# Influence of the Sympathetic Nervous System on Insulin Sensitivity and Adipose Tissue Metabolism: A Study in Spinal Cord–Injured Subjects

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**To evaluate insulin sensitivity and adipose tissue metabolism, seven spinal cord–injured (SCI) subjects (age, 43 ± 6 years; body mass index, 22.8 ± 1.4; mean ± SE) and their seven siblings (age, 45 ± 6 years; body mass index, 24.8 ± 0.8) were studied using oral glucose (100-g) tolerance tests (OGTTs), euglycemic insulin clamps (insulin infusion, 1 mU/kg · min), and microdialysis of the subcutaneous tissue. Blood glucose and insulin after oral glucose were significantly increased in SCI subjects as compared with their siblings. During insulin clamping, plasma adrenaline increased significantly in controls, but not in SCI subjects. However, the rates of glucose production (2.02 ± 0.36 *v* 1.59 ± 0.09 mg/kg · min) and utilization (5.13 ± 0.71 *v* 5.78 ± 0.34) were similar in the two groups. Furthermore, interstitial subcutaneous glycerol and lactate concentrations before and after oral glucose were similar in the two groups, even in neurally decentralized tissue with broken connection between the central nervous system and peripheral sympathetic nerves. The data suggest that (1) well-mobilized SCI subjects show minor insulin resistance, and (2) sympathetic nervous activity has a minor influence on adipose tissue metabolism in the postabsorptive state, but may affect insulin sensitivity during euglycemic clamping.**


TYPE II DIABETES, abdominal obesity, and essential hypertension are often seen in combination, and in general these diseases are complicated by insulin resistance.[1] These patients are at high risk for cardiovascular disease and also show a similar unfavorable plasma lipoprotein pattern.[1] In the search for common pathophysiological risk factors for such an insulin-resistance syndrome, it should be noted that insulin resistance could be either primary (inherited)[2,3] or secondary to abdominal obesity,[4] diabetes, disease, or other metabolic disturbances.[5] Furthermore, insulin resistance, albeit correlating with both cardiovascular morbidity[6] and essential hypertension,[7] may not be a causal factor, but could alternatively be a phenomenon coincident with other causal factors such as activation of sympathetic nerves and β-adrenergic stimulation, as well as cortisol oversecretion, both of which could regulate systemic blood pressure and reduce insulin sensitivity.[8]

To elucidate the above considerations, investigation of spinal cord–injured (SCI) subjects with disrupted sympathetic pathways may provide a special opportunity to differentiate between tentative causal factors of importance for insulin resistance. β-Adrenergic stimulation induces a rapid decrease in insulin sensitivity both in the liver and in the muscles.[9] The insulin resistance is exerted through activation of lipolysis and elevated plasma levels of free fatty acids (FFA),[10] as well as elevated intracellular cyclic adenosine monophosphate levels in the insulin-sensitive cells.[11] Paradoxically, SCI subjects with autonomic dysfunction are reported to have an increased risk for cardiovascular morbidity and mortality,[12] as well as insulin resistance,[13] even after the post-injury immobilization period,[14] although neither study specifically addressed the autonomic nervous system. It thus seems that the importance of insulin resistance, sympathoadrenergic activation, and lipolytic activity for cardiovascular morbidity may not be clear, or alternatively, other negative factors such as muscle dysfunction and abdominal obesity may overrule the sympathetic nervous influence, at least in SCI subjects.

In this study on a group of SCI subjects, data were compared with those obtained from their siblings to adjust for the possible presence of genetically inherited insulin resistance. Both groups were subjected to an oral glucose tolerance test (OGTT), determination of plasma levels of counterregulatory hormones, and euglycemic clamping. Furthermore, to elucidate the influence on insulin sensitivity, adipose tissue metabolism was monitored with a microdialysis catheter measuring the glycerol and lactate concentrations directly in the subcutaneous interstitial water space.[15] The calibrated microdialysis technique enables the measurement of lipolytic rates, as well as lactate release, in the adipose tissue.[16,17] In this study, microdialysis was performed in the subcutaneous adipose tissue at two sites, one above and one below the level of sympathetic decentralization, to evaluate the role of the central sympathetic nervous system in adipose tissue metabolism.

