Studies on Cardiac Function in Ski-Runners*

by

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Introduction

The so-called athlete's heart has been discussed from various points of view, since Henschen, a Swedish doctor, described it half a century ago. Summarizing them, we may conclude that:

a) Athlete's heart is not a pathological but a physiological phenomenon;

b) If an athlete got a pathological change in his heart during his athletic life, it may be the mere disclosure of the defects that had originally developed in his heart.

Nevertheless, there remain so many unknown facts about various changes in every portion of athlete's heart. Most of the studies carried out up to now were based on the anatomical or functional experiments at rest or under light stress, but not on the functional researches in extremely stressed conditions as by ECG taken immediately after or during a race.

The author chose the ski-runners in whom the cardiac strain was considered most distinctive (1), and has carried out the following studies by means of roentgenograph and electrocardiograph since 1949 in Hokkaido. The subjects here he wants to discuss about are 66 ski-runners who took part in cross country race, long distance race and relay race at the 4th National Ski Games in National Athletic Meeting in 1949 and in those at Princes' Memorial Ski Tornament in 1951. They were examined with respect to the following points:

a) Anatomical studies at rest by frontal roentgenograms;

b) Functional studies at rest by ECG;

c) Functional studies just after the races by ECG;

d) Anatomical and functional yearly development of the same runners' hearts.

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Part I. Roentgenograms at Rest

1. Method

The measurements of frontal cardiac images were carried out by means of indirect roentgenograph (see the author's paper (2)). Of course, the accurate determination of cardiac image by orthodiagraph or roentgen kymograph may be available for this purpose, but these will take too much time to take the pictures in practice, while the author's method needs only 1.2 seconds and quite sufficient for the measurements. The distance from X-ray source to fluorescent screen was 75 cm, from screen to film 84.5 cm and the focal length of camera lens 50 mm. Exposure time was 1.2 seconds which covered the instant of full relaxation of ventricles and auricles. Naturally the image of heart was enlarged on fluorescent screen as the distance from X-ray source to screen was too short. This deformation was corrected by graphical calculation after the average depth of each index point suggested by Bordet and Vaquez (3) was determined by using Holfelder's anatomical charts of horizontal sections of a man (4). Figure 1 shows a typical example of the relation between the screen image and the corrected image of Bordet-Vaquez's frontal cardiac duplicate triangles. The author used individual multiplication factor for each dimension of DD', GG', D'G, DG', etc. Koepplin (5) used a single factor to estimate the cardiac volume, but since, as shown in figure 1, the screen image is wider than the corrected image, the individual factor must be used in order to determine more accurate dimensions.

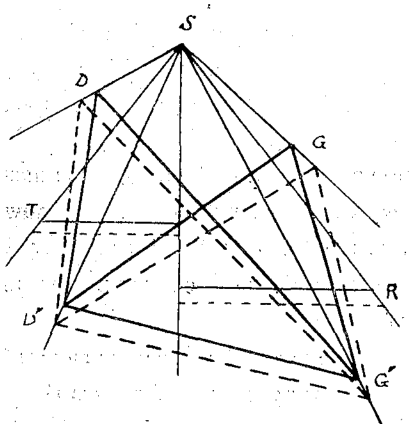


Fig. 1. Correction of Bordet-Vaquez's cardiac triangles. Solid line: corrected figure; Dotted line: screen image; S: X-ray source; Horizontal distance from T to R: transversal diameter.

2. Dimensions of frontal cardiac image of ski-runners at rest

Table 1 shows the comparison of the average cardiac dimensions of all subjects and of "A" class runners, the first one third of those who arrived at the goal, with those of 50 students in Hokkaido University and with the standard dimentions. In this table, the body weight was used as a comparison index. It is based on the fact that the correlation between body weight and cardiac image is most distinctive (H. Ludwig: Helv. Med. Acta, 8, p. 809, 1941: Koepplin (5)). Comparing the cardiac dimensions of runners with those of 50 students which are nearly the same as the standard values found by Holmes and Robbins (6), we see that the average cardiac image of runners is much larger than that of students. For example, the tiansversal diameter is 13–30 mm larger, while, according to White (7), the standard deviation of it in noimal body is 3–3.5 mm. The runners' time of experiences in their special fields of races varied from one winter to seventeen winters, but no distinctive correlation was found between the number of years of experience and the cardiac dimensions. It seemed to mean that the cardiac enlargement had developed in relatively earlier stage of training.

Table 1. Cardiac dimentions of ski-runners compared with those of students and with standard values. "A": First one third of the reunnrs who arrived at the finish.

	Number of subjects	Body weight	Length of longitudinal axis: DG'	Transversal diameter	Length of basal axis: D'G
All subjects in '49	44	58.4kg	15,7cm	13,4cm	11,5cm
"A" class only	14	59,8	15,9	13,6	11,7
All subjects in '51	18	59,9	16,3	14,1	12,5
"A" class only	5	64,2	16,7	14,6	13,1
Students	50	56,3	12,5	10,7	9,7
Standard values by Holmes & Robbins	—	54–59	12,6	10,9	—

Concerning the enlargement of heart by athletic tiaining, opinions of many researchers have not yet coincided with one another, but it is generally recognized at least that the enlargement depends on the kind of sports, extent and duration of training, age, adaptability, original cardiac failures and control of autonomic nervous system. Deutch and Kauf (8) found distinctive cardiac enlagrement in ski runners; White (7), on the other hand, recognized no distint cardiac enlargement in athletes in general, but only slight enlargement in professional ski runners, while Knoll (Med. Welt, 1933, p. 1345-1348) could not find any enlargement exceeding the normal limit among 496 ski racers. Knoll explained his results by assuming less minute blood volume for the same amount of stress in athletes than in non-athletes.

According to the present author's measurement, however, the extent of cardiac enlargement of ski-runners was very large and amounted to as much as about 12 % of the average heart size of students in linear measure, which corresponded to about 40 % volumetric increase (see Table 2). In Table 2 are given the cardiac dimensions of the subjects corrected to correspond to the body weight of 60 kg, which are to be obtained by the correction factors stated later in this section. We see from this table that the mean cardiac dimensions of "A" class best runners were different from those of the average runners: the length of longitudinal axis and the transversal diameter showed the tendency to decrease,

Table 2. Cardiac dimensions of ski-runners corrected to the body weight of 60 kg.

	Body weight	Corrected length of longitudinal axis	Corected trans-versal diameter	Corrected length of basal axis
All subjects in '49	60 kg	16,1 cm	13,7 cm	11,8 cm
"A" class only	60	16,0	13,6	11,7
All subjects in '51	60	16,3	14,1	12,5
"A" class only	60	15,7	13,7	12,7
Students	60	12,9	11,5	10,3

while basal axis was almost the same. The result might be interpreted as follows: cardiac enlargement of ski runners was brought about probably to increase minute blood volume against the stress, but in best runners, owing to the increase of body adaptability, less minute blood volume was required against the same stress, so that they had smaller cardiac dimensions in proportion to their body weights (see Table 1 & 2). The decrease of longitudinal axis might represent the decrease of the force to support their body by technical improvements.

Next problem is concerned with the balance of cardiac development. Mean ratios of longitudinal axis, transversal diameter and basal axis calculated by Table 1 were:

All subjects in 1949 .... 1 : 0.84 : 0.73
"A" class runners in 1949 .... 1 : 0.86 : 0.74
All subjects in 1951 .... 1 : 0.86 : 0.77
"A" class runners in 1951 .... 1 : 0.87 : 0.78
Students .... 1 : 0.86 : 0.78

Excessive development of longitudinal axis could be seen in the subjects in 1949, while almost balanced development in the subjects in 1951.

