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A Review on Impact of High Protein Breakfast on Appetite Hormones and Hunger Regulation in Obesity

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Abstract: Obesity is the major global health concern in the 21st century, distinguished by high accumulation of body fat and linked to chronic illness and mortality. Breakfast which provides the human body with majority of energy requirements (20-35%), plays a important role in weight management and appetite regulation. However modern lifestyle factors, such as time constraints and shift work, have led to breakfast skipping which subsequently contributes to obesity risk. Diet rich in protein, especially in breakfast, were found to increases satiety due to release of anorexigenic and orexigenic signals. Research evidence provide protein sources and amount affect appetite modulation, with high-protein breakfasts satisfying hunger, increasing feelings of fullness, and altering specifically in improved hormonal responses as compared to carbohydrate-based breakfast or skipping breakfast altogether. Tools to measure subjective appetite and eating behavior are variously validated, such as the Visual Analogue Scales (VAS) or the Three-Factor Eating Questionnaire (TFEQ). According to the literature, the implementation of high-protein breakfast as part of the diet strategy may be the effective method to address obesity due to its ability to modulate both hormonal responses to appetite and behavioral regulation of it. This review article highlights appetite regulation and satiety, including the roles of leptin, ghrelin, PYY, GLP-1, and cholecystokinin (CCK), the impact of protein on satiety, the effects of high-protein breakfasts on appetite control, methods for hunger assessment, and existing research gaps.

Keywords: Appetite hormones, Satiety, Obesity, Protein breakfast, Hunger assessment

I. INTRODUCTION

The prevalence of obesity is a emerging public health concern across the world in 21st century which is characterized by excessive body fat **[1].** According to the World Health Organization (WHO) the definitions of overweight and obesity are related to the excessive or abnormal fat deposits, the abnormal accumulation of fat that predisposes a person to health risk. Obesity is considered one of the biggest public health problems and globally, it is the fifth leading cause of death **[2].** Breakfast is an important meal, as the body needs nutrients after a period of fasting of several hours. In adults protein intake in the breakfast is needed for maintaining muscle function and overall strength **[3].** However, in a fast-paced lifestyle, limited time, change in work shift causes people to skip breakfast thus increasing chance of obesity **[4].** Among healthy individuals, the consumption of food is mediated via gastrointestinal peptides (GIP) that modulate perceptions of satiety and hunger. Abnormalities in GIP metabolism could be a cause of obesity **[5]**. Gastrointestinal peptides (GIP) which include cholecystokinin, peptide YY, nesfatin-1, glucagon-like peptide-1 and oxyntomodulin, signal the brain of the satiety, whereas ghrelin sends a brain signal of hunger. GIP is important in controlling food consumption levels and thus this needs to be studied well in order to control such health related conditions as obesity **[6].** Protein rich food promote leptin and trigger the activation of the satiety hormones, CCK, GLP-1 and PYY through the small intestine leading to reduction in food intake when compared to carbohydrates and fat due to lower food consumption **[7].** The recommended intake of 0.8 to 1 g/ kg/day is recommended value for maintining muscle mass and activity among adults **[8]**. GIP plays a major role in mediating the gut brain axis and therefore, could be the key to improving metabolic disorders. A in-depth understanding of the interaction between GIP and the neural pathways offers a more comprehensive knowledge about obesity and its therapeutic effect **[9].** Peptide Tyrosine Tryrosine (PYY) will reduce the intake of food by lowering acid secretion through delayed gastric emptying and has a possible role in managing energy consumption. Its level is often lower in obese individual. Whereas Ghrelin (Hunger hormone) stimulates food intake caused by an increase in hedonic response of the brain to food stimuli **[10]**.

A. Appetite hormones and Hunger Regulation

A wide variety of factors regulate appetite and energy intake, and these influences can be divided into both central and peripheral factors. When the person is eating, the oral cavity will be exposed to texture, taste and smell of food. After

