HHS Public Access

Author manuscript

Perspect Psychiatr Care. Author manuscript; available in PMC 2015 October 29.

Published in final edited form as:

Perspect Psychiatr Care. 2012 January ; 48(1): 34–40. doi:10.1111/j.1744-6163.2011.00304.x.

Regulating Satiety in Bulimia Nervosa: The Role of Cholecystokinin

Sandy Hannon-Engel, PhD(c), RN, CS [doctoral candidate]

Psychiatric/Mental Health Department, Connell School of Nursing, Boston College, Chestnut Hill, Massachusetts, USA

Abstract

PURPOSE—Individuals with bulimia nervosa (BN) report altered perceptions in hunger, fullness, and satiety. This article reviews the role of cholecystokinin (CCK), a satiety-producing hormone, in the regulation of binge eating in those who suffer from BN.

CONCLUSION—Studies have shown that CCK is decreased in individuals with BN when compared with healthy controls. Decreased CCK functioning may contribute to impaired satiety and thus binge eating in this patient population. Depending on the macronutrient composition of food choices, CCK release can be differentially influenced. For instance, protein is a potent stimulator of a CCK response. Eating more protein-rich meals increases the release of CCK, increasing satiety and ending a meal.

PRACTICE IMPLICATIONS—Knowledge of CCK functioning and the utility of manipulating the macronutrient composition of meals may inform standard behavioral treatment strategies for those who suffer from BN.

Search terms

Bulimia nervosa; cholecystokinin; eating disorder; satiety

Bulimia nervosa (BN) is a chronic and debilitating illness that is characterized by extreme alterations in eating patterns, including an irresistible urge to overeat followed most often by self-induced vomiting. BN's core defining feature, repeated binge-eating episodes and the associated compensatory behavior, has a serious impact on the psychological and physiological well-being of this vulnerable and often chronic population. The fourth edition, text revision of the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2000) identifies the cardinal feature of BN as binge eating, characterized as a "loss of control" during repeated episodes of eating excessively large amounts of food (American Psychiatric Association, 2000, p. 594). This is followed by inappropriate purging or nonpurging compensatory behaviors. Purging behaviors include self-induced vomiting, laxative abuse, diuretic abuse, and misuse of enemas. Nonpurging behaviors include fasting, strict dieting, or excessive exercising in an effort to maintain or lose weight. To meet diagnostic criteria, binge-eating and purging behaviors must occur at a minimum frequency of two times per week over the course of 3 months.

Author contact:hannonen@bc.edu.

This disorder often begins in adolescence and can persist through adulthood. Research suggests that BN is more common in young women than men, and is genetically linked (Bulik et al., 2003), with an estimated 1% lifetime prevalence (Hudson, Hiripi, Pope, & Kessler, 2007). Commonly, depression, anxiety, and substance use disorders co-occur with bulimia (Steinhausen & Weber, 2009) and can result in significant role impairment (Hudson et al., 2007) and a substantial economic burden (Simon, Schmidt, & Pilling, 2005). A pervasive devalued self-worth (including loathing of body weight and shape) is characteristic of BN. Common premorbid characteristics of impulsivity (Wolfe, Jimerson,& Levine, 1994), dysregulated emotions (Kaye, Bulik, Thornton, Barbarich, & Masters, 2004), low self-esteem, early menarche, dieting, and being criticized by others concerning their eating habits (Fairburn, Welch, Doll, Davies, & O'Connor, 1997) may contribute to the vulnerability and expression of this disorder. Individual risk factors can include genetic and familial vulnerabilities to dieting, obesity, psychiatric disorders, and substance misuse disorders (Fairburn & Harrison, 2003). Affected individuals are likely to maintain normal weight despite fluctuations and a decreased metabolic rate (Birketvedt et al., 2006). Food restriction and dieting generally precede episodes of binge eating; however, these attempts are generally futile against the cycle of repeated binge purge episodes (Beumont, 2002).

Comorbid medical conditions ensue with persistent illness. Teeth can become eroded secondary to the direct repeated exposure to gastric acids following a vomiting episode (Milosevic, 1999). The most frequent compensatory behavior, self-induced vomiting (Reba et al., 2005), can further compromise electrolyte status, requiring careful monitoring of specific laboratory values to avert complications (Wolfe, Metzger, Levine, & Jimerson, 2001). Surprisingly, even when individuals affected by BN present for routine medical care and/or eating disorder-related symptomatology, this illness often goes undetected (Johnson, Spitzer, & Williams, 2001) as patients may underreport symptoms secondary to shame, guilt, and/or a desire to retain this aberrant eating behavior.

