ORIGINAL ARTICLE

Echocardiographic characterisation of left ventricular geometry of professional male tennis players

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Background: The cardiac characteristics of various types of athletes have been defined by echocardiography. Athletes involved in predominately static exercise, such as bodybuilders, have been found to have more concentric hypertrophy, whereas those involved in dynamic exercise, such as long distance runners, have more eccentric hypertrophy. Tennis at the elite level is a sport that is a combination of static and dynamic exercise.

Objective: To characterise left ventricular geometry including left ventricular hypertrophy by echocardiography in male professional tennis players.

Design: Retrospective study of screening echocardiograms that were performed on male professional tennis players.

Setting: All echocardiograms were performed at the Mayo Clinic (Jacksonville, Florida, USA) between 1998–2000.

Participants: A total of 41 male professional tennis players, with a mean age of 23.

Results: Left ventricular hypertrophy was present in 30 of 41 subjects (73%, 95% CI: 57%–86%). The majority of players manifested eccentric hypertrophy ($n=22$, 54%). Concentric hypertrophy ($n=9$, 22%) and normal geometry ($n=7$, 17%) were encountered with similar frequency. Only 7% ($n=3$) manifested concentric remodelling. The mean thickness of both the interventricular septum and the posterior wall was 11.0 mm. The mean LVEDd was 55 mm. The mean RWT was 0.41. The mean LVMI was 130 gm/m² and the mean EF was 64%. Five of the 41 subjects had an abnormal septal thickness of 13 mm.

Conclusion: This was the first study to specifically describe the full range of echocardiographically-determined left ventricular geometry in professional male tennis players. The majority of subjects exhibited abnormal geometry, predominantly eccentric hypertrophy.

Tennis, as a sport, combines dynamic and static exercise, imposing components of unique cardiac demand on athletes participating in this activity. A single point in tennis can consist of a series of repetitive sprints and explosive ball-striking. Short breaks are taken between each point, with longer breaks between cross-overs (when the players change sides of the court). Matches can last 3–4 h, incorporating stamina into the physical demands required for competition. Furthermore, the tennis season is one of the longest professional seasons, lasting about 10.5 months.

In 1975, Morganroth *et al*¹ first proposed that endurance (dynamic) training caused primarily an increase in left ventricular cavity dimensions and strength (static) training caused primarily an increase in left ventricular wall thickness. Many subsequent studies have helped define echocardiogram dimensions in various elite athletic populations.^{2–18} The purpose of this study is to characterise echocardiographically-defined left ventricular geometry in professional male tennis players, including the prevalence of left ventricular hypertrophy.

MATERIALS AND METHODS

We retrospectively evaluated screening echocardiograms of 41 male professional tennis players participating in a medical evaluation for the ATP Tour that was performed at Mayo Clinic (Jacksonville, Florida, USA) between 1998–2000. Prior to their evaluation, the players had all been recently invited to join the ATP Tour and therefore were of an elite calibre. The study was approved by the Mayo Clinic IRB and was supported by a grant from the Mayo Clinic Foundation. All of the echocardiograms were performed on commercially available equipment (Sonos 5500, Philips Medical Systems, Andover, Maryland, USA)

utilising a 2.5 MHz transducer. Two-dimensional echocardiographically-guided M-Mode measurements of left ventricular geometry and systolic function were prospectively acquired according to established guidelines as described by the American Society of Echocardiography and the European Association of Echocardiography.¹⁹ Echocardiograms were recorded on SVHS videotape that was reviewed independently by two experienced echocardiographers (ML and KO) who repeated and verified the measurements. Disagreements regarding the measurements were resolved by consensus. The following echocardiographic parameters were studied: inter-ventricular septal thickness (IVS), left ventricular end diastolic diameter (LVEDd), left ventricular posterior wall thickness (PWT), left ventricular mass index (LVMI), relative wall thickness (RWT, defined as LVEDd/2 × PWT) and ejection fraction (EF). The presence of left ventricular hypertrophy (LVH) was defined as a LVMI >115 gm/m² and normal RWT was defined as ≤0.42.¹⁹ Left ventricular geometry was then defined according to Lang *et al*: Normal (LVMI ≤115 gm/m² + RWT ≤0.42), concentric left ventricular remodelling (LVMI ≤115 gm/m² + RWT >0.42), concentric left ventricular hypertrophy (LVMI >115 gm/m² + RWT >0.42), or eccentric left ventricular hypertrophy (LVMI >115 gm/m² + RWT ≤0.42).

