"Near Maximal" Exercise Test by Treadmill for Evaluation of Cardiac Function

Kohji Tamura, Takefumi Ozawa and Hiroshi Murooka

The magnitude of the stress in the exercise stress test has recently been raised to the tolerable maximum of the patient in order to provide more information. However, the end-point as the definition of the maximum is not uniform throughout all the cardiac laboratories. The exercise test taking the end-point of the pathological maximum has been used in certain laboratories since it is practical rather than the other "maximum" exercise stress test in clinical medicine. Therefore, we performed this "near maximal" exercise stress test in our laboratory based on Elgestad protocol.

The topics of this report were as follows: (A) Evaluation of "near maximal" protocol in healthy person, (B) evaluation of this protocol in the patient, (C) comparison of this test with Master's test and (D) application of this test to the diagnosis and evaluation of the cardiac function, cardiac surgery and cardiac drugs.

SUBJECTS AND METHODS

The subjects in this study were as follows: (I) 49 healthy male (age of 24 to 50 y.o.), and (ii) 445 patients of the ischemic heart disease (male of 365 and female of 80 with the age from 19 to 73 y.o.).

In the exercise stress test, two lead system with three electrodes of CM₅ and a vertical system as shown in the figure 1 were used. The blood pressure was measured by cuff. At first blood pressure and ECGs were taken when the patient was sitting and then again when standing.

Then the patient was asked to hyperventilate for 20 seconds while standing and the electrocardiographic response was noted. The exercise protocol of Elgestad was used. Namely, the treadmill (Avionics, Co., U.S.A.) was started at 2.7 km/hr (1.7 miles/hr) for three minutes with 10% grade. Then the speed was raised to 4.8 kg/hr (3 miles/hr) for 2 minutes, 6.4 kg/hr (3 miles/hr) for 2 minutes, 6.4 km/hr (4 miles/hr) and finally 8 km/hr (5 miles/hr) for 3 minutes. ECG and blood pressure were taken at the end of each minute of the exercise. After the termination of exercise the observation was continued at least up to 8 minutes. In healthy person, the oxygen consumption was continuously recorded during the test by metabo-auto dilute (Fukuda Sangyo, type MAH-606).

Interpretation of ECG was also performed according to new Elgestad criteria. Namely, ST segment depression in horizontal or in downsloping configuration of 1.0 mm more depressed than at rest and in upsloping configuration of 1.5 mm more depressed was abnormal. The other details of the positive criteria are described elsewhere. The test was terminated when symptom and sign appeared such as: (i) chest pain of increasing, (ii) lassitude, dyspnea or vertigo, (iii) cardiac failure, (iv) hemodynamic abnormalities, (v) electrocardiographic abnormalities and (vi) heart rate reached or exceeded his predicted maximum pulse rate.

RESULTS

A) Evaluation of this protocol in healthy person (Fig. 1)

The physiological response to exercise according to this protocol was studied in the healthy person as the control. As shown in the figure 1, the response of the heart rate and the blood

Key Words:
- "Near maximal" treadmill stress test
- Normal response
- Termination of test
- Cardiac functional evaluation

1st Department of Medicine, Niigata University School of Medicine, Niigata, 951 Japan