Less than half of those affected by BN seek treatment (Hoek & Van Hoeken, 2003) and less than 50% of those in treatment achieve a full and lasting response (Fairburn, 2002; Steinhausen & Weber, 2009). For example, cognitive–behavioral therapy (the most widely accepted and studied) results in less than 50% of individuals achieving full remission, and the only one Federal Drug Administration-approved medication, fluoxetine, merits a 40% success rate (American Psychiatric Association Workgroup on Eating Disorders, 2006). Finally, outcome studies show that at least one third of individuals who previously recovered were likely to relapse and over two thirds maintain eating disorder symptoms of clinical severity (Fairburn, Cooper, Doll, Norman, & O'Connor, 2000).

Binge Eating and Satiety

The biobehavioral aspects of binge eating are multifaceted and not fully understood. It has been suggested that those affected by BN may suffer from an impaired satiety system (Kissileff et al., 1996). Satiety refers to "the inhibition over hunger and further eating that arises as a consequence of food ingestion" (Blundell & Hill, 1993, p. 209). A functional satiety system consists of a complex integrative central and peripheral signaling network of positive and negative feedback mechanisms that sustain energy homeostasis (Smith &

Geary, 2002). Positive feedback signals begin feeding behavior, and in response, inhibitory feedback signals terminate an episode of eating (Smith & Gibbs, 2002). If there is a dysregulation in the potency of the negative feedback signaling mechanism, meal size and duration can be enlarged. Binge eating may reflect a dysregulation in the negative feedback mechanism of the satiety system (Figure 1).

Initial reports from patients with BN indicate an inability to distinguish fullness at the end of a normal meal and eating patterns that alternate between severe restriction and binge eating (Pyle, Mitchell, & Eckert, 1981). While self-reports of food consumption by those with BN appear dramatic (Mitchell & Laine, 1985), studies show a direct correlation between subjective accounts and laboratory measurement of food intake (Walsh, Kissileff, Cassidy, & Dantzic, 1989). Clinical laboratory studies show that patients with BN consume a significantly larger amount of food compared with controls (Guss, Kissilef, Walsh, & Devlin, 1994) and at a significantly more rapid pace (Zimmerli, Devlin, Kissileff, & Walsh, 2010). In contrast to healthy controls, despite eating quantifiably larger amounts of food, patients with BN reported less fullness and displayed increased motivation to eat as the meal progressed (Kissileff et al., 1996).

BN subjects consumed far fewer calories when instructed not to binge in comparison with controls (Hadigan, Kissileff, & Walsh, 1989), underscoring that persons with BN may regularly restrict when not engaged in a binge-eating episode. One plausible explanation is that due to a lack of inhibitory controls, patients artificially terminate meals in contrast to allowing the naturally occurring mechanisms of satiety to affect both meal size and duration.

These studies demonstrate a clear abnormality in eating behavior that may serve to perpetuate this incapacitating disorder.

Overview of Cholecystokinin

Researchers focused on the negative feedback mechanisms that terminate a meal are interested in the postprandial (after a meal) measurement of the hormone cholecystokinin (CCK). This well-known satiety-producing gastrointestinal hormone influences meal size and duration (Smith, 2002). CCK was originally discovered in 1928 (Ivy & Goldberg, 1928) for its ability to contract the gallbladder, and was later found to stimulate pancreatic exocrine secretion (Harper & Raper, 1943). Additional physiological actions include regulation of gastric emptying and induction of satiety. In a highly synchronized manner, CCK regulates the intake, digestion, and absorption of nutrients (Chandra & Liddle, 2007; Dockray, 2009b).

CCK is produced by the enteroendocrine cells located in the proximal mucosa of the small intestine (Chandra & Liddle, 2007). CCK-producing cells can be found in the small intestine, vagal afferent nerve fibers, and brain (Moran & Kinzig, 2004). CCK-1 receptors (previously identified as A-alimentary) are primarily located in the gastrointestinal system, whereas CCK-2 receptors (previously known as B-brain) are located in the central nervous system. It is the interactions of the CCK-1 receptors that are thought to contribute to satiety signaling (Dockray, 2009a; Moran, Ameglio, Schwartz, & McHugh, 1992).

The signal pathway that is involved with satiety begins with a robust CCK postingestive response to nutrients. After chyme (partially digested food) enters the proximal duodenum (through relaxation of the pyloric sphincter), CCK is released from the lumen mucosa into the periphery (Smith & Gibbs, 2002). CCK-1 receptor interacts with the vagus nerve projecting onto the nucleus tractus solitarius (NTS) of the hindbrain (Chandra & Liddle, 2007). Further influence extends to the arculate nucleus of the hypothalamus and the paraventricular nucleus (Rehfeld, 2004). This higher order integration evaluates inhibitory signals and metabolic state to determine energy storage needs for regulation, whereas the NTS primarily controls the amount of food eaten (Hellstrom et al., 2004). In summary, CCK stimulates the vagus nerve, which sends a robust signal to the hindbrain for the termination of a meal.

