



THE COMPLEXITY OF BLOOD GLUCOSE REGULATION AND AYURVEDIC INSIGHT

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Abstract:

Ayurveda takes a comprehensive approach to blood glucose regulation. *Agni*, is essential to this; food is converted into energy and tissues depends on strength of *agni*. When *agni* is disturbed, *Ama* (metabolic waste) builds up and affects *dhatu*s, especially *meda dhatu* (adipose tissue).ⁱ In addition, Ayurveda views *ojas*, *manas*, and *atma* as essential to metabolic and physiological health.

The intricate and precisely regulated physiological mechanism of blood glucose regulation is essential for preserving metabolic health and energy balance. According to contemporary physiology, this regulation entails the coordinated actions of several organs, including the brain, skeletal muscle, liver, adipose tissue, and pancreas, and is controlled by important hormones like glucagon and insulin.ⁱⁱ The systemic aspect of glucose homeostasis is highlighted by the responses of other regulators, including cortisol, catecholamines, and incretins, to variables including stress, circadian rhythms, and dietary intake.ⁱⁱⁱ

The multifaceted intricacy of glucose regulation is shown by the combination of contemporary and Ayurvedic paradigms, providing further insights into systemic health that go beyond molecular mechanisms.

Key Words: Agni, Kapha Imbalance, Ama, Meda Dhatu, Insulin, Glucose Regulation

Introduction-

Blood glucose regulation is viewed in *ayurveda* as a reflection of the body's intrinsic balance and vitality rather than as a separate metabolic process. *Agni*, controls nutrient transformation at all levels, is at the core of this balance. Disruption of *agni* results in the production of *ama*, *srotorodha* and disruption of tissue function, especially of *meda dhatu*. The accumulation of *kleda* and *kapha* imbalance further impede metabolic clarity. The power of *ojas*, the purity of *manas*, and alignment with *atma* are all linked to metabolic health in *ayurveda*, which takes a deeper approach.

In order to preserve energy balance, blood glucose regulation is a highly dynamic and complex physiological process involving several organ systems and signaling pathways. In contemporary physiology, the pancreas is not the only organ involved in this control; the liver, skeletal muscle, adipose tissue, central nervous system (CNS), and several endocrine glands also work together in concert.^{iv} Although cortisol (from the adrenal cortex), epinephrine (from the adrenal medulla), growth hormone (from the anterior pituitary), and incretins (from the gut) all influence the effects of insulin

and glucagon, these hormones play a major impact.

Through insulin-mediated GLUT4 translocation, skeletal muscle serves as a significant glucose sink during fed states, and the liver controls glucose release (gluconeogenesis, glycogenolysis) and storage (glycogenesis) in response to stress and fasting.^v Neuroendocrine reactions to physical and psychological stress are mediated by the hypothalamic-pituitary-adrenal (HPA) axis, which also reduces peripheral insulin sensitivity and increases hepatic glucose production. Moreover, glucose metabolism is influenced by gut bacteria, sympathetic nervous system activity, circadian rhythms, and nutrient-sensing mechanisms.^{vi}

Together, these frameworks, modern physiology and *ayurveda*, highlights the intricate and multi-organ nature of glucose regulation, emphasizing its sensitivity to both internal and external stimuli. Here are prominent roles in BSL regulation.

1.Role of *agni* in Glucose Regulation-

The term metabolism is used to refer all the chemical and energy transformations that occur in the body. everything in the universe, according to *darshana*. Among them, *agni* is one of the *mahabhuta*. In Ayurveda, the term "*agni*" refers to the entire process of releasing energy through digestion at the G.I.T. level and tissue metabolism. *Agni* transforms food into energy, which powers all of our body's essential processes *agni* divides into - Seven *dhatwagni*, Five *bhutagni* and *jatharagni*.

Jatharagni- It is found in the duodenum and stomach and is in charge of breaking down carbohydrates into simpler sugars like glucose. Amylase and other digestive enzymes aid in the digestion of carbohydrates in this process, which is comparable to contemporary ideas of the enzymatic breakdown of food. When *jatharagni* is working at its best, glucose is taken into the bloodstream effectively and with minimal volatility, guaranteeing a consistent flow of energy.

