Extreme subcutaneous insulin resistance: a misunderstood syndrome

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SUMMARY

Extreme subcutaneous insulin resistance (SIR) is a rare syndrome characterized by severe resistance to subcutaneous insulin with normal intravenous insulin sensitivity. Its pathophysiology is unknown, though an increased insulin degrading activity has been suggested. We report the case of a 35 year-old female patient with type I diabetes since the age of 3. Despite five shots of insulin/day, the patient progressively developed permanent ketosis related to severe acquired SIR with insulin doses as high as 500 U/day. Subcutaneous infusion of insulin and lispro insulin through an external pump did not improve resistance; HbA1c levels remained between 14 and 18% (N < 6.5%). After numerous ketoacidotic episodes, continuous ambulatory intravenous insulin infusion was attempted through a central port due to a lack of peripheral venous access. HbAlc improved (8.5%) and daily insulin needs decreased to below 40U. However, the treatment had to be discontinued because of thrombosis and infection at different times. Intraperitoneal insulin infusion with an external pump was then proposed. HbAlc improved to 8% during 18 months but several episodes of catheter infection and encapsulation led to its removal. An intraperitoneal pump was surgically implanted, leading to the stabilization of HbA1c to around 8%. An insulin degradation assay did not demonstrate any excess of insulin degrading activity in the patient’s or controls’ subcutaneous tissue; nevertheless, excessive amounts of insulin were found in the patient’s derm compared to controls. This case report of acquired SIR raises the question of its treatment and mechanisms. Regarding treatment, intraperitoneal delivery of insulin appears to be the best solution, but the mechanisms underlying SIR still remain unclear.

Key-words: Subcutaneous insulin resistance · Insulin-degrading enzyme · Intraperitoneal pump.

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RÉSUMÉ

Insulino-résistance sous-cutanée extrême : un syndrome mal compris

L’insulino-résistance sous-cutanée extrême (SIR) est un syndrome rare caractérisé par une résistance sévère à l’insuline sous-cutanée alors que la sensibilité à l’insuline intraveineuse est normale. La physiopathologie en est inconnue bien qu’une dégradation accrue de l’insuline ait été suggérée. Nous rapportons le cas d’une jeune femme de 35 ans présentant un diabète de type 1 depuis l’âge de 3 ans. En dépit de 5 injections d’insuline par jour, la patiente développait progressivement une cétose permanente liée à un SIR extrême acquis avec des doses d’insuline aussi élevées que 500 unités par jour. L’insuffusion sous-cutanée d’insuline et de lispro à l’aide d’une pompe ambulatoire n’améliorait pas l’insulino-résistance. Les taux d’HbA1c demeuraient entre 14 et 18% (N < 6.5%). Après de nombreux épisodes de cétose, l’insuffusion sous-cutanée d’insuline et de lispro a été entreprise via une pompe intra-péritonéale. Après 18 mois, plusieurs épisodes d’infection du cathéter et d’encapsulation conduisaient à son retrait. Une pompe intra-péritonéale était alors implantée chirurgicalement, conduisant à la stabilisation de l’HbA1c au voisinage de 8 %. Une mesure de la dégradation de l’insuline ne mettait pas en évidence d’accroissement de cette activité dans le tissu sous-cutané de la patiente par rapport aux témoins ; cependant des quantités excessives d’insuline étaient retrouvées dans le derme de cette patiente par rapport aux sujets contrôles. Ce cas clinique de SIR acquis soulève la question de son traitement et de ses mécanismes. Concernant le traitement, l’administration intra-péritonéale d’insuline semble la meilleure solution, mais les mécanismes demeurent mal élucidés.

Mots-clés : Résistance à l’insuline sous-cutanée · Enzyme de dégradation de l’insuline · Pompe intra-péritonéale.
xtreme subcutaneous insulin resistance (SIR) is a rare syndrome characterized by severe resistance to subcutaneous insulin with normal intravenous insulin sensitivity. The first cases were reported in the seventies by Schneider [1] and Paulsen [2]. The pathophysiology of SIR is unknown. An increased insulin degrading activity has been reported in the subcutaneous adipose tissue fraction [2]. We report a diabetic patient having developed insensitivity to subcutaneous but not to intravenous insulin who was dramatically improved by intraperitoneal insulin. A study of subcutaneous adipose tissue insulin content was performed. The objective of this case report was to review the data found in literature and, following, to define the clinical context in which SIR is diagnosed, the specific investigations that should be performed, and the treatments available.