## SUBJECTS AND METHODS

### *Subjects*

Characteristics of patients and controls are presented in Table 1. Seven SCI subjects (five men and two women) with a complete motor and sensory cord lesion at the TIII-TIV level (Frankel A) were investigated. All lived in their own homes. Five of the seven were working or studying, one was an old-age pensioner, and one was receiving a disability pension. The study group was also selected to represent an active section of the SCI population less susceptible to metabolic abnormalities from an inhibited life-style; the minimal level of fitness for all subjects fully met the needs for a totally independent life in a wheelchair. Five of the seven patients

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**Table 1. Clinical Characteristics of Study Subjects**

| | SCI (n = 7) | Control Siblings (n = 7) |
|---|---|---|
| Age (yr) | 43 ± 6 | 45 ± 6 |
| Weight (kg) | 70 ± 3 | 79 ± 3 |
| Lean weight (kg) | 56 ± 4 | 60 ± 3 |
| Body fat mass (kg) | 14 ± 2 | 18 ± 2 |
| Height (cm) | 177 ± 4 | 178 ± 3 |
| Body mass index | 22.8 ± 1.4 | 24.8 ± 0.8 |
| Level of injury | TIII-TIV | |
| Sex (M/F) | 5/2 | 5/2 |
| Systolic blood pressure (mm Hg) | 116 ± 5 | 119 ± 5 |
| Diastolic blood pressure (mm Hg) | 70 ± 4 | 72 ± 1 |
| Occupation | | |
| Working | | |
| Full-time | 1 | 4 |
| Part-time | 3 | 0 |
| Student | 1 | 1 |
| Pensioner | 1 | 2 |
| On sick leave | 1 | 0 |

NOTE. Values are the mean ± SE. All differences are nonsignificant.

also participated in regular wheelchair training or swimming. However, there is no physiological method for validating the impact of midthoracic paraplegia on performance in everyday life in a wide age range of subjects. Their primary care, periods of physiotherapy, and annual follow-up evaluation had been provided at the Spinal Unit, Sahlgrenska Hospital, Gothenburg, and the present study took place 2 to 10 years post-injury.

To control for inherited confounding factors, siblings were studied as controls. The history of subjects and controls did not reveal morbidity or medication interfering with the present investigation. Two SCI subjects smoked and were instructed to refrain from tobacco use for at least 24 hours before study. No control subject smoked. A family history of hypertension and type II diabetes mellitus was registered in one pair of siblings each. The mean age, body weight, height, and body fat mass, estimated with the bioelectric impedance method,[18] were similar in the two groups (Table 1). The bioelectric impedance methodology was recently validated in SCI patients by Spungan et al[18a] and in our laboratory by comparison with dual-energy x-ray absorptiometry ($r$ = .90). All subjects were normotensive (Table 1). All subjects except one were free from medication for 12 hours before the clamp. Because of severe spasticity, one SCI patient used 5 mg diazepam and 50 mg baclofen daily.

To visualize the broken sympathetic connection in the cord, we performed a forced-perspiration test. The subjects were placed with their hands and wrists in 40°C water, and the sweat droplets were visualized beneath a thin plastic film. The choice of a cord transection level at TIII-TIV was intended to provide a margin for the microdialysis to take place in neurologically intact and sympathetically decentralized adipose tissue. The level of anhidrosis, as modified from the study by Normell,[19] was found to be within ± one level of sensory disruption. The thickness of the subcutaneous adipose tissue in the clavicular region was measured by ultrasonography.

All subjects gave their informed consent to inclusion, and the study was approved by the Ethical Committee of the University of Gothenburg.