CCK and Satiety

Preclinical studies have been essential in demonstrating CCK as an integral component of the satiety system. These studies have shown that intravenous administration of CCK induced satiety in canine (Sjodan, 1972) and in rats (Gibbs, Young, & Smith, 1973). Additionally, intraperitoneal injection of CCK during sham feeding in the rat not only stopped feeding but elicited the complete behavioral sequence of satiety (Antin, Gibbs, Holt, Young,& Smith, 1975).

In humans, intravenously infused administration of CCK versus saline in a double-blind experimental fashion resulted in a decreased appetite in healthy normal- and obese-weight women (Lieverse, Jansen, Masclee, & Lamers, 1995), and an earlier termination of the meal without changes in the rate of eating or complaints of side effects in healthy lean (Kissileff, Pi-Sunyer, Thornton, & Smith, 1981) and obese men (Pi-Sunyer, Kissileff, Thornton, & Smith, 1982). Additionally, behavioral measures (postprandial visual analog satiety ratings) were positively correlated with CCK responses in healthy males (Boelsma, Brink, Stafleu, & Hendriks, 2010; Holt, Brand, Soveny, & Hansky, 1992). While initial studies showed administration of CCK reduced meal size and duration, studies using a CCK-1 receptor antagonist demonstrated an increase in caloric intake and feelings of hunger (Beglinger, Degen, Matzinger, D'Amato,& Drewe, 2001). The above evidence further illustrates the satiety-producing effects of CCK.

CCK and Satiety: BN

Individuals affected by BN consistently exhibit altered perceptions of hunger and fullness or satiety (Halmi, Sunday, Puglisi, & Marchi, 1989). A faulty satiety system fails to signal and subsequently inhibit the intake of food (Devlin et al., 1997; Kissileff et al., 1996). CCK's postprandial measurement, compared with controls, shows a blunted response in individuals with BN (Devlin et al., 1997; Geracioti & Liddle, 1988; Keel, Wolfe, Liddle, De Young, & Jimerson, 2007; Pirke, Kellner, Friess, Krieg, & Fichter, 1994). It has been suggested that this diminished response is due to a compilation of gastrointestinal dysfunctions (Hadley & Walsh, 2003; Walsh, Zimmerli, Devlin, Guss, & Kissileff, 2003). For example, subjects with BN have an enlarged gastric capacity, diminished sensitivity to distention, and slowed gastric emptying as compared to matched healthy controls (Zimmerli, Walsh, Guss, Devlin,

& Kissileff, 2006). An enlarged gastric capacity (the result of repeated binges) (Geliebter & Hashim, 2001), may take longer to fill, thereby delaying the entry of chyme into the small intestine. This slowed gastric emptying (Geliebter et al., 1992) could confound the expected robust release of CCK into the periphery (Devlin et al., 1997). A diminished CCK response to nutrients may fail to adequately signal and lead to an increased amount of food eaten or a binge episode (Figure 2).

In review, individuals with BN and altered satiety maintain the following characteristics in comparison with matched healthy controls:

1. Feel out of control while repeatedly consuming a significantly greater amount of food.
2. Rate and desire to binge eat accelerates instead of decelerates as the meal progresses.
3. After eating excessively large amounts of food, report feeling less, rather than more, satiated.
4. Exhibit altered perceptions of hunger and fullness.
5. Feel more anxious, depressed, sick, and less relaxed during an episode of bingeing.
6. CCK, a satiety-producing hormone, is diminished post-prandially when compared with matched healthy controls.

Influencing CCK Response and Binge Eating

Depending on the macronutrient composition of food choices, CCK release can be differentially influenced. For instance, protein is a potent stimulator of a CCK response (Geraedts et al., 2010). Research studies have observed a hierarchy among macronutrients concerning overall satiety effectiveness in humans, with these macronutrients being protein, carbohydrates, and fats, respectively (Veldhorst et al., 2008). A recent study of healthy but overweight/obese men ($N = 27$) were randomized to high (HP) versus normal protein (NP) and found that the HP group exhibited improved appetite control and satiety during an energy restriction-induced weight loss (Leidy, Tang, Armstrong, Martin, & Campbell, 2010). Research suggests that protein may induce satiety by influencing the release of gut hormones such as CCK, increasing energy expenditure through thermogenesis and raising plasma amino acids concentrations (Potier, Darcel, & Tomé, 2009).

However, those individuals with BN have shown a trend toward eating dessert and snack foods (Rosen, Leitenberg, Fisher,& Khazam, 1986). Further, a carbohydrate craving has been suggested as a driving force in the perpetuation of this behavior (Hadigan et al., 1989). Research examining the utility of dietary protein compared to carbohydrate supplementation (during a 2-week period) resulted in a 62% reduction of binge-eating episodes (Latner & Schwartz, 1999). These binge-eating participants also reported less hunger and greater fullness following supplementation with protein compared to carbohydrate. The addition of protein to a carbohydrate lunch reduced the amount eaten at a subsequent meal compared to carbohydrate alone (Latner & Schwartz, 1999). This suggests that the addition of protein to a mixed-macronutrient meal may enhance the satiating efficiency of those who engage in

binge eating. Latner and Wilson (2004) hypothesize that CCK may mediate the effect of protein on satiety. Further, they propose that increasing the proportion of protein in the diet may decrease the frequency of binge-eating episodes.