Dhatwagni- According to Ayurveda, *dhatwagni* regulates how nutrients are transformed within tissues. Hormones such as insulin, growth hormone (GH), testosterone, and thyroxin allow amino acids to reach muscle cells and be used. As *dhatwagni* stimulators, these hormones improve tissue nutrition and metabolic functions. There are two routes that amino acids can take after they enter the cell: Once inside the cell, amino acids follow either of two pathways:

- Anabolism: Supports tissue growth and repair, aligning with the concept of *mamsa dhatu poshana*.
- Catabolism: Amino acids convert into Acetyl CoA, entering the Krebs cycle (TCA cycle) to generate ATP, producing CO₂ and H₂O as metabolic waste, akin to *malotpatti* in *ayurveda*.

Metabolic disorders as well as Blood glucose regulation are deeply linked to *agni* dysfunction, especially *dhatwagni mandya* (weakened tissue metabolism):

- Insulin resistance leads to improper glucose and amino acid metabolism.
- Excessive amino acid breakdown may indicate *medo-mamsa dhatu dushti*, contributing to muscle wasting and obesity seen in metabolic disorders.^{vii}
- Accumulation of metabolic wastes (CO₂, H₂O, lactic acid) mirrors *mala sanchaya*, leading to *ama* formation, which further turns into *agnidusti*.

Bhutagni –

The five *bhutagnis* digest their own part of the element present in the food materials. There are five types of *agni* namely, *parthivagni*, *apyagni*, *agneyagni*, *vayuvyagni* and *akashagni*. Each and every cell in our body is composed of five *mahabhutas*. Naturally each cell consists of these *bhutagni* also. The five *bhutagnis* digest their own part of elements present in the food materials. Broken down and partially digested food is again exposed to *bhutagni*.

The GIT's digestive process should be followed right away by the *bhutagni paka* procedure. *asthaya dhatu* is thus delivered into the circulation through the hepatic vein, enabling *bhutagni* function to commence as soon as portal circulation to the liver. In order to support the *rasadi sapta dhatus, ahara*

rasa travels throughout the body as a result of the *bhutagni* processes that take place inside the portal system, liver, and circulatory system. The liver is hence considered to be the focal point of *bhutagni vyapara*. The intestine digesting process is completed by *bhutagni paka*, which comes after *jatharagni paka*. Only once *bhutagni paka* is finished can *ahara rasa* be fully formed, allowing *rasa dhatu* to be absorbed. Glucose is converted into glucose 6 phosphate and stored in the form of glycogen. Amino acids are converted into pyruvate and with the help of gluconeogenesis it converted into glucose.^{viii} Therefore, releasing of their *guna*/qualities in the food can be correlated to *bhutagni*.

2.Role of *ama* in Glucose Regulation-

Mandagni causes the metabolic residue known as *ama*, which is toxic, sticky, and undigested part. There is a buildup of partially metabolized nutrients in the body as a result of improper food digestion caused by poor *jatharagni*. By blocking *srotas* (microchannels), this *ama* circulates in *rasa dhatu* (plasma) and *meda dhatu* (fat tissue), resulting in insulin resistance and glucose imbalance.

Modern Scientific Correlation with *Ama*

- Mitochondrial dysfunction (inefficient ATP production) results into an excessive free radical generation, similar to an *ama* accumulation according to ayurveda.
- Glycation (AGEs – Advanced Glycation End Products) is a process where excess Glucose binds with proteins, forming toxic compounds like *ama* and obstructing cellular function.
- Inflammation & Oxidative Stress: *Ama* buildup corresponds to chronic low-grade inflammation seen in diabetes and metabolic disorders.^{ix}

How *ama* Leads to Glucose Dysregulation

Ama Disrupting Insulin Sensitivity & Glucose Uptake:

- *Ama* blocks the functions of *dhatwagni* and impairs the proper utilization of glucose.
- This leads to *Sama rasa dhatu* (toxic plasma), impairing insulin sensitivity.^x
- *Kapha dosha* dominance due to *ama* accumulation in *meda dhatu* worsens insulin resistance and also the obesity.
- Prolonged *ama* accumulation in *meda dhatu* (adipose tissue) results into adipokine imbalance also disrupting insulin signalling.

Ama plays a crucial role in insulin resistance, metabolic disorders, and also in diabetes by blocking *agni* and *srotas*, leading to glucose imbalances.^{xi} Ayurvedic detoxification and *agni* restoration therapies help in reversing glucose irregularities and helps in improving metabolic health.