## *Study Protocol*

*Microdialysis.* After fasting overnight, the subjects arrived at the laboratory at 8 AM . They were studied in the supine position. The room temperature was kept at 26°C to guarantee optimal microdialysis conditions. A polyethylene catheter was placed in the left forearm vein for blood sampling. The forearm was heated with electric pads (60° to 70°C) to arterialize the venous blood. Microdialysis catheters (30 × 0.3 mm, Cuprophan B4 AH, 3000 MV cutoff, Cobe, Denver, CO) were placed in the right abdominal subcutaneous adipose tissue 5 cm lateral to the umbilicus, and in the subcutaneous tissue 5 cm above the level of denervation on the right side. The nylon-tubing inlet of the microdialysis catheter was connected to a microinjection pump (Carnegie Medicine, Stockholm, Sweden), and isotonic saline with 2.5 mmol/L glucose perfused the system at a rate of 2.5 μL/min. After a 90-minute equilibration, a calibration procedure was performed. In this study, five different concentrations of glycerol (0 to 300 μmol/L) were administered, and the net change of metabolite concentration in the dialysate was recorded ($glycerol_{out} - glycerol_{in}$ = net change). A linear relationship was established between the added concentration of glycerol in the perfusate and the concentration change in the dialysate. Hence, the concentration of glycerol in the perfusate equilibrating with the interstitial glycerol concentration could be calculated by regression analysis. Recovery of interstitial lactate concentrations in dialysates were set to be 51% according to historical control data (N = 32). The use of standard recovery factors obtained in numerous control subjects has been validated in detail previously.[20] The dialysate was sampled in 10-minute fractions.

After calibration, the subjects ingested 100 g glucose dissolved in 100 mL lemon-flavored tap water. Blood samples were drawn just before the glucose load, and metabolite levels in the subcutaneous tissue and arterialized venous blood were evaluated for 2 hours. The samples were kept on ice and immediately centrifuged (3,000 × $g$, +4°C). Blood plasma and dialysates were stored at −20°C until analyzed.

*Fat cell characterization.* After completion of microdialysis, two fat biopsies were aspirated in each subject contralateral to the microdialysis sites. The mean fat cell size and fat cell number per kilogram adipose tissue were estimated as previously described.[21]

*Clamp study.* The second day, after an overnight fast, euglycemic hyperinsulinemic clamping was performed essentially according to the method of DeFronzo et al[22] as previously described in detail.[23] The insulin infusion started with a primed infusion for 10 minutes followed by a constant infusion of 1 mU/kg/min for 120 minutes.

To determine the glucose turnover, we used D-(3-$^3$H)glucose infusion. After a primed infusion of 25 μCi, a constant infusion (15 μCi/h) of D-(3-$^3$H)glucose for 120 minutes was performed. The blood glucose concentration was measured every 5 minutes with a reflectometer (Reflolux, Clinicon Boehringer, Mannheim, Germany) and test strips (BM-test glycemic 1-44, Boehringer). The rate of glucose infusion was adjusted to maintain blood glucose at normoglycemia 5 mmol/L. Potassium chloride was infused (7 mmol/h) to prevent hypokalemia.

## *Analysis of Samples*

The glycerol content in tissue dialysate and plasma was determined according to the method of Laurell and Tibbling.[24] Lactate in dialysate and plasma was treated according to the method of Loomis (1961), and aliquots were read on a spectrofluorometer.[25]

Glucose and plasma FFA contents were estimated enzymatically (Wako Chemicals, Germany), as were cholesterol and triglycerides (Boehringer).[26,27] High-density lipoprotein (HDL) was analyzed according to the method of Seigler and Wu,[28] and the low-density lipoprotein (LDL) content was calculated according to the formula given by Friedewald et al.[29] Insulin, growth hormone, cortisol, and

catecholamine levels in plasma were measured at the Department of Clinical Chemistry (accredited according to Organization for Economic Cooperation and Development [OECD] standards), University of Gothenburg, using radioimmunoassays.