Conclusion

Alterations in meal termination or satiation are common abnormal findings among those individuals affected by BN. A diminished CCK response to nutrients (potentially due to disturbances in gastric function) may fail to adequately signal and lead to an increased amount of food eaten or a binge episode. This ineffective physiological response may contribute to the perpetuation and frequent relapse of this disorder. Current knowledge of satiety, CCK functioning, and the possible utility of manipulating the macronutrient composition of meals may inform standard behavioral treatment strategies.

Implications for Nursing Practice

The Latner and Wilson (2004) study suggested that CCK may mediate the effect of protein on satiety, and that increasing the proportion of protein in the diet decreases the frequency of binge-eating episodes. These researchers also suggested that protein both at the beginning of meals and across daily intake may be a protective factor preventing overconsumption. Nurses may assess the clinical utility of these claims by asking their individual patients with BN to maintain a daily food diary. As in the Latner and Wilson study, this diary would include a record of each time and place the patient ate or drank, the amount eaten, and whether the patient considered this to be a snack, meal, or binge. This record should include whether the patient vomited, engaged in other compensatory behaviors, or experienced a loss of control over eating. An assessment of the macronutrient composition (protein, carbohydrate, and fat) of these meals should be tracked for a minimum of 1 week. After developing an understanding of the individual’s usual macronutrient intake, a purposeful evaluation of the effects of increasing dietary protein may yield a decrease in binge-eating episodes. An increased understanding of the pathophysiological mechanisms underlying impaired satiety will elucidate the future direction of clinically significant treatment strategies (e. g., behavioral and pharmacological). Concerning future research, nurses could replicate, expand on Latner and Wilson’s study, or conduct a single-subject design. Further, research targeting the enhancement of postprandial CCK responsiveness may point to novel treatments for this often chronic and debilitating disorder.

Acknowledgment

The project described was supported by Grant Number F31NR010453 from the National Institute of Nursing Research. The content is solely the responsibility of the author and does not necessarily represent the official views of the National Institute of Nursing Research or the National Institutes of Health.

References

American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4th ed.. Washington, DC: American Psychiatric Press; 2000. text revision

American Psychiatric Association. American Psychiatric Association Practice Guidelines for the Treatment of Psychiatric Disorders Compendium. Arlington, VA: American Psychiatric Press; 2006.

Antin J, Gibbs J, Holt J, Young RC, Smith GP. Cholecystokinin elicits the complete behavioral sequence of satiety in rats. Journal of Comparative and Physiological Psychology. 1975; 89:784–790. [PubMed: 1176672]

Beglinger C, Degen L, Matzinger D, D'Amato M, Drewe J. Loxiglumide, a CCK-A receptor antagonist, stimulates calorie intake and hunger feelings in humans. American Journal of Physiology. Regulatory, Integrative and Comparative Physiology. 2001; 280(4):R1149–R1154.

Beumont, PJ. Clinical presentation of anorexia nervosa and bulimia nervosa. In: Fairburn, CG.; Brownell, KD., editors. Eating disorders and obesity: A comprehensive handbook. 2nd ed.. New York: Guilford Press; 2002. p. 162-170.

Birketvedt GS, Drivenes E, Agledahl I, Sundsfjord J, Olstad R, Florholmen JR. Bulimia nervosa—a primary defect in the hypothalamic-pituitary-adrenal axis? Appetite. 2006; 46:164–167. [PubMed: 16499999]

Blundell, JE.; Hill, AJ. Binge eating: Psychobiological mechanisms. In: Fairburn, CG.; Wilson, GT., editors. Binge eating: Nature assessment and treatment. New York: Guilford Press; 1993. p. 206-224.

Boelsma E, Brink EJ, Stafleu A, Hendriks HFJ. Measures of postprandial wellness after single intake of two protein-carbohydrate meals. Appetite. 2010; 54(3):456–464. [PubMed: 20060863]

Bulik CM, Devlin B, Bacanu SA, Thornton L, Klump KL, Fichter MM, Kaye WH. Significant linkage on chromosome 10p in families with bulimia nervosa. American Journal of Human Genetics. 2003; 72(1):200–207. [PubMed: 12476400]

Chandra R, Liddle RA. Cholecystokinin. Current Opinion in Endocrinology, Diabetes and Obesity. 2007; 14(1):63–67.