It is known that the longitudinal cardiac enlargement is caused by the instantaneous rise of blood pressure which brings about the increase of resistance along the path of blood outflow in left ventricle in powerathletes (shot-put etc.), and the widening of heart is caused by the increase of blood inflow in duration-athletes (marathon race etc.) (E. Zdansky: Wien. klin. Wschr., 20, 6, 1947). Taking Zdansky's opinion for granted, it was doubtful whether the ski runners had the characteristic hearts of duration athletes or of power athletes. Since, however, the "A" class best runners had more balanced hearts than the average in both years, and most of the runners told the author that the training was harder in 1951 than in 1949, it seemed very probable that the more the training, the more normal was the balance of development. The reason why they had rather balanced cardiac dimensions might be explained by the fact that the ski runners have to run a long time undergoing the stress of climbing and supporting the weight of the body by sticks. In other words, it might be inferred that ski-

Table 3. Balance of the cardiac shape of ski runners compared with that of students.
%: Length of longitudinal axis of each group was taken as 100 %.

	Number of subjects	Right auricle: DD′	Right ventricle: D′G′	Left ventricle: GG′
All in 1949	44	8,6cm (55)%	13,0cm (83)%	10,1cm (64)%
"A" class	14	8,7 (55)	12,8 (81)	11,3 (71)
All in 1949	18	8,9 (55)	13,4 (82)	11,1 (68)
"A" class	5	9,6 (58)	13,8 (83)	11,6 (69)
Students	50	6,8 (54)	9,2 (74)	7,8 (62)

running has the characteristics of both duration- and power-athletics, which plays a chief role in the balanced cardiac development of ski-runners.

Table 3 gives DD', D'G', GG' of Boldet-Vaquez's duplicate triangles, so that the specific developments of right auricle, right ventricle, and left ventricle may be compared with one another. From the table, we can see the right (D'G') and the left ventricle (GG') of the subjects were fairly larger than those of students in propcrition, while the right auricle (DD') was nearly the same. But it is to be noticed that the accuracy of the measurement of D'G' was comparatively low, because no special method was applied to work out the details of the D'G' bow which was usually shaded into the shadow of the region under the diaphragm.

The enlargement of right ventricle in long distance runners (1), and that of left ventricle in power-athletes (5) are commonly believed to be true. That the ski runners' hearts have the properties of both duration-and power-athletes can therefore be inferred also from this point of veiw.

Figure 2 illustrates the correlation between cardiac dimensions and body weight. In the figure, individual dimensions are plotted, mean increment being shown by the slope of a line for each group. The relation between cardiac diment-ions and body weight are represented by the experimental formulas given in Table 4. The mean increment of longitudinal axis was fairly larger in ski runners than in students, while those of basal axis and transversal diameter were almost alike as compared with those of students. It seemed to be the case that the heavier the body weight, the more was the stress to support the body with sticks in climbing, thus causing the characteristics of power athlete's heart to appear in heavier runners.

Table 4. Experimental formulas for estimation of cardiac dimensions.
W: Weight of body in kg (from 45 kg to 75 kg).

	Longitudinal axis: DG′	Transversal diameter: Tr	Basal axis: D′G
Runners	(0,25W+1,3) cm	(0,21W+1,4) cm	(0,18W+1,3) cm
Students	(0,11W+6,3)	(0,21W−1,1)	(0,16W+0,7)

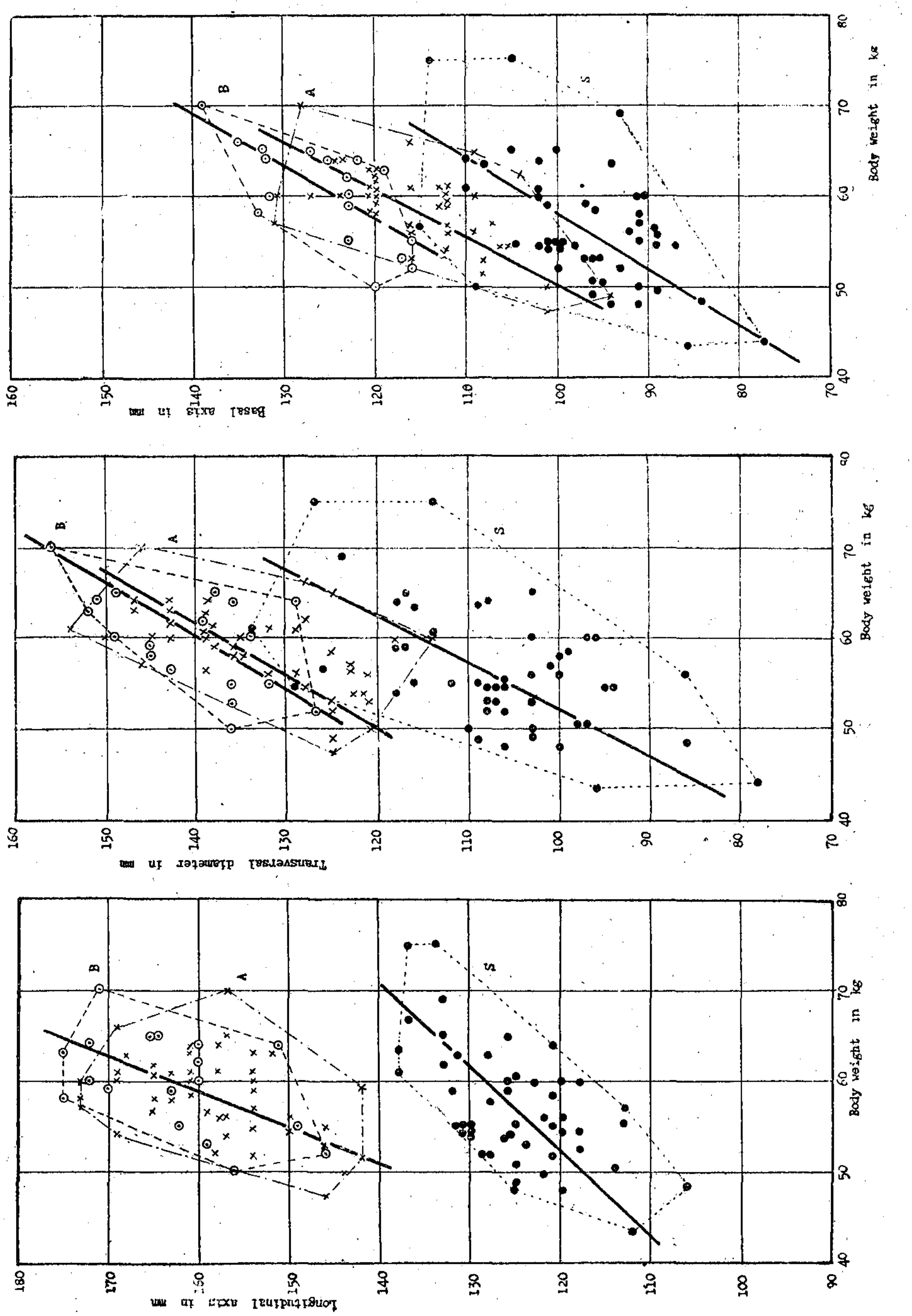


Fig. 2. The correlations between cardiac dimensions and body weight in ski runners and students.
A : Runners in 1949, B : Runners in 1951, S : Students.

3. Change of cardiac dimensions during two years in the same runners

Six subjects were examined to study the influence of training upon the development of cardiac dimensions during two years from 1949 to 1951. Table 5 shows the results. On the whole, there was no remarkable change during two years, except a pronounced change in the case of F. H. who was the best runner of all in 1951. His cardiac dimensions decreased after two year's training, while his body weight remained the same. What this fact means is very interesting: on the one hand, it seems to be explained as the compensative phenomenon caused by the decrease of minute blood volume against the same amount of stress just as Knoll's result ; on the other hand, it might as well be considered to have come from the decrease of training amount owing to the reversibility of hypertrophy or dilatation of athletic heart. Anyhow, it is worth noticing that the subject showed the best record, notwithstanding that his heart had shrinked or at least it had not enlarged during two years. Other 5 subjects showed slight cardiac enlargement. The mean increment of each linear dimension was compared with the value calculated from the mean increment of body weight by means of Table 4. The observed increments are almost coincident with the calculated values as shown in Table 6. This would be a proof for the results stated in section 2 of this part.