### *Calculations*

As a measure of glucose production, the rate of appearance was calculated as previously described.[23] The rate of glucose utilization was estimated under euglycemic clamp conditions by adding the mean rate of the calculated glucose infused. Data used in the calculations were obtained during steady-state conditions prevailing in the second hour of insulin clamping.

### *Statistical Analyses*

In microdialysis calculations, regression analyses were performed with the least-squares method and linear correlation was tested using Pearson's correlation coefficient. Student's two-tailed *t* test was used for unpaired data. All values are the mean ± SE.

## RESULTS

Postabsorptive values for blood glucose, plasma lipids, FFA, insulin, C-peptide, adrenaline, noradrenaline, glucagon, and cortisol were similar in the two groups (Tables 2 and 4). Plasma growth hormone was significantly increased in the SCI group (Table 4).

### *OGTT*

During the OGTT, the SCI group showed higher blood glucose than the control group, and the area under the curve was significantly increased ($P < .05$; Fig 1A). The insulin area under the curve during the OGTT was also significantly increased ($P < .05$; Fig 1B). Plasma catecholamines showed no differences between the groups after the glucose load (not shown).

### *Euglycemic Hyperinsulinemic Clamp*

Fasting insulin values in the SCI and control groups were 0.089 ± 0.042 and 0.121 ± 0.05 pmol/L, respectively. Mean values during the clamp were 0.835 ± 0.18 pmol/L in the SCI group, as compared with 0.795 ± 0.154 in the control group (NS). Plasma C-peptide was totally suppressed throughout the clamp (data not shown).

The glucose infusion rate (mg/kg/min) was similar in the two groups (Table 3). Accordingly, the hepatic glucose production rate, estimated by $^3$H-glucose infusion and indicated as the rate of glucose appearance and the rate of disappearance of glucose, which reflects the peripheral glucose uptake, was similar in the two groups (Table 3).

**Table 2. Biochemical Profiles of Study Subjects**

| | SCI | Control Siblings |
|---|---|---|
| B-glucose (mmol/L) | 4.6 ± 0.1 | 4.4 ± 0.1 |
| Insulin (pmol/L) | 0.089 ± 0.04 | 0.121 ± 0.05 |
| Triglycerides (mmol/L) | 1.20 ± 0.32 | 1.04 ± 0.37 |
| Cholesterol (mmol/L) | 1.13 ± 0.13 | 1.19 ± 0.16 |
| LDL fraction (mmol/L) | 3.17 ± 0.47 | 3.73 ± 0.49 |
| HDL (mmol/L) | 1.25 ± 0.11 | 1.19 ± 0.16 |
| LDL/HDL | 2.68 ± 0.52 | 1.26 ± 0.64 |
| FFA (mmol/L) | 0.75 ± 0.08 | 0.75 ± 0.05 |

NOTE. Values are the mean ± SE. All differences are nonsignificant.