Japanese Circulation Journal Vol. 43, March 1979 171
pressure was examined.
a) Heart rate: The heart rate was \(69.8 \pm 10.8\) beats/min at rest and sitting. It was \(80.6 \pm 15.4\) beats/min at rest and standing before the exercise. At the end of the exercise protocol, the heart rate increased to \(158.0 \pm 16.9\) beats/min and then after the completion of the test at 8 minutes the heart rate returned to \(88.6 \pm 14.5\) beats/min.
b) Blood pressure: The systolic blood pressure at rest and standing was \(120.7 \pm 11.2\) mmHg. This systolic blood pressure increased by the exercise at 10 minutes to \(153.8 \pm 16.5\) mmHg. After the completion of the exercise, the pressure decreased; at 4 minutes it became to \(116.7 \pm 14.9\) mmHg and at 8 minutes to \(111.1 \pm 16.2\) mmHg. The diastolic pressure was at rest and standing \(78.0 \pm 15.4\) mmHg and this pressure rather decreased to \(73.8 \pm 11.9\) mmHg by the exercise at 10 minutes. After the termination of the exercise, the diastolic pressure
gradually returned and at 8 minutes it became to 77.1 ± 18.4 mmHg. c) Oxygen consumption (\(\dot{V}O_2\), Fig. 2): \(\dot{V}O_2\) was measured at rest and standing 7.6 ± 1.2 ml/kg/min. At the end of the first stage of 3 minutes exercise \(\dot{V}O_2\) became to 16.9 ± 1.6 ml/kg/min, at 5 minutes of the second stage to 23.2 ± 1.9 ml/kg/min and at 7 minutes of the third stage to 31.7 ± 3.3 ml/kg/min, and finally at 10 minutes of 4th stage it became to 35.8 ± 6.4 ml/kg/min. After the completion of the test, at 8 minutes it became to 8.9 ± 2.0 ml/kg/min. d) The relationship between the heart rate, the blood pressure and \(\dot{V}O_2\) (Fig. 2). The mean value of both \(\dot{V}O_2\) and heart rate was correlated well and was almost linear in function (2.44X + 65.83, \(r = 0.97\)). The relationship between the mean value of \(\dot{V}O_2\), of pressure was also well correlation and was almost linear in function 1.16X + 109.77, \(r = 0.98\). e) Comparison of this treadmill stress test with Master's
test (Fig. 2): Master's single two step test was performed in 10 healthy male with age of 28 to 42 y.o. The heart rate at rest and lying was 76.3 ± 7.9 beats/min. By single Master's test, the heart rate increased to 116.8 ± 12.4 beats/min. Furthermore, by Master's double two step test it increased to 123.4 ± 13.5 beats/min. VO$_2$ at rest was 5.83 ± 0.94 ml/kg/min. By single Master's test it increased to 17.45 ± 2.19 ml/kg/min. By Master's double two step test it increased up to 23.4 ± 2.34 ml/kg/min. Therefore, the increases of both heart rate and VO$_2$ by Master's single and double tests were less compared to those by this treadmill stress test. f) Target heart rate (Fig. 3): The significance of the target heart rate examined in a healthy person of age 33 is shown. Measured VO$_2$ during exercise reached a maximum 30.2 ml/kg/min at 7 minutes, even though this VO$_2$ was less compared to estimated VO$_2$. The heart rate was 150 beats/min at this time. VO$_2$ started already to decrease by the further continuation of the exercise, although the heart rate was less than the target heart rate. Since the subject complained dyspnea and VO$_2$ was decreased, the exercise was terminated at 9 minutes. At that time, VO$_2$ was 23.6 ml/kg/min. ECG by this test was remained normal. Therefore, using the target heart rate alone would not totally be reliable to control the exercise in certain cases.

B) Evaluation of the protocol in patient (Fig. 4–7):

a) Cause of termination: Totally in 445 cases this test was performed. Among them 365 cases (82%) was male and 80 cases (18%) was female. In male, 55% of 365 cases was terminated during the protocol. The ratio of this termination was increased with the increase of the age, from 31% to 71%. In female, 74% of 80 cases was terminated during the protocol. The ratio of this termination seemed to increase according to the age of the patient. Therefore, in male of less than 50 y.o. the stress seemed to be rather less than “near maximum”. However, in the rest of the patient the magnitude of the stress seemed to be “near maximal”. The cause of termination was analysed as shown in the figure 5. In 149 males the symptom to stop the test appeared in 64% and the sign for the termination appeared in 36%. In the symptom, chest pain, lassitude dyspnea were seen frequently. In the sign, ST abnormalities were seen most frequently. Arrhythmia and hypertension were seen rather rarely. To the noteworthy change, the target heart rate was the cause of the termination only in 1%. In the 43 females the symptom appeared in 45%. Dyspnea and lassitude were seen most frequently and the chest pain was rather seen less
frequently. The sign appeared in 55% and ST abnormalities were the most frequent finding.

The relationship between the cause and its appearance time of the termination was examined as the figure 6. The peaks of the termination were mostly at 7 minutes and the distribution of each of the cause was more frequent before 7 minutes. Furthermore, the relationship between time and frequency in the chest pain and ST abnormalities was examined (Fig. 7). Namely ST change appeared most frequently at 5 minutes and this frequency gradually decreased. The disappearance of ST change, however, had two peaks, namely at the immediately following termination after 8 minutes. Chest pain appearance also had the peak at 5 minutes and its frequency gradually decreased. This chest pain started to disappear immediately after the termination of the exercise and it disappeared completely at 8 minutes in all cases.

b) Evaluation of the target heart rate (Fig. 8):
symposium on exercise testings of heart diseases

Fig. 8. The distribution of the heart rate with the age in the positive case at the termination of the exercise. The subjective maximal heart rate and its target heart rate are shown based on the report of Sheffield\(^3\) or Dohba\(^10\).