Table 5. Changes in runner's frontal heart image during two years from 1949 to 1951.

Person	Age	Body weight	Lohgitudinal axis	Transversal diameter	Basal axis
F. H.	27 29	64,0 # kg 64,0 (0)	15,7 cm 15,1 (−0,6)	14,3 cm 12,9 (−1,4)	12,4 cm 12,0 (−0,4)
S. M.	22 24	54,5 55,0 (0,5)	14,6 14,8 (0,2)	12,5 13,1 (0,6)	10,7 11,4 (0,7)
R. M.	25 27	57,0 58,0 (1,0)	16,9 17,4 (0,5)	15,0 14,5 (−0,5)	12,9 13,0 (0,1)
K. I.	24 26	58,0 64,0 (6,0)	16,5 17,2 (0,7)	14,3 15,1 (0,8)	11,8 12,6 (0,8)
K. Y.	24 26	61,0 62,0 (1,0)	15,7 16,0 (0,3)	13,6 13,9 (0,3)	11,6 12,0 (0,4)
K.Y.A.	24 26	61,0 65,0 (4,0)	15,3 16,5 (1,2)	13,0 13,8 (0,8)	11,6 12,0 (0,4)

#: Increment during two yesar.

Table 6. Mean increments of runners' heart images with respect to the increments of body weight during two years, compared with the calculated values.

	Observed increment	Calculated increment
Mean increment of body weight	2,5 kg	—
Mean increment of longitudinal axis	0,6 cm	0,62 cm
Mean increment of transversal diameter	0,6 cm	0,53 cm
Mean increment of basal axis	0,5 cm	0,45 cm

Part II. Electrocardiograms of Ski-Runners

1. Method and condition of experiment

The electrocardiograms of 39 healthy runners in 1949 and of 18 in 1951 were taken before and just after the races, and examined from various points of view.

Two portable electrocardiographs were used and all of the measuring devices including technicians and subjects were insulated from the ground by porcelain insulators, keeping all of them on equipotential level, so as to avoid the induction from commercial lines, because almost all experiments were carried out in the open field.

At first, the electrocardiograms (ECG) of all runners were taken one or two days before the races at Sapporo Health Center by the use of ordinary extremity leads. The experiments immediately after the completion of the races were carried out with the same method in the field within one or two minutes.

The weather conditions of those days on which the experiments were performed were:

March 4, 1949-Cross country race.....	Dry bulb temperature : 2.1°C, Wind : NNW 0.7 m/s, Fine.
March 5, 1949-Long distance race....	Dry bulb temperature : —0.9°C, Wind : N 2.8 m/s, Fine.
March 6, 1949-Relay race	Dry bulb temperature : −1.0°C, Wind : WNW 4.0 m/s, Fine.
January 26, 1951-Cross country race ..	Dry bulb temperature : −5.1°C, Wind : NE 1.7 m/s, Fine.
January 27, 1951-Long distance race ..	Dry bulb temperature : −1.2°C, Wind : NNE 2.2 m/s, Fine.

The distance and the time required for each of these races were:

Cross country race in 1949	39 km, 3-4 hours,
Long distance race in 1949	17 km, 1.5-2.5 hours,
Relay race in 1949	8 km, 0.5 hours,
Cross country race in 1951	40 km, 3-4 hours,
Long distance race in 1951	18 km, 1.5-2 hours.

2. Generation of cardiac impulses

As is recognized generally, the cardiac impulses generated at sinoauricular node and transmitted correctly to auricles will be indicated by the rising instant of P wave (auricular wave) of ECG, and if there is no abnormality of auriculo-ventricular conduction, their rate will coincide with ordinary pulse rate of ventricles. The period of generation of impluses was defined by mesauring successive 10 intervals of P waves and taking the mean value of them (P-P).

Table 7 shows the results when the athletes were at rest. The mean periods for runners at rest were apparently long as compared with ordinary values. The longest one was 1.6 sec. which was equivalent to 37.5 beats per minute. And also it was noticed that the faster the runner or the longer the experience, the longer

Table 7. Periods of cardiac impulses at basal condition (at rest), for all subjects, "A" class runners and those who had more than five years' experience in 1949 and 1951.

	No. of subjects	Mean age	Period of excitation:P-P
All runners in '49	39	24,3	1,12sec.
〃 〃 〃 '51	18	26,2	1,14sec.
"A" class in '49	14	25,5	1,19sec.
〃 〃 〃 51	6	27,2	1,25sec.
Experienced '49	15	27,8	1,20sec.
more than 5 years '51	8	27,6	1,15sec.

was the period, which was based on the fact that the mean periods of "A" groups and those of the runners who had the experience of more than five years were longer than those of the average. It is to be remarked that half of the "A" class runners had the experience of less than five years. These results show that the athletic bradycardia may be caused not only by the vagal effect, but also by the conditions by which the records are raised, such as the intensity and character of training, and also by the difference of cardiac compensation.

There have been so many reports about the pulse rate of athletes ; most experimenters have recognized the delay of pulsation, but some authors (Koepplin (5) and others) concluded that the athletes' bradycardia is not remarkable. Uhlenbruck (1), on the other hand, maintained the opinion that the bradycardia is to be recognized only in the case of the so-called vagus heart. The present author found the distinct enlargement of hearts as well as the extension of pulse period. It has been recognized that these two phenomena coexist with each other as was proved by Koepplin (5). The reason why such is the case with ski-runners is not quite obvious, but it is probably due to the increase of blood output per stroke and the training vagotony, as were explained by some authors. In short, it seems to be a compensation phenomena at rest against the stress of races. Herxheimer (9) supposed that the delay of pulsation might be recovered after the abandonment of athleitc exercise, but the author knows some cases in which the delay was still found three years after the abandonment. Further experiments are therefore needed for determining the cause of athletic bradycardia.

Next problem is the shortening of cyclic period immediately after each kind of races. In Table 8, the mean periods of all runners are contrasted with those of "A" class runners and veterans. On the wholse, the periods just after each race were approximately half as much as the values at rest or before the races. The reason why the periods after the races in this case are limited to about 0.55~0.64 sec. or 109~95/min. of pulse rate, while in hot and wet circumstances the pulse rate after some exercises will sometimes be raised up to 200/min. might be inferred from several points of view. One of the major causes seems to be the influence of atmospheric conditions in winter time, such as low temperature and low humidity upon the evaporation of perspiration and the radiation and conduction of heat from body surface to lower the body temperature. It is here worth noticing that the ratio of the periods after and before the cross country races in 1949 and 1951 was, on an average, about 0.53, that of long distance races 0.51 and that of relay races 0.5 ; in other words, the shortening of the period was the least at the cross country race which was the hardest race of the three, and that at the relay race which was the lightest was the greatest. It shows that the building-up of pulse rate takes place in an early stage of a race and the longer the time required, the lower is the pulse rate. This is a well-known fact and sometimes is explained as the compensation phenomenon of cardiac activity (Ueno (10)). If such is the case, skillful veteran runners must have lower pulse rate to keep better compensation against the stress. But from the author's data, it is observed that the best

Table 8. Periods of cardiac cycles (P-P) of ski-runners before and after the races, comparing "A" class runners with the others and experienced runners (with more than five years' experience) with the others in 1949 and 1951.