Numerical variable were summarised with the sample mean, SD and range. Categorical variables were summarised with

Abbreviations: EF, ejection fraction; IVS, interventricular septal thickness; LVEDd, left ventricular end diastolic diameter; LVH, left ventricular hypertrophy; LVMI, left ventricular mass index; PWT, posterior wall thickness; RWT, relative wall thickness

number and percent. An exact binomial 95% confidence interval (CI) was used to estimate the proportion of patients with LVH.

RESULTS

Demographic data are summarised in table 1. The mean age of subjects was 23. Mean height and weight were 183 cm and 83 kg respectively. None of the players were taking any medication that might affect cardiac morphology.

Subject demographic data

Echocardiographic data are presented in table 2. The mean thickness of both the interventricular septum and the posterior wall was 11.0 mm. The mean LVEDd was 55 mm. The mean RWT was 0.41. The mean LVMI was 130 gm/m² and the mean EF was 64%.

Left ventricular hypertrophy was present in 30 of 41 subjects (73%, 95% CI: 57%–86%). The majority of players manifested eccentric hypertrophy (n = 22, 54%). Concentric hypertrophy (n = 9, 22%) and normal geometry (n = 7, 17%) were encountered with similar frequency. Only 7% (n = 3) manifested concentric remodelling. Of the 41 subjects, 5 had an abnormal septal thickness of 13 mm; 3 of these had symmetrical posterior wall thickness of 13 mm and the remaining 2 had posterior wall thickness of 12 mm. No player manifested septal or posterior wall thickness greater than 13 mm. None were felt to have pathological heart disease by other echocardiographic or Doppler features. Based on the echocardiogram results no player required any further work-up and none were restricted with respect to athletic participation.

DISCUSSION

Our study suggests a high prevalence of left ventricular hypertrophy in this elite group of male professional tennis players (73%). Most of the subjects manifested eccentric left ventricular hypertrophy (54%). To our knowledge, this is the first study dedicated to reporting the full spectrum of left ventricular geometry, including concentric left ventricular remodelling, in professional male tennis players. Our findings imply that professional tennis should be added to the list of other sports involving a significant degree of dynamic and static exercise (such as rowing or cycling) that are most prone to causing eccentric left ventricular hypertrophy. The results of the present study are consistent with what has been described as the “athletic heart syndrome”.^{2–18} The wide variability in cardiac adaptations to exercise amongst highly-trained athletes, the considerable overlap in cardiac morphologic parameters between highly-trained athletes and the general population and the apparent role of genetics in determining at least part of these adaptations suggest that it is appropriate to include concentric remodelling, a prognostically significant structural change that has been identified in hypertensive patients.²⁰

Cardiac adaptations to exercise vary according to type of exercise.^{3 12 14} Eccentric hypertrophy has generally been

observed in athletes engaged in dynamic activities, such as running. Concentric hypertrophy has been associated with athletes engaged in primarily static activities, such as weightlifting and bodybuilding. Nonetheless athletes engaged in predominately resistive training most commonly manifest normal LV geometry.²¹ Sports that combine significant degrees of endurance and strength-training, such as swimming and cycling, assert greater influence on cardiac structure than other forms of exercise.¹⁴ Combined training elicits symmetrical increases in left ventricular wall thickness and LV internal diameter, often resulting in eccentric left ventricular hypertrophy.

Pluim¹⁵ performed a meta-analysis of echocardiographic studies of the athlete’s heart and characterised athletic endeavours into three categories: endurance (dynamic), strength (static) and combined forms (dynamic and static) of training. Data from our study suggest that cardiac adaptations to professional tennis training most closely match the changes manifest in those engaged in combined dynamic and static training such as swimming and cycling. The mean RWT in our population is closest to the RWT of combined dynamic and static training demonstrated in Pluim’s meta-analysis. The mean PWT of the subjects in our study was identical to that demonstrated by athletes engaged in predominantly static and combined static/dynamic training in this meta-analysis.

