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Hunger associations with meal timing and adherence to meal timing recommendations for weight loss

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HUNGER ASSOCIATIONS WITH MEAL TIMING AND ADHERENCE TO MEAL TIMING RECOMMENDATIONS FOR WEIGHT LOSS

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DEDICATION

I would like to dedicate this work to my dog Danger, grandmother and grandfather, mother and father, aunt and uncle, sisters, and cousins.
Without them, I never would have mustered the courage to apply for a second degree, nor would I have made it this far without their support.

I would also like to dedicate this work to Kim Seokjin, Min Yoongi, Jung Hoseok, Kim Namjoon, Kim Taehyung, Park Jimin, and Jeon Jungkook, for their message of healing and inspiring me to not give up.

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HUNGER ASSOCIATIONS WITH MEAL TIMING AND ADHERENCE TO MEAL TIMING RECOMMENDATIONS FOR WEIGHT LOSS

ELLIE WEI

ABSTRACT

Those who practice poor meal timing habits such as irregular day-to-day eating, eating late at night, and have a short overnight fast are more at risk for weight gain, reduced weight loss with weight loss attempts, and increased risk for developing and/or worsening health conditions such as type 2 diabetes mellitus and cardiovascular disease and/or risk factors for said conditions. Recent studies have identified possible factors that influence meal timing, one of which is hunger. Hunger is defined as a physiologic need to eat, and can be triggered by a rise in the hormone ghrelin. Hunger in general, or greater hunger at certain times of day, may lead to poor meal timing and/or difficulty adhering to meal timing recommendations made in behavioral interventions. The goal of our study was to determine if the overall hunger level and time of onset of greatest hunger were associated with poor meal timing cross-sectionally and lower adherence to meal timing recommendations. The meal timing behaviors we examined were eating late at night, having a longer overnight fast, and an earlier ingestive period midpoint based on published evidence suggesting these are important for weight control. We hypothesized that a greater overall hunger level and later onset of greatest hunger would be inversely associated with poor meal timing cross-sectionally and a lower adherence to potential meal timing recommendations to be applied to future interventions.

Our cross-sectional study was a secondary analysis of data from a previous study on diet and energy regulation in 116 healthy adults (mean BMI 24.3 kg/m$_2$; SD 3.8, mean age 29.4 years; SD 11.9). Both continuous and categorical meal timing outcomes were examined. The continuous outcomes were eating late at night (defined as eating past 20:00 h), length of overnight fast (defined as the length of time between the last meal consumed before bedtime and first eating occasion after waking), and timing of the largest meal, which we measured using the midpoint of the ingestive period. Categorical outcomes, which had cutoff values determined based on evidence from published research, were: not eating after 20:00, achieving an overnight fast of ≥13 hours, and having the midpoint of the ingestive period before 15:00. Associations of hunger variables with continuous meal timing outcomes were examined in three separate models using analysis of covariance, with hunger variables as the independent variables and the meal timing patterns as the dependent variables. Associations of hunger variables with categorical (bivariate) outcomes had the same independent variables but were examined with logistic regression analysis. Covariates included in both continuous and categorical models were age, sex, race, physical activity level, weighted average bedtime on weekdays and weekends, dietary restraint score, dietary disinhibition score, sleep duration, and sleep quality.

After inclusion of all covariates, a higher hunger score was associated with having an overnight fast lasting ≥13 hours (p=0.026), suggesting that participants were able to achieve a longer overnight fast despite being hungrier. There was no significant association between hunger variables and eating late at night or midpoint of ingestive period ($p>0.05$), although the p-value was marginally non-significant with eating late at night ($p=0.080$). Time of greatest hunger was not associated with any of the meal timing variables ($p>0.05$). As previous studies have shown that a longer overnight fast improves weight loss, a possible application of our findings, namely the length of overnight fast, is for individuals who aim to achieve an overnight fast of ≥13 hours to lose weight by consuming a greater proportion energy in the morning/afternoon as opposed to dinner/later at night.. This suggestion is based on previous studies showing eating a larger breakfast decreases feelings of hunger at night. Additionally, including more protein and fiber in the diet can increase satiety at any time of day. Future studies are needed to examine relationships between hunger score and a longer overnight fast, in larger, more diverse populations and with randomized controlled designs, as our study was cross-sectional and was unable to determine causality.

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LIST OF ABBREVIATIONS

Avg	Average
BMI	Body mass index
CI	Confidence interval
D	Day
EI	Energy intake
FFQ	Food frequency questionnaire
H/Hr	Hour(s)
Kcal	Kilocalories
Kg	Kilogram
M	Meters
Mos	Months
NR	Not reported
NS	Not significant
OR	Odds ratio
PAL	Physical activity level
SD	Standard deviation
SEM	Standard error of the mean
TEI	Total energy intake
TRF	Time restricted feeding
W/	With
W/i	Within

WC	Waist circumference
Wk	Week(s)
Y	Year(s)

INTRODUCTION

I. Overview

"Meal timing" is a broad term used to describe when meals and/or snacks are consumed during a 24-hour period, such as irregular day-to-day eating, eating late at night, or short overnight fast. Those who practice poor meal timing habits are more at risk for weight gain, reduced weight loss with weight loss attempts, and increased risk for developing and/or worsening health conditions such as type 2 diabetes mellitus and cardiovascular disease and/or risk factors for said conditions[1,2]. In a recent review on meal timing, the authors concluded that experimental studies have collectively shown that appropriate meal timing habits have beneficial effects on body weight, fat mass, blood pressure, diabetes mellitus, LDL cholesterol, and coronary heart disease[3]. Thus, meal timing is an important dietary factor to consider when aiming to prevent and/or manage these health conditions.

Literature Review

II. Meal timing in relation to adiposity

In this thesis, the outcome measures will be three key meal timing behaviors that based on strong evidence, affect weight and/or obesity measures, explained more in detail below. The evidence from experimental, longitudinal, and cross-sectional studies published through November 2019 will be briefly summarized below for each of the three meal timing patterns.

Eating late at night

Studies that pertain to eating late at night are summarized in **Table 1**. Out of the seven studies reviewed, there were no randomized controlled trials, three prospective studies[4–6], and four cross-sectional studies[7–10]. Although eating late at night may be generally defined as consuming calorie-containing foods and/or beverages sometime in the evening, there is no standard definition and thus the specific timeframes varied between studies. Across the studies, definitions of eating at night ranged from eating after 7 pm, after 8 pm, the last meal before bedtime, and eating within 2 h of bedtime (Table 1).

Cross-Sectional Studies

Findings were varied amongst the cross-sectional studies. Only one study[8] reported an increased risk of obesity between eating late at night and adiposity related results; the others found that this relationship was not significant[7,9]. The lack of agreement may be due to the former study's focus on only the timing of calorie-containing foods and beverages as opposed to what and how much participants consumed, which the other two cross-sectional studies did.

Two cross-sectional studies found an association between eating late at night and greater overall energy intake[9,10], whereas another study found that percent energy intake from morning and midday periods were inversely associated with increasing energy intake in the evening. The two former studies reported that eating the last meal later and/or closer to sleep onset was associated with greater overall energy intake[9] and that obese women had more eating occasions after 8 PM compared with non-obese women[7]. There were several inconsistences across the cross-sectional studies that could have accounted for differing results, such as the operational definition of “late night eating”, control groups or lack thereof, dietary assessment methods, participant characteristics and sample size.

Longitudinal Studies

The longitudinal studies had varying results. Two studies reported that late night eating was positively associated with increased obesity markers[5,6], whereas the other reported no association between and eating late at night and weight change[4]. These conflicting results may be due to differences in dietary assessment methods, as the two studies reporting an association between obesity markers and late-night eating assessed used more in-depth dietary assessment methods such as a standardized questionnaire[6] and 3-day food records[5], whereas the study that reported no significance used a single 24-hour dietary recall at baseline. Two of the studies showed that participants consumed over 40% of their total daily calories during the evening/night period[4,5] whilst calories consumed at night was not assessed in the other study[6]; this provides a possible explanation for why those that consume more later during the day may see increased obesity markers—due to different lifestyle factors such as work schedules and amount of leisure time, participants may find themselves overeating at night to compensate for a lack of sustenance during other times of day.

Table 1—Summary of Studies on Eating Late at Night

First Author, Year	Exposure or Intervention	Control	Dietary Assessment Method	Sample size and Characteristics	Adiposity Related Results	Energy Intake Related Results
			Cross sectional studies			
Kant, 1995[7]	Eating after 20:00	None	One 24-h recall in person, followed by five 24-hour recalls conducted by telephone over 1 year.	n=1802 women aged 19-50 years with 4 complete days of dietary data.	NS	< 1/3 responders ate >50% of daily EI in the evening % EI from morning and midday periods inversely associated with increasing EI in the evening.
Bertéus Forslund, 2002[10]	Eating occasions after 20:00	Number of eating occasions before 20:00	A questionnaire for type of food consumed and time consumed.	177 women (83 of whom were obese) from the Swedish Obese Study		Number of eating occasions per day obese 6.1 per d; non-obese 5.2 per d ($p<0.0001$) Consumption of meals per day shifted later 83% obese; non-obese 60% ($p<0.001$
Kutsuma, 2014[8]	Dinner w/i 2h of sleeping.	Normal eating behavior (no late-night dinner eating or breakfast skipping)	Dietary habits assessed through questions such as “do you eat dinner within two hours before bedtime at least 3 times per week?”	60,800 aged 20-75 years.	Night eating was associated with increased risks of obesity (both adjusted for confounders in addition to age and sex); odds ratio and 95% CI for obesity (late dinner habit alone): Men: 1.3 (1.14 - 1.49) ($P<0.01$) Women: 1.53 (1.25 - 1.88) ($P<0.001$)	
Baron, 2012[11]	Calories in the evening defined as kcal consumed after 20:00	None	7 d food diary	N=52 Mentally healthy individuals who did not report a morning diurnal type preference	Caloric consumption after 20:00 was an independent predictor of BMI after controlling for age, sleep duration, and sleep timing (($\beta = 0.44$, r2Δ = 0.09, $P = 0.03$). -	Later timing of last meal or snack of the day associated with shorter sleep duration and **higher** overall energy intake.