	Cross country race				*Long distance race*			*Relay race*		
	Date	Persons	Mean age	P-P	Persons	Mean age	P-P	Persons	Mean age	P-P
				sec.			sec.			sec.
All runners: at rest after the race	49	18	25,3	1,13 0.59	17	24,4	1.16 0,59	13	24,8	1,14 0,57
	'51	12	26,1	1,15 0,62	9	27,7	1,17 0,59	—	—	—
"A" class:	49	10	26,3	1,19 0,60	5	24,4	1,23 0,56	4	26,3	1,27 0,56
	'51	5	27,2	1,25 0,61	4	27,5	1,31 0,55	—	—	—
The others:	49	8	24,0	1,06 0,57	12	24,3	1,12 0,60	9	24,2	1,08 0,56
	'51	7	25,3	1,09 0,63	5	28,1	1,07 0,57	—	—	—
Runners who have experience more than 5 years:	'49	8	27,6	1,20 0,59	8	27,3	1,23 0,57	5	27,2	1,25 0,59
	'51	6	28,0	1,14 0,63	7	27,2	1,16 0,55	—	—	—
The others:	'49	10	23,4	1,08 0,59	9	21,5	1,08 0,61	8	23.4	1,06 0,56
	'51	6	24,2	1,17 0,61	2	28,5	1,16 0,64	—	—	—

and veteran runners usually have larger increment of pulse rate in comparison with the basal value at rest. Therefore, it should be explained from the point of view of strain. Nishikaze and others (11) measured the strain in the same runners and found that the fatigue after a cross country race was maximum and that after the relay race was minimum, in addition, that the better the runners, the lower was the strain. The result seems to give one of the reasons why the best and veteran runners show higher pulse rate immediately after the races.

3. Auriculo-ventricular conduction

The auriculo-ventricular (A-V) conduction of impules in ski-runners involves many important problems.

The mean value of A-V conduction time after the races was 0.16 sec., while that before the races was 0.18 sec. It seemed to be a natural shortening, since the pulse rate after the races was almost twice as much as the rate at rest. No differences were found among the groups of runners, such as "A" class runners, veterans and so on. Most important was not the average A-V conduction time but the abnormal conductions in some ski-runners.

Table 9 shows the numbers of runners who had A-V conduction failures. The author found that about 17 % of all runners had abnormal A-V conduction. This seemed to be comparatively high rate. The frequency of occurence did not show any tendency to concentrate in some special group of runners but uniformly distributed. Therefore, A-V conduction failure does not necessarily occur depending on the amount and intensity of training. Such a high persentage of conduction failures can not, however, be regareded simply as a phenomenon by chance. It is natural to consider that such a cardiac conduction failure is induced by the disclosure of pre-settled cause brought about through long and intense training. The reason why there are so many cases of conduction failures in athletes is not clear, but it seems to be suggested by the experimental study by Osborne and others who proved the instability of A-V conduction system induced by simple and slight pressure on the system (12). In the author's case, most of runners who showed A-V conduction abnormality could not establish good records. If such a failure is to be made worse by stress, for example, if the delay of conduction time at rest has the possibility to be multiplied by stress and finally to fall into the condition

Table 9. Number of runners who showed abnormal atrioventricular conduction.

Date	No. of subjects	*Prolonged conduction*		*Dissociation*				Total no.	%
		Compensated	Decompensated	Complete Comp.	Complete Dec.	Incomplete Comp.	Incomplete Dec.		
1949	48	4	1	1	1	0	1	8	17%
1951	18	2	0	0	0	1	0	3	17%

of block, that will lead to serious results for runners, but if such a failure recovers compensatively by stress, that will not be a definite defect for them. The abnormal cases will be discussed later.

4. Function of ventricles

All subjects examined were free from myocardial failures. The mean value of propagation time of excitation (QRS) in ventricles at rest were 0.084 sec. and that of immediately after the races was 0.080 sec. ; namely, the time required just after the stress was 4.5% shorter than the time at rest, while the pulse rate was nearly doubled. The mean value of propagation time required at rest seems to be more or less longer than the ordinary value which may be explained by the considerable cardiac enlargement of runners. If the cardiac enlargement is pathologic, the propagation time may be longer than this, as has been recognized in the enlarged left ventricle of a patient suffering from valvular defect. The enlarged heart with a propagation time 0.084 sec. may be physiological and the shortening of propagation time after the races seems quite natural, considering the intensity of stress and the pulse rate after the stress.

Table 10 shows the changes of maximum vectors of QRS loop of vectorcardiogram and Schlomka's form indices before and immediately after the stress. The mean maximum vector at rest was 1.53 mV. which was fairly larger than the ordinary value. The magnitude of instantaneous vector of ECG

Table 10. Maximum vectors of QRS loops of ski-runners and wax and wane of Schlomka's form indices of them before and immediately after the races.

	No. of subjects	*Maximum vector*		*Schlomka's form index*	
		Before	After	Before	After
At rest	39	1,53 mv	—	0,70	—
Cross country race	17	1,42	1,92	0,69	0,70
Long distance race	17	1,72	1,99	0,79	0,78
Relay race	11	1,50	2,12	0,67	0,72

depends primarily on the electrical activity of muscle, the simulataneity of stimulation and the direction of emf. On the one hand, therefore, the enlarged mass and dimension would increase emf, and on the other hand, the balanced development of heart would not disturb the simultaneity, thus increasing the maximum vector. The increments of maximum vector immediately after the races were the largest at relay race which was the lightest in stress among the three races, and the smallest at cross country race which was the hardest in stress. As was described in Section 2, the pulse rate after the relay race was the highest.

Considering these two facts, cardiac activity seems greater at the shorter distance race than at the longer one, while the neurological effects on pulse rate or on blood pressure may be almost alike after the lapse of relatively short time since each start. It seems very natural to consider this phenomenon as a kind of strain too.

The variation of Schlomka's index before and just after the stress was observed and the results are shown in Table 10. The form indices before the stress were not largely different from those after the stress, only the latter were slightly larger, especially in the case of the relay race. The positive deviation of Schlomka's index is the result of voltage increase in lead I of ECG and the decreases in lead II and III. Therefore, the comparative superiority of left ventricle was slightly more remarkable after the relay race than after longer and harder races. In addition, it seems, from the functional point of view, that the effort against the ski-races has in part the characteristics of power-sports.

Table 11. Maximum vectors of QRS loops of "A" class runners and wax and wane of Schlomka's indices before and immediately after the races.

	No. of subjects ("A")	*Maximum vector*		*Schlomka's form index*	
		Before	After	Before	After
At rest	13	1,54 mV	—	0,70	—
Cross country race	9	1,64	1,86	0,69	0,72
Long distance race	5	1,52	1,81	0,77	0,87
Relay race	4	1,58	2,18	0,72	0,82

The maximum vectors and form indices of ventricles of "A" class runners are shown in Table 11. The mean value of maximum vectors at rest, that of form indices at rest and the increments of maximum vectors just after the stress, all showed little difference from those of average runners, but the increments of form indices caused by the stress, hence the relative increase of load in the left ventricle, were distinctly larger than the average. In short, the myocardial function of the best runners seems to be characterized only by the slight functional predominance of left ventricle in the presence of stress. This is in accordance with the comparative development of the length of GG′ in the frontal cardiac image of "A" class runners (see Table 3).

The S-T interval of ECG did not show any unfavourable change such as rise or fall by the stress of running in all runners, except one who showed bundle branch block.

Table 12 concerns the absolute changes of T wave induced by the stress. The subjects whose T waves increased or decreased in amplitude were nealy equal in number, and, in addition, the author could not find any difference between "A" class and the average. It is to be noticed that, since the maximum vectors of QRS waves were raised largely by the stress (see above), the T waves, whose absolute amplitudes remained the same or slightly increased, showed the relative decrease in amplitude.

Table 12. Number of cases of various changes in voltage and form of "T" waves of ski-runners immediately after the races.

	Increaase	Decrease	Same volt.	Deformed
Just after cross country race (17cases)	7	7	0	3
Just after long distance race (17cases)	8	7	1	1
Just after relay race (11cases)	5	5	0	1

The T wave of ECG which is called the final wave or the relaxation wave has a great significance in the myocardial disorder and has been discussed by many authors. The present author (13) is inclined to consider that the T wave in normal persons is produced primarily by the passive physical relaxation of ventricle muscle starting from apex, and the electromotive force is induced directly by biochemical reactions in ventricle muscle accompanying the physical relaxation. Thus, the deformation of the T wave seems to be caused by a partial overload of muscle, which induces the delay of biochemical change against physical relaxation, or by the superposition of the delayed excitation wave with the high or low S-T interval and the relaxation wave. Thus the increase or decrease of voltage seems to depend on the direction and simultaneity of relaxation and the intensity of accompanying biochemical reactions. Taking the above hypothesis for granted, it must be considered that there is little correlation between the maximum vector of QRS and the T wave when the QRS interval is normal; while an intimate correlation exists only between the partial overload or defect of ventricle muscle and the T wave. The "relative" decrease of T wave in the present case has, therefore, no important meaning, whereas the absolute values of T waves must be taken into consideration in connection with the muscular problems of ventricles. From these points of view, the deformation and the marked decrease of T wave must have serious meaning.