The Classification of Sport from the 36th Bethesda Conference Task Force 8²² places tennis as a high dynamic, low static activity, similar to cross-country skiing, field hockey, long-distance running and soccer. This classification scheme is based on the demands of a sport during competition and not the characteristics of training. Our results suggest that professional tennis players’ training elicits cardiac adaptations more consistent with high dynamic/high static activity. Not only are the findings in our subjects similar to those observed in athletes engaged in combined static/dynamic exercise, they are dissimilar to the cardiac adaptations to training noted in athletes engaged in sports currently classified with tennis as high dynamic/low static exercise. For example, cycling is considered a high dynamic/high static sport. Abergel *et al*²³ demonstrated that the majority (51%) of elite cyclists manifested substantial left ventricular enlargement indexed for body surface area, analogous to the eccentric hypertrophy we observed in professional male tennis players. Increased left ventricular wall thickness was present in only 9% of the cyclists, none of whom manifested left ventricular wall thickness greater than 15 mm. These results are very similar to those observed in our subjects who manifested a 12% incidence of increased septal thickness and a maximal wall thickness of 13 mm.

Conversely, our study found a much higher prevalence of abnormal left ventricular geometry than previous studies of athletes engaged in sports classified with tennis as high dynamic/low static exercise. Most notably, we observed a high prevalence of eccentric hypertrophy. Although meta-analysis of studies involving long-distance runners revealed an increased left ventricular internal diameter and an increase in septal and posterior wall thickness relative to population norms, the majority of athletes in these studies manifested echocardiographic characteristics still within the normal range.²⁴ Further, Muir⁹ observed only a 12% incidence of abnormal geometry in his study of 141 male Scottish pro footballers, including a 5% incidence of eccentric and concentric hypertrophy and a 2% incidence of concentric left ventricular remodelling. We believe what would be abnormal geometry in other populations of patients is most likely a physiological response to high level training and competition in the elite tennis player and therefore part of the spectrum of athletic heart syndrome.

Table 1 Subject characteristics

Characteristic	Summary (n = 41)
Age	23 (2.1) (19–26)
Height (cm)	183 (7.2) (165–195)
Weight (kg)	83 (7.4) (71–101)
Systolic blood pressure (mmHg)	120 (12.7) (90–142)
Diastolic blood pressure (mmHg)	73 (7.7) (56–90)
Heart rate (bpm)	65 (8.2) (48–88)

The sample mean (SD) and range are given for numerical measurements.

Table 2 Subject echocardiographic measurements

Echo measure	Summary (n = 41)
Ejection fraction (%)	64 (4.4) (56–71)
Septal thickening	11 (1.0) (9–13)
Posterior wall thickening	11 (0.9) (9–13)
LVED dimension	55 (3.8) (48–65)
LVES dimension	35 (3.5) (26–40)
Left atrial diameter	38 (4.3) (28–45)
Wall/cavity ratio	0.41 (0.04) (0.35–0.50)
Mass index	130 (19.4) (76–181)

The sample mean (SD) and range are given for numerical measurements.

We found only one abstract that was dedicated to describing echocardiographic findings in professional male and female tennis players, but the authors did not classify the types of LV geometry.²⁵ These authors did find that in 50 male professional tennis players studied at Roland Garros, 36% had LVH. Our study found a significantly higher percentage of subjects with LVH. Whyte¹⁸ in 2004 published data on 306 male and 136 female elite British athletes of which 33 male tennis players were included. Their data specifically in these tennis players, was similar to the present study with respect to mean septal thickness (10.5 mm), PWT (10.8 mm) and LVEDd (54.7 mm). Pelliccia *et al* in 1991 reported on cardiac dimensions in 947 elite Italian athletes from 25 different sports.¹⁴ That study included 32 male and 15 female tennis players and the left ventricular wall thickness of 9.1 mm, LVEDd of 50 mm and mass index of 88 gm/m² were lower than the present study. However, the former study included male and female tennis players in that mean data.