						Late sleepers consumed significantly more calories at dinner and after 20:00 (Mean (S.D.)) **At Dinner:** Normal sleep timing: 630 (198) Late sleep timing: 825 (352) **After 20:00:** Normal sleep timing: 376 (237) Late sleep timing: 754 (373)
Reid, 2014[9]	Dinner was defined as "the last meal before sleeping".	None	7-day food diary	59 mentally healthy individuals.	NS	Eating a later last meal and eating closer to sleep onset were associated with greater energy intake.
Prospective studies						
Yoshida, 2018[6]	Dinner w/i 2 h of bedtime and snacks after dinner	Participants who did not have dinner w/i 2 h of bedtime or snacks after dinner	Self-administered standardized questionnaire	n=8153; aged 40-55 y	**BMI:** *Dinner w/i 2h of bedtime:* 22.9 kg/m$_2$ *Snacks after dinner:* 23.1 kg/m$_2$ *Neither habit:* 22.9 kg/m$_2$. **WC:** *Dinner w/i 2h of bedtime:* 81.6 cm, *Snacks after dinner:* 81.9 cm *Neither habit:* 81.7 cm. All individuals who had both habits had higher odds of abdominal obesity than those with neither habit (multivariable adjusted OR, 1.42%; 95% CI, 1.03-1.97)	NR

Bo, 2014[5]	Dinner 19:00—20:00	Lowest tertile of dinner energy intake	3-d food record (2 consecutive weekdays, 1 weekend day)	n=1245; aged 45-64 y; healthy	Incident obesity (%); fully adjusted Lower tertile 1.0 OR Middle tertile: 1.79 OR (0.89—3.62; p=0.1) Higher tertile: 2.33 OR (1.17—4.65; p=0.02)	Total daily EI: *Lower tertile:* 2054± 657 kcal *Middle tertile:* 2166 ± 6312 kcal *Higher tertile:* 2133 ± 678 kcal
Kant, 1997[4]	Eating after 20:00	None	One 24-h dietary recall at baseline	n=7147, aged 25-74 y; healthy	NS; data NR	Men after 17:00 intake 46% TEI: evening 33 ± 0.5%; night 13 ± 0.4% Women after 17:00 intake 45% TEI: evening: 34 ± 0.4%; night 11 ± 0.3%

Conclusion

Based on the small number of studies done so far, while findings were somewhat mixed, it appears overall that late night eating is associated with higher adiposity, higher energy intake, and more calories consumed at night in most studies[4–9].One possible explanation for these observations is that eating late at night provides extra opportunities to consume additional calories. During the day, many individuals have obligations such as work or school, thus may be restricted to a timeframe or social setting in which they are allowed to eat, such as lunch breaks with co-workers. Nighttime may be a more leisurely time for many individuals, during which eating time is not as restricted and there may be less social constraints, though this remains speculation as the studies involved did not state whether participants excluded night shift and/or swing shift workers or social dynamics. Moreover, it is possible that individuals' energy intake was greater than their energy output, thus leading to weight gain. Hunger in general or at different times of day may also play a role, as reviewed later, but has rarely been measured in meal timing studies. Additional studies are needed, as not all existing studies were in agreement and there have been no experimental studies isolating the effects of eating late at night on adiposity.

a. *Overnight fasting length*

Studies that pertain to the overnight fasting length are summarized in **Table 2**. The length of an overnight fast is generally defined as the duration between last calorie-containing food and/or beverage consumed before sleep and the first intake of calorie-containing food and/or beverage after waking the next day. Out of eleven studies reviewed, three were randomized controlled trials[12–14], two were experimental non-randomized trials[15,16], two were prospective studies[17,18], and five were cross-sectional[15,19–22]. One paper included both experimental and cross-sectional studies [15], whilst another had both cross-sectional and longitudinal analyses[18]. While the definitions of the overnight fast varied across studies, some examined this variable categorically with a specific minimum duration as important, e.g., 8, 11, 11.5 hours etc., while others simply assessed the duration as a continuous variable (Table 2).

Cross-Sectional Studies

Three of the cross-sectional studies generally reported that greater durations of overnight fasting was associated with lower adiposity[18,21,22]. In contrast, studies that examined specific duration cut-offs (e.g. >8, 11, 11.5, 13 hours, etc.) for overnight fast showed that overnight fast ≥12 hours was positively associated with adiposity [19,21], although two studies reported no significance[15,20].The inconsistency of results may be due to the differences in dietary assessment. It should also be noted that one of the studies reported no significance between length of overnight fast and adiposity measures for one group but found a statistically significant association in another group[22]. Additionally, three of the studies showed that length of overnight fast[15,19,22] was negatively associated with total energy intake, meaning that those who had a longer overnight fast had a lower daily energy intake, which may provide a potential explanation for the inverse association between overnight fasting duration and adiposity. However, this does not make sense for all studies, as some had higher BMI with a lower energy intake; this may be due to problems with underreporting of energy intake by participants or differences in study designs.

Longitudinal Studies

The two longitudinal studies were conflicting, with one showing that a longer overnight fast was associated with a decrease in BMI, and shorter overnight with an increase in BMI[17] and the other study showed that a shorter overnight fast was associated with a lower BMI when compared to a longer overnight fast[18]. The discrepant findings between the two studies may be due to how the participants in each study differed—one had healthy men and women[17], whereas the other had only women with early stage breast cancer[18]. Only one of the studies assessed energy intake related results and found that those with a shorter overnight fast consumed more daily calories than their counterparts[18], which is similar to the results from the cross-sectional studies.

Experimental Studies

There were two experimental studies that implemented an intervention to increase overnight fasting duration. Despite the two studies having differing overnight fast durations (13—14-hour vs 16 hour), they both showed that an increased fasting duration led to a reduction in body weight, BMI, and daily calorie intake. However, these findings should be interpreted with caution, as they were not randomized controlled trials with one not having a control group[15] and the other having a historical control group from a previous study.

Randomized Controlled Trials

The randomized controlled trials all had a control group that partook in their normal diet pattern, whilst the experimental group restricted their late night eating to increase the length of their overnight fast. Two of the three randomized controlled trials found that a longer length of overnight fast improved obesity measures such as weight loss[12], decreased BMI[12], and increased loss in fat mass[14] compared to their respective control groups. The remaining study reported no statistical significance between treatment and control groups in adiposity-related outcomes[13]; however, this could be due to the study including resistance training and specific participant characteristics, as participants were recreationally active men, who were relatively lean to begin with. Concerning energy intake, the study that involved resistance training also showed that an increased overnight fast resulting from time-restricted feeding (defined as consuming all daily calories within a strict time period) reduced total calorie intake significantly[13]. The other two studies did not assess energy intake.

Table 2—Summary of Studies on the Length of Overnight Fasting

First Author, year (ref)	Exposure or Intervention	Control	Dietary Assessment Method	Sample size and Characteristics	Adiposity Related Results	Energy Intake Related Results
Cross-Sectional Studies						
Marinac, 2015[19]	Tertile of overnight fasting length: Tertile 1: <11.5 h Tertile 2: 11.5—13.49 h Tertile 3: >13.5 h	None	24h dietary recall by telephone	N=2212; Healthy, non-pregnant women from the NHANES 2009-2010 study. BMI/age NR	BMI associated with length of overnight fasting (p=0.01) Avg. BMI per tertile (kg/m^2) (SEM) Tertile 1: 27.5 (0.4) Tertile 2: 27.9 (0.4) Tertile 3: 29.1 (0.3)	%TEI associated with overnight fasting tertiles (p<0.001) Total daily energy intake of overnight fast tertiles (SEM) Tertile 1: 1914 (51.8) Tertile 2: 1798 (39.2) Tertile 3: 1623 (32.4)
Gill, 2015[15]	Length of time between last EI before sleeping and first EI after waking the next day.	None	21-d food record using an app that involved taking pictures of all consumed items	N=156; Healthy, non-smoking adults from baseline study with BMI >25 kg/m^2 Male avg. age 34.4 ± 2.9 y Female avg. age 36.3 ± 4.3 y	NS	First and last EI of the day were weakly positively correlated (p<0.0001) Correlation between last EI and eating duration p<0.0001
Gupta, 2017[20]	Length of time between last EI before sleeping and first EI after waking the next day.	None	21-day food record on a provided camera phone.	N=94; Physically and mentally healthy, non-smoking, non-pregnant adults aged 19-58 y, BMI 14.8—34.8 kg/m^2	NS	None
Ha, 2019[21]	Q1— < 8h fasting Q2—8-10 h fasting Q3—10-12 h	None	1 24-hour dietary recall	N=14,279; Healthy, non-pregnant adults ≥19 years	Fasting 10-12 h/day decreased prevalence of overall obesity vs. fasting >16 h/day (OR	None