The author found five cases of deformation, as shown in Table 12. Three of them were after the cross country race which produced the greatest stress, while only one case in each of other races. It seems very probable that the accumulation of strain brought about the unbalanced propagation of relaxation. In all cases of deformation, the characteristic features of the change were the decrease of T1 (voltage of T in lead I) and the increase of T3, which meant that the inclination of T loop became steeper ; in other words, the left ventricle reamined negative longer than the right one, or more strain existed in left ventricle. This result accords with the overwork of left ventricle during its contraction, as mentioned already. Since, however, the amount of change was very little, it could not be of pathological origin. An example is given in the following :

Subject : No. 1,

At rest .... T1 : 0.33 mV, T2 : 0,30 mV, T3 : 0,02 mV,

Immediately after cross country race ..... T1 : 0;17 mV, T2 : 0,31 mV, T3 : 0,13 mV.

It was remarkable that no deformation case was found among "A" class runners and all five cases appeared among lower class runners. It seemed, therefore, that such a deformation of T wave is a representative mark of cardiac strain and it is a very unfavourable sign for ski-runners. The decrease of T wave was only very slight in all of the 19 cases given in Table 12.

The time required for total ventricular complex (Q-T), from the beginning of Q to the end of T, was also measured and compared with the value calculated by means of Hegglin and Holzmann's formula (Zschr. klin. Med., 132, 1, 1937). The mean Q-T interval at rest was 0.42 sec. (normal calculated value : 0.42 ± 0.04 sec.), while the mean value just after cross country race was 0.33 sec. (normal value : 0.30 ± 0.04 sec.), that after long distance race was 0.35 sec. (normal value : 0.30 ± 0.04 sec.) ; that was the Q-T interval at rest was normal, but that after relay race was slightly beyond the upper limit of normal range and those after two other races showed the tendency to become longer. The prolognation of the duration is usually observed in pH disturbance, in hypocalcemia, during hypoglycemia shock, in myocardial diseases and so on. In the present case, however, the prolongation was the more remarkable at the race of lighter stress, which seems to indicate that in a race of longer distance, the Q-T duration went on recovering with distance as well as increasing stress. Although, it can not be decided from the present data, whether such a transient prolognation is due to biochemical disturbance or not, it might presumably be correlated to some transient nervous control and myocardial response.

5. Function of auricles

The voltage of auricular wave (P) increased after the stress, especially in lead II and III in the present case. Winternitz (Med. klin., 31, 1575, 1935) shed light on the relation between the superiority of left or right auricle and the P wave : P1 and P2 increase when the action of left auricle is superior, while P2 and P3 increase when that of right auricle is more active. The former case is denoted by "Left Type", the latter by "Right Type" and the normal one by "Medium Type". The variation of these types before and immediately after the races is shown in

Table 13 Number of cases of electrocardiographic changes of auricles in ski-runners before and just after the reaces by Winternitaz's classification.

	Left type		*Right type*		*Medium type*	
	Before	After	Before	After	Before	After
Cross country race	1	1	5	14	11	2
Long distance race	1	1	3	14	12	1
Relay race	0	0	3	8	5	0

Table 13. Before the races, the munber of medium type was the largest and that of left type was the least, while, after the races, the number of right type was the largest, the net increase having been transformed from the medium type. Thus the functional superiority of right auricle was definitely recognized immediately after the stress in ski-runners, though the relative enlargement of right auricle was not found by measurement of DD' (Section 2, Part I).

6. Variation in runners' electrocardiograms during two years

As was explained in Section 3, Part I, the author also observed the variation of ECGs of six runners during two years. Their X-ray images and ECGs at rest were taken in 1949 and 1951.

Table 14 shows the comparison of important characteristics of ECGs.

The cyclic period (P-P) in each runner did not vary so much during two

Table 14. Changes in runners' electrocardiograms during two years from 1949 to 1951.

Person	Date	Period of impulse P-P	A-V conduction: P-Q	Propagation in ventricles: QRS	Ventricle complex: Q-T	Form index
		sec.				
F. H.	'49	1,26	0,16	0,10	0,40	0,46
	'51	1,27	0,16	0,09	0,42	0,93
S. M.	'49	1,30	0,17	0,07	0,43	1,05
	'51	1,23	0,19	0,06	0,43	0,91
R. M.	49	1,45♯	0,16	0,08	0,50	0,88
	51	(1.62)	WBP	0,08	0,50	0,84
K. I.	49	1,00	0,15	0,09	0,43	0,62
	'51	0,92	0,16	0,07	0,40	0,70
K. Y.	'49	1,05	0,17	0,08	0,40	0,59
	51	1.23	0,17	0,08	0.40	0,93
K.Ya.	'49	1,02	0,20	0,07	0,40	1,03
	'51	1,02	0,18	0,07	0,36	1,00
Mean	'49	1,18	0,17	0,08	0,43	0,77
	'51	1,13	0,17	0,08	0,42	0,89

♯: Waves of auricle and ventricle are incompletely isolated because of A-V incomplete block.

WBP: Wenckebach's period.

years, except the subject R. M. who had become to show Wenckebach's period. The propagation time of excitation in ventricles (QRS) and the interval of ventricle complex (Q-T) were almost the same, whereas the form index deviated slightly to the positive side. This deviation, however, be on account of the incrseae of body weight (see Table 5). Generally speaking, the runners maintained functionally very stable cardiac conditions throughout these two years.

7. Cardiac disorders in ski-runners

The author found A-V conduction failures in 17 % of all subjects and one case of bundle branch block among 66 subjects. In this section, typical cases of them will be discussed.

Case 1. Subject No. 21, the best runner in 1949, age : 29.

Condition at rest :

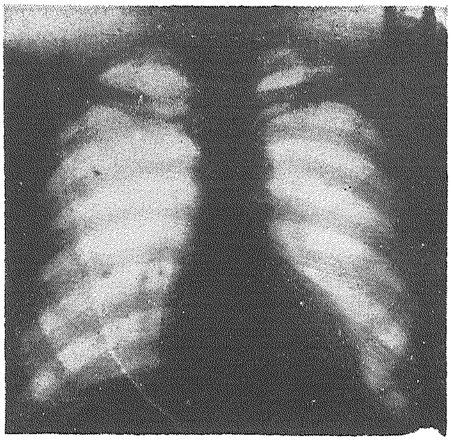
Bradycardia (P-P : 1.4 sec. or 43/min.), A-V conduction delay (0.23 sec.), extremely high maximum vector of ventricle excitation emf (2.35 mV).

Condition after the races :

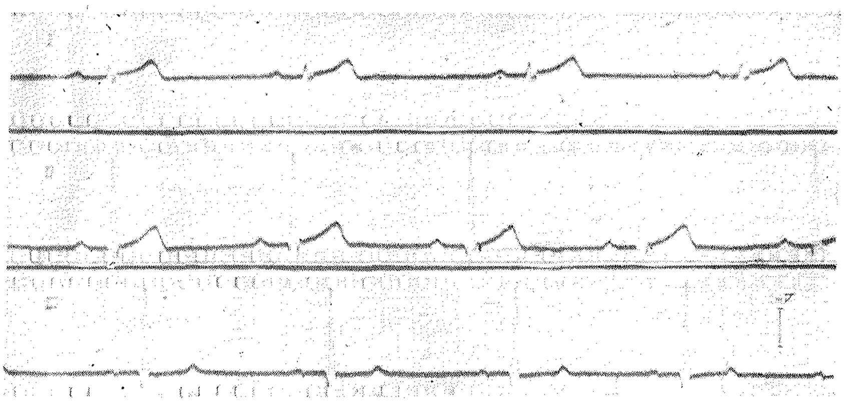
Decompensated delay of atrio-ventricular conduction, incomplete A-V block, complete A-V block.