Devlin MJ, Walsh BT, Guss JL, Kissileff HR, Liddle RA, Petkova E. Postprandial cholecystokinin release and gastric emptying in patients with bulimia nervosa. American Journal of Clinical Nutrition. 1997; 65(1):114–120. [PubMed: 8988922]

Dockray GJ. Cholecystokinin and gut-brain signalling. Regulatory Peptides. 2009a; 155(1–3):6–10. [PubMed: 19345244]

Dockray GJ. The versatility of the vagus. Physiology & Behavior. 2009b; 97(5):531–536. [PubMed: 19419683]

Fairburn, CG. Cognitive-behavioral therapy for bulimia nervosa. In: Fairburn, CG.; Brownell, KD., editors. Eating disorders and obesity. 2nd ed.. New York: The Guilford Press; 2002. p. 141-146.

Fairburn CG, Harrison PJ. Eating disorders. Lancet. 2003; 361(9355):407–416. [PubMed: 12573387]

Fairburn CG, Cooper Z, Doll HA, Norman P, O'Connor M. The natural course of bulimia nervosa and binge eating disorder in young women. Archives of General Psychiatry. 2000; 57(7):659–665. [PubMed: 10891036]

Fairburn CG, Welch SL, Doll HA, Davies BA, O'Connor ME. Risk factors for bulimia nervosa. A community-based case-control study. Archives of General Psychiatry. 1997; 54(6):509–517. [PubMed: 9193191]

Geliebter AA, Hashim SA. Gastric capacity in normal, obese, and bulimic women. Physiology & Behavior. 2001; 74(4–5):743–746. [PubMed: 11790438]

Geliebter AA, Melton PM, McCray RS, Gallagher DR, Gage D, Hashim SA. Gastric capacity, gastric emptying, and test-meal intake in normal and bulimic women. American Journal of Clinical Nutrition. 1992; 56:656–661. [PubMed: 1414964]

Geracioti TD, Liddle RA. Impaired cholecystokinin secretion in bulimia nervosa. New England Journal of Medicine. 1988; 319(11):683–688. [PubMed: 3412386]

Geraedts MCP, Troost FJ, Tinnemans R, Söderholm JD, Brummer RJ, Saris WHM. Release of satiety hormones in response to specific dietary proteins is different between human and murine small intestinal mucosa. Annals of Nutrition & Metabolism. 2010; 56(4):308–313. [PubMed: 20530962]

Gibbs J, Young RC, Smith GP. Cholecystokinin decreases food intake in rats. Journal of Comparative and Physiological Psychology. 1973; 84(3):488–495. [PubMed: 4745816]

Guss JL, Kissilef HR, Walsh BT, Devlin MJ. Binge eating behavior in patients with eating disorders. Obesity Research. 1994; 2(4):355–363. [PubMed: 16358396]

Hadigan CM, Kissileff HR, Walsh BT. Patterns of food selection during meals in women with bulimia. American Journal of Clinical Nutrition. 1989; 50(4):759–766. [PubMed: 2801580]

Hadley SJ, Walsh BT. Gastrointestinal disturbances in anorexia nervosa and bulimia nervosa. Current Drug Targets. CNS and Neurological Disorders. 2003; 2:1–9. [PubMed: 12769807]

Halmi KA, Sunday S, Puglisi A, Marchi P. Hunger and satiety in anorexia and bulimia nervosa. Annals of the New York Academy of Sciences. 1989; 575:431–444. [PubMed: 2633673]

Harper AA, Raper HS. Pancreozymin, a stimulant of the secretion of pancreatic enzymes in extracts of the small intestine. Journal of Physiology. 1943; 102(1):115–125. [PubMed: 16991584]

Hellstrom PM, Geliebter A, Naslund E, Schmidt PT, Yahav EK, Hashim SA, Yeomans MR. Peripheral and central signals in the control of eating in normal, obese and binge-eating human subjects. British Journal of Nutrition. 2004; 92(Suppl. 1):S47–S57. [PubMed: 15384323]

Hoek HW, Van Hoeken D. Review of the prevalence and incidence of eating disorders. International Journal of Eating Disorders. 2003; 34:383–396. [PubMed: 14566926]

Holt S, Brand J, Soveny C, Hansky J. Relationship of satiety to postprandial glycaemic, insulin and cholecystokinin responses. Appetite. 1992; 18(2):129–141. [PubMed: 1610161]

Hudson JI, Hiripi E, Pope HG, Kessler RC. The prevalence and correlates of eating disorders in the National Comorbidity Survey Replication. Biological Psychiatry. 2007; 61(3):348–358. [PubMed: 16815322]

Ivy AC, Goldberg E. A hormone mechanism for gallbladder contractin and evacuation. American Journal of Physiology. 1928; 65:599–613.