Case report

Case history

A 35-year-old female patient was referred for extreme insulin resistance when insulin was injected subcutaneously. Her family history included a mother with type 2 diabetes, while her personal history was marked by type 1 diabetes since the age of 3 with undetectable C peptide and HLA susceptibility DR1/DR4 to type 1 diabetes. No information about the balance of her diabetes during childhood was available. She had been referred to our department fifteen years ago because of poor glycemia control attributed to dietary indiscretions and inappropriate scheduling of insulin injections. Despite her compliance, imbalance progressively worsened with permanent life-threatening ketosis. It became obvious that ketosis could only be reduced via intravenous insulin therapy, since subcutaneous injections were totally ineffective. When the patient was referred to our department again, there was no sign of macroangiopathy but microangiopathy had appeared, characterized by laser-treated retinopathy, microalbuminuria and mild axonal neuropathy. Her body mass index was 32 kg/m² and waist/hip ratio < 0.85. Permanent ketosis was noted despite subcutaneous insulin doses as high as 500 U/day. The patient was hospitalized for months on account of numerous ketoacidotic episodes that occurred as soon as she was switched from intravenous insulin back to subcutaneous injections. Infections (urinary tract infection, sinusitis) were extremely frequent. Because of repeated antibiotic treatments and unbalanced diabetes, systemic candidosis developed. It was resistant to common antifungic drugs, and required intravenous antifungic treatment that induced transient nephrotoxicity.

Treatment

The follow-up of weight, glycated HbA₁c, and insulin delivery route is given in Figure 1. Briefly, subcutaneous injections of human insulin and lispro insulin analog were inefficient: HbA₁c levels remained between 14 and 17.9% (N < 6.5%). Subcutaneous infusion of insulin through an external pump did not improve this resistance (HbA₁c: 14.5%). After numerous ketoacidotic episodes and permanent ketosis, continuous ambulatory intravenous insulin infusion was attempted through an implanted venous access port due to a lack of peripheral venous access. HbA₁c subsequently improved (8.5%) and daily insulin need decreased to below 40U. However, the treatment had to be discontinued because of thrombosis and infection at different times. Intraper-
During 12 months. Insulin needs averaged 30 to 40 U/day.

**Causes of insulin resistance**

This patient had none of the known causes of insulin resistance, whether physiological or pathological. She had no hormonal dysregulation, no increase in the circulating antibodies to insulin or to insulin receptors. Her sensitivity to intravenous insulin was not in favor of a genetic cause. She had neither lipo-dystrophy, atrophy nor dyslipidemia. Plasma levels of adipokines such as PAI-1 (0 UI/ml-N < 16) and interleukine 6 (12.3 pg/ml-N < 20) were normal, as was the urinary THE/THF ratio reflecting 11-betahydroxysteroid dehydrogenase activity. Increased plasma leptin levels (33 ng/ml-N; 7.4 ± 3.7) related to her mild obesity were noted. No evidence of surreptitious administration of insulin could be found. An insulin challenge testing comparing insulinemia after 0.1 or 0.5 units of insulin/kg of body weight, injected either subcutaneously or intravenously, was performed with difficulties in reason of very poor peripheral veins. The results (Fig 2) showed 1) a significant decrease of glycemia only when insulin was injected intravenously by comparison with subcutaneous injections whatever the dose; 2) higher insulinemia levels with intravenous insulin/kg of body weight, injected either subcutaneously or intravenously, was performed with difficulties in reason of very poor peripheral veins. The results (Fig 2) showed 1) a significant decrease of glycemia only when insulin was injected intravenously by comparison with subcutaneous injections whatever the dose; 2) higher insulinemia levels with intravenous insulin compared to subcutaneous insulin resistance related to a possible excess of insulinase and undertook a study of subcutaneous tissues.