Figure 3 shows the ECGs before and immediately after the races in this case. This subject had a simple A-V conduction delay at rest, but the delay was decompensatively lengthened by stress and finally fell into blocking condition. He showed complete A-V block after the cross country and the long distance races, and incomplete block after the relay race. When the subject fell into the condition of complete block, the rhythm of auricles and that of ventricles were almost alike and did not seem to cause serious disturbance on his circulatory system. But, under the condition of incomplete block, contraction period of ventricles might be modulated by the period of stimulation from A-V conduction system, and as the result, his heart might show arrhythmia and the minute circulating blood volume would become irregular. It is no doubt an unfavourable defect that might be disclosed under a long and intense stress. The author noticed that there must be some hardships he would undergo in a long distance or cross country race. After one year from the date on which this experiment was carried out, he ran cross country race at National Ski Tornament in 1950, and could not but gave up the race halfway. It is true, such a A-V block cannot be one and only one cause of the failure, but it seems to be one of the important factors at least. His ECG taken eight minutes after the races did not show the block but perfectly reassumed its ordinary condition.

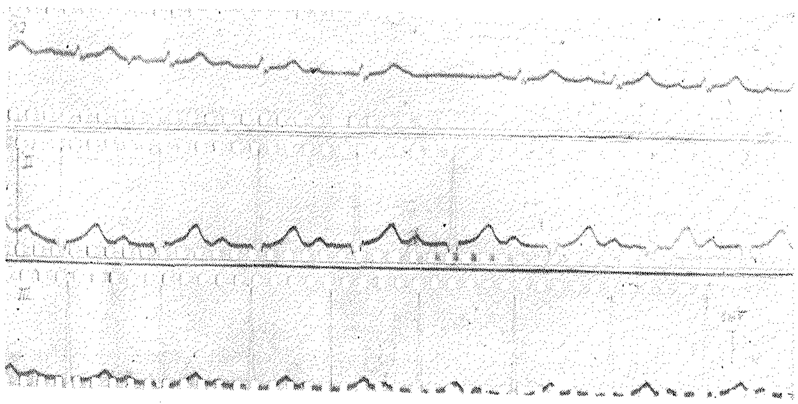
Case 2. Subject No. 5, Age : 33 (Figure 4).



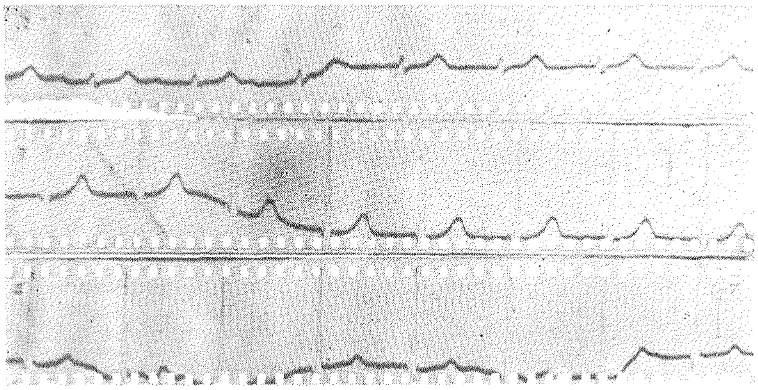
Heart image.



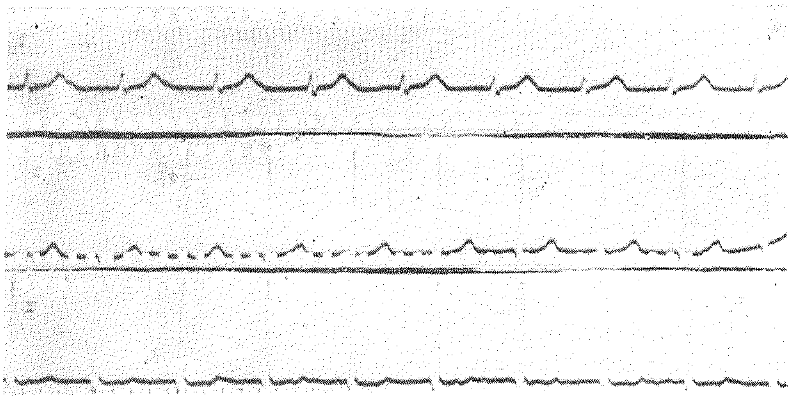
ECG at rest.



ECG just after cross country race.



ECG just after long distance race.



ECG just after relay race.

Fig. 3. Electrocardiorams of the subject No. 21 before and just after the races.

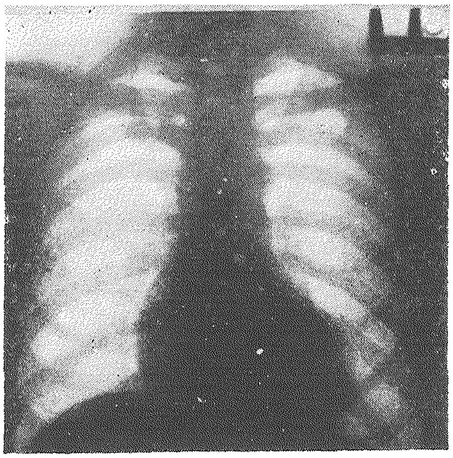
Condition at rest :

A-V incomplete block, period of auricular excitation : 0.78 sec., period of ventricular automatism : 1.5 sec., excessive maximum vector of ventricular excitation wave (2.6 mV).

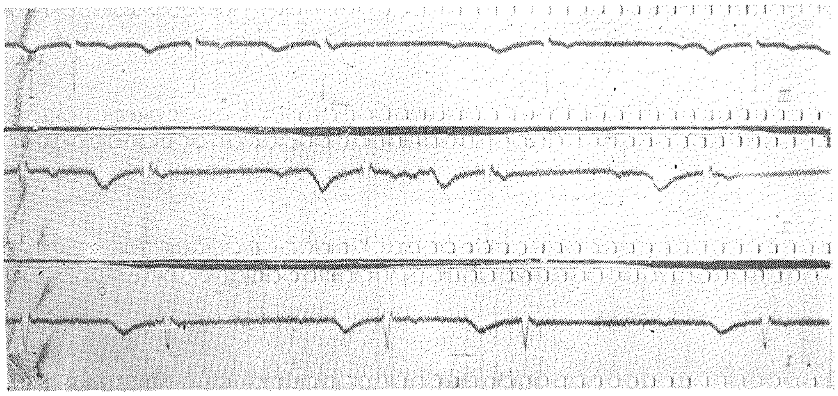
Condition immediately after the races :

Decompensated A-V incomplete block, period of auricular excitation : 0.53 sec., period of ventricular automatism : 0.73 sec., remarkable arrhythmia.

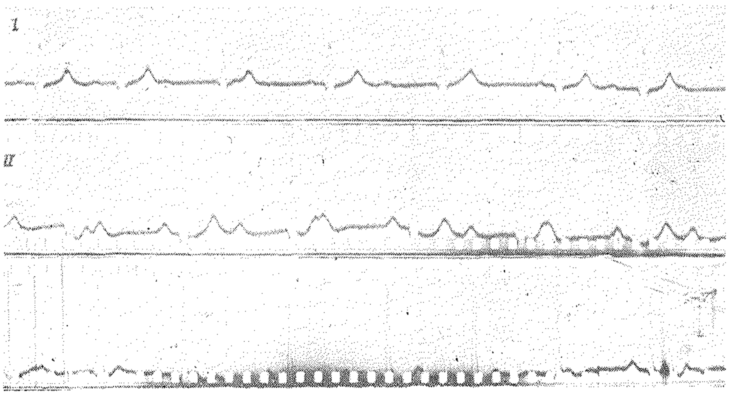
This subject showed decompensatively increasing dissociation of A-V conduction by the stress of races. The period of ventricular automatism became one half of that at rest, but it differed very much from the period of P wave and the subiect showed remarkable arrhythmia by interfering dissociation. His pulse



Heart image.

