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Attenuation of high sucrose diet–induced insulin resistance in tryptophan 2,3-dioxygenase deficient *Drosophila melanogaster* vermilion mutants

Valeriya Navrotskaya¹, Gregory Oxenkrug², Lyudmila Vorobyova¹, and Paul Summergrad²

¹Department of Genetics and Cytology, V.N. Karazin Kharkiv National University, Kharkiv, Ukraine

²Psychiatry and Inflammation Program, Department of Psychiatry, Tufts University/Tufts Medical Center, Boston, MA, USA

Abstract

Exposure to high sugar diet (HSD) serves as an experimental model of insulin resistance (IR) and type 2 diabetes (T2D) in mammals and insects. Peripheral IR induced by HSD delays emergence of pupae from larvae and decreases body weight of *Drosophila* imago. Understanding of mechanisms of IR/T2D is essential for refining T2D prevention and treatment strategies. Dysregulation of tryptophan (TRP) – kynurenine (KYN) pathway was suggested as one of the mechanisms of IR development. Rate-limiting enzyme of TRP – KYN pathway in *Drosophila* is TRP 2,3-dioxygenase (TDO), an evolutionary conserved ortholog of human TDO. In insects TDO is encoded by vermilion gene. TDO is not active in vermilion mutants. In order to evaluate the possible impact of deficient formation of KYN from TRP on the inducement of IR by HSD, we compared the effect of HSD in wild type (Oregon) and vermilion mutants of *Drosophila melanogaster* by assessing the time of white pupae emergence from larva and body weight of imago. Delay of emergence of pupae from larvae induced by high sucrose diet was less pronounced in vermilion (1.4 days) than in Oregon flies (3.3 days) in comparison with flies maintained on standard diet. Exposure to high sucrose diet decreased body weight of Oregon (but not vermilion) imago. Attenuation of high sucrose diet–induced IR/T2D in vermilion flies might depend on deficiency of TRP – KYN pathway. Besides IR/T2D, HSD induces obesity in *Drosophila*. Future studies of HSD-induced obesity and IR/T2D in TDO deficient vermilion mutants of *Drosophila* might help to understand the mechanisms of high association between IR/T2D and obesity. Modulation of TRP – KYN metabolism might be utilized for prevention and treatment of IR/T2D.

Keywords

type 2 diabetes; drosophila; high sugar diet; insulin resistance; kynurenine; tryptophan; obesity

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Correspondence to: Gregory F. Oxenkrug, Tufts Medical Center, 800 Washington St, #1007, Boston, MA, 02111, USA, goxenkrug@tuftsmedicalcenter.org.

Introduction

About 344 million people were diagnosed with type 2 diabetes (T2D) worldwide in 2013. T2D is the 8th leading cause of death in the world [1]. In the US about 16 million people have impaired glucose tolerance (pre-diabetes), a high-risk state for T2D: up to 70% of individuals with prediabetes eventually develop T2D [2]. Prediabetes is associated with presence of insulin resistance (IR) before T2D could be diagnosed. Understanding of mechanisms of IR, a hallmark of T2D, is essential for developing T2D prevention and treatment strategies. Dysregulation of kynurenine (KYN) pathway of tryptophan (TRP) metabolism (KP) was suggested as one of the mechanisms of development of IR and T2D [3–7]. Recently reported elevation of plasma levels of major derivatives of KP in T2D and a strong correlation between dysregulation of KP and severity of IR might further support the suggestion of KP involvement in mechanisms of IR/T2D [8,9]. Exposure to high sugar diet (HSD) induces experimental model of IR/T2D in mammals [10] and insects [11]. HSD causes metabolic dysfunction, including hyperglycemia, hyperinsulinemia, and IR in *Drosophila* [12]. There are four distinct stages in the life of *Drosophila melanogaster*: egg, larva, pupa, and imago (adult). Peripheral IR induced by HSD delays emergence of pupae from larvae and decreased body weight of imago [11–13]. *Drosophila* model allows for further studies of KP involvement in mechanisms of IR/T2D due to availability of natural mutants with deficient KP. Rate-limiting enzyme of KP in *Drosophila* is TRP 2,3-dioxygenase (TDO), an evolutionary conserved ortholog of human TDO, that is encoded by vermilion gene. TDO is inactive in vermilion mutants of *Drosophila melanogaster* [14]. In order to evaluate the possible impact of deficient formation of KYN from TRP on the inducement of IR by HSD, we compared the effect of HSD on development of IR in vermilion mutant and wild type (Oregon) *Drosophila melanogaster*.

Materials and methods

Wild-type stock Oregon and vermilion mutants of *Drosophila melanogaster* from the collection of V.N. Karazin Kharkiv National University were maintained at 23°C in a 12:12 light: dark period on a standard nutrition medium consisting of sugar, yeast, agar and semolina. Eggs were obtained from synchronized egg laying from fertilized flies. Sucrose (0.67M) was added to nutrition medium before eggs laying. Emerging time was taken as the period from the time of synchronized egg laying to the time of larvae emergency into white pupae as described elsewhere [15]. Imago (males) were weighed in groups of 10 flies, with a precise balance. The study was carried out between April and July 2014.

Statistics data from three replicated experiments was used for the statistical analyses. The data were expressed as mean \pm standard deviation (hours for pupae emergence and mg for body weight). Differences between experimental groups were evaluated by Mann Whitney, two-tailed test.

Results

Pupae emergence from larva

Emergence time of pupae from larva of Oregon flies maintained on standard nutrition medium was 16% shorter than emergence time of vermilion flies (Table 1).

High sucrose diet delayed pupae emergence from larva of wild type flies (Oregon) in comparison with flies maintained on standard nutrition medium by 3.3 days.

