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# The Importance of Doppler-echocardiography in the Assessment of the Athlete's Heart

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## 1. Introduction

Summarizing observations of several authors characteristics of the athlete's heart can be divided into three groups:

- morphological characteristics, among which the most important modification of athlete's heart is a marked left ventricular (LV) hypertrophy,
- functional characteristics, which could mean better systolic and diastolic function and
- regulatory characteristics, a higher parasympathetic and a lower sympathetic activity at rest, resulting mostly in a lower heart rate, lower cardiac output, circumferential shortening velocity (*Pavlik et al. 2010*).

In the general medical practice LV hypertrophy is considered as a risk factor caused by some diseases as hypertension, obesity, cardiomyopathy, etc. To separate pathological and physiological hypertrophy the most important factors are functional and regulatory characteristics of the heart which can be mostly detected by Doppler-echocardiography.

## 2. The importance of Doppler-echocardiography in the distinguishing between physiologic and pathological left ventricular hypertrophy

### 2.1 Flow velocities

With the help of Doppler echocardiography the flow velocities and the time durations of different intervals can be estimated. The ratio between the early and late peak velocities (E/A) is linearly proportional to the diastolic function, i.e. to the ventricular distensibility. Data of different authors are in accordance that against the LV hypertrophy, E/A quotient does not decrease in athletes. Whether it is higher in athletes, or there is no difference between athletic and non-athletic groups, data are discordant. Based on different data and on our own investigations it seems that in young age, when diastolic function is perfect also in non-athletic subjects, regular physical training does not cause a marked improvement. If there is any, it is manifested in the male endurance athletes. It seems to be more probable; however, that regular physical activity attenuates the age-associated impairment of the diastolic function. A collection of data is shown in the Table 1.

| AUTHORS | STUDY | RESULT |
|---|---|---|
| Shapiro, Smith 1983 | different athletes | = |
| Granger et al. 1985 | different athletes | = |
| Fagard et al. 1987 | cycle racers | = |
| Missault et al. 1993 | cycle racers | = |
| Pearson et al. 1986 | weight lifters | = |
| Pavlik et al. 2001 | children athletes | = |
| Pavlik et al. 1999a | women athletes | = |
| Vinereanu et al. 2001 | power athletes | = |
| D'Andrea et al. 2007 | power athletes | = |
| Perseghin et al. 2007. | different athletes | = |
| Teske et al. 2009. | different athletes | = |
| Matsuda et al. 1983 | different athletes | + |
| Colan et al. 1985 | different athletes | + |
| Douglas et al. 1986 | triathlonists | + |
| Möckel et al. 1992 | triathlonists | + |
| Finkelhor et al. 1986. | endurance athletes | + |
| Pavlik et al. 2001 | different athletes | + |
| Vinereanu et al. 2001 | runners | + |
| Rodrigues et al. 2006 | 6 months training | + |
| D'Andrea et al. 2007 | endurance athletes | + |
| Spurgeon et al.1983 | animal experiments | + |
| Starnes et al. 1983 | animal experiments | + |
| Tate et al. 1990 | animal experiments | + |
| Gwathmey et al. 1990 | animal experiments | + |
| Schulman et al. 1992 | older humans | = |
| Fleg et al. 1995 | older humans | = |
| Sadaniantz et al. 1996 | 1 yr training in older humans | = |
| Baldi et al. 2003. | older humans | = |
| Teske et al. 2009. | older humans | = |
| Takemoto et al. 1992 | older humans | + |
| Douglas, O'Toole 1992 | older humans | + |
| Levy et al. 1993 | 6 months training in older humans | + |
| Pavlik et al. 2001 | older humans | + |
| Galetta et al. 2004 | older humans | + |
| Limongelli et al. 2006 | older soccer players | + |
| Prasad et al. 2007 | older humans | + |

Table 1. Effect of regular physical training on the E/A quotient in different studies.
= : physically trained hearts and non-trained hearts show similar values, + : physically trained hearts demonstrates an increased quotient

In our studies altogether 3076 subjects of different ages have been investigated since 1994 until now. The number of males was 1896 (non-athletic: 243, physically trained: 1653), number of females was 1180 (non-athletic 290, physically trained: 890). Results are shown in the Figure 1.