3.Role of *tridosha* in blood glucose Regulation-

In *ayurveda*, *tridosha* refers to the three fundamental energies or bio elements governs all physical and mental processes in the body.

Vata Dosha- *Vata* is *ruksha* (dry), *laghu* (light), and *chala* (mobile), regulating movement, communication, and impulse conduction. It is the functional force behind the nervous system (*manovaha srotas*) and hormonal coordination. *Vata* parallels the autonomic nervous system (ANS), HPA axis, and catecholamine regulation and also influences blood glucose via Cortisol, adrenaline, and noradrenaline, especially during stress.^{xii} Stress-induced hyperglycemia, elevated cortisol levels, and insulin resistance due to persistent sympathetic overactivity are all consequences of an imbalanced *vata*. This is evident in *vata prakopa*, which aggravates *agni* and disrupts hormonal cycles and glucose absorption, according to ayurveda.

Pitta Dosha- *Pitta* is *ushna* (hot), *tikshna* (sharp), and *sara* (fluid). It governs digestion, *pitta* relates to hepatic metabolism, mitochondrial activity, and ROS regulation and supports Gluconeogenesis, glycogenolysis, and fatty acid oxidation through liver enzymes and hormonal regulation (glucagon, cortisol).^{xiii} Increased *pitta* brought on by oxidative stress, mitochondrial

dysfunction, and β -cell damage can impair the synthesis of insulin. Ayurvedic principles state that *pitta dushti* results in metabolic “burnout” and inflammatory disease (*agnidushti* → *dhatupaka*).

Kapha Dosha- *Kapha* is *snigdha* (unctuous), *guru* (heavy), and *sthira* (stable), governing structure, nourishment, and tissue building. It nourishes *meda dhatu* and supports *ojas*, the essence of immunity and the vitality. *Kapha* mirrors insulin function, adipose metabolism, and anabolic hormonal activity. It also promotes glucose uptake via insulin-mediated GLUT-4 transporters in skeletal muscle and adipose tissue and it Supports lipogenesis and glycogen storage.^{xiv} Excess *Kapha* can lead to adipocyte hypertrophy, chronic low-grade inflammation, and insulin resistance via elevated TNF- α , IL-6, and free fatty acids. This aligns with Ayurvedic understanding of *kapha dushti* leading to *meda vridhhi* and *prameha*.^{xv}

The following table shows the role of *dosha* in glucose metabolism-

Dosha	Primary Function	Modern Physiology	Role in Glucose Metabolism
Vata	Movement, nerve signals, communication	Nervous system, neurotransmitters (e.g., vagus control of insulin)	Regulates nervous signals for insulin release, glucose transport, hunger cues
Pitta	Digestion, metabolism, transformation	Enzymatic digestion, liver metabolism, pancreatic beta-cell activity	Manages <i>agni</i> , pancreatic enzyme function, insulin production
Kapha	Structure, stability, storage	Insulin resistance, adipose storage, anabolic hormones	Governs anabolism, glucose storage, fat formation, and insulin sensitivity

4.Role of *saptadhatu* in blood glucose Regulation-

The *saptadhatu* are the seven fundamental bodily tissues described in ayurveda.

1.Rasa (plasma/lymph)- It is formed by *rasa dhatvagni* from the essence of food that has been digested (*ahara rasa*). It is the main source of nourishment for all *dhatu*s that follow. It delivers glucose and other nutrients throughout the body. By promoting the circulation of hormones like insulin, which control blood glucose levels, and aiding in the removal of metabolic waste products, *rasa dhatu* contributes significantly to glucose metabolism and preserves cellular health. *Rasa dhatu* correlates with plasma, lymph, and interstitial fluids. Study shows that lymphatic abnormality promotes obesity and insulin resistance.^{xvi} *Rasa dhatu dusthi* can lead to impaired glucose transport and utilization, contributing to metabolic disorders.