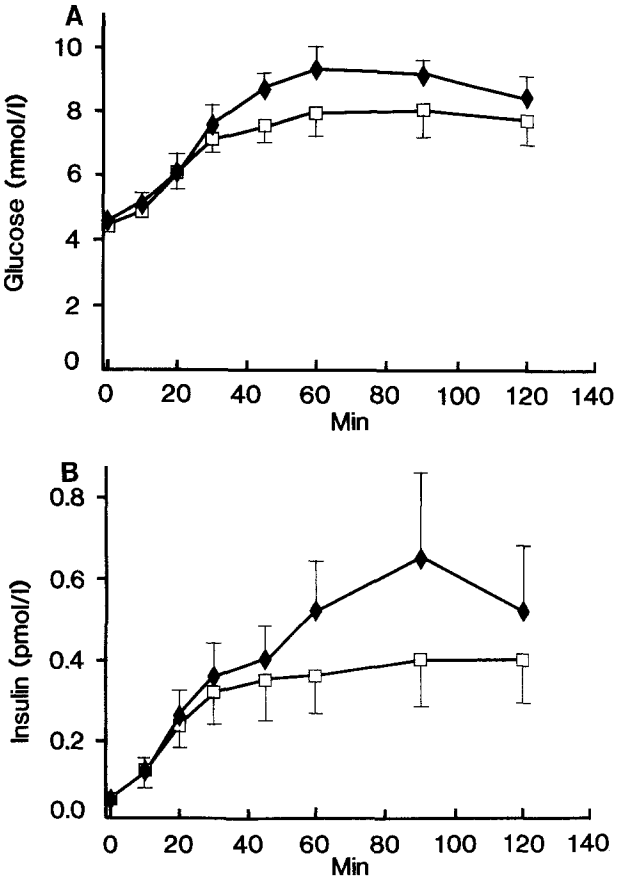


**Fig 1. Plasma (A) B-glucose and (B) insulin during an OGTT. Each subject ingested 100 g glucose at time zero. (◆) SCI subjects (n = 7); (□) control siblings (n = 7). Data are the mean ± SE.**

Plasma adrenaline was significantly decreased in SCI subjects during the insulin clamp (Table 4). Moreover, in the control group plasma adrenaline increased significantly during the clamp, whereas no such increase was seen in SCI patients. However, noradrenaline in plasma was maintained similarly in the two subject groups throughout the study period (Table 4).

Plasma glucagon at the start of the clamp was similar in the two groups. However, at the end of the clamp, there was a significant difference in plasma glucagon between the groups, with the control group showing higher values than the SCI group (Table 4).

In the postabsorptive state, growth hormone was significantly increased in SCI patients (Table 4). However, during the insulin clamp period this difference was not apparent.

**Table 3. Euglycemic Hyperinsulinemic Clamp Results**

| | SCI | Control Siblings |
|---|---|---|
| Glucose infusion rate | | |
| mg/kg body weight/min | 4.37 ± 0.7 | 5.20 ± 0.6 |
| mg/kg lean weight/min | 5.35 ± 0.78 | 6.81 ± 0.79 |
| Rate of appearance (mg/kg/min) | 0.47 ± 0.47 | −0.40 ± 0.20 |
| Rate of disappearance (mg/kg/min) | 5.13 ± 0.71 | 5.78 ± 0.34 |

NOTE. Values are the mean ± SE. All differences are nonsignificant.

**Table 4. Hormone Concentrations Before and During Insulin Clamp**

| | Time (min) | SCI | Control Siblings | P |
|---|---|---|---|---|
| Growth hormone (nmol/L) | 0 | 4.14 ± 1.33 | 1.01 ± 0.46 | .05 |
| | 120 | 3.64 ± 2.28 | 3.16 ± 2.44 | NS |
| | 180 | 3.60 ± 1.79 | 2.85 ± 1.51 | NS |
| | 240 | 1.47 ± 0.76 | 6.73 ± 4.07 | NS |
| Adrenaline (nmol/L) | 0 | 0.01 ± 0.01 | 0.13 ± 0.07 | NS |
| | 120 | 0 ± 0 | 0.18 ± 0.13 | NS |
| | 180 | 0.03 ± 0.02 | 0.23 ± 0.06 | NS |
| | 210 | 0.03 ± 0.02 | 0.15 ± 0.04 | .02 |
| | 240 | 0.02 ± 0.02 | 0.20 ± 0.06 | .01 |
| Noradrenaline (nmol/L) | 0 | 0.99 ± 0.29 | 1.53 ± 0.36 | NS |
| | 120 | 0.81 ± 0.16 | 1.31 ± 0.28 | NS |
| | 180 | 0.96 ± 0.22 | 1.54 ± 0.34 | NS |
| | 210 | 0.86 ± 0.17 | 1.54 ± 0.36 | NS |
| | 240 | 0.89 ± 0.16 | 1.60 ± 0.39 | NS |
| Glucagon (pmol/L) | 0 | 17.44 ± 1.43 | 16.54 ± 0.85 | NS |
| | 180 | 12.73 ± 0.60 | 14.74 ± 0.78 | NS |
| | 240 | 12.39 ± 0.46 | 16.03 ± 1.28 | .02 |
| C-peptide (nmol/L) | 0 | 0.60 ± 0.12 | 0.53 ± 0.05 | NS |
| | 210 | 0.52 ± 0.05 | 0.39 ± 0.04 | NS |
| | 240 | 0.48 ± 0.06 | 0.31 ± 0.03 | NS |
| Cortisol (nmol/L) | 0 | 340.66 ± 26.68 | 367.27 ± 47.47 | NS |
| | 120 | 208.03 ± 20.27 | 252.26 ± 40.74 | NS |
| | 180 | 301.10 ± 65.10 | 394.84 ± 36.07 | NS |
| | 240 | 248.70 ± 24.21 | 260.16 ± 31.33 | NS |