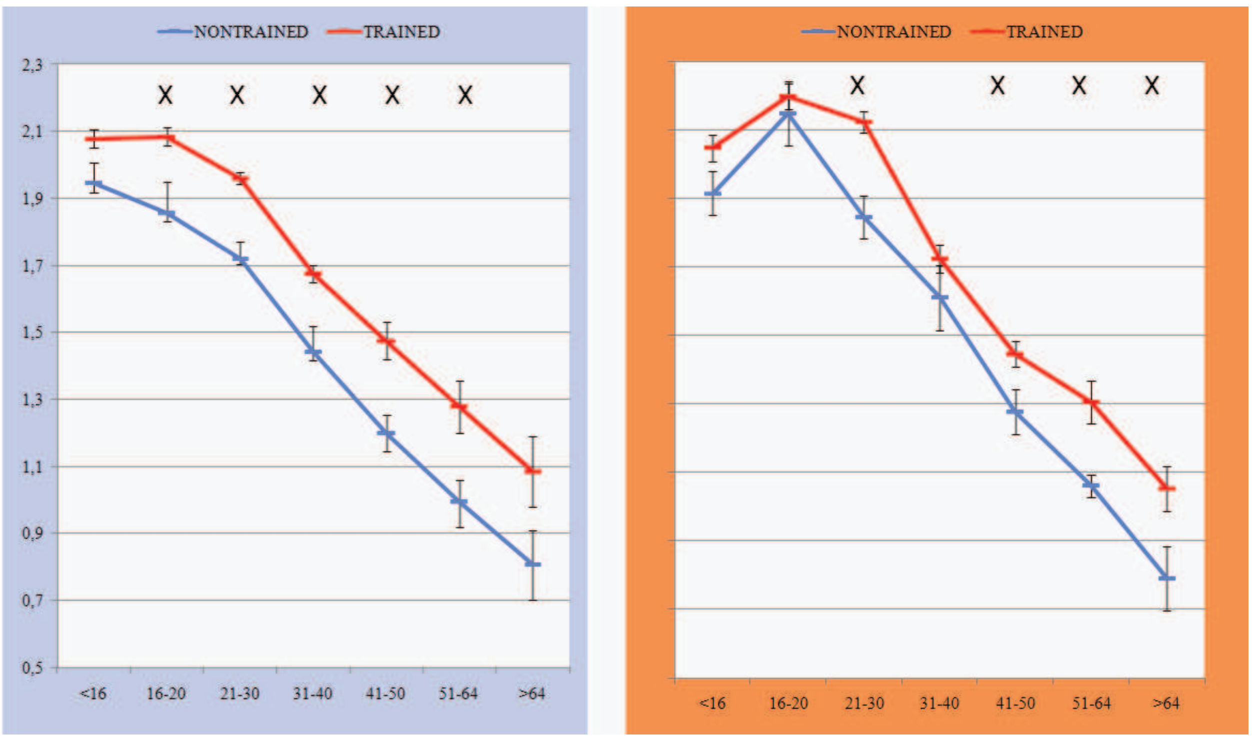


Fig. 1. The E/A quotient in the function of age in athletic (red lines) and non-athletic (blue lines) males (left graph) and females (right graph) (mean ± s.e.m.). x: significant difference ($p < 0.05$)

Results are quite similar to those published in our older studies (*Pavlik et al. 1999a, 1999b, 2001*). In the younger groups LV distensibility is very good also in the non-athletic subjects; regular physical training does not induce a further improvement. In the adult and older groups E/A of the athletic groups is markedly higher than that of non-athletic groups.

In the evaluation of E/A it is disturbing that the quotient is inversely related to the heart rate: the higher is the heart rate, the lower is the E/A. The bradycardia of the athlete's heart is well known, sometimes it is very difficult to establish: the higher E/A of some athletic groups is a consequence of their lower heart rate, or it is an independent effect of the regular physical training. In our recent analysis heart rate dependent equations of the E/A quotient were compared between athletic and non-athletic subjects in different ages. It seems that in young subjects differences can be attributed to the frequency differences, while in older subjects the higher E/A is an independent effect of regular physical activity (*Kneffel et al. 2011*).