Only five of the tennis players in our study had an abnormal septal wall thickness and none were greater than 13 mm. No player demonstrated characteristics of hypertrophic cardiomyopathy or any other echocardiographic evidence of cardiac pathology. This is also true for the single player that had an LVEDd of 65 mm. These changes were felt to be physiologic and related to athletic heart syndrome. The observed mean septal thickness of 11.0 mm was similar to previous studies of athletes.^{15 23 26} Abernethy *et al*²⁶ found a mean septal wall thickness of 11.2+/-0.2 mm in a group of professional American Football players. Abergel *et al*²³ reported an average septal wall thicknesses of 11.1 mm (SD1.3 mm) in professional cyclists competing in the Tour de France. In the largest echocardiographic study Pelliccia *et al*¹⁴ found a mean septal thickness of 10.1 mm in a broad cross-section of Italian National team members.

Screening athletes with echocardiography, to evaluate the presence of cardiac conditions that place the athlete at risk for sudden cardiac death, during pre-participation evaluations is controversial. The Italian experience suggests that in addition to an appropriate history and physical exam a screening ECG can be of benefit.²⁷ Harris *et al*²⁸ assessed the required practices of cardiac screening in males participating in the major professional athletic organisations in North America for baseball, basketball, football and ice hockey. Of 122 teams, 92% utilised screening ECG, while only 13% used echocardiography as a screening tool. The sample size of the present study was too small to draw any conclusions regarding the effectiveness of echocardiography as a screening tool for the elite male tennis player.

This small, descriptive study was not designed to address the important issues of the specific training characteristics that elicit the observed cardiac adaptations, their prognostic significance, or their influence on performance. As there is scant data to define the long-term prognostic significance of even more profound morphologic adaptations to exercise (ie,

What is already known on this topic

- Athletic heart syndrome has been defined in various athletic populations.
- Athletes involved predominantly in static exercise tend to exhibit concentric hypertrophy, whereas those involved in dynamic exercise usually show eccentric hypertrophy.
- Patients with hypertension can develop abnormal left ventricular geometry but athletes have not been characterised in this manner.

What this study adds

- Full spectrum LV geometry is defined, specifically in elite male tennis players.
- Most players exhibited abnormal geometry. We believe that these changes are related to athletic heart syndrome in these athletes.

concentric or eccentric left ventricular hypertrophy), it is not possible to justify inclusion of concentric remodelling solely based on its prognostic significance in athletes. The correlation between structural cardiac adaptations to training and performance has been very inconsistent.^{8 29} Thus, one cannot justify the inclusion or exclusion of concentric ventricular remodelling based on this association either. However, as the precipitants of “physiological” cardiac remodelling and “pathologic” cardiac remodelling share at least some genetic, biochemical and haemodynamic features, to analyse the full spectrum of left ventricular geometry in elite athletes seems appropriate in our descriptive study. Other authors studying non-hypertensive populations have also chosen to include this parameter of left ventricular geometry.^{30 31}

CONCLUSIONS

This was the first study to specifically describe the full range of echocardiographically-determined left ventricular geometry in professional male tennis players. The majority of subjects (83%) exhibited abnormal geometry, predominantly eccentric hypertrophy. This study raises the question as to whether or not tennis as a sport should be reclassified as high or moderate static and high dynamic exercise. The small sample size and the lack of female participants limit confidence in the study's conclusions. In addition, it is not at all clear whether the cardiac adaptations we report are related to playing and practicing tennis or to other facets of the athletes' training regimen. Further studies are needed to confirm these findings and to expand the echocardiographic assessment to include 2D and 3D echocardiographic assessment of left ventricular geometry and function in professional tennis players. Future studies should explore cardiac adaptations in professional female tennis players, the relative impact of playing tennis compared to other aspects of the training regimen and the clinical and performance impact of cardiac adaptations to exercise.

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COMMENTARY

The characterisation of echocardiographic findings in male professional tennis players has been invaluable in classifying tennis as a dynamic and static sport. The majority of the players in this study were found to have primarily eccentric but also concentric left ventricular hypertrophy. Such cardiac adaptations are typical of combined strength and endurance sports, such as swimming and cycling. How factors such as modes of training, sex and skill level relate to development of these cardiac abnormalities, as well as the long-term significance of these changes, is still largely unknown.

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