Johnson JG, Spitzer RL, Williams JB. Health problems, impairment and illnesses associated with bulimia nervosa and binge eating disorder among primary care and obstetric gynecology patients. Psychological Medicine. 2001; 31(8):1455–1466. [PubMed: 11722160]

Kaye WH, Bulik CM, Thornton L, Barbarich N, Masters K. The Price Foundation Collaborative Group. Comorbidity of anxiety disorders with anorexia and bulimia nervosa. American Journal of Psychiatry. 2004; 161(12):2215–2221. [PubMed: 15569892]

Keel PK, Wolfe BE, Liddle RA, De Young KP, Jimerson DC. Clinical features and physiological response to a test meal in purging disorder and bulimia nervosa. Archives of General Psychiatry. 2007; 64(9):1058–1066. [PubMed: 17768271]

Kissileff H, Pi-Sunyer F, Thornton J, Smith G. C-terminal octapeptide of cholecystokinin decreases food intake in man. American Journal of Clinical Nutrition. 1981; 34(2):154–160. [PubMed: 6259918]

Kissileff HR, Wentzlaff TH, Guss JL, Walsh BT, Devlin MJ, Thornton JC. A direct measure of satiety disturbance in patients with bulimia nervosa. Physiology & Behavior. 1996; 60(4):1077–1085. [PubMed: 8884936]

Latner JD, Schwartz M. The effects of a high-carbohydrate, high-protein or balanced lunch upon later food intake and hunger ratings. Appetite. 1999; 33(1):119–128. [PubMed: 10447984]

Latner JD, Wilson GT. Binge eating and satiety in bulimia nervosa and binge eating disorder: Effects of macronutrient intake. International Journal of Eating Disorders. 2004; 36(4):402–415. [PubMed: 15558650]

Leidy HJ, Tang M, Armstrong CLH, Martin CB, Campbell WW. The effects of consuming frequent, higher protein meals on appetite and satiety during weight loss in overweight/obese men. Obesity. 2010 Sep 16.

Lieverse RJ, Jansen JB, Masclee AA, Lamers CB. Satiety effects of a physiological dose of cholecystokinin in humans. Gut. 1995; 36(2):176–179. [PubMed: 7883212]

Milosevic A. Eating disorders—a dentist's perspective. European Eating Disorders Review. 1999; 7(2):103–110.

Mitchell JE, Laine D. Monitored binge-eating behavior in patients with bulimia. International Journal of Eating Disorders. 1985; 4(2):177–183.

Moran TH, Ameglio PJ, Schwartz GJ, McHugh PR. Blockade of type A, not type B, CCK receptors attenuates satiety actions of exogenous and endogenous CCK. American Journal of Physiology. Regulatory, Integrative and Comparative Physiology. 1992; 262(1):R46–R50.

Moran TH, Kinzig KP. Gastrointestinal satiety signals II. Cholecystokinin. American Journal of Physiology. Gastrointestinal and Liver Physiology. 2004; 286(2):G183–G188. [PubMed: 14715515]

Pirke KM, Kellner MB, Friess E, Krieg JC, Fichter MM. Satiety and cholecystokinin. International Journal of Eating Disorders. 1994; 15:63–69. [PubMed: 8124328]

Pi-Sunyer X, Kissileff HR, Thornton J, Smith GP. C-Terminal octapeptide of cholecystokinin decreases food intake in obese men. Physiology & Behavior. 1982; 29(4):627–630. [PubMed: 6294699]

Potier M, Darcel N, Tomé D. Protein, amino acids and the control of food intake. Current Opinion in Clinical Nutrition and Metabolic Care. 2009; 12(1):54–58. [PubMed: 19057188]

Pyle RL, Mitchell JE, Eckert ED. Bulimia: A report of 34 cases. Journal of Clinical Psychiatry. 1981; 42(2):60–64. [PubMed: 6936397]

Reba L, Thornton L, Tozzi F, Klump KL, Brandt H, Crawford S, Bulik CM. Relationships between features associated with vomiting in purging-type eating disorders. International Journal of Eating Disorders. 2005; 38(4):287–294. [PubMed: 16261604]

Rehfeld JF. Cholecystokinin. Best Practice & Research Clinical Endocrinology & Metabolism. 2004; 18(4):569–586. [PubMed: 15533776]

Rosen JC, Leitenberg H, Fisher C, Khazam C. Binge-eating episodes in bulimia nervosa: The amount and type of food consumed. International Journal of Eating Disorders. 1986; 5(2):255–267.

Simon J, Schmidt U, Pilling S. The health service use and cost of eating disorders. Psychological Medicine. 2005; 35(11):1543–1551. [PubMed: 16219112]

Sjodan L. Influence of secretin and cholecystokinin on canine gastric secretion elicited by food and by exogenous gastrin. Acta Physiologica Scandinavica. 1972; 85:110–117. [PubMed: 4559392]

Smith, G. Cholecysokinin: A molecular negative-feedback control of eating. In: Pfaff, DW.; Arnold, AP.; Etgen, AM.; Rubin, RT., editors. Hormones, brain and behavior. St. Louis, MO: Elsevier Science; 2002. p. 143-152.

Smith, GP.; Geary, N. The behavioral neuroscience of eating. In: Davis, KL.; harney, DC.; Coyle, JT.; emeroff, CN., editors. Neuropsychopharmacology: The fifth generation of progress. Vol. 5. New York: Lippincott; 2002. p. 1665-1673.