The relationship between the age and the heart rate at the termination of the exercise was examined to clarify the significance of the target heart rate in the figure 8. The dotted line (thin) is the target heart rate proposed by Sheffield\(^3\) and the solid line (thin) is the heart rate proposed by Dohba\(^13\). Taking Sheffield's heart rate, the patient who showed the heart rate of more than 90% of the subjective maximum was rare in this study. On the other hand taking 90% of subjective maximum of Dohba, 5% of our cases and, taking 85% of the subjective maximum, 12% of patients showed the heart rate exceeding the target heart rate. This implied that the further examination of the heart rate of the subjective maximum in the healthy subjects and then the examination of the target heart rate should be done.

c) Comparison of this maximal treadmill stress test and Master's test (Fig. 9):

Based on above mentioned data, the exercise stress test was compared as follows (Fig. 9). In the figure 8, the relationship between the heart rate and the number of the case of positive responder are plotted. Thus, the approximate curve was obtained. If it is accepted to use this approximate curve, the following interpretation could be made. Since "near maximal" test by the treadmill increased the heart rate to 160 beats/min in average, 94% of all true positive responder, in other word % of the scratched area of the figure until 160 beats/min to total area under the curve, would be expected to become positive by this treadmill test. In Master's single two step test with telemetry the maximal heart rate was 116 beats/min in average. Therefore, the percentage of the positive responder would be decreased compared to that by treadmill test. In Master's test without telemetry the maximal heart rate was 88 beats/min. Thus, this method showed slowest "maximal heart rate". In Master's double two step test with telemetry the maximal heart rate became 123 beats/min in average. Therefore, only 64% of all patients of estimated positive responder would be positive if diagnosed by the same diagnostic criteria using the treadmill stress test. On the other hand, since the subjective maximal exercise test caused the heart rate of 160 to 170 beats/min, the positive responder increase slightly in percentage than "near maximal" test. Thus, the diagnostic sensitivity would be increased. On the other hand, however, this type of test would cause more risk to the patient and thus difficulties to perform\(^1^4\).

d) Application of the exercise stress test by treadmill (Fig. 10–13):

As shown in the figure 9, the stress test by treadmill was used to prove the validity of the aorto-coronary bypass surgery to angina pectoris. This patient was proved to have ST depression and anginal pain at 5 minutes by the stress test and 2 vessels involvement by the coronary angiography. Therefore, aorto-coronary bypass sur-
Fig. 10. The evaluation of the aorto-coronary bypass surgery in a case of angina pectoris. The data of the treadmill stress test was compared with other data. LAD=left anterior descending coronary artery, RCA=right coronary artery, C=control period, Max.P.R.=maximal pacemaker rate at the stress test, HR=heart rate, CBF=coronary sinus blood flow measured by continuous local thermodilution method, \( E_{x_L} \)=myocardial extraction ratio of lactate.

Fig. 11. The therapeutic evaluation in a case of angina pectoris. The data of the treadmill stress test was also compared with other diagnostic data. CBF=coronary sinus blood flow, LVEDP=left ventricular enddiastolic pressure.
gery was performed. The pacing stress test after the surgery, compared to the test before the surgery, showed the increase of the coronary sinus blood flow and the improvement of the myocardial lactate extraction ratio. Furthermore, the stress test by treadmill after the surgery revealed the improved tolerance up to 10 minutes and it caused the normal response. Thus, the validity of the coronary surgery was proved in this case.

In the figure 11, this stress test was used to prove the efficacy of the therapy. This patient started to complain dyspnea at 7 minutes and also ST elevation was recognized in ECG. Even at rest transient ST elevation was recognized by Holter monitor as shown in middle and upper part of this figure. The coronary angiogram revealed the critical stenosis in the left anterior descending coronary artery. The pacing stress caused the lesser increase of the coronary sinus blood flow, decrease of the myocardial lactate extraction ratio, the increase of left end-diastolic pressure. Therefore, by these polyparametric approach, the diagnosis of the angina pectoris was made. Pindolol of beta blocker was given and the stress test was performed. The increment of the heart rate and modified tension time index was decreased. However at 7 minutes
ST depression and anginal pain appeared even after the administration of Pindolol. Nifedipine was given and then the treadmill test was completed up to 10 minutes. Therefore, the effect of Nifedipine was proved in this case.