Also, plasma cortisol was similar in the two groups throughout the study.

*Interstitial and Plasma Glycerol and Lactate Concentrations*

Interstitial subcutaneous glycerol concentrations as estimated by the microdialysis approach before and during an OGTT are depicted in Fig 2. There were no differences either between the groups or between the regions in subcutaneous interstitial glycerol before the glucose load. Interstitial glycerol was approximately three times the plasma level (Fig 2A and B). Also, plasma glycerol was similar in the two groups.

During the OGTT interstitial glycerol decreased, following similar kinetics in both groups. There were no significant differences within groups when comparing values from the clavicular region with those from the umbilical region (Fig 2A and B). Moreover, the interstitial-arterial difference in glycerol was similar in both regions in both study groups (not shown).

The lactate concentration in plasma and in interstitial water was measured concomitantly (Fig 2C and D). There were no differences between groups or between regions when comparing interstitial values. Plasma lactate was increased in the SCI group, showing significantly higher values at the end of the OGTT (Fig 2C). However, the interstitial-arterial lactate concentration difference was similar in the regions investigated in the two groups (not shown).

*Fat Cell Size*

The mean fat cell size in the two adipose tissue regions was similar in the two groups. At the umbilical level, the mean fat cell surface area was 27 ± 3 $\mu m^2$ in the SCI group versus 33 ± 1 in the control group. In the clavicular region, the mean cell surface area was 28 ± 3 and 33 ± 1 $\mu m^2$, respectively.

## DISCUSSION

This study shows a clear but small insulin resistance in physically active, independently living SCI subjects as compared with their siblings. The data indicate normal glucose tolerance, whereas the significantly higher plasma insulin levels during the OGTT indicate insulin resistance. However, insulin sensitivity during euglycemic insulin clamping appeared only slightly and insignificantly decreased when the effect of insulin on glucose production, as well as glucose uptake, was assessed. The discrepancy in data is not explained by the present investigation. However, our design, allowing correction for inherited factors for insulin resistance in the present study, may have importance for the prevalence of insulin resistance and the similarity in the two groups. The patients participating in the present study were all physically active and thus may have compensated for the insulin resistance by enhanced insulin sensitivity in active muscle groups. Besides this discrepancy in data, there is also an obvious controversy in the finding of normal insulin sensitivity during clamp conditions, whereas insulin sensitivity was slightly decreased during an OGTT in the present study group. However, it should also be noted that plasma catecholamine were not increased in either of the study groups during the OGTT, whereas the control siblings had significantly higher plasma values during the insulin clamp, indicating that sympathicoadrenergic activation took place only in this group. Hence, it is possible that sympathetic nervous activity induced by the clamp conditions but not during the OGTT influenced the insulin sensitivity in control subjects, but not in SCI subjects lacking central sympathetic nerve activation. It is well known that a spinal cord injury at a high thoracic or cervical level implies a loss of the increase in sympathetic nervous activity and adrenaline release seen after insulin-induced hypoglycemia.[30] The major source of noradrenaline during rest in this SCI study is most likely the decentralized sympathetic nervous system. The levels found accord with those reported by others.[31] β-Adrenergic stimulation during insulin infusion and hypoglycemia effectively and rapidly induces insulin resistance by activation of lipolysis,[10] as well as a direct influence on the insulin target cell by elevated cyclic adenosine monophosphate levels interacting with the insulin receptor signaling system.[11] It may thus be concluded from the present study that well-rehabilitated SCI subjects actually have a slight insulin resistance. Furthermore, the data suggest the possibility that sympathetic nervous activation influences the measurement of glucose metabolism during an insulin clamp in normal man.