### 2.2 Cardiac cycle intervals

Bradycardia of the athlete's heart results significantly longer duration of the cardiac cycle in athletes than in non-athletes, there are, however, very few reports about the training induced modifications of the different phases of the cardiac cycle. Doppler echocardiographic investigations help to reveal differences between the modifications of the different phases and sub phases. In our previous study (*Pavlik et al. 1999b*) in 221 male athletes and non athletes we made two main establishments.

1. There is one period, which is definitely increased in the athletes: it is the E-A period, i.e. the period of diastasis extending from the end of the early filling till the onset of the atrial systole.
2. The lengths of the two main cardiac phases are also different: the proportion of the systole is decreased in the athlete's heart.

Our further investigations confirmed the above mentioned establishments. Our data since 1994 until now are summarized in the Table 2 and 3. In this analysis data of different athletes were collected to common groups, in the tables data of 19-35 yr. old 846 males (62 non-athletes and 784 athletes) and 561 females (84 non-athletes and 477 athletes) are demonstrated.

| Interval | Non-athletes | | Athletes | |
|---|---|---|---|---|
| | Abs. (ms) | Rel. (%) | Abs. (ms) | Rel. (%) |
| ICT | 41.2 ± 13.2 | 4.62 ± 1.58 | **46.4 ± 19.7** | 4.31 ±1.78 |
| AOAT | 91.5 ± 18.6 | 10.37 ± 2.21 | 93.6 ± 16.5 | **8.81 ± 1.75** |
| AODT | 190.6 ± 20.4 | 21.28 ± 2.81 | **205.7 ± 24.6** | **19.1 ± 2.69** |
| SYSTOLE | 323.6 ± 30.0 | 36.28 ± 4.45 | **345.5 ± 36.8** | **32.25 ± 4.22** |
| IVRT | 77.9 ± 20.5 | 8.95 ± 2.55 | **88.4 ± 21.6!** | **8.29 ± 2.11** |
| EACC | 87.6 ± 14.3 | 9.81 ± 1.69 | **95.7 ± 16.3** | **8.94 ± 1.72** |
| EDT | 147.4 ± 42.0 | 16.06 ± 3.81 | 155.5 ± 34.6 | **14.36 ± 3.18** |
| E-A | 108.6 ± 82.3 | 11.30 ± 7.48 | **233.5 ± 136.7** | **20.27 ± 9.50** |
| A | 157.4 ± 36.1 | 17.60 ± 4.00 | **169.6 ± 39.2** | **15.90 ± 4.06** |
| DIASTOLE | 579.0 ± 109.9 | 64.2 | **742.0 ± 154.1** | 68.2 |
| TOTAL | 902 ± 121.4 | | **1087.5 ± 121.4** | |

Table 2. Absolute and relative time durations of the cardiac cycle (mean ± s.d.) in 19-35 yr. old men. ICT: isovolumetric contraction time, AOAT: acceleratory phase of the aortic flow, AODT: deceleratory phase of the aortic flow (=decreased ejection), IVRT: isovolumetric relaxation time, EACC: acceleratory phase of the early transmitral flow (E), EDT: deceleratory phase of the early transmitral flow (E), E-A: a period from the end of the early transmitral flow (E) to the beginning of the atrial systole (A) (diastasis), A: atrial systole. Bold numbers: significant difference from the control values, where $p < 0.05$

| Interval | Non-athletes | | Athletes | |
|---|---|---|---|---|
| | Abs. (ms) | Rel. (%) | Abs. (ms) | Rel. (%) |
| ICT | 38.2 ± 11.9 | 4.46 ± 1.58 | **43.7 ± 16.2** | 4.19 ±1.57 |
| AOAT | 87.6 ± 16.6 | 10.30 ± 2.22 | **92.0 ± 15.9** | **8.92 ± 1.95** |
| AODT | 198.3 ± 21.9 | 23.00 ± 3.20 | **214.6 ± 22.2** | **20.5 ± 2.99** |
| SYSTOLE | 325.9 ± 27.6 | 37.76 ± 4.98 | **350.4 ± 30.8** | **33.61 ± 4.53** |
| IVRT | 77.4 ± 18.5 | 9.18 ± 2.02 | **85.8 ± 19.5** | **8.23 ± 2.01** |
| EACC | 83.7 ± 14.7 | 9.65 ± 1.71 | **91.6 ± 13.0** | **8.82 ± 1.70** |
| EDT | 135.8 ± 30.6 | 15.18 ± 2.98 | **155.0 ± 32.5** | 14.69 ± 3.06 |
| E-A | 81.2 ± 73.8 | 8.58 ± 6.81 | **207.4 ± 138.8** | **18.12 ± 9.85** |
| A | 171.7 ± 42.9 | 19.65 ± 4.09 | 172.9 ± 39.9 | **16.54 ± 4.04** |
| DIASTOLE | 549.6 ± 111.1 | 62.8 | **712.9 ± 161.4** | 67.1 |
| TOTAL | 875.5 ± 117.9 | | **1062.5 ± 176.7** | |