The effect of Pindolol to hypertension was examined by the single blind cross over method with trichlormethiazide using the treadmill exercise stress test (Fig. 12 and 13). In the group A (Fig. 12), Pindolol (5-20 mg, t.i.d.) was given for 2 weeks initially followed by 2 weeks of trichlormethiazide (2 mg, t.i.d.). The first stress test was performed before the medication as the control. The second stress test was given after 2 weeks administration of Pindolol. Pindolol, compared to the control period, depressed the increase of heart rate, of the blood pressure and of the pressure pulse product from the early stage of the exercise. The third stress test was given after 2 weeks administration of trichlormethiazide. Pindolol also depressed the increase of the heart rate and the pressure product more than trichlormethiazide did. Moreover, in the group B (Fig. 13), trichlormethiazide was given prior to Pindolol, namely in a reversed sequence of the order of the medication. Trichlormethiazide did not cause much difference compared to the control. However, Pindolol compared not only with the control but also with trichlormethiazide depressed more definete-

*Fig. 13. Anti-hypertensive effect of Pindolol. In the group B, Pindolol was given after Trichlormethiazide.*

*Japanese Circulation Journal Vol. 43, March 1979*
TABLE 1 COMPARISON OF OUR DATA WITH THOSE OF THE LITERATURE OBTAINED BY SUBJECTIVE MAXIMAL EXERCISE STRESS TEST

<table>
<thead>
<tr>
<th>1. Report</th>
<th>Doihba</th>
<th>Bruce</th>
<th>Pollack</th>
<th>Pollack</th>
<th>Pollack</th>
<th>Scheffeld</th>
<th>Elstead*</th>
<th>Blackburn</th>
<th>Tamura</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Protocol</td>
<td>Bruce</td>
<td>Bruce</td>
<td>Bruce</td>
<td>Elstead</td>
<td>Astrand</td>
<td>Scheffeld</td>
<td>Elstead</td>
<td>---</td>
<td>Elstead</td>
</tr>
<tr>
<td>3. Age (years)</td>
<td>20-29</td>
<td>30-39</td>
<td>45</td>
<td>40.5</td>
<td>40.5</td>
<td>40.5</td>
<td>30</td>
<td>30</td>
<td>28-42</td>
</tr>
<tr>
<td>4. VO₂ max (ml/min/kg)</td>
<td>46.9</td>
<td>41.7</td>
<td>40.5</td>
<td>35.3</td>
<td>36.6</td>
<td>37.7</td>
<td>35.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. HR max.</td>
<td>180</td>
<td>174</td>
<td>189</td>
<td>182</td>
<td>181</td>
<td>184</td>
<td>193</td>
<td>190</td>
<td>191</td>
</tr>
<tr>
<td>a. 90%</td>
<td>162</td>
<td>154</td>
<td>170</td>
<td>164</td>
<td>163</td>
<td>166</td>
<td>174</td>
<td>171</td>
<td>172</td>
</tr>
<tr>
<td>b. 85%</td>
<td>153</td>
<td>148</td>
<td>161</td>
<td>155</td>
<td>154</td>
<td>156</td>
<td>164</td>
<td>162</td>
<td>162</td>
</tr>
<tr>
<td>6. SBP (mmHg)</td>
<td>185</td>
<td>180</td>
<td>59*</td>
<td>171</td>
<td>169</td>
<td>167</td>
<td>153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. DBP (mmHg)</td>
<td>82</td>
<td>88</td>
<td></td>
<td>75</td>
<td>77</td>
<td>76</td>
<td></td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>

(*)=magnitude of change, (**)=modified Elstead protocol (1976), VO₂ max=maximal oxygen consumption, HR max=maximal heart rate, SBP=systolic blood pressure, DBP=diastolic blood pressure.

ly the increase of the heart rate, of the blood pressure and the pressure pulse product by the exercise. By this approach for the evaluation of Pindolol as the anti-hypertensive agent the stronger depressant effect on the blood pressure and on the heart rate by the exertion were proved. Therefore, by this stress test, Pindolol was proved to be effective as the antihypertensive agent in a different manner from trichlormethiazide.