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food enters the stomach, it combines with gastric secretions to form chyme and slowly distends the stomach producing a feeling of fullness. As gastric emptying progresses, specific receptors on enteroendocrine cells are activated by the intestinal contents-including nutrients, digestion products, metabolites, and bile acids, as well as additional compounds such as bitter substances-and this causes the secretion of intestinal hormones . The effect of these hormones involves the modification of stomach motor activity which in turn regulates the emptying of the gastric region as well as expelling receptors on vagal afferents reporting the consumption of a meal to the brain. This is the process, because of which the meal is terminated, and reward perception takes place. The composition of a meal is recognized in the oral cavity and all the lumen of the gastrointestinal tract **[13].** The stomach serves as a storage organ and also as a food container and after eating several hours, plays a significant role in the immediate control of appetite. Gastric distension that results when one eats leads to the sensation of fullness, an indication of satiation and the stimulation that drives the emptying of the gastric stimulates the transport of the nutrient. to the small intestine where the release of gut hormones and uptake of the nutrient take place **[11][12].** Appetite and homeostasis are regulated by hypothalamus by the synthesis of the afferent signals from intestine and brain stem after which it involves in the production of the efferent signals in order to manage nutrition **[13].** The arcuate nucleus of the hypothalamus (ARC) is an important appetite regulator situated near the third ventricle of the brain. This nuclei has a more specialized and permeable blood-brain barrier than other parts of the brain **[13].** Satiety can be endocrinologically regulated with the help of gastrointestinal hormones. Leptin, Ghrelin, PYY, CCK and GLP-1 are the most important endocrine regulators. Cholecystokinin (CCK) is the principal peptide that has been shown to have a causal relationship to satiation.Ghrelin is the only circulating hormone whose systemic and centrally administered actions strongly stimulate adiposity and food consumption **[14].**

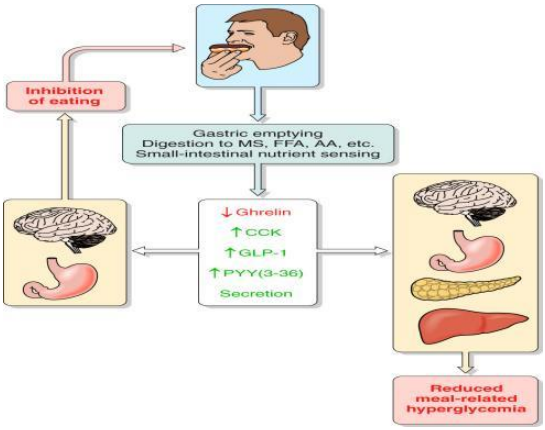

Fig. 1 Physiological Role of Eating in Obesity

1) Leptin:

Leptin is a hormone produced mainly by the fat tissue based on the amount of fat reserves in the body and its main role is the regulation of lipid stores. Other tissues, including stomach, placenta and mammary gland produce leptin beside the production of adipose tissue **[17].** Leptin controls food consumption, total body weight, and reproduction and contributes to fetal development, proinflammatory immune responses, angiogenesis and lipolysis. The timing of meals and circadian rhythm is also affecting levels of leptin, as the highest level is observed after eating and in the period before sleep. Factors which decrease the Leptin levels include androgens, free fatty acids (FFA), the growth hormone, sympathetic nervous system stimulation, and prolonged starvation **[18].** One of the key leptin signaling pathway is its interaction with the hypothalamus in the regulation of metabolic homeostasis via modulation of the central nervous system. Insulin interacts with leptin which affects glucose and lipid homeostasis. Under normal physiologic conditions, serum leptin rise during the fed state, falls during fasted state and is directly proportional with total body fat mass: the more adipose tissue, the higher the leptin, a good representation of long-term energy availability **[19].** In people, circulating levels of leptin are proportional to body fat, and they are elevated in obesity and reduced in leanness. Leptin concentration is higher in women than in men, although this can be attributed partially to body fat and to the possible role of sex steroids **[20].**

2) Ghrelin:

Ghrelin is a peptide hormone with 28 amino acids, which is mainly secreted by the stomach, although its minor quantities are also secreted by the hypothalamus, pituitary, and peripheral organs. It is important in energy balance and control of hunger **[21].** Ghrelin plays an important role in increasing appetite, growth hormone production, and other physiological process. It increases in between meals and during fasting, which is an indication of hunger. Ghrelin administration causes increased food consumption, decreased energy expenditure, and weight gain **[22].** Ghrelin plays the primary role of controlling food intake between meals. This orexigenic activity prior to meals is substantially carried out by ghrelin in

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the direct and basic effect on parts of the brain dependent on controlling hunger and its regulation **[23].** An appetite-stimulating hormone known as ghrelin has also been proposed to increase ACTH and prolactin secretion as well as releasing the growth hormone. Physiological doses delivered intravenously trigger hunger and a transient increase in food consumption. Its levels increase nearly double during a pre-meal and decline very quickly. In anorexic individuals, levels are increased but in the case of obese persons, levels are less **[24].**

3) PYY and GLP-1:

The surface of the intestine is densely covered with many hormone-producing enteroendocrine (EE) cells constituting the largest reservoir of endocrine cells of the body. These EE cells are distributed between billions of absorptive epithelial and other types of cells, and can notice and respond to changes in the gut environment. They also produce numerous signaling molecules that serve as hormones such as glucagon-like peptide (GLP-1) and peptide (PYY) that are co-secreted by L-cells **[25].** In the relationship of the GI tract hormone levels, the two gut hormones (GLP-1 and PYY3-36) when released by L-cells in response to food are more able to suppress appetite in combination, compared to separately. The co-secretion of GLP-1 and peptide YY (PYY) produced by the L-cells following food ingestion is cleaved by DPPIV to PYY336 which specifically activates the Y2 receptor to produce anorectic actions, raising interest in obesity and diabetes research. PYY is released with glucagon hormones like GLP-1 by L-cells located in the lower gut. Its plasma level increases following a food intake, and it undergoes quick biodegradation by dipeptidyl peptidase-4 into its major circulating effective form, the PYY3-36. This highly active form controls satiety and energy equilibrium **[26].**

4) Cholecystokinin:

Cholecystokinin is one of the first digestive peptides to act as an appetite regulator . Its major production source is the small intestine with the prominent concentration in the proximal areas. CCK receptors occur on pancreatic nerves, gallbladder muscle, the gastrointestinal nerves and muscles, and other brain areas. The dietary protein and fat cause its release in the digestive tract **[27].** CCK is primarily released as a result of fatty acids and is a vital part of digestion. It reduces gastric emptying, thereby delaying food passage between the stomach and small intestine and triggers pancreatic digestive enzyme secretion to help in breakdown of nutrients in the small intestine **[28].** It affects both the peripheral and central nervous system and produces strong satiety signals which assist in regulation of food intake and body weight. It can also aid in digestion and absorption of nutrient throughout the digestive tract. Several hormones, that is leptin, ghrelin, insulin, regulate CCK release **[29].** It is a gastric hormone released by enteroendocrine cells in response to food consumption. It controls appetite by inducing satiety, delaying the rate of gastric emptying, and releasing digesting enzymes.It has been demonstrated to reduce food intake through CCK1 receptors as well as vagal nerve signaling, in a variety of experimental models **[30].**

B. Protein for Satiety

Among the three macronutrients, dietary protein is unique one to supply essential amino acids. The essential amino acids are vital and people need them to survive but mammals cannot create them and therefore must include them as part of the diet.The value of protein as a source of energy is due to metabolic activity and the amino acids they provide are essential. Dietary protein quality differs, with quality sources providing neutral levels of essential and non-essential amino acids to satisfy nutritional demands, whereas low-quality protein sources tend to possess unequal ratios of non-essential and disproportionate shortage of essential amino acids **[31].** The energy dense protein/amino acids supplementation is an effective means of decreasing the overall energy consumption through satiety, in comparison to carbohydrates and fats.Protein administration is linked with the release of the proteins cholecystokinin (CCK), glucagon-like peptide-1(GLP-1), and peptide YY (PYY) secreted by the enteroendocrine cells of the small bowel and constitute the anorexigenic (appetite-reducing) hormones **[7].** The consumption of protein breakfasts has been observed to reduce hunger more than a carbohydrates rich breakfast. Adding high protein meals as a way of reducing food consumption at the next meal is a popular method of achieving a negative energy balance when losing weight or minimizing gain when trying to maintain a stable weight . Also, breakfasts high in protein contribute to healthier glucose levels after meals, which is directly related to a decreased risk of diabetes 2, blood pressure and heart conditions **[32].** The short-term decrease in food intake also depends on the protein content of food or a meal in humans. It is evident that a protein content of 50g in a meal or food has higher power in determining satiety compared to either fat or carbohydrates **[33].** Central and peripheral neuro-humoral mechanisms are involved in the regulation of satiety by dietary proteins that are affected by proteins depending on amino acids content, physical form, food matrix and interactions with other nutrients. The satiating effect of protein has been demonstrated by behavioral measures of eating motivation in humans, with confirmatory effects on food intake and metabolic markers, such as satiety- and appetite-modulating hormones **[34].** The quality of protein is defined by two important elements: (1) properties of protein itself and food matrix in which protein is supplied, and (2) needs of an individual consuming that protein, which varies because of several factors including age, health condition and state, level of physiological processes, and energy balance **[35].** Bioavailability or digestibility of a protein is defined as the capacity of supplying the body tissues and organs with metabolically available proteins in terms of nitrogen and amino acids.