Smith, GP.; Gibbs, J. Peripheral physiological determinant of eating and body weight. In: Fairburn, CG.; Wilson, GT., editors. Eating disorders and obesity: A comprehensive handbook. New York: Guilford Press; 2002. p. 11-15.

Steinhausen H-C, Weber S. The outcome of bulimia nervosa: Findings from one-quarter century of research. American Journal of Psychiatry. 2009; 166(12):1331–1341. [PubMed: 19884225]

Veldhorst M, Smeets A, Soenen S, Hochstenbach-Waelen A, Hursel R, Diepvens K, Westerterp-Plantenga M. Protein-induced satiety: Effects and mechanisms of different proteins. Physiology & Behavior. 2008; 94(2):300–307. [PubMed: 18282589]

Walsh BT, Kissileff HR, Cassidy SM, Dantzic SS. Eating behavior of women with bulimia. Archives of General Psychiatry. 1989; 46(1):54–58. [PubMed: 2910221]

Walsh BT, Zimmerli E, Devlin MJ, Guss J, Kissileff HR. A disturbance of gastric function in bulimia nervosa. Biological Psychiatry. 2003; 54(9):929–933. [PubMed: 14573321]

Wolfe BE, Jimerson DC, Levine JM. Impulsivity ratings in bulimia nervosa: Relationship to binge eating behaviors. International Journal of Eating Disorders. 1994; 15(3):289–292. doi: 10.1002/1098-108X(199404)15:3<289:AID-EAT2260150314>3.0.CO;2-U. [PubMed: 8199611]

Wolfe BE, Metzger ED, Levine JM, Jimerson DC. Laboratory screening for electrolyte abnormalities and anemia in bulimia nervosa: A controlled study. International Journal of Eating Disorders. 2001; 30(3):288–293. [PubMed: 11746288]

Zimmerli EJ, Devlin MJ, Kissileff HR, Walsh BT. The development of satiation in bulimia nervosa. Physiology & Behavior. 2010; 100(4):346–349. [PubMed: 20303999]

Zimmerli EJ, Walsh BT, Guss JL, Devlin MJ, Kissileff HR. Gastric compliance in bulimia nervosa. Physiology & Behavior. 2006; 87:441–446. [PubMed: 16376390]