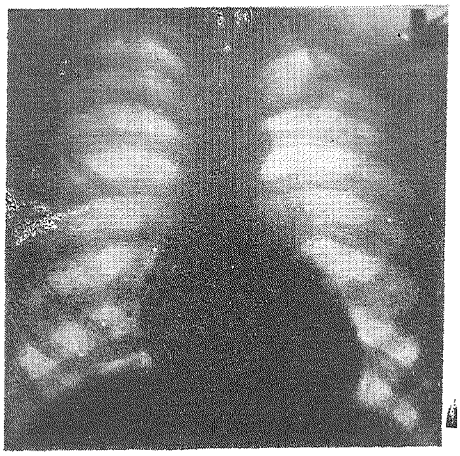


ECG at rest

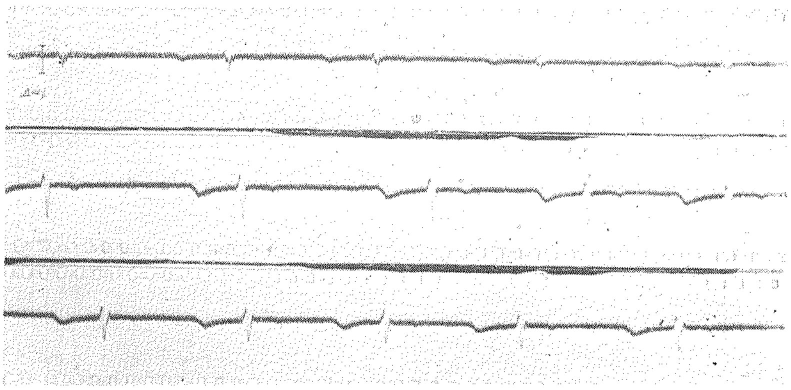


ECG just after long distance race.

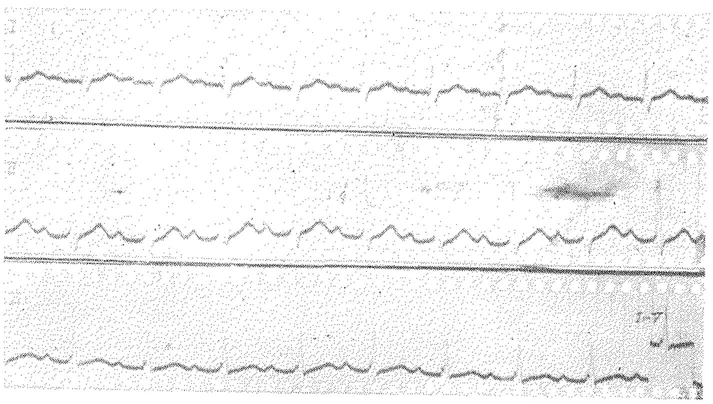
Fig. 4. Electrocardiograms of Case 2.



Heart image.



ECG at rest.



ECG just after long distance race.

Fig. 5. Electrocardiograms of Case 3.

rate decreased by 5 % after slight stress of knee-bending. His cardiac condition seemed to be unfavourable to the continuation of his athletic life, and in fact, he gave up sports soon after the year the experiment was made. In this case, we see if incomplete block is seriously decompensative, the runner can not bear such a severe stress as in ski races.

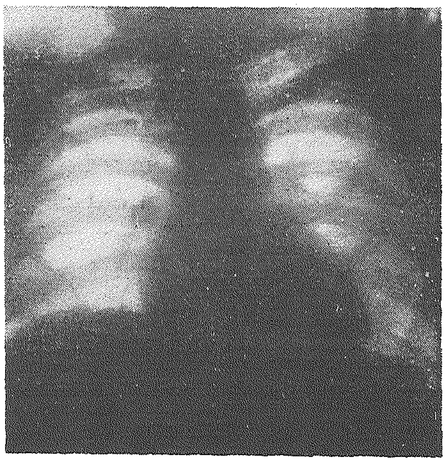
Case 3. Subject No. 8. "A" class runner, age: 20, Figure 5.
Condition at rest:
A-V conduction delay (0.255 sec.), pulse rate: 50/min.
Condition immediately after the race:
A-V conduction: 0.20 sec., pulse rate: 122/min.

This case displayed the longest P-Q interval among all subjects at rest. But it shortened compensatively after the races and its decrement was very large (0.055 sec.) in comparison with the increase of pulse rate.

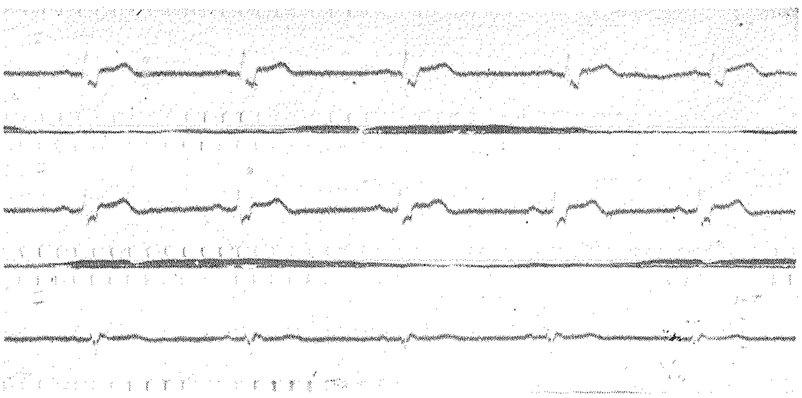
Case 4. Subject No. 7, "A" class runner, Age: 29.
Condition at rest:
Right bundle branch block (typical), QRS: 0.13 sec., Q-T: 0.35 sec., pulse rate: 57/min.
Condition after stress:
QRS: 0.13 sec., Q-T: 0.30 sec., pulse rate 120/min., T3 turned to negative, S-T3 lowered a little.

Figure 6 shows the ECG of this case. The QRS wave showed the typical form of right bundle branch block. Prognosis of this kind of block had been considered very serious, but in this case, the subject ran the total course of 39 kms with good record (7th from the top runner) and showed no subjective hardships. It was very interesting to know that a runner who had apparent symptoms of bundle branch block could endure hard stress of ski-race. Immediately after the stress, he still showed the obviously characteristic ECG of the block, there appearing inverted T3 and lowered S-T3, which meant the increasing of delay in right ventricle. The pulse rate was doubled and circulation system seemed to be compensated by this rise against the stress.

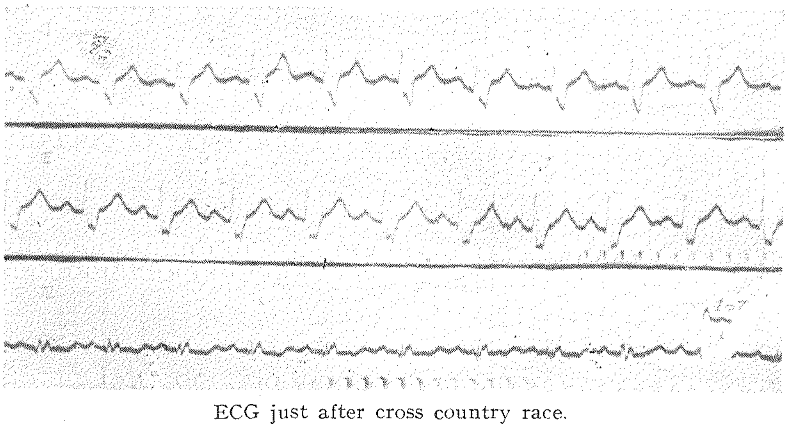
As mentioned above, the delay of A-V conduction alone does not mean any definite defect in so far as it is compensative as in Case 3, while if it is decompensative and falls into blocking condition by stress, it may be unfavourable. As a matter of fact, a case of compensative dissociation (dissociated at rest but not after the stress) was found both in 1949 and 1951. The essential problem lies, therefore, not in the delay nor in the block but in the decompensation by stress. In the same way, not all of bundle branch block can be considereds dangerous for acute and intense stress. Table 15 shows the anatomical balance of cardiac image of ski-runners who showed atrioventricular disorders, expressing main



Heart image.