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These amino acids have a high potential of affecting the availability of the amino acids in terms of satisfying metabolic requirements, which depends largely on the food matrix through which the protein is ingested **[36].** Animal proteins compared to the plant proteins have been shown to increase the levels of postprandial, substrate oxidation and diet induced thermogenesis. Amino acid composition greatly determines the satiety of a meal and postprandial metabolism and may be dependent on other conditions, such as the physiological state of the subject or conditions prescribed to them, time of the day when a protein is consumed, or quantity **[37].**

C. Hunger Assessment Tools

The satiety process on the basis of hunger is an outcome of neuroendocrine processes that recover the metabolic stability. When there is food deprivation, homeostatic hunger is activated through neuroendocrine, endocrine, and metabolic mechanisms that relay the message to the body that it requires food. Conversely, hedonic hunger is a type of hunger that arises when no imminent calorie requirement is present, and the availability of food caused by agriculture has favored this kind of hunger relative to homeostatic. Furthermore, the structure and modulation of the intestinal microbiota can also interfere with the hunger-regulating mechanisms, but the precise mechanism underlying intake regulation by the microbiota has yet to be determined **[38].**

1) Three Factor Eating Questionnaire (TFEQ)

Three-Factor Eating Questionnaire(TFEQ) is a self assessment tool that is generally applied to measure eating behaviours of the overweight and normal individuals **[39].** It measures three cognitive and behavioral eating dimensions: cognitive restraint (CR) which refers to the intentional constriction of food in order to control weight or support weight loss; uncontrolled eating (UE), i.e., the inability to resist the urge to eat more than usual amounts due to lack of control over consumption; and emotional eating (EE) which is the overeating induced by negative emotions **[40].** TFEQ is a useful instrument to not only predict weight loss in a clinical patient but also monitor changes in weight loss throughout treatment. It possesses good psychometric qualities and it is one of the most commonly used scales to inquire eating behaviors in people with obesity **[41].**

2) Visual Analog Scale (VAS)

Visual analogue scales (VAS) are widely used in the assessment of subjective appetite and satiety. The appetite questionnaires based on VAS are sensitive to fluctuations in appetite as expected and are able to forecast food intake, and are thus a very valid instrument of measuring subjective appetite. This is a standard tool in measuring appetite in normal adults as well as eight years and above children **[42].** Measurements of appetite and associated feelings were conducted using visual analogue scales (VAS) of 100mm, which were given internally every 10-30 minutes in the course of the studies. Awareness was created among the participants on the scales prior to the study. The 100-mm lines were one that matched an appetite sensation (e.g. hunger, fullness, nausea) or mood state (e.g. calmness, boredom, drowsiness) with its opposite (e.g. hungry vs. not hungry or calm vs. anxious). To determine the rating, the respondents were asked to identify a vertical line at the position which was good to describe their present feeling where the scores were measured based on the distance between the left side of the line and the mark there. To quantify hunger, Visual Analog Scales were first established that had six questions: How hungry do you feel? how full are you? What would your urge to eat ? How many do you think you can eat now? What is your desire to eat? What is your obsession over the thoughts of food? People respond to each questions by selecting single mark on a 100 mm straight scale [**43].**

3) Pictorial Measures of Hunger

Since there are no objective measures to measure eating behaviours, picture scales have become a popular alternative to measure subjective feelings in research in measuring children **[44].** The pictorial measures of hunger were initially created to determine the body part that was associated to the sensations of hunger and also quantify the intensity of the hunger sensations **[45].** In this technique, subjects draw on an outline of a human body the extent to which they experience hunger feelings, the larger the extent of marked region indicates the degree of the hunger feelings. Being a novel instrument, it still needs to be validated and would not be applied as a standalone tool of hunger measurement. Although this pictorial instrument has been tested in subject with obesity, the instrument was developed on the normal weight subjects and the ensemble of the body outlines in the measure represent ABC measures the normal weight body **[46].**

II. MATERIALS AND METHODS

This review combines current evidence on the impact of a high-protein breakfast on appetite hormones and hunger regulation in obesity. A systematic search was carried out to identify the relevant literatures in various databases that include PubMed, Scopus, Web of science, and Google scholar. Appropriate studies were identified by using specific keywords such as “Protein breakfast,” “Appetite hormones,” and “Hunger assessment”. This review article considered studies conducted or published between 2000 and 2025 to include both early and recent publications. Articles other than

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English language and non-human subjects were excluded. The inclusion criteria were randomized controlled trials, observational studies, systematic reviews, covering a wide range of perspectives regarding the topic. The aim was to determine the effect of protein-enriched breakfast on the regulation of satiety hormones and subjective responses of hunger. Specific emphasis was placed on the hormones that regulate appetite, including ghrelin, leptin, and peptide YY as well as GLP-1. By compiling existing evidence, the review explain the role of protein based breakfasts as a dietary intervention in obesity. The findings are expected to contribute to nutritional interventions targeting improved appetite regulation and weight control.