	Q4—12-16 h fasting Q5—≥16 h fasting			BMI NR	0.75; 95% CI 0.57-0.98) Fasting 10-12 h/day decreased prevalence of abdominal obesity in women vs. > 16 h/day (OR 0.74; 95% CI 0.56-0.98)	
Tiuganji, 2019[22]	Length of time between last EI before sleeping and first EI after waking the next day.	None	3 non-consecutive 24-h dietary recalls (1 day off; 2 work days).	N=68; Working individuals living in Acre or Sao Paulo and had an excessive consumption of fat Rural avg. BMI 24.95 kg/m^2 Town avg. BMI 28.07 kg/m^2	BMI: NS for those who lived in rural and town areas. Rho = 0.48; $p < 0.05$ for eating duration/overnight fast for city dwellers.	Duration of eating period associated w/ TEI $r = -0.44$, $p = 0.004$
Longitudinal Studies						
Kahleova, 2017[17]	Long (≥18 h) Medium (12-17 h) Short (< 12 h) over 7 ± 1 years	Baseline data[a]	FFQ at baseline, follow-up 24-hour recalls.	N=50,660; Individuals between 14.0 and 60 kg/m^2 over 30 y who had their last meal of the day after 11:00 and had complete data.	BMI change/y (95% CI): Long overnight fast: -0.02 kg/m^2 (0.03, -0.004) Short overnight fast: 0.02 kg/m^2 (0.01, 0.03) Medium overnight fast NR Long and short fasts vs medium fast, $p<0.001$.	None
Marinac, 2016[18]	Fasting tertile 1 (<11.5h) Fasting tertile 2 (11.5—13.49h)	None	Random, prescheduled 24h recall	N=2413; Women 27-70 y at diagnosis of breast cancer, had	Mean BMI (SEM): Tertile 1: 27.5 (0.4) Tertile 2: 27.9 (0.4) Tertile 3: 29.1 (0.3)	TEI (kcal/day) (SEM) Tertile 1: 1914 (51.8) Tertile 2: 1798 (39.2) Tertile 3: 1623 (32.4)

	Fasting tertile 3 (≥13.5h)			early-stage breast cancer at the time of study and participated in the WHEL between 1995 and 2007		P < 0.001
Experimental Non-Randomized Controlled Trials						
Gill, 2015[15]	Fasting for a 13-14-h interval	Baseline data	Electronic food-logging	8 healthy subjects from the baseline study with a BMI of > 25 kg/m^2 and had over 14 h of energy intake.	Avg weight loss: 3.27 kg (95%CI 0.9081-5.624 kg) Avg BMI reduction: 1.15 kg/m^2 (95% CI: 0.32–1.98 kg/m^2)	Avg. kcal reduction: 20.26% (95% CI: 4.92%–35.6%) P<0.05
Gabel, 2018[16]	Fasting between 6 PM to 10 AM; historical control group	Historical control group	7-d food diary during baseline period and week 12.	N=23; Healthy, non-smoking, sedentary to lightly active individuals aged between 25 and 65 y, BMI 30—45 kg/m^2	Body weight: –2.6% ± 0.5 in the TRF group compared to the control group (p<0.001) BMI: TRF group: 35 ± 1 kg/m^2 (baseline) 34 ± 1 kg/m^2 (week 12) Control group: 34 ± 1 kg/m^2 (baseline) 34 ± 1 kg/m^2 (week 12) p<0.001	–341 ± 53 kcal/day change in the TRF group compared to the control group (p<0.05)
Randomized Controlled Trials						
LeCheminant, 2013[12]	Fasting overnight for 11 hours (19:00 – 06:00); during control period instructed to continue with normal diet, eating patterns, and lifestyle in	Normal diet, lifestyle, eating patterns	Multiple pass 24-hour recalls (ASA24)	27 healthy, non-drinking, non-smoking, non-dieting adults aged 18-26 years.	Weight change (SD) Fasting period: -0.4 (1.1) kg Control period: +0.6 (0.9) kg P<0.001 BMI change (SD):	Fasting period: 2420 kcal intake/day Control period: 2664 kcal intake/day p=0.018

	crossover design; 5 wks incl. 1 wk washout period				Fasting period: -0.1 (0.3) kg/m^2 Control period: +0.2 (0.3) kg/m^2 P<0.001	
Tinsley, 2017[13]	Consume all kcal in any 4 h window between 16:00—00:00 on non-workout days (4 d/wk); control group performed resistance training 3 non-consecutive d/wk and consumed normal diet at any time of day.	Resistance training + normal diet	4-d dietary record (≥1 training day; ≥1 non-training day)	N=18; Healthy, recreationally active men who had not followed a consistent resistance program over the past 3 months. BMI NR	NS	TRF reduced energy intake by ~650 kcal/day
Moro, 2016[14]	Fasting for 16 h; consuming 100% of energy needs in remaining 8-h time period;	Normal diet	7-d food diary	34 healthy individuals with no previous use of anabolic steroids.	Fat mass change: TRF: -16.4% Control: -2.8% p=0.04 Fat free mass change NS	NR

Conclusions

All studies except one[13] examined the association between length of overnight fast and the adiposity, with the majority[2,4,5,7,8,11] also assessing the link between length of overnight fast and energy intake. While some studies had conflicting results, taken together they suggested that an overnight fast of at least 10 hours would be beneficial to adiposity, with even greater benefits with a longer overnight fast. One problem with the experimental studies was the control group[15–17]—because the studies in question had historical control groups[15] or baseline controls[16,17] yet were not randomized clinical trials, and their sample sizes were relatively small. However, the two randomized controlled trials, which are considered to be the gold standard of studies, provided some evidence for a causal relationship. These studies were relatively short, ranging from five to eight weeks, and longer studies will be needed to provide stronger evidence.

b. *Temporal pattern of energy intake within a day (timing of largest meal)*

Studies that pertain to the timing of the largest meal over the course of twenty-four hours are summarized in **Table 3**. Out of the sixteen studies reviewed, six were randomized controlled trials[23–28], four were longitudinal[17,29–31], and six were cross-sectional[11,32–36]. Timing of the largest meal was defined as time of the meals with the highest energy intake and/or volume of food consumed. Other studies specified time frames over which a greater proportion of total energy was consumed, e.g. 60% of energy before or after 1400 h[33].

Table 3—Literature Review of Timing of the Latest Meal

First Author; year	Exposure or Intervention	Control	Dietary Assessment Method	Sample Size and characteristics	Adiposity Related Results	Energy Intake Related Results
			Cross-Sectional Studies			
Aljuraiban, 2015[32]	Participants sorted into quartiles depending on their ratio of evening to morning energy intake (EMEI) Morning: 06:00 - 11:55 Evening: 18:00 - 23:55	None	4 standard 24 h dietary recalls (2 consecutive days followed by a 3 wk break)	N=2385; Healthy, aged 40-59 y	Lower BMI associated with: more frequent eating per 24h (<4 EO vs. ≥6 EO; Mean BMI of 29.2 and 27.3 kg/mg^2 respectively), consuming more earlier in the day, and an EMEI ratio of ≤1.8 (p=0.01).	Lower TEI associated with: more frequent eating per 24 hours (<4 EO vs. ≥6 EO; mean EI of 2548 kcal and 2189 kcal respectively) (p<0.0001)
Aparicio, 2017[33]	Eating before and after 14:00.	Individuals w/o central adiposity	3 d food record (2 weekdays and 1 weekend day)	N=1655; Healthy, non-therapeutic dieting individuals neither living in an institutional setting or working in consumer science and/or media under 64 y	**Percentage of energy consumed at each meal (%)** WHR < 0.5 (SD) WHR > 0.5 (SD) *Breakfast* 16.1 (8.3) 16.6 (8.7) *Mid-morning snack* 5.2* (6.6) 4.1* (5.9) *Lunch* 38.0*(9.6) 41.1*(9.8) *Mid afternoon snack* 6.3* (6.9) 4.9* (6.1) *Dinner* 30.6*(10.2)	EMEI ratio (SD) (cut @ 14:00) Total 4.5 (19.7) Men 4.65** (10.31) Women 4.35** (25.49) **p<0.05

					30.4*(9.7) * $p<0.001$	
Berg, 2009[35]	NR	None	FFQ	N=3610; Healthy, non-pregnant persons aged 25-74 y living in the Vastra Gotaland region	Omission of breakfast and lunch likely to lead to overeating later in the day amongst obese persons. Obesity significantly associated with eating at night (Adjusted OR 1.62; 95% CI 1.10, 2.39) and omitting breakfast and lunch	NR
de Castro, 2004[36]	Meal time periods (hh:mm): 06:00–09:59, 10:00–13:59, 14:00–17:59, 18:00–21:59 22:00–01:59	None	7 d food diary	N=867; Non-pregnant, non-chronic medication taker, non-alcoholic previous participants of intake control studies	NR	Proportion of intake in the AM was negatively correlated with overall intake ($r = -0.13$, $P < 0.01$); proportion ingested late in the evening was positively correlated with overall intake ($r = 0.14$, $P < 0.01$)
Xiao, 2019[34]	Participants sorted into quintiles; Q1 = lowest energy intake; Q5 = highest energy intake. Windows of intake:	None	Six 24 h dietary every 2 mos. for 1 y incl. baseline measurement	N=872; Healthy, non-dieting individuals w/ BMI between 18.5 and 40 kg/m^2 from American Association of Retired Persons (AARP)	Highest quintile of % TEI during morning window associated w/ approx. 50% decrease in odds of being overweight or obese compared to lowest quintile (OR 0.53; $p = 0.008$)	NR

	-Morning (w/i 2 h of waking) -Night (w/i 2h of bedtime) -2 midday periods (split by midpoint of waking period)				Highest quintile of % TEI during night time intake 82% more likely to be overweight or obese compared to those in the lowest quintile (OR 1.82; p = 0.02)	
Longitudinal Studies						
Purslow, 2008[31]	Meal times: Pre-breakfast Breakfast Midmorning Lunch Mid-afternoon Evening Late evening Total daily energy intake	None	7-d food diary	N=6764; Healthy individuals that attended baseline health check and follow-up health check who had complete food diary data.	**Association between % of TEI consumed at breakfast and weight gain over the course of follow-up:** Fully adjusted: Weight gain: -0.021 kg 95% CI: -0.035, -0.007 P=0.004	%TEI consumed at breakfast inversely correlated with %TEI consumed in the evening (r=-0.39; p <0.001).
Garaulet, 2013[30]	Early lunch eaters: Lunch before 15:00 Late lunch eaters: Lunch after 15:00	None	24h dietary recall for each day of the week before treatment; 7-d food diary during intervention	N=420; Non-dieting, non-diabetic, obese or overweight individuals from Murcia, Spain, who had complete data and were not suffering from chronic renal failure, hepatic diseases, or cancer.	Early lunch eaters lost more weight than their counterparts. Early lunch eaters: 9.9 kg lost; 11.3% of initial weight Late lunch eaters: 7.7 kg lost; 7.1% of initial weight	
Hermengildo, 2016[29]	NR	Lowest quartile of percent energy intake at each	NR	N=4243; Healthy individuals that did not have missing data.	Higher energy intake at breakfast associated with lower BMI: Q1: 27.4 kg/m^2 Q4: 26.7 kg/m^2	Higher %EI at lunch associated with a lower %EI at the rest of eating occasions.