Table 3. Absolute and relative time durations of the cardiac cycle (mean ± s.d.) in 19-35 yr. old women. ICT: isovolumetric contraction time, AOAT: acceleratory phase of the aortic flow, AODT: deceleratory phase of the aortic flow (=decreased ejection), IVRT: isovolumetric relaxation time, EACC: acceleratory phase of the early transmitral flow (E), EDT: deceleratory phase of the early transmitral flow (E), E-A: a period from the end of the early transmitral flow (E) to the beginning of the atrial systole (A) (diastasis), A: atrial systole. Bold numbers: significant difference from the control values, where $p < 0.05$

It is quite obvious that due to training bradycardia, the cardiac cycle of the athletes is longer. The contribution of the different phases can be seen on the tables. There is a basic difference in the elongation of the systole and of the diastole: systole is slightly (6.8 % in males, 7.5 % in females) longer in athletes, while the difference in the diastole is very definite (28.2 % and 29.7 % respectively).

The absolute duration of most of the subphases are a little longer in athletes. This increase can be attributed due to the resting bradycardia, but it is not proportional to the elongation of the whole cardiac cycle, the relative durations are decreased. There is only one period which shows a definite increase in absolute as well as in relative duration: E-A, i.e. the period from the end of the early phase to the beginning of late filling, when flow velocity is minimal or zero. This phase seems to be the most sensitive to the exercise training.

If we investigate the stability or variability of the different periods of the cardiac cycle, the ratio of the standard deviations to the mean absolute values can be calculated. Results are indicated in Table 4.

| | Males | | Females | |
|---|---|---|---|---|
| Period | non-athletes | athletes | non-athletes | athletes |
| ICT | 32.0 | 42.5 | 31.1 | 37.1 |
| AOAT | 20.3 | 17.6 | 18.9 | 17.3 |
| AODT | 10.7 | 11.6 | 11.0 | 10.3 |
| SYSTOLE | 9.3 | 10.7 | 8.5 | 8.8 |
| IVRT | 26.3 | 24.4 | 23.9 | 22.7 |
| EACC | 16.3 | 17.0 | 17.6 | 14.2 |
| EDT | 28.5 | 22.3 | 22.5 | 21.0 |
| E-A | 75.8 | 58.5 | 90.9 | 66.9 |
| A | 22.9 | 23.1 | 25.0 | 23.1 |
| DIASTOLE | 19.0 | 20.8 | 20.2 | 22.6 |
| TOTAL | 13.5 | 11,2 | 13.5 | 16.6 |

Table 4. Ratio of the standard deviation to the mean value of different periods of the cardiac cycle in male and female subjects (s.d./mean)

Systole is more stable than diastole. Among the sub phases of the cardiac cycle in which an active flow is occurring are the most stable: AOAT, AODT, EACC, EDT. It is outstanding that the phase from the end of E to the beginning of A (E-A period) is very variable: its coefficient of variation is much higher than those of other periods.

The stability of systole is quite obvious: the pumping function, the ejection of the blood needs a rapid, abrupt contraction in any case, so it cannot be much longer even in case of the bradycardia of the athletic heart. All that means that training bradycardia arises from the elongation of diastole, which means a more economic cardiac function: longer relaxation time, more time for recovery and, as coronary circulation is free only during diastole, better coronary circulation.