In this study, adipose tissue metabolism was investigated with the microdialysis technique. Previous investigation has shown that the estimated interstitial glycerol concentration serves as a marker for the cellular lipolytic rate.[32] Notably, glycerol concentrations in interstitial water were similar in the two groups, and interestingly, glycerol tissue concentra-

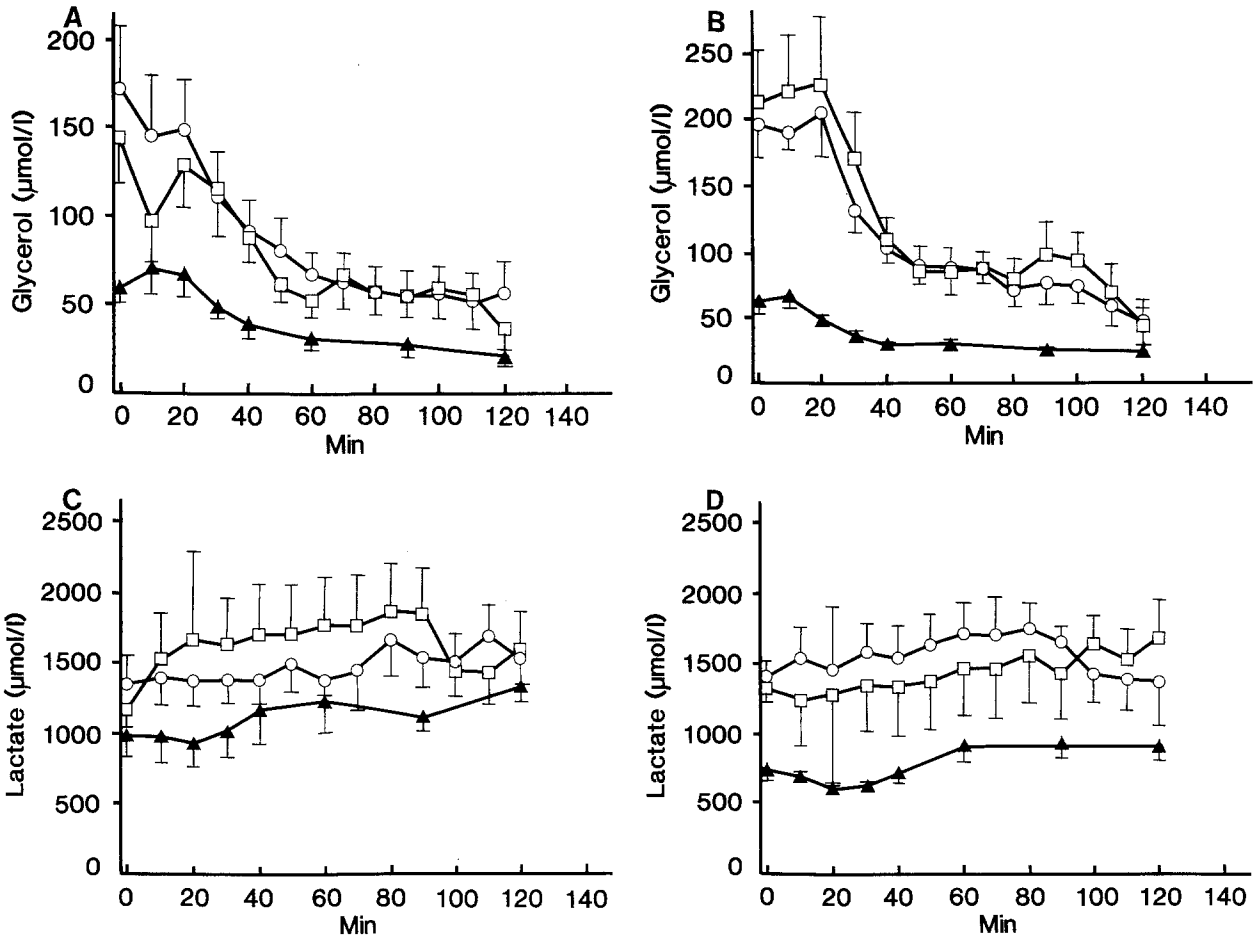


**Fig 2. Glycerol levels in (A) SCI subjects as compared with (B) control siblings before and after oral glucose (100 g). (▲) Plasma glycerol; (□) interstitial glycerol in the clavicular region; (○) interstitial glycerol in the umbilical region. Lactate levels in (C) SCI subjects as compared with (D) control siblings before and after oral glucose (100 g). (▲) Plasma lactate; (□) interstitial lactate in the clavicular region; (○) interstitial lactate in the umbilical region. Data are the mean ± SE.**

tions were not different in denervated tissue in SCI subjects (Fig 2A). The interstitial glycerol concentration is dependent on the lipolytic rate and the tissue blood flow.[32] Adipose tissue blood flow is subject to autoregulation,[33] and this seems to be normal in tissue lacking centralized sympathetic nervous activity.[34] Although adipose tissue blood flow was not measured in this study, it may then be reasonable to suggest that the data indicate a minor influence of sympathetic nervous activity and catecholamine stimulation on the lipolytic rate during the basal postabsorptive state. Accordingly, the decline in interstitial glycerol after an oral glucose load did not differ between the groups even in tissue lacking central regulation of sympathetic nervous activity. Oral glucose leads to subcutaneous vasodilation, and this might be of importance for the decline in interstitial glycerol.[32] However, the present finding that plasma glycerol levels were normal and that the decline in glycerol was kinetically normal even in denervated tissue indicates that this mechanism may be less important for glycerol output under nonstressed conditions. Instead, the interstitial insulin concentration[35] is suggested to play a more important role in the regulation of subcutaneous glycerol output. It should be noted in this context that growth hormone levels were elevated in plasma from SCI subjects postabsorptively, and that this might compensate for the reduced catecholamine influence on the lipolytic rate. However, this may be considered less likely, since plasma growth hormone levels were not elevated and lipolysis was still normal in these subjects following oral glucose.