In vermilion mutants high sucrose diet delayed pupae emergence from larvae by 1.4 days in comparison with flies maintained on standard nutrition medium.

High sucrose diet-induced delay of pupae emergence from larvae was shorter in vermilion than in Oregon flies (Table 1).

Body weight of imago

There were no differences in body weight of male imago Oregon and vermilion flies maintained on standard nutrition medium (Table 1).

High sucrose diet decreased body weight of wild type flies (Oregon) imago by 37%.

In vermilion mutants high sucrose diet did not affect body weight of imago.

Discussion

The main finding of the present study is that high sucrose diet induced three times shorter delay of pupae emergence from larvae and did not decrease body weight of imago in vermilion flies in comparison with wild type flies. We are not aware of studies of the effect of HSD on preimaginal stages of TDO deficient vermilion flies. Considering that HSD-induced delayed emergence of pupae and decreased body weight is caused by IR [11–13], our data suggest that inducement of IR by high sucrose diet is attenuated in vermilion mutants in comparison with wild type *Drosophila*.

Attenuation of HSD-induced IR in vermilion flies most likely depends on deficiency of TDO. In *Drosophila*, TDO-regulated KYN formation from TRP begins at the end of the third larval instar in the cells of the anterior region of fat body (analog of liver and fat tissues in humans) [14].

Transition from larva to pupae in *Drosophila* is triggered by a steroid hormone, ecdysone [16]. Considering that insulin activates ecdysone formation, HSD-induced resistance to insulin effects might impair ecdysone formation and, consequently, delay pupariation [16]. Attenuation of IR development in KP deficient vermilion mutants might attenuate HSD-induced delay of transition from larvae to pupae by facilitation of ecdysone formation.

It is noteworthy that HSD induces IR/T2D in mammals as well. Immediate metabolic response to HSD is an increase of glucose in insects [12] and in mammals [10]. Hyperglycemia activates hypothalamic-pituitary-adrenal axis and increases cortisol secretion

in rat model of T2D [17] and in T2D patients [18]. Cortisol activates TDO, rate-limiting enzyme of KP, that converts TRP into a number of biologically active metabolites, including KYN, a precursor of kynurenic acid (KYNA) and xanthurenic acid (XA) [19]. Although end products of KYN pathway of TRP metabolism are different in humans (NAD⁺) and flies (ommochrome, brown eye pigment) [20], both species produce KYNA and XA [21]. Clinical and experimental studies suggested that XA and KYNA exert diabetogenic effects [22–26]. Therefore, inducement of IR by HSD might be mediated via increased production of diabetogenic KYN derivatives, XA and KYNA, in mammals (Figure 1).

Currently, mechanism of HSD-induced IR is considered to depend on Lipocalin *Neural Lazarillo*, a secreted protein homologous to the Retinol-Binding Protein 4 (RBP) involved in the onset of T2D in human [27,28] and mice [29]. It is noteworthy that linear correlation was found between the postprandial increases of TRP and RBP in morbidly obese subjects [27].

Obesity is highly associated with T2D [30]. The mechanisms of such association are not clear. Dysregulation of KP in obesity was suggested [3–7] and supported by clinical and experimental data [31–34]. It is noteworthy that in *Drosophila* HSD induces not only IR/T2D but obesity as well [11]. Future studies of HSD-induced obesity in vermilion mutants might provide better understanding of the role of KP in mechanisms of obesity and T2D.

Present data suggest disturbances of KP as one of the mechanisms mediating HSD-induced IR/T2D. KP might be a new target for prevention and treatment of IR and T2D.

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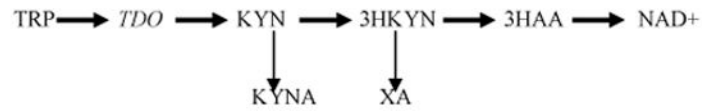
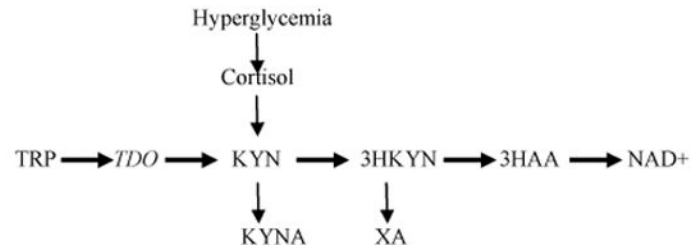
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A. Standard diet**B. High sugar diet****Figure 1.**

Hypothetical effect of high sugar diet on TRP – KYN pathway.

Abbreviations: TRP: Tryptophan; TDO: TRP 2,3-dioxygenase; KYN: kynurenine; 3-HKYN: 3-hydroxyKYN; 3-HAA: 3-hydroxyanthranilic acid; KYNA: kynurenic acid; XA: xanthurenic acid

Table 1

Effect of high glucose diet on time of pupae emergency from larvae and body weight in vermilion and Oregon flies.

Genotype and treatment	Emergence of pupae (hrs)	Weight of imago (mg)
Oregon (control)	151.2 ± 19.2 (n=150)	0.99 ± 0.004
Oregon + High Sucrose Diet	232.5 ± 23.1 (n=150) *	0.62 ± 0.003 *
Vermilion (control)	176.5 ± 27.6 (n=360) **	0.93 ± 0.004
Vermilion + High Sucrose Diet	208.9 ± 22.2 (n=360) **#	1.07 ± 0.003

Mann-Whitney two tailed test

* p<0.0001 in comparison with respective controls

** p<0.0001 in comparison with Oregon controls

p<0.0001 in comparison with Oregon + high sucrose diet