		eating occasion.			p<0.001	
Kahleova, 2017[17]	Breakfast: 05:00—11:00 Lunch: 12:00—16:00 Dinner: 17:00—23:00	BMI at baseline	FFQ	N=50,660; Individuals between 14.0 and 60 kg/m^2 over 30 y who had their last meal of the day after 11:00 and had complete data.	Breakfast as largest meal: BMI change compared to dinner group: -0.04 kg/m^2; 95% CI: -0.05, -0.03 Lunch as largest meal: BMI change compared to dinner group: 0.02 kg/m^2; 95% CI: -0.03, -0.01; p<0.001	NR
Randomized Controlled Trials						
Jakubowicz, 2011[37]	Kcal difference at breakfast vs. dinner HCPb (high CHO, protein) group: More kcal at breakfast, less at dinner LCb (low CHO) group: Less kcal at breakfast, more at dinner 16 wks.	None	NR	N=193; Healthy, mobile adults 20—65 y w/ BMI of 25—37 kg/m^2	*Weight (kg) (SD)* HCPb Baseline: 91.2 ± 9.8 Week 32: 70.6 ± 8.7 LCb Baseline: 90.4 ± 9.2 Week 32: 86.9 ± 9.7 p<0.001 for week 32 **BMI** *(kg/m2)* HCPb Baseline: 32.2 ± 1.9 Week 32: 24.9 ± 1.9 LCb Baseline: 32.3 ± 1.9 | Week 32: 30.9 ± 2.0	NR

					p<0.001 for week 32 **Waist circumference** *(cm)* <u>HCPb</u> Baseline: 110.7 ± 3.1 Week 32: 96.4 ± 5.3 <u>LCb</u> Baseline: 110.4 ± 3.2 Week 32: 108.7 ± 3.6 p<0.001 for week 32	
Jakubowicz, 2013[26]	Meal energy intake (large breakfast, small dinner (G1) OR small breakfast, large dinner (G2)) 12 wks	None	Weekly 3-d food diary	N=93; Women aged 20—65 y with metabolic syndrome who were non-diabetic and were free of other serious health conditions.	Large breakfast group showed greater weight loss than the large dinner group (−8.7 ± 1.4 vs. −3.6 ± 1.5 kg respectively) (p<0.0001). Also showed greater waist circumference loss (−8.5 ± 1.9 vs. −3.9 ± 1.4 cm, respectively) (p< 0.0001)	NS
Lombardo, 2014[27]	Distribution of calories throughout the day (70% TEI at breakfast vs 55% TEI at breakfast) 3 mos.	Those who had 55% of total calories consumed in the first part of the day and the remaining 45%	NR	N=42; Healthy, non-pregnant or lactating, non-alcoholic individuals 18—65 y	Subjects in the higher intake at breakfast group and control group lost on average 8.2 ± 3.0 kg and 6.5 ± 3.4 kg (p = 0.028), respectively) Mean BMI change was	NS

		consumed later.			3.1 ± 0.2 kg/m2 (G1) and 1.8 ± 0.4 (G2; p = 0.046) Reduction in waist circumference also higher in intervention group (-7 ± 0.6 cm; control group, -5 ± 0.3 cm, p = 0.033) % BF: Intervention group: -6.8 ± 2.1 vs Control group: -4.5 ± 2.9 kg, p = 0.031	
Rabinovitz, 2014[25]	Big breakfast for 3 mos.	Small breakfast group	None (meals were prepared by research team)	N=59; Obese/overweight non-pregnant, largely healthy individuals with Type II DM individuals not on obesity medications	Changes in BMI, waist circumference, hip circumference, and body fat percent NS Weight loss was −2.43 ± 0.46 kg (2.75% of body weight) in the big breakfast group vs. −1.86 ± 0.4 kg (2.22% of body weight) in the small breakfast group, p = 0.35.	NR
Madjd, 2016[24]	Consume either: 15% of TEI at breakfast 15% w/ snacks 50% at lunch 20% at dinner OR	None	Food diary	N=80; Physically and mentally healthy, non-smoking, non-pregnant women aged 18—45 y w/ BMI of 27.0—35.0kg/m_2	Main meal at lunch group lost more weight (-5.73±1.91 kg (p≤0.001)) than the main meal at dinner group (-4.31±1.93 (p≤0.001))	NR

	15% of TEI at breakfast 15% w/ snacks 20% at lunch 50% at dinner 12 wks.				Main meal at lunch group had greater BMI decline at end of intervention (-2.21±0.75 ($p \leq 0.001$)) than main meal at dinner group (-1.67±0.74 ($p \leq 0.001$))	
Raynor, 2018[23]	"Morning" participants: consume 50% of TEI in 1st meal, 30% in their 2nd meal, and 20% in their 3rd meal. "Evening" participants: consume 20% of TEI in 1st meal, 30% in 2nd meal, and 50% in 3rd meal. 8 wks.	Baseline measurement	3 d food diary	N=8; Healthy, non-pregnant, non-dieting adults w/ BMI between 27.0—45.0 kg/m^2 who woke up between 05:00—08:00 w/ ≥6 h of sleep ≥5/7 days of the week (no shift workers)	Morning group showed greater decrease in % weight loss than the Evening group (−8.9 ± 1.4% vs −4.8 ± 1.3%, d = 3.0; p=0.014)	R

Cross-Sectional Studies

The cross-sectional studies examined show that individuals who had the largest meal at dinner were largely at higher risk of obesity (higher BMI[11,32], waist circumference[33]). Two studies in particular did not specify obesity measures that were affected, but confirmed that participants who had the largest meal later in the day were more likely to be overweight or obese compared to those who had the largest meal in the morning or earlier in the day[34,35]. The likelihood of being more at risk of obesity was theorized by one of the studies as eating less earlier may lead to overeating later in the day[35], which could be caused by increased hunger from a non-satiating meal. The remaining cross-sectional study did not examine adiposity related results, but found that a higher energy intake in the morning was inversely associated with overall intake, whilst higher energy intake in the evening was associated with a higher overall intake[36], which matched findings of other studies [11,32,33]. Taken together these studies suggest that consuming a higher proportion of calories for dinner compared with breakfast or in the evening compared with morning is associated with a higher energy intake and may provide an explanation for the higher adiposity also associated with this eating pattern.

Longitudinal Studies

Three of the four longitudinal studies reported that individuals who did not have dinner as their largest meal of the day had greater weight loss and a smaller BMI compared with individuals who did have dinner as the largest meal of the day[17,30,31]. Similarly, the remaining study reported decreasing BMI over time in participants who consumed more at breakfast than those who consumed less at breakfast[29]. Two of the four longitudinal studies examined in this literature review also published results related to energy intake; one found that a higher percent of total energy intake at lunch was associated with a lower overall energy intake at the other eating occasions[29], whilst the other reported an inverse association between percent total energy intake at breakfast and percent total energy intake in the evening[31].

Randomized Controlled Studies

When the largest energy intake was shifted to earlier in the day (e.g. morning or lunch), most randomized controlled trials reported some degree of success in one or more of the following areas: weight loss[23,24,26–28] , lowered BMI[24,27,28], waist circumference[26–28], and/or body fat percentage[27,28], although there were some conflicting results when one RCT found no association with meal energy intake and weight or BMI[26]. The conflicting results could be due to differences in meal macronutrient composition for each group, as the meal plan for each group differed despite the study confirming that macronutrient composition and calorie amount were the same for the two groups; thus creating a possible inconsistency within some of the macronutrients (e.g. saturated fat levels). One study reported more weight loss in the group that had a higher intake at breakfast[25]. Studies that also examined energy intake results found that timing of largest energy intake did not affect energy intake[26,27]. The randomized controlled studies all involved controlling the distribution of calories as an intervention, although one in particular[25] also changed macronutrient composition at the same time, which may have confounded the results.

Conclusions

Although there were some inconsistencies in results across the three types of studies, the general consensus was that a higher intake of calories not at dinner/not late in day compared to other eating occasions was associated with decreased obesity measures. One explanation for these findings may be that a satiated feeling arises from a large energy intake at breakfast that persists until lunch, during which individuals consume less/avoid overeating due to an absence of overwhelming hunger. However, additional studies are needed to understand why eating patterns are affected so, as existing studies largely concentrate on how timing of the largest meal affects obesity measures and total energy intake.

III. Potential meal timing recommendations

Based on the meal timing studies reviewed above, three meal timing recommendations can be suggested as potential behavioral interventions to reduce adiposity:

1. Refrain from eating past 20:00 (eating late at night)
2. Having at least a thirteen hour overnight fast (length of overnight fast)

3. Consuming a higher portion of energy intake earlier in the day (timing of the largest meal)

These meal timing recommendations were tested in Dr McCrory's lab in a pilot study assessing a behavioral meal timing intervention, where adiposity measures were the outcome. This thesis examined one potential physiological factor that could affect individuals' ability to adhere to these recommendations, i.e. hunger, as there is a need to understand factors associated with meal timing habits and the ability to follow meal timing recommendations to help inform counselling strategies.