**Study of subcutaneous tissue**

**Methods**

**Specimens**

The subcutaneous injections of insulin were withheld for more than 3 weeks before sampling. Having obtained the informed consent of the patient, subcutaneous biopsy specimens were taken from the periumbilical region when the pump was implanted, rinsed briefly in cold isotonic sodium chloride, immediately chilled to 4 °C and frozen within one hour at – 20 °C. Control subcutaneous biopsy specimens were also obtained in two non diabetic, non obese women who had undergone other surgical procedures.

**Preparation of tissue extracts**

Measurement of insulin proteolytic activity and insulin content was performed in tissue extracts (adipose tissue and derm). The homogenization of samples was adapted from Paulsen et al. [2] and Tetaert et al. [3]. Thawed samples were homogenized in a 200 mM sucrose -250 mM NaCl solution (1ml per gram of tissue) at 4 °C using a Potter-Elvehjem teflon-glass homogenizer and centrifuged at 3300 g for 15 minutes at 4 °C. The sucrose solutions were collected. Moreover, the fat layer (for the adipose tissue homogenates) and the particulate pellet (for the derm homogenates) were resuspended in 1 ml of the sucrose-NaCl solution + 0.1% Triton X-100/gm and incubated at room temperature on a rotating mixer for one hour before centrifugation at 3300 g for 15 minutes at 4 °C. The Triton was used at 0.1% in order to lyse the intact cellular structures since this concentration did not inhibit the insulinase activity from haemolysed sera (data not shown). The sucrose solutions were collected again. The protein content of each of these soluble extracts was determined by the method of Bradford [4] using the Bio-Rad Protein assay kit (Biorad, Ivry s/Seine, France) with bovine serumalbumin as reference standard. Before measuring the insulin degrading activity, the fractions were diluted in the sucrose-NaCl solution in order to get a protein concentration of 2 g/l.

**Insulin degradation assay**

Incubation conditions were adapted from Shearet al. [5]. Briefly, for each of the tissue extracts, we incubated at 37 °C for 60 minutes: (I) 100 µl of a 500 mUI/l insulin standard solution with (II) 40 µl of 20 mM 2-(N-Morpholino)ethanesulfonic acid (pH 7.5) (Sigma, St. Louis, MO, USA) containing 1.5 mM MgCl2, 5 mM KCl and 0.5% bovine serum albumin, (III) 50 µl of the sucrose-NaCl solution, and (IIII) 10 µl of the diluted soluble extracts. The reaction was stopped by the addition of 10 µl of a 50 mM p-hydroxymercuribenzoic acid (Sigma, St. Louis, MO, USA) in 0.02 N NaOH/water solution [6] and the incubation media were immediately frozen at – 80 °C. The insulin concentration of each preparation was measured before and after the incubation using a radioimmunometric sandwich assay (Bi-Insulin IRMA, Cis-Bio International, Gil sur Yvette, France). In these incubation conditions we were able to evidence a 16.4% degradation of the added insulin in 60 minutes at 37 °C using a hemolysed serum (hemoglobin: 2.7g/l) instead of soluble extracts. Moreover, the insulin concentration of the soluble extracts was assayed using the same kit.

**Results**

**Insulin degradation assay**

The recovery of insulin was about 100% whatever the extract we tested. Consequently, these results did not evidence any insulin degrading activity in the tissues of the patient (Tab I.).
Insulin concentration in the tissues

The insulin levels yielded by the IRMA kit were higher in the soluble extracts of the patient than in the control ones. Moreover, we observed in the patient that the insulin concentrations are higher in the derm extracts than in the adipose tissue extracts (Tab II). These results are in favor of an insulin sequestration in the derm.

Discussion

The case we present had type 1 diabetes documented by young age of occurrence, undetectable C peptide and genetic susceptibility. The patient progressively developed extreme insulin resistance as demonstrated by repeated infections and numerous ketoacidotic episodes when insulin was given subcutaneously, but she remained sensitive to intravenous insulin.