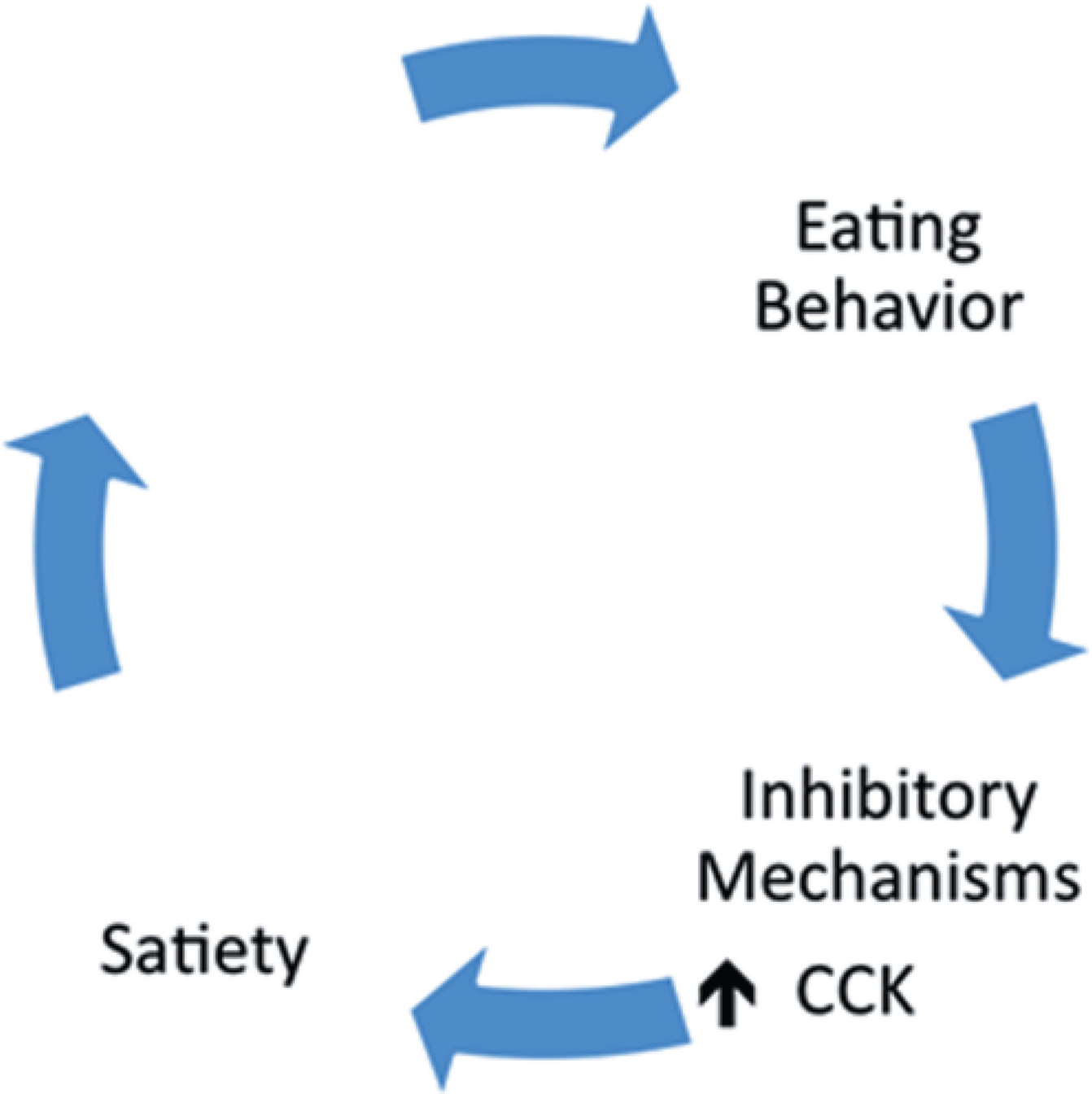

Figure 1.
Normal Eating Behavior

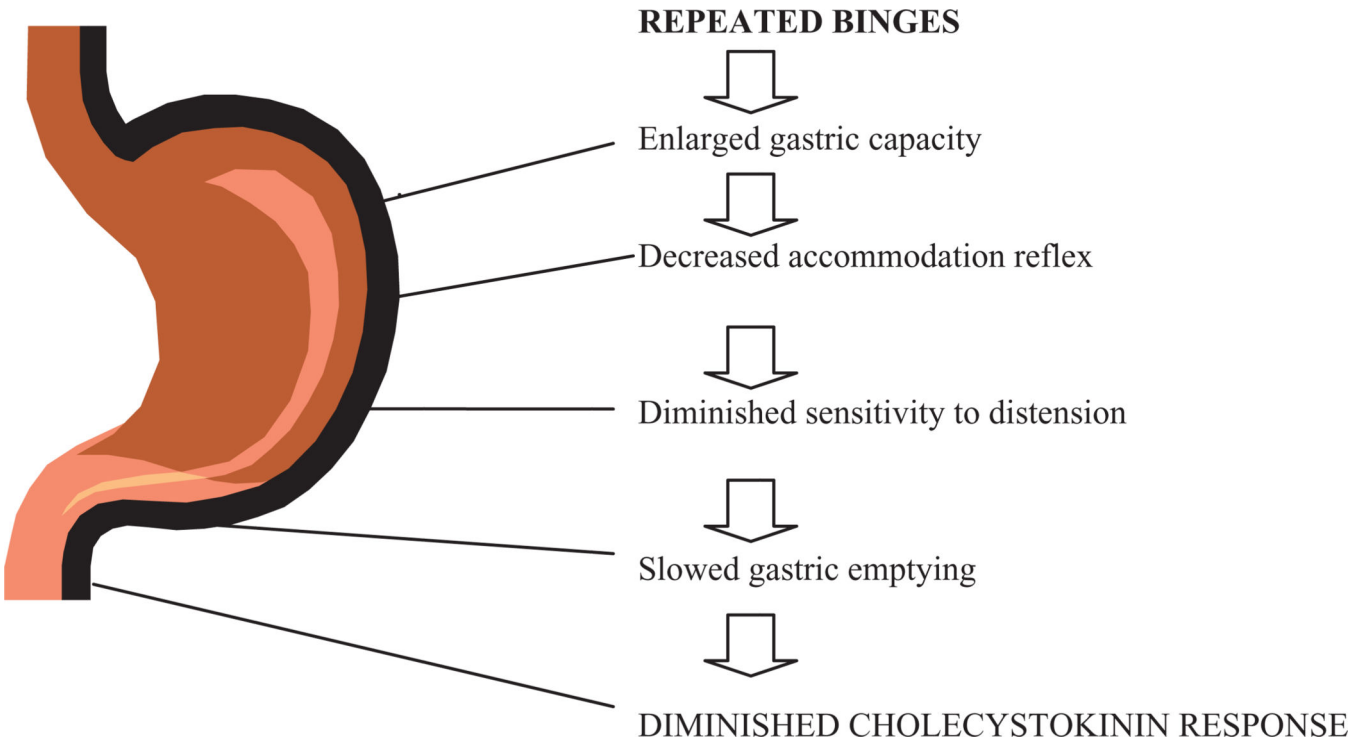

Figure 2.
Compilation of Gastrointestinal Dysfunctions in Bulimia Nervosa