2.Rakta (blood) – All tissues are nourished by *prana* and nutrients carried by *rakta*. Any *rakta dhatu* malfunction impairs the supply of nutrients, such as glucose, and interferes with the creation of energy within cells. As the site of *ranjaka pitta*, the liver, is an essential metabolic organ that regulates glucose storage, glycogenolysis, and gluconeogenesis in contemporary medicine. Therefore, a healthy *rakta dhatu* supports glucose metabolism, indirectly influencing blood glucose levels. *rakta dushti* (vitiation) may reflect in impaired glucose metabolism or inflammatory conditions, akin to insulin resistance.

3.Mamsa (muscle)- It is a major site of glucose utilization. Skeletal muscle accounts for over 70% of postprandial glucose disposal, and its ability to uptake glucose efficiently is crucial in maintaining normoglycemia.^{xvii} Study shows that there is a role of muscle in insulin sensitivity, glucose uptake, and glycogen storage. Healthy *mamsa dhatu* indicates good muscle mass and metabolism, crucial for glucose uptake via insulin action.^{xviii}

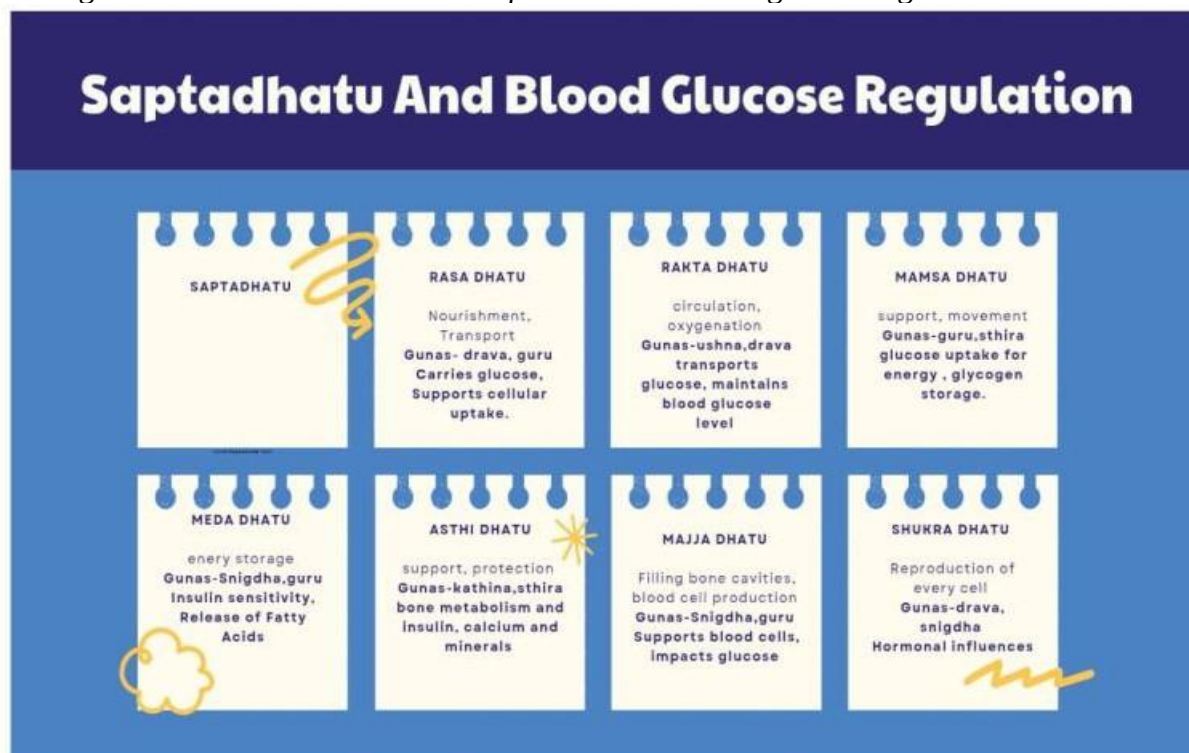
4.Meda (fat/adipose tissue) – Increased *dravatva* and *kleda* in the body are caused by vitiation of *kapha dosha*, which is associated with an imbalance in *medo dhatu*. As a result, *Medo Dhatu's sthiratva* is lost, leading to *dhatu shaithilya*, which may exacerbate metabolic diseases. Adipose tissue in the body is symbolized by *medo dhatu*. It is known that adipose tissue is an active endocrine

organ that secretes a variety of hormones and cytokines that affect glucose metabolism and insulin sensitivity. Excessive adiposity leads to increased production of pro-inflammatory cytokines and contributing to insulin resistance and impaired glucose uptake by muscles.^{xix}