About 20 to 25 cases of diabetic patients with insensitivity to subcutaneous but not intravenous insulin have been reported in literature [1, 2, 7-19] (Tab III). As in our case, most of the reported patients were young women with insulin-dependent diabetes. Their subcutaneous insulin resistance was revealed by numerous DKA or permanent ketonuria and recurrent infections. It sometimes was simply transient, and sometimes transient and recurrent. In 1979, Paulsen [2] rigorously defined this syndrome according to three criteria: 1) resistance to the hypoglycemic action of subcutaneous insulin, but not to intravenous insulin, associated with 2) lack

Figure 2
Insulin challenge testing adapted from Schade’s protocol (Tab IV). A) Evolution of blood glucose (G). B) Evolution of insulin plasma level (I) after subcutaneous (SC) or intravenous (IV) injection of 0.1 or 0.5 unit of insulin/kg of body weight. The results show 1) a significant decrease of blood glucose only when insulin was injected intravenously (G IV 0.1 and G IV 0.5) by comparison with subcutaneous injections (G SC 0.1 and G SC 0.5) whatever the dose; 2) higher insulinemia levels with intravenous (I IV, especially at the dose 0.5 units of insulin/kg of body weight) than with subcutaneous route (I SC 0.1 and 0.5). All times could not be sampled in reason of very poor vein net. Abbreviations: for instance: G SC 0.1: Curve of blood glucose after subcutaneous injection of 0.1 unit of insulin/kg of body weight. I IV 0.5: Curve of insulinemia after intravenous injection of 0.5 unit of insulin/kg of body weight.
and skin temperature. These hypotheses cannot be elimi-
to day, especially according to the site and depth of injections
may greatly vary from one patient to another and from day
physiological degradation of insulin in subcutaneous tissue
factitious, is very difficult [20, 21]. Moreover, it is known that

teria, differential diagnosis with brittle diabetes, sometimes
report [11]. However our patient never experimented hy-
subcutaneous tissue of the patient as in Freidenberg's case
hypothesis of excessive degradation by subcutaneous pro-
hibitor, has been considered as arguing for the
insulin. In several reports, the effectiveness of aprotinine, a
activity during the periods of insulin sensitivity was checked
in at least one case [13]. A tritiated-insulin absorption test has
also shown abnormalities in insulin degradation products
[10]. Contrasting with these data some authors have found
large amounts of insulin in subcutaneous tissue, associated
with very severe hypoglycemias that rather suggest that in-
studied a series of 16 patients with apparent SIR syndrome
according to a strictly controlled protocol following Paulsen's criteria and completed the study with a tritiated-insulin
absorption study (Tab IV). He was unable to demonstrate
any defect of insulin absorption or the presence of insulin
degrading enzyme in any patients. Two of the patients in his
series had been previously reported by Freidenberg [11] and
successfully treated with aprotinine and then intraperitoneal
insulin. In several reports, the effectiveness of aprotinine, a
protease inhibitor, has been considered as arguing for the
hypothesis of excessive degradation by subcutaneous pro-
cases. In our case, we found very high levels of insulin in the
subcutaneous tissue of the patient as in Freidenberg's case
report [11]. However our patient never experimented hy-
poglycemias and we were unable to demonstrate any increase
of insulin-degrading activity.

Insulin degradation is a regulated process that includes the
uptake, processing and degradation of the hormone [23,
24]. It is mediated through a multifunctional insulin degradi-
ing enzyme (IDE) which is an intracellular binding, regula-
tory and degradative protein controlling insulin action in
association with other systems such as lysosomes and other
enzymes. IDE is a sulfhydryl-dependant metalloproteinase
with a zinc-binding site. This component of a cytosolic pro-
teolytic complex is relatively specific for a number of growth
factors and hormones, such as insulin, ANP, IgF1, amylin,
and proinsulin. It increases proteasome and steroid hormone
receptor activity, a procedure that is reversed by insulin. Pro-
tasome, a multicatalytic proteinase (MCP) is believed to be
important in non-ubiquitin pathways of cellular protein

| Table I | Insulin concentrations in incubation media after 60 minutes at 37°C. The results are expressed as percentages of initial insulin concentrations in the media before the incubation. |
|-----------------------------------------------|
| Residual insulin in whole adipose tissue soluble extract (%) | Patient 1 | Control patient 1 | Control patient 2 |
|---------------------------------------------------------------|
| 108 | 101 | 96 |
| Residual insulin in fat layer soluble extract (%) | 103 | 101 | ND |
| Residual insulin in whole derm soluble extract (%) | 104 | 106 | ND |
| Residual insulin in derm particulate pellet soluble extract (%) | 100 | 102 | ND |