IV. Hunger in relation to meal timing

There have been recent studies that have identified possible factors that influence meal timing, such as cultural and environmental factors, physiological behavior, and personal preference. One potential factor is hunger. Hunger is defined as a physiologic need to eat [38]. Ghrelin, produced and released mainly by the stomach, is a hormone that functions mainly to stimulate appetite. Because hunger is associated with increased concentrations of ghrelin, overall hunger will increase as a result and may lead to poor meal timing and/or difficulty adhering to the meal timing recommendations in the intervention study due to a higher desire to eat.

The circadian rhythm in acylated ghrelin (active form) shows that concentrations are higher during the evening (20:00 h) and lower during the morning (08:00 h), meaning that individuals may be hungrier in the evening as opposed to the morning[39]. The rise in ghrelin may also be linked to a declining satiety ratio as the day progresses, a term which here means a decline in satiety from meals consumed as the day progresses, which is resultant of less time in between meals such as lunch and dinner[36]. The satiety ratio is calculated as the ratio between meal size and latency to onset of the next meal and is provided in energy/time units[40].

Given that acylated ghrelin concentrations are higher during the biological evening than they are in the morning, it would imply that a longer overnight fast should be possible since ghrelin concentrations suggest that individuals are likely to be less hungry in the morning. However, the onset of hunger later on in the day due to the natural circadian rhythm in acylated ghrelin concentrations may pose a problem for improving meal timing, as the circadian rhythm in hunger naturally rises as the day progresses and individuals would consume more food as they become hungrier towards the end of the day.

V. Aim and hypothesis

Aim

Conduct a secondary data analysis on data previously collected in 116 adults to examine associations of overall hunger score and time of onset of greatest hunger within a day with meal timing patterns and ability to follow specific meal timing recommendations.

Hypothesis

A greater overall hunger level and later onset of greatest hunger are associated with poor meal timing cross-sectionally and lower adherence to meal timing recommendations, thus affecting weight loss

MATERIALS AND METHODS

This was a secondary analysis of data from a previous study on diet and energy regulation in adults conducted in the laboratory of Dr. Megan A. McCrory (unpublished observations). The 10-day observational study took place at the Department of Nutrition Science at Purdue University in West Lafayette, IN. The study was approved by the Institutional Review Board at Purdue and all participants provided written informed consent prior to participation.

Participants and Study Design:

Participants were recruited through advertisement placed in academic buildings around campus and at local retail and community centers, on Craigslist, and by notifying individuals who had previously participated in other studies conducted in the McCrory laboratory about the study. Inclusion criteria were non-smoking, weight-stable men and women, aged 18-65 years with a BMI of 18.5—45 kg/m$_2$. Exclusion criteria were smoking or tobacco use within the past 6 months, pregnancy or lactation within the past year, ≥ 5 lb. weight change within the past 6 months, moderate or vigorous physical activity ≥ 12 hours per week, consuming > 3 alcoholic beverages per day, chronic diseases (cardiovascular disease, HIV, cancer, and metabolic abnormalities such as thyroid disorders), eating disorders, mental disorders, and use of medications or dietary supplements that would affect energy regulation, appetite, mood, or taste.

Participants were pre-screened for eligibility by a telephone interview, followed by a detailed written health questionnaire. Those who qualified after the pre-screening procedures were scheduled for an in-person health screening visit which included height and weight measurement, a pregnancy test, blood pressure, and a blood draw, which was sent to Mid America Clinical Labs (Indianapolis, IN) for analysis of a standard metabolic panel, a thyroid test, and complete blood count. Those who qualified to participate were scheduled to enroll. Participants arrived at the research center after an overnight fast of ≥10 hours for anthropometric and body composition measurements. With the exception of the 7d-PAR, which was done in person at the first study visit, all questionnaires were given to participants to complete at home and return by the end of the study. Anthropometric and body composition measurements were repeated on day 10.

Measurements

Meal Timing:

To assess meal timing, participants completed the usual eating pattern questionnaire (UEPQ), a modified version of the meal pattern grid[10], describing the times of day an individual usually eats meals and snacks during a 24-hour period (within the course of the past 1 month), separately for weekdays and weekends. Eating times during weekdays and weekend days were assessed separately and grouped into 8 time periods that covered typical eating times: 05:00—08:59, 09:00—10:59, 11:00—12:59, 13:00—14:59, 15:00—16:59, 17:00—19:59, 20:00—22:59, and 23:59—04:59.

Hunger:

Overall hunger score was assessed by using the Three-Factor Eating Questionnaire (TFEQ)[41] which assesses hunger along with restraint and disinhibition through questions aimed at participants' eating habits and behaviors. The questionnaire includes fourteen questions related to hunger, defined as a "susceptibility to hunger". Each question had the possibility of either one point or none for a maximum of fourteen points, with a higher score indicating greater susceptibility to hunger. The time of day participants felt most hungry was assessed by adding a question to the end of the Morningness-Eveningness questionnaire (MEQ)[42], modelled after question eighteen of said questionnaire. Participants were asked "At what time of day do you feel MOST hungry?"

Physical activity:

Physical activity level (PAL) was assessed using the Stanford Seven-Day Physical Activity Recall (7d-PAR) conducted by in-person interview[43]. Participants were asked to recall the approximate times of days they went to sleep, woke up, and participated in activities of moderate, high, and very high intensity for at least 10 minutes on each day over the past week. Hours of sleep and levels of physical activity (ranging from moderate to very hard) were summed, with hours of light activity calculated by subtracting the sum of those values from the total number of hours in a week. Total daily energy expenditure (TDEE) was then calculated according to the 7d-PAR instructions, using the dietary reference intake (DRI) basal energy expenditure (BEE) equation based on sex, weight, height, and age to predict resting metabolic rate (RMR)[44] and multiplying be each participant's average MET-hr per day.

Restraint and disinhibition:

Dietary restraint is defined as conscious control of eating behavior and dietary disinhibition is defined as the tendency to overeat; restraint and disinhibition were assessed using the TFEQ[41]. The questionnaire included twenty-one questions related to restraint, with a possible score ranging from 0 to 21, with a higher score indicating higher dietary restraint. The questionnaire has sixteen questions related to disinhibition with a possible score of 0-16 on the disinhibition scale, and a higher score meaning higher disinhibition

Usual bedtime

The Usual Eating Pattern Questionnaire (UEPQ), a modified version of the Meal Pattern Grid[10], was used to assess participants' bedtime habits by asking for their usual bedtime on weekdays and weekend days for the past 1 month separately.

Sleep duration and sleep quality

Sleep duration and sleep quality were assessed with the Pittsburgh Sleep Quality Index[45] (PSQI), which assesses sleeping habits and behaviors within the past month. The following questions were used to determine participants' sleep duration and quality: "when have you usually gone to bed?", "how long (in minutes) has it taken you to fall asleep each night?", "when have you usually gotten up in the morning?", and "how many hours of actual sleep did you get that night?" Each question was weighted equally on a 0-3 scale dependent on the answer and the total score was summed to yield a PSQI score, with higher scores indicating worse sleep quality (a PSQI score of >5 is considered to be poor quality sleep), as is done in the original questionnaire itself. Sleep duration was calculated by subtracting number of minutes it took participants to fall asleep from hours elapsed between bed time and wake time. With these questions, we were able to use the information as covariates in this study.

Sex and race

Individuals self-reported their ethnicity as black or African American, white, Alaskan native or American Indian, Asian, native Hawaiian or Pacific Islander, or other as well as their sex on a questionnaire to assess demographic information. For the present analysis participants were classified as white, Asian American, or black/other because only one participant answered "other".

Anthropometry:

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body mass and composition was measured using air displacement plethysmography (BOD POD Gold Standard Body Composition Measurement System, Cosmed USA, Concord, CA). Body weight was recorded to the nearest 0.01 kg on the accompanying scale with the BOD POD (Tanita Corp, Arlington Heights, IL). BMI was calculated as mass (kg) divided by height (m) squared.

Calculations and statistical analysis:

Calculations were performed for the total number of eating occasions per day and within each time period, durations of participants' overnight fast (defined as the amount of time elapsed between the last eating occasion before sleeping and the first eating occasion after waking), and time elapsed between the last eating occasion and bedtime. The midpoint of the ingestive period is a crude index of the timing of food intake, allowing for determining if individuals are relatively early or late eaters (Garaulet et al.[30], unpublished observations, ASN LIVE 2020). The midpoint of the ingestive period was calculated by taking the midpoint between participants' first and last eating occasion timeframe. All meal timing variables and usual bedtime were computed as averages weighted for the ratio of weekdays to weekend days (5:2) and used in the analysis. Two systems were used to categorize the three meal timing outcomes, one based on a cut-point determined by consensus from previous research (as reviewed in the Introduction section) and another based on a median split. Hunger predictors of eating occasions between 20:00 and 22:59 (weighted average) were examined first to determine if participants ate during this timeframe, after which the eating occasion weighted average (for both weekend and weekdays) was taken and calculated. Secondly, eating occasions between last eating occasion and bedtime (weighted average) were similarly examined to determine if participants ate during this timeframe; however, as there was no set variable, we used the number of eating occasions between 23:00 and 04:59 (weighted average).

For the late-night eating meal timing pattern, participants were classified as late-night eaters if they had eating occasions between 20:00-22:59 (coded as 1) or if they did not (coded as 0). The 23:00-04:59 timeframe was ignored due to a large number of participants not having an eating occasion during this time. For the midpoint of the ingestive period meal timing pattern, the cut-off value was having a midpoint of the ingestive period before 15:00 (coded as 1) or at or after 15:00 (coded as 0). For overnight fast, participants were categorized as having met the criteria for overnight fast (coded as 1) if they had ≥ 13 hours (coded as 1) or not meeting the criteria (coded as 0).