5,6 Asthi & Majja Dhatu (Bone & Marrow) – *Asthi dhatu* represents body's skeletal system and *majja dhatu* is associated with bone marrow and the nervous system. Modern research has identified bones as active endocrine organs. Recent studies have shown that osteocalcin, produced by osteoblasts and modulated by bone marrow activity, can influence pancreatic β -cell proliferation and insulin sensitivity^{xx}, thereby linking *asthi-majja dhatu* axis with glucose homeostasis where as the nervous component of *majja dhatu* plays a central role in regulating glucose levels through neuroendocrine mechanisms, including the hypothalamic-pituitary-adrenal (HPA) axis.

7.Shukra (reproductive tissue) – *Shukra dhatu* correlates with the reproductive endocrine system and also regeneration of each cell, including the hypothalamic- pituitary-gonadal (HPG) axis. The HPG axis regulates the production of sex hormones like testosterone and estrogen, which play significant role in glucose metabolism. Low levels of testosterone are associated with increased insulin resistance in men and in women, estrogen enhances insulin sensitivity and modulates adipose tissue distribution, offering a protective effect against metabolic disorders. Sex hormones influence insulin sensitivity and glucose uptake in tissues, thereby affecting overall glucose homeostasis.^{xxi} Disrupt in HPG axis, leading to hormonal imbalances that affect both reproductive health and glucose metabolism.

Following table shows relation between *saptadhatu* and blood glucose regulation-



5.Role of *Trimala* in Blood Glucose Regulation -

According to Ayurveda, the three main waste products (*mala*) of the body are called the *Trimala*, which are *sweda* (sweat), *purisha* (feces), and *mutra* (urine). Although they are mostly linked to excretion, they also show the condition of metabolism and have a significant but indirect impact on blood glucose control.

Mutra (Urine)- *Mutra* is mala of *ambu vaha* and *medo vaha srotas*, produced during fluid and fat metabolism. A systemic metabolic disturbance is caused by the excessive and changed *mutra* that is

produced when *meda dhatu* rises inappropriately. *Madhura mutratva* is seen when the kidneys start excreting too much glucose into the urine. Blood glucose levels have a direct impact on urine production and composition. Polyuria occurs when blood glucose exceeds renal reabsorption threshold (~180 mg/dL), leading to glycosuria (glucose in urine). Persistent hyperglycemia can lead to diabetic nephropathy, where protein (albumin) starts leaking into urine.^{xxii}

Purisha (Feaces)- It is a digestive byproduct that represents *agni*. While heavy or sticky feces is a sign of *ama*. *Mandagni* results in reduced tissue absorption of glucose when there is insulin resistance or metabolic abnormalities. Hyperglycemia results from the cell's ineffective use of the extra glucose in the blood. Buildup of glucose in the circulation might result from poor digestion and *ama* development that block metabolic channels (*srotorodha*), which impairs the intestine's ability to absorb and metabolize glucose. Insulin resistance and glucose homeostasis are influenced by the gut flora. Chronic inflammation, poor food metabolism, and altered glycemic control are all consequences of dysbiosis, or disruption of the gut flora. Production of short-chain fatty acids (SCFAs) by beneficial bacteria (e.g., butyrate) improves insulin sensitivity and modulates gluconeogenesis.

Sweda (sweat)- *Meda dhatu*'s excretory product, *sweda*, is essential for detoxification and temperature control. According to ayurveda, *sweda* is involved in the body's effort to rid itself of excess *kapha* and *ama*. Higher insulin levels are linked in modern medicine to increased fat storage and metabolic inefficiencies, which might show up as greater perspiration as a result of the sympathetic nervous system being activated.. Excessive sweat in the context of insulin resistance can indicate poor fat metabolism and high insulin levels, which are both linked to metabolic syndrome.^{xxiii} Recent innovations show that the sweat contains measurable glucose, which can be used to non-invasively monitor blood sugar. Sweat glands reflect interstitial glucose levels. Wearable biosensors can detect sweat glucose, electrolytes, and the lactic acid, offering an alternative to testing the blood.