ND: not determined.

| Table II | Insulin concentration (mUI/g protein) in the tissue soluble extracts of the diabetic patient and the non diabetic control subjects. |
|-----------------------------------------------|
| Insulin concentration in whole adipose tissue soluble extract (mUI/g) | Patient 1 | Control patient 1 | Control patient 2 |
|---------------------------------------------------------------|
| 846 | 1.5 | 1.5 |
| Insulin concentration in fat layer soluble extract (mUI/g) | 477 | 1.5 | ND |
| Insulin concentration in whole derm soluble extract (mUI/g) | 1098 | 1.5 | ND |
| Insulin concentration in derm particulate pellet soluble extract (mUI/g) | 1406 | 6 | ND |

ND: not determined.
There is a direct insulin/IDE interaction that may modulate fat and protein turnover by inhibiting protein degradation [26]. Last, the IDE/MCP complex can be purified by affinity, conventional or ion exchange chromatography [27]. As of today, it is not well known whether IDE and insulin-degrading activity are the same enzymes, even though it has been suggested previously [28].

Suggested treatments of SIR are based on either additives to prevent enzymatic degradation or alternative routes of insulin delivery. Among additives, protease inhibitors [9, 10, 18], Aprotinine [19, 21], Chloroquine [20], and regular, freeze-dried and lispro insulin [33] have been used. Table II summarizes the cases of subcutaneous insulin resistance reported in literature.

### Table II
Cases of subcutaneous insulin resistance reported in literature.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Number of Patients/age (years)/gender</th>
<th>SC resistance</th>
<th>Levels of free insulin tested</th>
<th>Insulin degrading activity</th>
<th>Trititated-insulin study</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schneider [1]</td>
<td>1/16/F ketosis transient</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td>IV injections/infusion (+)</td>
<td></td>
</tr>
<tr>
<td>Paulsen [2]</td>
<td>1/17/F DKA/infections transient</td>
<td>yes</td>
<td>yes</td>
<td>present in sera/SC tissue</td>
<td>ND</td>
<td>IV infusion (+)</td>
</tr>
<tr>
<td>Dandona [7]</td>
<td>1/14/F</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td>Aprotinine/SC injection (+)</td>
<td></td>
</tr>
<tr>
<td>Henry [8]</td>
<td>1/18/F</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td>Aprotinine (+)</td>
<td></td>
</tr>
<tr>
<td>Müller [9]</td>
<td>1/52/F DKA/infections</td>
<td>yes</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Mc Eilduff [10]</td>
<td>1/16/F transient</td>
<td>yes</td>
<td>yes</td>
<td>ND</td>
<td>IV infusion (±)</td>
<td></td>
</tr>
<tr>
<td>Freidenberg [11]</td>
<td>5/14 to 31/F DKA Hypoglycemia in 4 M 1/24/M</td>
<td>yes</td>
<td>Present in sera</td>
<td>ND</td>
<td>IM injections (+)</td>
<td></td>
</tr>
<tr>
<td>Maberly [13]</td>
<td>1/20/F DKA/infections transient</td>
<td>yes</td>
<td>yes</td>
<td>Increased in adipose tissue and muscle</td>
<td>ND</td>
<td>SC infusion (–)</td>
</tr>
<tr>
<td>Shade [14]</td>
<td>3/15 to 27/2F-1M</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td>IP infusion (+)</td>
<td></td>
</tr>
<tr>
<td>Campbell [15]</td>
<td>1/22/F DKA/infections</td>
<td>yes</td>
<td>ND</td>
<td>ND</td>
<td>IP/IPP (+)</td>
<td></td>
</tr>
<tr>
<td>Blazar [16]</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
<td>Chloroquine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dandona [17]</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>ND</td>
<td>IP infusion (+)</td>
<td></td>
</tr>
<tr>
<td>Brossard [18]</td>
<td>1/26 DKA</td>
<td>yes</td>
<td>yes</td>
<td>ND</td>
<td>IV infusion (±)</td>
<td></td>
</tr>
<tr>
<td>Riveline [19]</td>
<td>1/36/M AP/hyperosmolar</td>
<td>yes</td>
<td>yes</td>
<td>ND</td>
<td>SC infusion (–) with regular, freeze-dried and lispro insulin</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: SC: subcutaneous; IV: intravenous; IP: intraperitoneal; IPP: intraperitoneal implanted pump; (+): effective; (–): ineffective; (±): effective but complications; DKA: diabetic ketoacidosis; AP: acute pancreatitis.
Aprotinine is a protease inhibitor that has been used in the treatment of acute pancreatitis, chronic urticaria, acne and fibrinolysis. It is a polypeptide of 58 amino acids initially obtained from bovine lung and parotid gland. Aprotinine enhances absorption by inhibiting insulinase and increasing vasodilation. The side effects most frequently reported are nausea, vomiting, diarrhea and myalgia but also hypoglycemia and anaphylaxis. The main commercially available products are Trasylol® (Bayer Laboratory) or Iniprol® (Choay, Gentilly, France) used at a final dilution of 4 to 160 kallikrein-inactivity units (KIU)/Unit of insulin [11], mixed with insulin, either subcutaneously or intravenously over a period of 30 mn every 8 hours. It forms a cloudy suspension when it is mixed with insulin. Otherwise chloroquine [16] used as an enzyme inhibitor and plasmapheresis [30] have been used only once each, which is why their effectiveness is difficult to assess. Among other routes of insulin delivery, intramuscular insulin therapy [12, 13, 18, 31] has been used during periods of as long as one year, but with a risk of fibrosis. Intravenous insulin therapy [2, 7, 11, 18, 19], either by continuous infusion from an external pump or by intravenous bolus injections every two hours through an indwelling venous-access needle is a temporary yet reasonable solution. Nevertheless, the risk of thrombosis, sepsis and catheter breakage is major. Last, peritoneal devices [14, 15, 17, 19] have been found to be effective in 7 of the 8 previously published cases. Two of them were treated with an implantable pump [15, 19].