Analyses were performed using SPSS Statistics for Macintosh version 26 (IBM Corporation, Armonk, NY). Variables were examined for normality and log transformed if not normally distributed. Descriptive statistics including mean, standard deviation, minimum, and maximum were calculated. For all of the following statistical tests, and p-value of 0.05 was used to determine statistical significance. However, in general, p-values are reported, as advocated by the American Statistical Association[46].

Associations of hunger variables (overall hunger and the time of day that participants felt most hungry) with meal timing outcomes (eating late, midpoint of the ingestive period, and overnight fasting duration) were examined using analysis of covariance (ANCOVA), in which hunger variables were dependent variables and the meal timing patterns the independent variables. Each ANCOVA had three models, with Model 1 having only the meal timing hunger variable as the independent variable and included no covariates. Model 2 included log-age, sex (M/F; coded as 0 and 1 respectively), race (Asian American, Black and other, and white (coded as , 2, and 3 respectively)), and physical activity level as covariates., Model 3 included all covariates in Model 2 along with average usual bedtime, dietary restraint and dietary disinhibition scores, sleep duration, and sleep quality as additional covariates.

To determine if significant differences existed in hunger score (used to determine how hungry participants were), time of day that participants felt most hungry, age, physical activity level, dietary restraint and disinhibition, sleep duration, sleep quality, and average bedtime by meal timing categorical variables (e.g. meeting a cut-point or not based on existing research or as median split), unpaired t-tests were performed with the meal timing categorical variables as the grouping variables. Cross-tabulation tests were used in lieu of the t-tests for categorical variables (sex and race) but the dependent meal timing variables remained the same. Logistic regression analysis was performed to examine associations between categorical meal timing outcomes (both as meeting a specified cut-off and as median split) and hunger. Covariates were included as described above for Models 1-3 for ANCOVA.

RESULTS

Participant characteristics

Participants were mostly female and young adults (Table 4). Regarding lifestyle habits, mean physical activity level was low active with little or no strenuous leisure activity[47], mean sleep quality was poor as measured by the PSQI[45], and mean sleep duration was adequate[48]. Concerning dietary restraint and disinhibition, compared with

Table 4—Participant characteristics[1]

	n	**Mean**	**SD**	**95% CI**
Age (y)	116	29.4	11.9	27.2, 31.6
BMI (kg/m^2)	116	24.3	3.8	23.7, 25.0
Body fat (%)	116	27.5	9.6	25.7, 29.3
Physical Activity Level	116	1.5	0.2	1.5, 1.6
Sleep duration (h)	109	7.0	1.2	6.8, 7.2
Sleep quality (score)	106	5.4	3.0	4.8, 6.0
Bed time (hh:mm)	112	23:54	1:16	23:40, 00:09
Dietary restraint (score)	113	7.8	3.8	7.1, 8.5
Dietary disinhibition (score)	113	5.6	2.9	5.0, 6.1
Overall hunger (score)	116	5.4	3.2	4.8, 6.0
Time feel most hungry (hh:mm)	52	14:16	3:35	13:16, 15:16
Total daily eating frequency (#/day)	116	5.1	1.4	4.8, 5.4
Eating frequency during 20:00 – 22:59 (#/day)	116	0.8	0.5	0.7, 0.9
Duration between last eating occasion and bedtime (h)[2]	112	3.2	1.4	3.0, 3.5

Overnight fasting duration (h)[2]	115	12.0	1.8	11.8, 12.4
Length of the ingestive period (h)[2]	116	12.1	1.8	11.7, 12.4
Midpoint of the ingestive period (hh:mm)[2]	116	14:28	1:16	14:15, 14:42

[1] Participants were 63% F with race/ethnicity distribution of 76% white, 15% Asian American, 9% Black/African American or other. [2] Meal timing variables were weighted for the ratio of weekdays to weekend days (5:2).

U.S. norms, mean scores were moderate for women and high for men[49]. Overall hunger score was moderate, while the time participants felt hungriest was approximately mid-afternoon. Eating frequency during different time segments of the day is shown in Figure 1, in which the highest frequency can be seen during the 17:00—19:59 timeframe, followed by 11:00—12:59 and 20:00—22:59 time frames, indicating that these are common time periods for consumption.

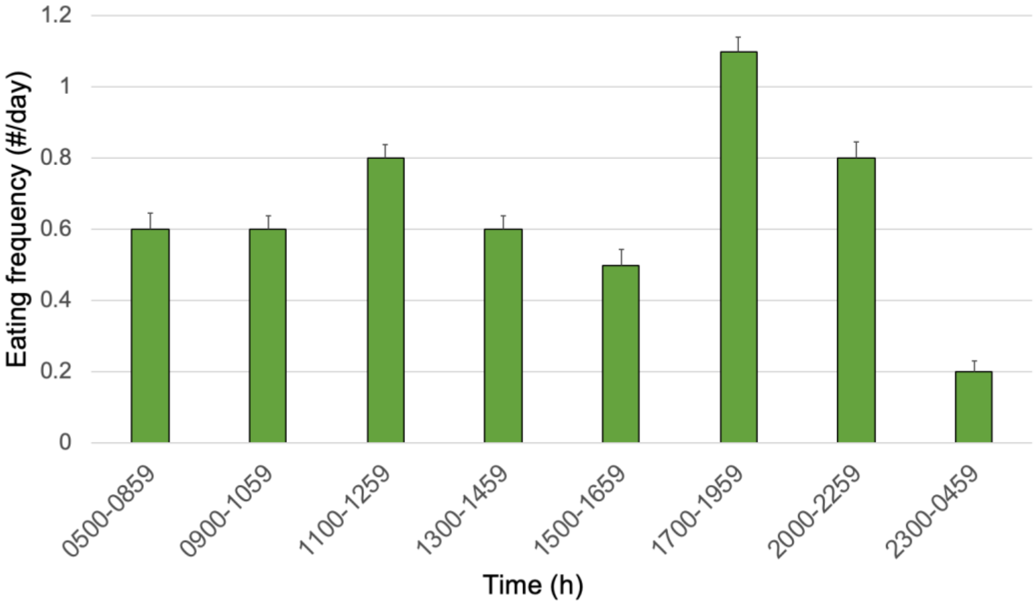

Figure 1. Summary of weighted average number of eating frequencies during each time timeframe for all participants

Hunger predictors of meal timing patterns

The associations of hunger variables with variables representing eating late at night are shown in Tables 5-7. As shown, the relationship between overall hunger score, which indicates how hungry an individual is, and frequency of eating between 20:00-22:59 was not significant, even after the inclusion of covariates in the model (Table 5). The relationships between overall hunger score and frequency of eating between 23:00 – 04:59 (Table 6) and overall hunger score and last eating occasion before sleeping (Table 7) were also not significant. Similarly, none of the relationships between the time of day participants felt most hungry and all three variables representing eating late at night were significant.

Table 5—Hunger predictors of frequency of eating 20:00-22:59 (#/day)

Predictor	**Model**[1]	**β±SE**	**p-value**
Hunger (score)			
	1	0.004±0.015	0.773
	2	0.001±0.098	0.946
	3	-0.018±0.020	0.356
Time most hungry (hh:mm)			
	1	-0.012±0.022	0.604
	2	-0.013±0.023	0.581
	3	-0.027±0.028	0.328

[1] Model 1 has no covariates (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time (n=100 for hunger score predictor and n=45 for time most hungry predictor).

Table 6— Hunger predictors of frequency of eating 23:00-04:59 (#/day)

Predictor	**Model**[1]	**β±SE**	**p-value**
Hunger (score)			
	1	0.014±0.010	0.165
	2	0.004±0.010	0.661
	3	-0.006±0.065	0.540
Time most hungry (hh:mm)			
	1	0.018±0.012	0.118
	2	0.014±0.011	0.229
	3	0.000±0.008	0.985

[1] Model 1 has no covariates (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time (n=100 for hunger score predictor and n=45 for time most hungry predictor).

Table 7— Hunger predictors of duration between last eating occasion and bedtime (h)

Predictor	**Model**[1]	**β±SE**	**p-value**
Hunger (score)			
	1	0.034±0.042	0.423
	2	0.006±0.043	0.885
	3	0.024±0.051	0.634
Time most hungry (hh:mm)			
	1	0.017±0.058	0.776
	2	-0.020±0.058	0.728
	3	-0.006±0.064	0.922

[1] Model 1 has no covariates (n=112 for hunger score predictor and n=52 for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL (n=112 for hunger score predictor and n=52 for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time (n=100 for hunger score predictor and n=45 for time most hungry predictor).

There were no statistically significant relationships between overall hunger score or the time of day participants felt most hungry and overnight fasting duration (Table 8) whether or not covariates were included in the model. However, Model 3 for the hunger score predictor variable was approaching statistical significance, with a positive slope, indicating a higher overall hunger score was associated with a longer overnight fast.

Table 8— Hunger predictors of overnight fasting duration (h)

Predictor	**Model**[1]	**β±SE**	**p-value**
Hunger (score)			
	1	0.073±0.052	0.165
	2	0.052±0.054	0.332
	3	0.109±0.060	0.071
Time most hungry (hh:mm)			
	1	-0.101±0.075	0.182
	2	-0.116±0.075	0.127
	3	-0.032±0.073	0.660

[1] Model 1 has no covariates (n=115 for hunger score predictor and n=51 for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL (n=115 for hunger score predictor and n=51 for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time (n=99 for hunger score predictor and n=44 for time most hungry predictor).

The relationship between overall hunger score and midpoint of the ingestive period was significant in Model 1and was positively associated (Table 9), indicating a higher overall hunger score was associated with a later midpoint of the ingestive period, signifying that participants who had the majority of their energy intake later in the day were hungrier. However, the association became non-significant in models 2 and 3 after controlling for covariates. None of the relationships between the time of day participants felt most hungry and their midpoint of the ingestive periods were significant.

