes | No  |
9–I do not sleep as well as before                                     | Yes | No  |
10–I drowse and yawn in the daytime                                    | Yes | No  |
11–The time between training sessions seems to me too short            | Yes | No  |
12–My sexual libido has decreased                                      | Yes | No  |
13–My performances are poor                                            | Yes | No  |
14–I frequently catch a cold                                           | Yes | No  |
15–I put on weight                                                     | Yes | No  |
16–I have memory problems                                             | Yes | No  |
17–I often feel tired                                                  | Yes | No  |
18–I underestimate myself                                              | Yes | No  |
19–I often have cramps, muscular pain                                 | Yes | No  |
20–I suffer from headaches more frequently                             | Yes | No  |
21–I do not feel fit                                                   | Yes | No  |
22–I sometimes feel dizzy, on the point of fainting                    | Yes | No  |
23–I do not confide in others so easily                                | Yes | No  |
24–I often feel seedy                                                  | Yes | No  |
25–I have a sore throat more often                                     | Yes | No  |
26–I feel nervous, insecure, anxious                                   | Yes | No  |
27–I do not bear training so well                                      | Yes | No  |
28–At rest, my heart rate is faster than before                        | Yes | No  |
29–During exercise, my heart rate is faster than before                | Yes | No  |
30–I often feel rotten                                                 | Yes | No  |
31–I get tired more easily                                             | Yes | No  |
32–I often have digestive disorders                                    | Yes | No  |
33–I feel like staying in bed                                           | Yes | No  |
34–I am not so confident in myself                                     | Yes | No  |
35–I get injured more easily                                          | Yes | No  |
36–I have more difficulties in organising my thoughts                 | Yes | No  |
37–I have more difficulties in concentrating in my sports activity    | Yes | No  |
38–My sporting gestures are less precise, less skilful                | Yes | No  |
39–I have lost force and aggressiveness                                | Yes | No  |
40–I feel as if I have no one to talk to                               | Yes | No  |
41–I sleep longer                                                      | Yes | No  |
42–I cough more often                                                  | Yes | No  |
43–I do not enjoy practising my sports as much                         | Yes | No  |
44–I do not enjoy my leisure activities as much                        | Yes | No  |
45–I get irritated more easily                                        | Yes | No  |
46–I am less efficient in my school or professional activity           | Yes | No  |
47–People around me think that I have become less pleasant             | Yes | No  |
48–Training seems harder and harder                                    | Yes | No  |
49–It is my fault if my results are worse                              | Yes | No  |
50–My legs feel heavy                                                 | Yes | No  |
51–I lose my personal things more easily (wallet, keys, etc)           | Yes | No  |
52–I am pessimistic, I have the blues                                 | Yes | No  |
53–I have lost weight                                                  | Yes | No  |
54–My motivation, will and tenacity are weaker                         | Yes | No  |

Put a cross to range between these two opposite states

<table>
<thead>
<tr>
<th>Physical level</th>
<th>Great form</th>
<th>Bad form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feel fatigued</td>
<td>I feel fatigued</td>
<td>More slowly</td>
</tr>
<tr>
<td>I recover from my state of tiredness</td>
<td>More quickly</td>
<td>More slowly</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>I feel</td>
<td>Very relaxed</td>
<td>Very anxious</td>
</tr>
<tr>
<td>I feel that my muscular strength has increased</td>
<td>Increased</td>
<td>Decreased</td>
</tr>
<tr>
<td>I feel that my endurance has increased</td>
<td>Increased</td>
<td>Decreased</td>
</tr>
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Have you had any difficulties in understanding some of the questions?

<table>
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<th>Yes</th>
<th>No</th>
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If Yes, which questions did you find difficult to understand (write the numbers)

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Each “Yes” answer receives one point, giving a score of between 0 and 54. According to the French multicentric study (F Maso, in press) scores > 20 are highly suggestive of overtraining and are constantly found in overtly overtrained individuals.

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**Sports Physician required for LTA Academies**

Doctors with experience in Sport and Exercise Medicine (minimum 5 years) and a passion for tennis are required for one session per week at the LTA academies. Two positions are available (Bath and Loughborough), starting in September 2005.

In addition to providing medical support for the LTA Academy players (aged 13–16 years), the appointed doctor will be required to act as a tournament medical officer (Nottingham, Birmingham, Eastbourne, Bournemouth). This would involve no more than 1 week—twice per annum—for each doctor.

The appointed doctors will be involved in coach education and be required to attend monthly meetings at the LTA National Centre (Queens Club or Roehampton). They will also be expected to ensure continued professional development in the field of “tennis medicine” (e.g. attendance at seminars, workshops, and conferences focusing on injury prevention, racket sports, etc).

Remuneration and expenses would be at rates no less than those currently paid by the British Olympic Association, UKSport, and the EIS.

Each applicant should submit the following documentation: complete Curriculum Vitae, a copy of the current GMC Registration Certificate, a certificate of medical malpractice indemnity, and a Child Protection Enhance Disclosure Certificate.

All correspondence should be sent to:
Dr Michael Turner
Chief Medical Adviser
The Lawn Tennis Association
Queens Club
London W14 9EG
Email: michael.turner@LTA.org.uk