DISCUSSION

In the so-called "maximal" stress test there are at least 3 types "maximum" used as the endpoint of the exercise! First, the end-point is "physiological maximum" that is accepted only in the work physiology1.4,8 Secondary the end-point is "subjective maximum" to that the patient can tolerate before attaining to the maximum of oxygen consumption1.4. Thirdly the end-point is "pathological maximum" or "near maximum" of the patient1,2,5,6 In this method the exercise is continued to "near maximum", namely to a certain level of the exercise that is estimated by the target heart rate, the duration of the exercise and other1,5 The advantage of this third method is that it is practical considering both costs and benefits of the exercise test1,2,5,6 Therefore, we used this type of test by treadmill according to Elstead protocol and his criteria.

The evaluation of this protocol in the healthy person was performed in our laboratory9 In order to determine how near this protocol is to the subjective maximum, our data was compared with those of the subjective maximum reported in the literature (Table I). This comparison study revealed that our VO₂ was 75-101% of the subjective maximum, the maximal heart rate 88-97% and the systolic blood pressure 83-92%. Thus, the proximity to the subjective maximum of Elstead protocol in our hand was determined. The relationship between the heart rate, the blood pressure and VO₂ was almost linear. Therefore, the heart rate was proved to be useful for the determination of the magnitude of stress while the patient is exercising. However, as shown previously, the target heart rate was not totally reliable in following the exercise. However, to measure VO₂ of each patient during the exercise is very difficult. Therefore, the electrocardiographic monitoring without VO₂ measurement paying attention to the patient while he is exercising would be practical. The magnitude of this stress test was much higher than that of Master's single or double two step test. The multistage test would be better to increase the magnitude of the stress than Master's test.

Furthermore, our protocol was applied to the patient? 55% of male and 74% of female were terminated before the completion of the estimated maximum. This percentage of the termination was increased according to the increase of the age. Therefore, in young male this protocol might be too easy to perform but to the rest of the patient this protocol would be satisfactory since we are asking to the patient not to walk to the maximum of his ability. This percentage of the termination would also indicate the magnitude of the proximity to the subjective maxi-

Japanese Circulation Journal Vol. 43, March 1979
The cause of the termination was variable. However, for the diagnostic view point the chest pain and ST change were important. The important point in our data was that the chest pain and ST change appeared even later stage of the exercise. Namely, this magnitude of the stress was necessary, even though the peaks of them appeared at 7 minutes by exercise. The disappearance of the chest pain and ST change after the termination of the exercise showed two peaks. The immediate disappearance of these changes after the exercise would indicate the necessity of the continuous monitoring of ECG in this exercise test. Again in Master’s test the telemetry would increase the detection ratio of the positive case.

The significance of the target heart rate in our study was not great because the heart rate exceeded that of target heart rate of Sheffield was rare. The reaction of Japanese to the exercise test might differ from that of American. Therefore, the target heart rate was calculated based on Dohba’s data. Even if 90% of Dohba’s subjective maximum was taken as the target heart rate, the termination was only 5%. These discrepancy would indicate the necessity for more detailed research in Japanese in this field.

From the comparison study based on the reaction of the heart rate and number of the positive case, the assumption of the superiority of the stress test by treadmill to Master’s test was indicated. The superiority of the multistage exercise stress test with either treadmill or ergometer to single stage test of Master’s test was well accepted throughout the world. However, in this country Master’s test is still popular and this might be based on the difference of the basic philosphy in the exercise. Therefore, this should be debated in near future with more other supporting data than heart rate response as shown in this data. Finally the end-point of the stress test should be determined considering its costs and the benefits. This problem should be further examined in the future.

The application of this protocol as the functional evaluation of the heart rate was examined. The validity of the aorto-coronary surgery to angina pectoris was examined by the treadmill test. The effect of the drug was also evaluated by this test. Furthermore, the effect of Pindolol as the anti-hypertensive agents was examined by this treadmill stress test. The main advantages of the exercise stress test by the treadmill compared with Master’s test was that it could evaluate the cardiac function. The significance in the cardiac diagnosis, the prediction of the prognosis and the judgement of the therapeutic effect should be more examined in the future. Furthermore, the significance of ST change should be solved with other supportive methods and should be analysed with the polyparametric approach.

REFERENCES
15. HIGUMA, N., SATO, H., BANNAI, S., AOYAGI, R., IZUMI, T., TAMURA, K., MATSUOKA, M.,

Japanese Circulation Journal Vol. 43, March 1979