Hunger associations with meal timing recommendations

Hunger associations with meal timing recommendations are shown in Tables 10-15. Hunger associations with the risk of not meeting the meal timing recommendation of abstaining from food past 20:00 are shown in Table 10 and were non-significant, although marginally so for Model 3. Hunger score had a negative relationship with eating past 20:00, indicating that participants generally felt hungrier if they met the meal timing recommendation of not eating during this time frame. Model 3 also showed a 20% decrease in the risk of eating during this time frame with greater hunger, based on the odds ratio. The time most hungry predictor was non-significant in models 1 and 2, but model 3 was indeterminate due to only four participants not eating during this time period.

Table 9— Hunger predictors of midpoint of the ingestive period time of day (hh:mm)

Predictor	**Model**[1]	**β±SE**	**p-value**
Hunger (score)			
	1	0.081±0.037	0.028
	2	0.039±0.034	0.252
	3	0.022±0.034	0.515
Time most hungry (hh:mm)			
	1	0.034±0.046	0.454
	2	0.004±0.044	0.921

	3	-0.009±0.038	0.811

[1] Model 1 has no covariates (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL (n=116 for hunger score predictor and n=52 for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time (n=100 for hunger score predictor and n=45 for time most hungry predictor).

Table 10—Hunger associated with risk of eating during 20:00-22:59 (Y/N)

Predictor	**Model**[1]	**β±SE**	**OR (95% CI)**	**p-value**
Hunger (score)				
	1	-0.016±0.082	0.984 (0.837, 1.156)	0.844
	2	-0.022±0.086	0.978 (0.826, 1.158)	0.799
	3	-0.220±0.126	0.803 (0.627, 1.027)	0.080
Time most hungry (hh:mm)				
	1	0.055±0.125	1.057 (0.827, 1.349)	0.659
	2	0.069±0.153	1.071 (0.794, 1.446)	0.653
	3	—[2]	—	—

[1] Model 1 has no covariates. n=116 (n=99 ate; n=17 did not eat) for hunger score predictor and n=52 (n=46 ate; n=6 did not eat) for time most hungry predictor. Model 2 includes covariates log age, sex, race/ethnicity, and PAL. n=116 (n=99 ate; n=17 did not eat) for hunger score predictor and n=52 (n=46 ate; n=6 did not eat) for time most hungry predictor. Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=100 (n=87 ate; n=13 did not eat) for hunger score predictor and n=45 (n=41 ate; n=4 did not eat) for time most hungry predictor. [2] Model 3 for time most hungry predictor due to only n=4 participants not eating from 20:00-22:59.

Hunger associations with the risk of a higher eating frequency between 20:00 and 22:59 are shown in Table 11. Hunger associations with meeting the cut-off of eating earlier than 15:00 for the midpoint of the ingestive period are shown in Table 12 or with having an earlier midpoint of the ingestive period is shown in Table 13. None of the relationships in any of these models were significant.

Table 11— Hunger associated with risk of higher eating frequency 20:00-22:59 (low/high)

Predictor	Model[1]	β±SE	OR (95% CI)	p-value
Hunger (score)				
	1	-0.001±0.059	0.999 (0.889, 1.122)	0.981
	2	-0.023±0.064	0.977 (0.862, 1.107)	0.713
	3	-0.125±0.089	0.882 (0.741, 1.051)	0.161
Time most hungry (hh:mm)				
	1	0.001±0.079	1.001 (0.858, 1.169)	0.988
	2	-0.014±0.086	0.986 (0.833, 1.167)	0.871
	3	-0.114±0.105	0.892 (0.727, 1.096)	0.277

[1] Model 1 has no covariates. n=116 (n=50 w/low and n=66 w/high eating frequency during 2000-2259) for hunger score predictor and n=52 (n=23 w/low and n=29 w/high eating frequency during 2000-2259) for time most hungry predictor. Model 2 includes covariates log age, sex, race/ethnicity, and PAL. n=116 (n=50 w/low and n=66 w/high eating frequency during 2000-2259) for hunger score predictor and n=52 (n=23 w/low and n=29 w/high eating frequency during 2000-2259) for time most hungry predictor. Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=100 for hunger score predictor (n=41 w/low and n=59 w/high eating frequency during 2000-2259) and n=45 (n=26 w/low and n=19 w/ high eating frequency during 2000-2259) for time most hungry predictor.

Table 12— Hunger associated with meeting cut-off of 15:00 for midpoint of the ingestive period (Y/N)

Predictor	Model[1]	β±SE	OR (95% CI)	p-value
Hunger (score)				
	1	-0.052±0.061	0.950 (0.843, 1.070)	0.398

	2	0.007±0.071	1.007 (0.875, 1.158)	0.926
	3	0.027±0.114	1.028 (0.821, 1.286)	0.810
Time most hungry (hh:mm)				
	1	-0.059±0.082	0.943 (0.803, 1.107)	0.472
	2	-0.007±0.097	0.993 (0.820, 1.201)	0.939
	3	0.594±0.528	1.811 (0.644, 5.095)	0.261

[1] Model 1 has no covariates. n=116 (n=74 w/earlier and n=52 w/later midpoint of the ingestive period) for hunger score predictor and n=52 (n=33 w/earlier and n= 19 w/later midpoint of the ingestive period) for time most hungry predictor). Model 2 includes covariates log age, sex, race/ethnicity, and PAL. n=116 (n=74 w/earlier and n=42 w/ later midpoint of the ingestive period) for hunger score predictor and n=52 (n=33 w/earlier and n= 19 w/later midpoint of the ingestive period) for time of day most hungry predictor. Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=100 (n=64 w/earlier and n=36 w/later midpoint of the ingestive period) for hunger score predictor and n=45 (n=29 w/earlier and n=16 w/ later midpoint of the ingestive period) for time most hungry predictor).

Table 13— Hunger associated with risk of having an earlier midpoint of the ingestive period (low/high)

Predictor	**Model[1]**	**β±SE**	**OR (95% CI)**	**p-value**
Hunger (score)				
	1	0.065±0.060	1.067 (0.949, 1.200)	0.276
	2	0.014±0.071	1.015 (0.883, 1.165)	0.838
	3	0.005±0.119	1.005 (0.796, 1.269)	0.967
Time most hungry (hh:mm)				
	1	0.003±0.079	0.966 (0.860, 1.170)	0.966
	2	-0.037±0.087	0.963 (0.812, 1.143)	0.668
	3	-0.193±0.150	0.825 (0.614, 1.108)	0.200

[1] Model 1 has no covariates. n=116 (n=58 w/earlier and n=58 w/later midpoint of the ingestive period) for hunger score predictor and n=52 (n=24 w/earlier and n=28 w/later midpoint of the ingestive period) for time most hungry predictor. Model 2 includes covariates log age, sex,

race/ethnicity, and PAL. n=116 (n=58 w/earlier and n=58 w/later midpoint of the ingestive period) for hunger score predictor and n=52 (n=24 w/earlier and n=28 w/later midpoint of the ingestive period) for time most hungry predictor). Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=100 (n=50 w/earlier and n=50 w/later midpoint of the ingestive period) for hunger score predictor and n=45 (n=20 w/earlier and n=25 w/later midpoint of the ingestive period) for time most hungry predictor.

Hunger associations with meeting the cut-off of having a ≥13 h overnight fast (Table 14) showed statistically significant values for all three models of the hunger score variable. Hunger score was positively associated with the cut-off, and based on the odds ratios, the three models showed a 20—26% increase in the likelihood of having a 13h or longer overnight fast with a greater hunger level. None of the models for time most hungry were significant, and none of the models for hunger associations with having a longer or shorter overnight fast (Table 15) were significant.

Table 14— Hunger associated with meeting cut-off of ≥13 h overnight fast (Y/N)

Predictor	**Model**[1]	**β±SE**	**OR (95% CI)**	**p-value**
Hunger (score)				
	1	0.194±0.068	1.214 (1.063, 1.387)	0.004
	2	0.183±0.072	1.200 (1.042, 1.382)	0.011
	3	0.228±0.102	1.256 (1.028, 1.534)	0.026
Time most hungry (hh:mm)				
	1	0.008±0.084	1.008 (0.854, 1.189)	0.926
	2	0.018±0.101	1.019 (0.835, 1.242)	0.856
	3	0.103±0.119	1.108 (0.877, 1.399)	0.389

[1] Model 1 has no covariates. n=115 (n=34 met and n=81 did not meet the overnight fast cut-off) for hunger score predictor and n=51 (n=16 met and n=35 did not meet the overnight fast cut-off) for time most hungry predictor. Model 2 includes covariates log age, sex, race/ethnicity, and

PAL. n=115 (n=34 met and n=81 did not meet the overnight fast cut-off) for hunger score predictor and n=51 (n=16 met and n=35 did not meet the overnight fast cut-off) for time most hungry predictor. Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=99 (n=29 met and n=70 did not meet the overnight fast cut-off) for hunger score predictor and n=44 (n=13 met and n=31 did not meet the overnight fast cut-off) for time most hungry predictor.

Table 15— Hunger associated with having a longer overnight fast (low/high)

Predictor	Model[1]	β±SE	OR (95% CI)	p-value
Hunger (score)				
	1	0.072±0.060	1.075 (0.956, 1.209)	0.228
	2	0.073±0.063	1.076 (0.951, 1.217)	0.245
	3	0.106±0.085	1.112 (0.942, 1.313)	0.209
Time most hungry (hh:mm)				
	1	-0.002±0.079	0.998 (0.855, 1.165)	0.981
	2	0.002±0.086	1.002 (0.847, 1.187)	0.977
	3	0.106±0.107	1.112 (0.902, 1.371)	0.320

[1] Model 1 has no covariates. n=116 (n=58 w/shorter and n=58 w/longer overnight fast) for hunger score predictor and n=52 (n=23 w shorter and n=29 w/longer overnight fast) for time most hungry predictor. Model 2 includes covariates log age, sex, race/ethnicity, and PAL. n=116 (n=58 w/shorter and n=58 w/longer overnight fast) for hunger score predictor and n=52 (n=23 w shorter and n=29 w/longer overnight fast) for time most hungry predictor. Model 3 includes all Model 2 covariates plus dietary restraint, dietary disinhibition, sleep duration, sleep quality, and bed time. n=100 (n=51 w/shorter fast and n=49 w/longer overnight fast) for hunger score predictor and n=45 (n=21 w/shorter fast and n=24 w/longer overnight fast) for time most hungry predictor.