Similar to the interstitial glycerol levels, the interstitial lactate concentration also was not different in the two study groups in either tissue region. This, in turn, indicates that nonoxidative glucose metabolism in adipose tissue[17] is normal in SCI subjects. The significantly increased plasma lactate found after the OGTT in SCI subjects accords with the previous report on insulin-resistant subjects and the finding that plasma lactate correlates with the degree of insulin insensitivity.[36] The present data suggest that lactate production from tissues other than adipose tissue, such as splanchnic organs and muscles, may explain these increased plasma lactate levels in SCI patients. Lactate release from

adipose tissue is directly proportional to the adipose tissue mass,[37] which was not significantly increased in these subjects (Table 1).

When the levels of other plasma hormones and lipoproteins, as well as other risk factors for cardiovascular disease such as adipose tissue mass, the waist to hip ratio, and systemic blood pressure, were measured, very small or no differences appeared between the two study groups. This supports the previous view[38] that traditional risk factors for cardiovascular disease are not different in SCI subjects as compared with their siblings, and that an active life-style and successful rehabilitation are of importance for maintaining favorable plasma risk factor levels. The importance as a risk factor of the slight insulin resistance found in the present study remains to be evaluated in longitudinal investigations.

In summary, compared with their siblings, well-mobilized and physically active SCI subjects appear to have only minor insulin resistance. The data in the present study also indicate that the central autonomic nervous system does not influence lipolytic activity during basal nonstressed postabsorptive conditions.

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