III. RESULT AND DISCUSSION

A study by **Braden *et al.,* (2023)** on the effect of different protein sources such as whey, soy, pea and caesin compared on appetite and satiety hormones was conducted on 32 adults were given 250kcal with 24g of protein in each meal for 3 days and in the last day appetite assessment were undergone. Result shown caesin and pea protein significantly reduced appetite and increased peptide YY levels compared to soy protein. Whey protein had intermediate effect which were not significantly different to others. There was no difference in total energy intake . The study concluded that protein source has an effect on short term appetite and satiety **[47]**.

Leidy *et al.,* (2013) investigated a study on high protein, normal protein and breakfast skipping on appetite and eating behaviours in overweight or obese girls. In this study participants consumed 350Kcal breakfast with normal protein (13g), High protein (35g) and skipped breakfast for 6 days each and in the 7 th day of every week appetite hormone, brain responses and eating behaviour has been assessed. Result of the study showed both normal protein and high protein breakfast reduced hunger and increased fullness compared to girls skipping breakfast. High protein shown significant reduction in ghrelin , increase in PYY. Based on thses findings researcher suggested High protein breakfast help in regulating appetite and could be used in the management of obesity **[48].**

Another study by **Lanuza *et al.,* (2022)** in the city of Santiago, Chile explored the relationship between fasting concentrations of appetite hormones with breakfast protein consumption in 655 adolescents. In this study 4 hormones such as Leptin, Ghrelin, Insulin and Orexin-A were assessed. Result showed that higher levels of leptin, ghrelin and orexin- A were related to high energy breakfast, whereas higher insulin is linked with low breakfast intake. The participate consumed on an average of 637 ± 239 kcal . The result indicate appetite hormone modulation will be a potential stratergy to control excessive food intake and body weight **[49].**

Yang *et al.,* (2021) conducted study on 27 non obese pre-menopausal women and examined how high protein and high carbohydrate breakfast affect appetite and cravings after habitual sleep and curtailed sleep. The result showed lack of sleep increased hunger, desire to eat and reduced fullness irrespective of the type of breakfast. Contrast to that High protein breakfast high protein breakfast reduced food cravings when compared to high carbohydrate breakfast under both the sleep conditions. The study recommends that appropriate sleep and rest is important to increase the satiety benefits of high protein breakfast **[50].**

A effect of calorie restricted diet and exercise was studied by **Alyar *et al.,* (2024)** in 62 obese adults for 12 weeks and compared to control group of 48 healthy adults.The intervention resulted in siginificant decrease in ghrelin level and increase in PYY levels indicating increased appetite regulation.The fndings suggest calorie restricted diet and exercise show positive influence on appetite hormones and aid in weight loss **[51].**

Zhu *et al.,* (2023) validated digital version of Visual analog scale (VAS) to measure appetite using smartphone. It's a crossover study comprising 102 individuals, paper and electronic version of Visual Analog scale were used to measure appetite response after 230 or 460 kcal breakfast.The researchers concluded, that digital VAS on smart phone was a real world validated instrument used to measure appetite **[52].**

Although previous evidences have shown that high protein breakfast can impact appetite hormones like ghrelin and PYY which favoured short duration in adolescent and obese women. However no studies in the past has examined the impact of high protein breakfast in obese adults in relation to improving appetite hormones. Study seeks to fill this gap assessing long term effect of high protein breakfast on appetite hormones and assessing hunger management in obese adults using both hormonal assays and tool like Visual Analog Scale (VAS).

IV. CONCLUSION

This review concludes that high-protein breakfasts contribute to appetite control, satiety, and the management of hunger, mainly due to effects on gastrointestinal peptides (CCK, GLP-1, PYY) and appetite hormones including leptin and

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ghrelin. These processes helps in reducing food consumption, an increase in satiety, and control energy balance more than carbohydrate or fat-rich breakfasts. Numerous experimental and clinical investigations indicate that high-protein breakfasts not only reduce the feeling of hunger but also improve hormonal reactions related to satiety, which makes it a feasible approach in preventing obesity and other related metabolic factors.

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CONFLICT OF INTEREST

All authors have no conflict of interest or any affiliation or involvement in any organization, academic, commercial, financial, personal or professionally relevant to the work.

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