Considering all cardiac phases, the greatest variability was seen in the period occurring between the end of the E and the beginning of the A phase, i.e. during which transmitral flow is practically minimal: the period of diastasis. This period is the most variable among all of the periods; the s.d./mean ratio of the absolute length is above 50 % in both groups. Thus, it seems that this is the period that can be modified to the greatest extent; training bradycardia seems to develop through elongation of this period.

Periods of the cardiac cycle seem to provide further data on the function and regulation of the athletic heart. Some data and some indices may widen the arsenal of the different signs characterising of the athlete’s heart. Our data indicate that the E-A period, namely the diastasis period of the diastolic filling is the most characteristic of the physically trained heart.

## 3. Tissue Doppler echocardiography

During the last two decades the used of the methods has been richer with the Tissue Doppler Imaging (TDI) technique. The main advantage of this method is that it offers direct measurements of local myocardial movements and velocities, it is less dependent on hemodynamic conditions and it makes also possible to establish wall movements at different segments of the heart. These advantages are used mostly in clinical cardiology for detailed investigations of some cardiac diseases or damages. The method has been introduced to the sports medicine as well. Several authors compared cardiac morphology, traditional Doppler and TDI indices of athletes to those of non-athletic healthy subjects and some cardiac patients (*Caso et al. 2000, Vinereanu et al. 2001, Baldi et al. 2003, Galetta et al. 2004, Kasikcioglu et al. 2006, Rodrigues et al. 2006, D'Andrea 2007, Prasad et al. 2007, Caselli et al. 2009*). An extensive review has been published recently (*Krieg et al. 2007*).

The main advantages of the TDI vs. traditional Doppler investigations in the sports medicine can be summarized as follows:

1. TDI results are less dependent on the heart rate than the traditional transmitral Doppler investigation findings (*Caso et al. 2000, Baldi et al. 2003*),
2. it offers a new index: ratio of the blood flow to tissue movement velocity (E/E') is inversely related to the LV filling pressure and hence, it is postulated to be lower in athletes (*Baldi et al. 2003*, *Kasikcioglu et al. 2006*),
3. it is not excluded that an enhanced systolic wall movement velocity (S') might show a better dynamic systolic function of the athletes heart (*Baldi et al. 2003, Rodrigues et al. 2006, D'Andrea 2007*).

During the last years we also made some investigations with TDI, our results are presented in the focus of the above mentioned three points.

1. Correlation coefficients between heart rate and the transmitral E/A and TDI determined E'/A' quotients were established in 19-35 yr old males and females (Table 5 and 6).

| Heart rate / E/A | N | r | p |
|---|---|---|---|
| Transmitral E/A | 144 | **-0.305** | **< 0.001** |
| Mitr. med. E'/A' | 144 | -0.090 | > 0.2 |
| Mitr. lat. E'/A' | 144 | -0.080 | > 0.3 |
| Tric. med. E'/A' | 144 | -0.068 | > 0.4 |
| Tric. lat. E'/A' | 144 | -0.130 | > 0.1 |

Table 5. Correlation coefficients between heart rate and E/A quotients in 19-35 yr old males. E: early phase of the diastolic filling, A: late (atrial) phase of the diastolic filling, E', A': TDI determined velocities

| Heart rate / E/A | N | r | p |
|---|---|---|---|
| Transmitral E/A | 44 | **-0.366** | **< 0.02** |
| Mitr. med. E′/A′ | 44 | **-0.517** | **< 0.001** |
| Mitr. lat. E′/A′ | 44 | -0.181 | > 0.2 |
| Tric. med. E′/A′ | 44 | -0.090 | > 0.5 |
| Tric. lat. E′/A′ | 44 | -0.002 | > 0.9 |

Table 6. Correlation coefficients between heart rate and E/A quotients in 19-35 yr old females
E: early phase of the diastolic filling, A: late (atrial) phase of the diastolic filling, E′, A′: TDI determined velocities

Results indicate that the disturbing effect of the heart rate is really stronger in case of the E/A, both in males and in females significant correlations were found. Relationship is much poorer with E′/A′ values: it was only the mitral medial wall movement which correlated significantly with heart rate in women, the other r values were negative but not significant.

