SERUM INSULIN AND GLUCOSE RESPONSE TO GRADED EXERCISE IN ADULTS

PART I:
THE INFLUENCE OF FITNESS STATUS

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ABSTRACT

The effect of acute exercise upon serum immunoreactive insulin levels (IRI) and serum glucose concentrations (GC) was studied in groups of middle-aged men of contrasting physical fitness status. Two groups of subjects, one active and one sedentary (both N = 11, mean age 44 years), performed a graded cycle ergometer exercise test in the post-absorptive state. Venous blood samples were taken at rest, during low and high work intensities, and after recovery. The response of serum IRI to exercise was similar in both groups of subjects with significant increases observed during exercise followed by a return to resting values during recovery. However, the magnitude of serum IRI response was lower in the active group. In contrast, the sedentary group demonstrated little or no change in serum GC during exercise, whereas significant increases in serum GC were observed during exercise in the active group.

INTRODUCTION

Considerable variation in the response of circulating insulin levels has been reported in studies involving human subjects during exercise. Decreased plasma insulin levels have been observed during acute exercise (Cochran et al., 1966) and during heavy and prolonged severe exercise (Pruett, 1969; Pruett, 1970; Pruett and Oseid, 1970; Wahren et al., 1971) in spite of an increase glucose utilisation (Hartley et al., 1972; Wahren et al., 1971). Moreover decreased serum insulin levels have been demonstrated during moderate work where little or no change occurred in blood glucose concentration (Hartley et al., 1972 a; Métivier et al., 1971; Nikkilä et al., 1968; Oseid and Hermansen, 1971; Pruett and Oseid, 1970). In contrast some investigations have shown that exercise to fatigue (Rottini et al., 1971), intermittent maximal exercise (Hermansen et al., 1970), and even moderate exercise (Reinheimer, Davidson and Albrinck, 1968; Schwartz et al., 1969) have led to significantly increased serum insulin levels as well as increased serum glucose concentrations.

Such variations in insulin levels during exercise may possibly be explained in terms of the inhibition of insulin by catecholamines (Conard et al., 1969), alterations in the catabolic rate of endogenous insulin (Francxson et al., 1971), or by variations attributable to differences in the fitness status of the subjects under investigation (Björntorp et al., 1972).

In the present investigation we have studied the patterns of serum immuno-reactive insulin level (IRI) and serum glucose concentration (GC) during exercise in order to discern differences related to fitness status.

SUBJECTS

Twenty-two men, aged 27-57 years, were used in this investigation. Two groups were established, one active and one sedentary (both N = 11), based upon the physical fitness criterion of Ismail, Falls and MacLeod (1965). The physiological characteristics of the subjects are given in Table I. The two groups represent non-obese and moderately obese men as opposed to weight-matched sedentary and active individuals, as demonstrated by the differences in weight and percentage of lean body weight. All subjects gave their informed consent and had undergone medical examinations before participating in the investigation.

METHODS

On reporting to the laboratory the subjects were allowed
TABLE I
Physical characteristics and physiological responses of the two groups of subjects who participated in the study

<table>
<thead>
<tr>
<th></th>
<th>Active Group</th>
<th>Sedentary Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± S.E.</td>
<td>Mean ± S.E.</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>44.6 ± 2.5</td>
<td>43.7 ± 2.5</td>
</tr>
<tr>
<td>(range 27-54)</td>
<td></td>
<td>(range 28-57)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181.3 ± 1.6</td>
<td>182.9 ± 2.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.9 ± 3.4</td>
<td>102.3 ± 7.8</td>
</tr>
<tr>
<td>% Lean</td>
<td>84.2 ± 1.6</td>
<td>77.1 ± 1.2</td>
</tr>
<tr>
<td>Blood Pressures (mm Hg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>126.4 ± 4.3</td>
<td>133.1 ± 3.6</td>
</tr>
<tr>
<td>Diastolic</td>
<td>77.8 ± 1.7</td>
<td>88.7 ± 3.5</td>
</tr>
<tr>
<td>Pulse</td>
<td>47.7 ± 2.9</td>
<td>44.4 ± 2.2</td>
</tr>
<tr>
<td>Heart Rates (b.min⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>58.7 ± 2.4</td>
<td>66.7 ± 2.8</td>
</tr>
<tr>
<td>Low Intensity</td>
<td>110.0 ± 4.1</td>
<td>124.4 ± 5.4</td>
</tr>
<tr>
<td>High Intensity</td>
<td>157.3 ± 3.8</td>
<td>154.6 ± 2.4</td>
</tr>
<tr>
<td>V̇O₂ ml kg⁻¹ min⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Intensity</td>
<td>22.6 ± 1.2</td>
<td>24.8 ± 2.0</td>
</tr>
<tr>
<td>High Intensity</td>
<td>45.4 ± 1.6</td>
<td>36.4 ± 2.0</td>
</tr>
<tr>
<td>Respiratory Quotient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Intensity</td>
<td>0.82 ± 0.02</td>
<td>0.85 ± 0.02</td>
</tr>
<tr>
<td>High Intensity</td>
<td>0.92 ± 0.02</td>
<td>0.94 ± 0.02</td>
</tr>
<tr>
<td>% Predicted V̇O₂ max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Intensity</td>
<td>45%</td>
<td>59%</td>
</tr>
<tr>
<td>High Intensity</td>
<td>92%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Low/high intensity exercise expressed as % predicted V̇O₂ max