ECG at rest.



ECG just after cross country race.

Fig. 6. Electrocardiograms of Case 4.

dimensions of Boldet-Vaquez's duplicate triangles in percentage and comparing them with those of all subjcets and of students. From the table, we can recognize that the basal axis D'G of the subject with A-V conduction disorder was 4 % larger than that of the average and the transversal diameter was larger too. The enlargement of D'G and transversal diameter may be the results of continuous overwork of heart during races with circuration disturbance caused by irregular systole of ventricles in A-V blocked heart. It is very interesting that this type of enlargement resembles the type of enlargement found in duration athletes.

Table 15. Anatomical balance of heart image of ski runners with atrioventricular disorder as compared with that of all subjects and of students. DG', D'G, etc. are the main dimensions of Boldet-Vaquez' duplicate triangles and their percentage values are given with longitudinal axis DG' taken as 100 %.

	No. of Subjects	DG'	D'G	Trans-versal diameter	GG'	D'G'	DD'
Subjects with A-V disorder	11	100 %	78 %	95 %	66 %	83 %	54 %
All subjects	57	100	74	85	65	83	55
Students	50	100	78	86	62	74	54

Part III Conclusive Disscussion

The author carried out the investigations of roentgenograms of 66 ski runners' hearts at rest and ECG of 57 runners out of these at rest as well as immediately after cross country, long distance and relay races in 1949 and 1951, and got the following results :

a) Cardiac enlargement was distinctive in the runners ; the mean increment was about 12 % in linear measure as compared with students. The enlargement seemed to have developed at the earlier stage of training. Development of major and minor axes of heart in runners were almost balanced. The best runners had smaller and more balanced hearts than the average runners.

b) Development of ventricles was more distinctive than other part. Mean increment of longitudinal axis with respect to the body weight was fairly larger in runners than in students, while those of transversal diameter and basal axis were nearly the same.

c) Bradycardia was frequently observed in ski runners and the better the runner or the longer his experience, the more frequently the bradycardia appeared. The upper limit of pulse rate immediately after the races was about 95-120/min. and the shorter the race, the more was the rate.

d) Atrioventricular conduction failures were found in 17 % of ski runners. They were of the sorts : compensated and decompensated delay of A-V conduction, and complete and incomplete dissociations. Their frequency of occurence did not show any tendency to concentrate in some group of runners. Basal axis and transversal diameter were larger in these cases.

e) Types of auricular waves deviated to the right after stress.

f) Function of ventricles was very good against the stress in general. The time of ventricular excitation QRS was 0.084 sec. at rest and it was shortened 4.5 % just after the stress. Maximium vector of QRS was 1.53 mV at rest and it incresaed 50–15 % after the stress. Positive deviation of Schlomka's form index was recognized just after the stress, especially after relay races and in better runners. Both increase and decrease of T wave were found under stress and three of five cases showing deformation of T were found after cross country races.

g) There was no distinctive change in heart during two years both anatomically and functionally in ski runners who had continued their athletic lives.

h) Three representative cases of atrioventricular block were discussed individually and it was found that the delay of A-V conduction alone did not necessarily cause any definite defect in so far as it was compensated, but decompensated A-V conduction failures seemed unfavourable for long and intense stress of ski races. A case of right bundle branch block was found and discussed. This case did not show any difficulties in completing the cross country race.

The conclusive discussions with special references to the relation between roentgenogram and electrocardiogram are given in the following.

1. Abaptation of heart to the stress of ski races

At the earlier stage of training, runners' hearts seem to become adapted to the stress of ski races with acute cardiac enlargement, since no definite correlation between the duration of training and the cardiac enlargement could be found and no distinctive changes of cardiac dimensions and functions were observed during two years in the same runners. At the later stage of training, however, the personal cardiac development becomes slow both functionally and anatomically.

There are two questions whether the enlargement is caused by simple dilatation or hypertrophy or by both of them and whether it is well-balanced or not. Although, from the present data, no definite answers can be given to all of them, it has been brought to light at least (i) that the enlargement is fairly well-balanced as was proved by the X-ray images of the left and right sides of ventricles and auricles, and also by the fact that the form index of ECG, S-T interval, and the form of P wave were normal at rest, (ii) that the blood capacity of heart must be increased to maintain their metabolism at work as well as at rest, since the pulse rate at rest is verylow and the dilatation is undeniable, and (iii) that no objection can be found in assuming the existence of hypertrophy of ventricular wall. In best runners, the cardiac enlargement is more balanced or the proportion of every cardiac dimension is closer to that of normal heart, and sometimes the enlargement is even less than the average runners. It seems that the best runners utilize their energy better than the other runners, the increment of minute blood volume being less for the same stress.

Electrocardiographic findings of adaptations consist in the bradicardia at rest to incresae the minute blood volume at work, and the high maximum ventricular vector to pump out the increased blood volume within normal systolic duration. The best and veteran runners show slower pulse rate at rest than the average, but their maximum ventricular vector is nearly the same as that of the average. At the races, however, cardiac response is called forth. The acute and intense stress of ski races gives rise to the increase of pulse rate up to almost twice as much as that at rest, the increase of maximum vector of ventricular excitation up to over 2 mV, the slight deviation of form index to the left or positive side, and the deviation of auricular wave form to the right type. The increase of pulse rate and the increase of ventricular maximum vector suggest the incresae of minute blood volume, while the deviations of form index and auricular wave form represent the superior activity of left ventricle and right auricle along the systemic circulation path.

2. Cardiac strain by ski races

Several kinds of cardiac strain can be found by means of ECG:

a) Pulse rate: The longer the race, the lower was the pulse rate, and also, the better the runner, the larger was the percentage increase of the rate. This seems a characteristic feature of strain in runner's heart. It can not be supposed to be a compensatory phenomenon nor nervous reaction, because the best runners show higher percentage increase of the pulse rate immediately after the longer race as compared with the average, and the time required for each race is long enough to neglect the consideration of nervous effect. Some causes may be expected to explain the fall of pulse rate: one is the decrease of work-done resulting from the general fatigue of whole body, and the other might be intracardial strain.

b) Deformation of T wave: Five cases of deformed T wave were found among low class runners only, but not any among "A" class runners. Three of them were found at cross country races. The deformation indicated the over strain of left ventricle, while we know already that electrical activity of left ventricle, when it is excited, is superior at longer races in best runners. These two facts seem to be contradictory each other, but, according to the author's opinion (13), the T wave represents the effect of metabolic products produced by the excitation of ventricles, and QRS and T waves in this case must be a remarkable signs of ventricular fatigue especially in left ventricle.

c) Prolongation of QT duration: Relative prologation of QT duration took place mostly at the relay race, but it tended to return to the normal condition in longer races. This prologation of QT seems to have a character of a transient strain of ventricular activity and is probably caused by some decay of biochemical metabolic adaptation as the interval is very sensitive to chemical balance of body fluid.

3. Cardiac disorder associated with ski-running

If any runner has a pathological defect in his heart, he would not be able to maintain the demand of increasing circulating blood volume in such a long and intense stress as ski-races. Neverthless, A-V conduction disturbance has been frequently observed among ski-runners. It begins with prolonged A-V conduction and falls into incomplete and complete dissociation without subjective symptoms, and the decompensatively progressing dissociation by the stress seems to lower the runners' records. In most cases, such a trifling failure would not be noticed by athletes, and indeed, it is not actually dangerous to the maintenance of ordinary circulation. But it is worth calling attention that the early discovery of the symptoms is of considerable importance in the future planning of athletic life.

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