2. E/A, TDI determined E′/A′, E/E′ and S′ values are indicated in the Table 7.

| | Males | | Females | |
|---|---|---|---|---|
| | Non athletes | Athletes | Non athletes | Athletes |
| E/A | **1.63 ± 0.34** | **1.93 ± 0.40** | **1.88 ± 0.55** | **2.08 ± 0.55** |
| Mitr. med. E′/A′ | **1.56 ± 0.49** | **1.88 ± 0.62** | **1.54 ± 0.39** | **2.01 ± 0.60** |
| Mitr. med. E/E′ | 6.99 ± 1.27 | 7.48 ± 1.50 | 7.58 ± 1.12 | 7.77 ± 1.47 |
| Mitr. med. S′ | 0.088 ± 0.013 | 0.088 ± 0.015 | 0.088 ± 0.015 | 0.084 ± 0.013 |
| Mitr. lat. E′/A′ | 2.56 ± 0.59 | 2.69 ± 0.97 | 2.26 ± 0.68 | 2.43 ± 0.93 |
| Mitr. lat. E/E′ | 5.76 ± 1.98 | 5.07 ± 2.07 | 6.30 ± 1.71 | 5.62 ± 1.47 |
| Mitr. lat. S′ | 0.11 ± 0.030 | 0.12 ± 0.033 | 0.10 ± 0.015 | 0.12 ± 0.024 |
| Tric. med. E′/A′ | 1.94 ± 0.21 | 2.01 ± 1.05 | 2.09 ± 1.06 | 2.05 ± 0.62 |
| Tric. med. S′ | 0.094 ± 0.014 | 0.098 ± 0.026 | 0.088 ± 0.012 | 0.091 ± 0.013 |
| Tric. lat. E′/A′ | 1.59 ± 0.86 | 1.65 ± 0.67 | 1.50 ± 0.36 | 1.94 ± 0.66 |
| Tric. lat. S′ | 0.137 ± 0.022 | 0.140 ± 0.029 | 0.127 ± 0.021 | 0.131 ± 0.023 |

Table 7. Transmitral and TDI determined velocities and indices in 19-35 yr old male and females
E: early phase of the diastolic filling, A: late (atrial) phase of the diastolic filling, E′, A′: TDI determined velocities. S′ systolic velocity. Bold numbers: significant difference from the control values where, $p < 0.05$

Significant differences were seen only in the E/A values and in the TDI measurements of the medial part of the mitral valve (med. E′/A′). If we examine other parameters in which differences were suggested by other authors, only some small, non-significant differences were seen. It is possible that by a refined selection restricted to top-level endurance athletes more significant differences could be found.

## 4. Conclusion

Doppler echocardiography is a very important method in distinguishing physiologic hypertrophy from the pathologic one.
In this respect the most important point is the LV diastolic function. Commonly, the increase of the LV wall thickness and the LV muscle mass is associated with a decreased distensibility, an impaired diastolic function. In the athlete's heart despite of the LV hypertrophy an improved diastolic function can be detected either by transmitral or by TDI echocardiography.
Doppler echocardiography is also suitable to establish changes in the duration of the phases of the cardiac cycles. Training bradycardia results in a much more marked elongation of diastole than systole. Among the sub phases the E-A period i.e. the final phase of the diastole changes the most consequently, in the athlete's heart in will be longer.

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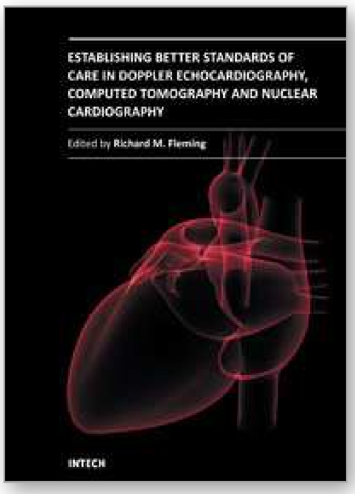


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Since the introduction of Doppler Echocardiography, Nuclear Cardiology and Coronary CT imaging, clinicians and researchers have been searching for ways to improve their use of these important tools in both the diagnosis and treatment of heart disease. To keep up with cutting edge improvements in these fields, experts from around the world have come together in this book to provide the reader with the most up to date information to explain how, why and when these different non-invasive imaging tools should be used. This book will not only serve its reader well today but well into the future.

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