Two exercise levels were selected to produce low (~50% predicted V̇O₂ max) and high (~90% of predicted V̇O₂ max) work intensities in each group of subjects. Maximal oxygen uptake capacity was predicted using the procedure of Astrand and Ryhming (1954) with a correction factor for age. In view of the limitations of this procedure (Davies, 1968) and in the interests of the safety of the subjects concerned, the upper limit of high intensity exercise was established by an HR in excess of 160 b.min⁻¹ (Balke, 1960), or prior to this if the subject indicated that he was exhausted or could no longer maintain the required work rate, at which point oxygen intake (V̇O₂) was measured.

The exercise consisted of a low intensity work of 10 min duration at 100 W (600 kpm/min) and a pedalling frequency of 50 rpm. This involved work at 45% and 59% of predicted V̇O₂ max for the active and sedentary groups respectively. Following the low intensity work bout the subjects immediately performed a bout of high intensity exercise which involved an increase in the work load of 25 W/min (150 kpm/min) until the relative work output demanded 92% and 88% of predicted V̇O₂ max for the active and sedentary groups, respectively.

Oxygen intake (V̇O₂)

The subjects inspired through a 3-way “J” valve and expired air was collected during the last 30 seconds of each exercise bout in a 150 litre Tissot gasometer equipped with a kymograph. All volumes of expired air were corrected to STPD and duplicate samples were analysed for O₂ and CO₂ using a Beckman 777 oxygen analyser and a Beckman BII medical gas analyser, respectively. Both instruments were calibrated at frequent intervals using commercial gas mixtures of known concentrations which had been checked using the micro-Scholander apparatus. Respiratory quotients (RQ) were calculated from the O₂ and CO₂ data.

Heat rates (HR) were monitored at rest and throughout the exercise period using a stethoscope placed at the apex of the heart. HR was noted during the last minute of each level of exercise. Blood pressure was recorded under resting conditions using a standard clinical sphygmomanometer and a stethoscope placed over the brachial artery. Systolic and diastolic pressures were noted and pulse pressure determined. The percentage of lean body weight (% LBW) was estimated using the method of Wilmore and Behnke (1969).

Blood samples were centrifuged at 3,000 rpm for 10 min and serum was separated and frozen in aliquots at -20°C until analysed. Serum immunoreactive insulin (IRI) level was determined using the Phadebas R radioimmunoassay test for insulin (Pharmacia Laboratories Inc., Piscataway, N.J.) based on the procedure by Yalow...
and Berson (1960). Serum glucose concentration (GC) was determined by a standard clinical laboratory procedure using a 'Technicon' autoanalyser based on a modification of the method of Hoffman (1937). Serum corticosteroid (SC) concentration was determined by a modification (Few and Cashmore, 1971) of the competitive protein binding technique of Murphy (1969). Serum free fatty acid (FFA) concentration was assessed by the method of Dole (1956) as modified by Trout, Estes and Friedberg (1960).

The differences between means were tested using the Student's 't' test with the appropriate degrees of freedom.

RESULTS

The physical characteristics of the two groups of subjects are presented in Table I. The active group had significantly lower body weight and % LBW (p < 0.05) and tended to have lower systolic and diastolic pressures but higher pulse pressure than the sedentary group although the differences were not statistically significant. The changes in serum insulin and glucose of the two groups of subjects are presented in Table II, and the time course of changes in mean serum insulin level and glucose concentration for both groups of subjects during the exercise test is presented in Figure 1.

The active group displayed a significant rise in mean insulin level over a resting value of 19.2 ± 4.5 μU/ml during exercise at 92% predicted VO₂ max (33.0 ± 8.0 μU/ml, p < 0.05), followed by a significant fall during recovery to 15.9 ± 4.2 μU/ml (p < 0.05). This was accompanied by a progressive, but non-significant rise in mean glucose concentration over the resting value of 82.7 ± 3.5 mg% during exercise, but becoming significantly elevated to 89.9 ± 2.5 mg% during recovery (p < 0.05).