DISCUSSION

To our knowledge, this study was the first to examine an association between hunger and key meal timing behaviors for which some evidence exists may be important for weight control. Hunger score was positively associated with meeting the cut-off of having at least a thirteen hour overnight fast and the positive association was marginally nonsignificant with the overnight fasting pattern after controlling for multiple demographic and lifestyle factors. On the other hand, hunger variables were not significantly associated with the midpoint of the ingestive period or eating late at night before or after controlling for confounders. Findings were not in line with expectations, as we had hypothesized an inverse rather than a positive association between hunger and meal timing variables, and we further hypothesized that overall hunger and the time of greatest hunger would be significantly associated with all three meal timing behaviors we examined and not just the overnight fast. Future studies should examine whether these greater feelings of hunger occurring with a longer overnight fast lead to overeating the next day, hence negating the beneficial effect of the longer overnight fast. To help prevent such overeating, behavioral meal timing interventions for prolonging the overnight fast could emphasize advice on lifestyle measures to help reduce hunger levels to help prevent overeating and promote a longer overnight fast, such as consuming more fiber[50] and protein[51] or achieving adequate sleep[52].

We had hypothesized that a greater overall hunger level and later onset of greatest hunger would be associated with poor meal timing cross-sectionally and lower adherence to meal timing recommendations. Regarding the overnight fast, we had thought that participants with less hunger would be able to have a longer overnight fast; instead, we found that a *higher* hunger score was associated with having an overnight fast lasting thirteen hours or longer, indicating that participants were able to achieve a longer overnight fast despite being hungrier. One potential explanation for this positive association is reverse causality, meaning that a longer overnight fast may have caused them to be hungrier. The results of our study are supported by a randomized controlled trial in which participants were hungrier upon waking after being placed on night eating restriction for two weeks, not eating from 19:00 h to 0:600 h (thus prolonging the overnight fast), compared to when they were not restricted[12]. However, an experimental non-randomized controlled trial is inconsistent with our findings. In that study, investigators asked participants to reduce the length of their ingestive period from ≥14 h to 10-12 h (thus increasing their overnight fasting length), which resulted in decreased hunger at bedtime after four weeks[15]. Possible reasons for conflicting findings across studies are several. The studies had different study designs and lengths: ours was cross sectional whereas the other two were short term interventions: one a randomized crossover design[12] and the other nonrandomized with no control group[15]. Although the studies also had different overnight fast lengths, this is likely not an explanation for the conflicting findings since the non-randomized controlled trial[15] in conflict with our findings had an overnight fast duration (12-14 h), that was between that of the crossover trial (11 h)[12] and ours (≥13 h) which were in agreement. Another possibility is that BMIs differed across the studies, with the non-randomized controlled trial[15] having no lean participants, and the randomized crossover[12] and our study including both lean individuals and those with obesity. Leaner individuals may be able to better withstand a longer overnight fast in the face of hunger, possibly due to a greater capacity to be able to do so. Future studies are needed to determine if variation in hunger affects the length of an overnight fast, and if so, the mechanism behind the relationship, including a potential modifying effect of weight status on this relationship.

We did not expect a non-significant association between hunger variables and the midpoint of ingestive period or eating late at night, although the association between greater hunger and eating less often late at night was marginally non-significant after controlling for all measured confounders, and the direction was consistent with our findings on hunger in relation to overnight fast. Therefore, future studies should continue to investigate the association between hunger variables and late night eating. Other studies, two randomized controlled trials[25,26] and one cross sectional study[36], conflict with our findings. These studies all show that lower hunger occurred with a higher energy intake at breakfast, while a higher hunger score, indicative of a greater hunger level, occurred with a higher energy intake at dinner. One of these studies also assessed fasting ghrelin, with results corroborating the hunger ratings[36]. However, the two RCTs changed both macronutrient composition and the relative amount of energy intake at breakfast versus dinner simultaneously; therefore the lower hunger with greater energy at breakfast could be due to the potential confounding effects of higher protein intake at breakfast compared with dinner, as increased protein intake has been shown to cause higher satiety[51]. Furthermore, in the cross-sectional study, the higher hunger score at dinner was not quite statistically significant[26]. It should be noted that although we did not examine energy intake at different meals in our study, we used the midpoint of the ingestive period as a substitute since the midpoint of an individual's ingestive period relates to the timing of meals. An example would be an individual who eats breakfast versus one who does not—the person who consumes breakfast would have an earlier midpoint compared to the individual whose first meal was lunch. The conflicting results between the other studies and ours may be due to multiple factors, including our lack of information on energy or macronutrient intake at the different eating occasions, which could have provided an insight as to why a hunger score was associated with a longer overnight fast (e.g. having a small dinner); different study designs (e.g. RCT versus our cross-sectional study), which would be able to identify causality; and differences in participant characteristics across studies. With respect to the latter, there were few commonalities between the three studies in conflict with ours. Our study included lean as well as those with overweight and obesity, Rabinovitz et al.[25] recruited only overweight and/or obese participants and Jakubowicz et al.[26] recruited individuals with metabolic syndrome, who may have been obese, as obesity is one of the symptoms for metabolic syndrome. Regarding health status, our study and de Castro et al.[36] included only healthy participants, whereas Rabinovitz et al.[25] sought out exclusively individuals with type 2 diabetes, and Jakubowicz et al.[26] recruited participants with metabolic syndrome. Future studies are needed to determine if health status affects the midpoint of ingestive period and/or eating late at night.

This study had several strengths, including a relatively large sample size for a clinical study, control for multiple demographic and lifestyle factors, and two different types of hunger variables. However, the study also had some limitations. Although there were over 100 participants in whom we assessed overall hunger score, there were only 52 participants in whom we were able to assess time of day of greatest hunger. We also did not take into account energy intake at the different eating occasions, which was available from 24h dietary recall data but we were focused on meal timing so used a questionnaire which has been recommended for studies on meal timing[10]. We did not examine the relationship between hunger score and obesity measures and/or energy intake for meal timing recommendations, although these associations have been examined in several previous studies; there are several variables that have to do with ingestion that may not be related solely to hunger that were not examined in this study, such as emotional and/or habitual eating and cravings, that could be examined for their associations with meal timing recommendations. We also did not assess how participants accomplished a longer overnight fast, as it was not within the scope of our research, but this would be important to do in future studies, and even to determine if a longer overnight fast is easier accomplished (i.e. with less hunger) by finishing dinner earlier or waiting until later to eat breakfast, or a combination—whilst we examined eating late at night and time between last meal to bedtime, hunger was not significantly related to either of these variables. However, we controlled for bedtime as a covariate and found that it did not make a difference in most cases, with the exception of eating late at night. Additionally, this study was cross sectional, and therefore was only able to determine the presence (or lack thereof) of associations, not the causality.

In summary, we found that that hunger score was positively associated with an overnight fast lasting thirteen hours or longer and a marginally nonsignificant (p=0.08) trend toward eating less often late at night, while the time of greatest hunger was not associated with any of the meal timing variables. Previous studies have shown that a longer overnight fast improves weight loss [12,15–19,21,22]. An application of our findings then is that for individuals who desire to achieve an overnight fast of thirteen hours or more with the goal of losing weight, it may be helpful to consume more energy in the morning/afternoon as opposed to dinner/later at night, which has been shown to decrease feelings of hunger at night/before bedtime[15], as well as to include more protein and fiber at all meals, both of which increase satiety[50,51]. Experimental and mechanistic studies could be conducted to determine underlying relationship between hunger score and a longer overnight fast. If necessary, these further studies can help determine the best approaches to reduce hunger in order to promote adherence to healthy meal timing patterns to better prevent and/or manage blood pressure, diabetes mellitus, LDL cholesterol, coronary heart disease, and other comorbidities that are associated with obesity[3].

LIST OF JOURNAL ABBREVIATIONS

Adv Nutr	Advances in Nutrition
Am J Clin Nutr	American Journal of Clinical Nutrition
Am J Epidemiol	American Journal of Epidemiology
Am Stat	The American Statistician
Br J Nutr	British Journal of Nutrition
Cancer Epidemiol Biomarkers Prev	Cancer Epidemiology, Biomarkers, and Prevention
Cell Metab	Cell Metabolism
Eur J Clin Nutr	European Journal of Clinical Nutrition
Eur J Sport Sci	European Journal of Sport Science
Int J Chronobiol	International Journal of Chronobiology
Int J Gen Med	International Journal of General Medicine
Int J Obes	International Journal of Obesity
J Acad Nutr Diet	Journal of the Academy of Nutrition and Dietetics
J Am Coll Nutr	Journal of the American College of Nutrition
J Nutr	Journal of Nutrition
J Nutr Metab	Journal of Nutrition and Metabolism
J Psychosom Res	Journal of Psychosomatic Research
J Transl Med	Journal of Translational Medicine
JAMA Oncol	JAMA Oncology
Nutr Heal Aging	Nutrition and Health Aging
Nutr Res	Nutrition Research
Physiol Behav	Physiology & Behavior
Psychiatry Res	Psychiatry Research
Public Health Nutr	Public Health Nutrition
Sleep Heal	Sleep Health

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