**Conclusion**

This case report of acquired SIR raises the question of accurate diagnosis according to Paulsen's and Schade's criteria. These criteria have rarely been respected in literature because of the scarcity of cases. The treatment of SIR remains difficult even if intraperitoneal delivery of insulin today appears to be the safest solution. And last, mechanisms of SIR still remain unclear even if excessive degradation or sequestration of insulin is probably involved.

**References**


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**Table IV**

Study protocol of subcutaneous insulin resistance according to Schade et al. [20].

**Insulin challenge testing**

- Before admission no intermediate or long-acting insulin within 48 hours before the study
- Check for undetectable C-peptide
  - On admission: continuous intravenous insulin infusion overnight (0.5 to 2U/hour plus 5U boluses before meal to maintain blood glucose between 1 and 2 g/l)
  - Next morning 8am: discontinuation of insulin with glycemia allowed to rise to at least 2.5 g/l; injections of insulin made by the physician, from a new bottle
  - Whenever hypoglycemia did occur, 20 ml of a solution that contains 30g of glucose per deciliter was given as an intravenous bolus dose
- Day 1: 0.1U of regular insulin per kilogram of body weight subcutaneously
- Day 2: 0.1U intravenously
- Day 3: 0.5 U of regular insulin per kilogram of body weight subcutaneously
- Next morning 8am: discontinuation of insulin with glycemia allowed to rise to at least 3.5 g/l
- Day 4: 0.5 U intravenously
- Sampling for glucose, C-peptide and insulin every fifteen minutes during four hours

**Biopsy specimens for insulin degrading activity**

Subcutaneous biopsy specimens 2 to 10g obtained from the periumbilical region, rinsed briefly in cold isotonic sodium chloride to remove blood, immediately chilled to 4°C and frozen within one hour at -20°C

**Tritiated-insulin-absorption study**

Sampling before and at 60mn intervals for five hours after subcutaneous injection by the physician of tritiated insulin (1 microcurie/ml; 100 microliters diluted in 0.5ml of sterile saline solution

Counting of aliquots in a liquid-scintillation counter and chromatography on a SephadexG-50 column run with TRIS-HCl, 0.1M; pH 7.5