The sedentary group showed a similar response pattern in mean insulin levels to exercise, with a significant rise over a resting value of 30.0 ± 6.7 μU/ml during

![Figure 1. Mean (± S.E.) serum insulin level and glucose concentration of the active and sedentary groups.](http://bjsm.bmj.com/)

### TABLE II

<table>
<thead>
<tr>
<th>Test Phase</th>
<th>Serum Insulin (μU/ml) (Mean ± S.E.)</th>
<th>% Predicted VO₂ max</th>
<th>Serum Glucose (mg %) (Mean ± S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sedentary Group (P)</td>
<td>Active Group</td>
<td>Sedentary Group</td>
</tr>
<tr>
<td>Rest</td>
<td>30.0 ± 6.7</td>
<td>N.S.</td>
<td>19.2 ± 4.5</td>
</tr>
<tr>
<td>Low Intensity</td>
<td>31.8 ± 6.2</td>
<td>&lt; 0.05</td>
<td>24.5 ± 4.6</td>
</tr>
<tr>
<td>High Intensity</td>
<td>49.6 ± 10.8</td>
<td>N.S.</td>
<td>33.0 ± 8.0</td>
</tr>
<tr>
<td>Recovery</td>
<td>32.6 ± 8.6</td>
<td>&lt; 0.06</td>
<td>15.9 ± 4.2</td>
</tr>
</tbody>
</table>

Low/high intensity exercise expressed as % predicted VO₂ max.
exercise at 88% of predicted VO₂ max (49.6 ± 10.8, p < 0.05), and a corresponding decline to a recovery value of 32.6 ± 8.6 μU/ml (p < 0.05). However, in contrast to the active group, mean glucose concentration fell significantly from a resting value of 88.5 ± 3.2 mg% during exercise at 88% of predicted VO₂ max (80.8 ± 2.8 mg%, p < 0.05), but returned towards the resting value during recovery.

The active group had significantly lower mean insulin level than the sedentary group in recovery, although no significant differences in mean glucose concentration were observed between the groups before, during or after exercise (Table II).

**DISCUSSION**

The results of this investigation demonstrate a pronounced similarity in the response of serum insulin levels in active and sedentary subjects during acute exercise, although differences in the magnitude of insulin levels were observed. However, differences in both the response pattern and the magnitude of serum glucose concentration during acute exercise were noted between active and sedentary subjects.

The variability in the responses of serum insulin and glucose to exercise reported by other studies cited in this investigation may be due to the differences in experimental protocol as well as in the nature of the subjects under investigation. It is possible therefore, that by taking into account the intensity and duration of the exercise procedures employed in other works, as well as the fitness status of the subjects tested, the results of this investigation selectively support, and to some extent help explain, the findings of other studies.

The findings support evidence for an increase in insulin level and a decrease in glucose concentration in untrained subjects exercised to fatigue (Rottini et al., 1971) as indicated by the response of our sedentary group. Likewise the insulin and glucose responses of the active group supports work which has suggested similar increases in trained subjects exposed to intermittent "maximal" exercise bouts of short duration (Hermansen et al., 1970). Furthermore, increases in serum insulin and glucose have been observed during exercise of moderate intensity in obese subjects or patients with reduced performance capacity due to cardio-vascular disease (Nikkilä et al., 1968) as well as "normal healthy" individuals following moderate exercise (Reinheimer, Davidson and Albrinck, 1968).

The importance of blood glucose as an energy substrate in exercise has been demonstrated despite reduced insulin levels (Wahren et al., 1971). Furthermore glucose assimilation into exercising muscle and its utilisation rate during exercise has been shown to be somewhat inde-
However, under conditions where augmented glucose utilisation and reduced insulin levels have been observed during muscular activity, the existence of local insulin-like activity factors have been suggested but not proven conclusively (Couturier, Rasio and Conard, 1971; Devlin, 1963; Havivi and Wertheimer, 1964; Szabo, Szabo and Mahler, 1972).

In the present study the variability in the magnitude of insulin levels between active and sedentary subjects reflected physiological differences between the two groups of subjects. The sedentary group were heavier, with a lower percentage of lean body weight and a higher resting insulin level than the active group. These observations are consistent with evidence that demonstrates that variability of basal insulin level is a function of relative adiposity (Porte and Bagdade, 1970), although the influence of dietary regime on basal insulin level cannot be overlooked (Muller, Falloon and Unger, 1971). Furthermore the proportionately greater elevation of insulin level observed in the sedentary subjects during exercise, may have been due in part to an increased rate of insulin secretion by these subjects (Nikkilä et al., 1968) and possibly to a higher insulin sensitivity on the part of the active subjects (Björntorp et al., 1972). Indeed this may explain why, in the case of active subjects, blood glucose concentrations were maintained at or increased above resting values during exercise when compared with their sedentary counterparts.

It is possible that the responses observed in the sedentary group may have represented hyperinsulinaemic obese subjects, whereas the active group represented normal insulinaemic non-obese subjects, although no glucose tolerance tests were carried out to determine if any sub-clinical diabetics were included in the sample.

In summary, the variations in serum insulin and glucose observed between active and sedentary subjects in this study, probably represent chronic differences associated with subjects of widely contrasting fitness status (Björntorp et al., 1972). Furthermore, it is likely that the differences observed between the two groups reflect not only the long term effects of physical conditioning, but also variations in lifestyle, since it was ascertained by personal interview, that the groups of subjects selected had maintained "active" and "sedentary" lifestyles since early adulthood.

The experiments described in this paper were approved by the Committee on the Use of Human Subjects in Research at Purdue University.

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The second part of this work will be published shortly in another number of B.J.S.M.

REFERENCES