The below table shows relation between *trimala* and blood glucose regulation:

<i>Mala</i>	Primary Function	Role in Glucose Metabolism
<i>Mutra</i>	Elimination of water-soluble waste	Reflects glucose imbalance (glycosuria in diabetes); excessive urination is a key symptom
<i>Purisha</i>	Elimination of undigested food and toxins	Tied to <i>agni</i> , improper digestion leads to <i>ama</i> which disturbs metabolism
<i>Sweda</i>	Removal of toxins through skin; Regulates temperature	Disturbed in <i>prameha</i> ; excess or foul smelling sweat reflects imbalance in glucose and fat metabolism

6.Role of Hypothalamus, CNS and *Mana* in Blood Glucose Regulation

Mana, or the mind, is closely related to *doshas*, *agni*, and *ojas* and is regarded as one of the three pillars of life in ayurveda, along with the body and soul. *Rajas* (activity), *tamas* (inertia), and *sattva* (clarity) control the mind. Stress, worry, and depression are caused by an imbalance between the *rajas* and *tamas*, which upsets the *pitta* and *vata doshas*. *Agni* is impacted, which results in impaired glucose metabolism and *ama*. This affects *agni*, leading into *ama* (toxins) and poor glucose metabolism.

According to contemporary research, stress and psychological variables significantly influence how glucose metabolism is regulated by intricate neuroendocrine and neuroimmune networks. The hypothalamic-pituitary-adrenal (HPA) axis is stimulated by psychological stress, which raises cortisol release. By increasing hepatic gluconeogenesis, lowering insulin sensitivity, and preventing peripheral tissues from absorbing glucose, cortisol elevates blood glucose levels. Additionally, stress triggers the sympathetic nervous system, which releases norepinephrine and adrenaline. Particularly in times of acute stress, these catecholamines cause hyperglycemia, inhibit insulin production, and promote glycogenolysis and lipolysis. Neuroinflammation, which interferes with insulin receptor signaling, is associated with mental illness and chronic stress. TNF- α and IL-6 are examples of pro-

inflammatory cytokines that disrupt insulin action and increase insulin resistance. Lifestyle behaviors such as dietary habits, physical activity and sleep patterns collectively contribute to blood glucose regulation and metabolic health. Also there is a major neuronal control of blood sugar levels. Role of CNS in particular hypothalamus is important.^{xxiv}

Discussion –

In addition to being a physiological phenomenon, blood glucose imbalance is a sign of a *dosha* imbalance, particularly between *kapha* and *vata*. When *agni* is disturbed, *ama* (toxic metabolic byproducts) is produced and in metabolism imbalance occurs. Ayurveda monitors metabolism at the *dhatu* level, particularly at the *mamsa* (muscle), *rasa* (plasma), and *medas* (fat).^{xxv} Imbalance is said to be caused by mental and emotional elements, such as stress, worry, and the repression of natural drives.

Multi-Organ Coordination, which includes the brain, gut hormones, muscle, fat tissue, liver, and pancreas, is involved in blood glucose regulation.^{xxvi} Depending on dietary intake, physical activity, stress, and circadian rhythm, the pancreas must release specific amounts of glucagon and insulin. Blood sugar regulation is also impacted by cortisol, adrenaline, growth hormone, and incretins (GLP-1, GIP), frequently in response to stress, physical activity, or variations in the circadian rhythm.

Conclusion-

The intricate process of blood glucose management demonstrates the tight interconnections among the body's numerous systems. From a modern biomedical standpoint, it encompasses external influences like lifestyle, stress, and nutrition, as well as carefully controlled hormone signaling, organ coordination, and cellular responses. The intricacy is caused by the complicated interactions of insulin synthesis, tissue sensitivity, and a number of hormonal and environmental variables.

An imbalance in blood sugar indicates a systemic illness that affects the *doshas*, *dhatu*, *agni*, and mental-emotional health. In this instance, in addition to the physiological disturbance, complexity is observed in the energy, digestive, and behavioral misalignments that underlie the illness. Prevention, personalization, and the holistic restoration of internal balance are all highly valued in Ayurveda. At the end, both systems provide insightful knowledge: Ayurveda offers a more comprehensive, customized strategy based on balance and long-term well-being, while Contemporary medicine specializes in acute management and quantifiable diagnoses. A genuinely integrative perspective recognizes that both scientific accuracy and holistic knowledge are necessary for efficient blood glucose regulation.

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