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# Aim 2: Examine the effect of early time-restricted feeding in the perinatal period on maternal health. Dams exposed to time-restricted feeding during gestation will be compared to age-matched ad libitum fed controls. Food intake, body composition, energy expenditure, gestation length, and mechanisms of insulin sensitivity will be evaluated.

## Background:

### Pregnancy is a critical time for maternal health and physiological adaptation

Nutrient composition and nutrient restriction have been well studied in the physiological state of pregnancy (Will add the right citations over the weekend). There is sufficient evidence to support that diet may significantly alter not only offspring health, but also the health of the mother during, and long after gestation (Walter, 2014; Donnelly, 2019).

Pregnancy is a time of profound physiological change for expectant mothers; including the onset of insulin resistance without hyperglycemia and increases in body weight and food intake. This suggests there is a molecular driver to reassign the desired set point, making the study of pregnancy a relevant and important implication for not only overweight and obese women of childbearing age, but also obese adults in general.

The physiological adaptations to pregnancy are thought to maximize nutrient availability for the fetus.

### Insulin Resistance

The induction of insulin resistance in the mother during mid and late gestation has evolved to make available extra glucose and free fatty acids in maternal circulation and further prevent maternal storage of these substrates, allowing consistent nutrient flux toward the developing fetus. Although insulin resistance and weight gain are considered normal adaptations to pregnancy, there are many women who experience excessive, pathological insulin resistance and gestational weight gain. Cho and colleagues estimate that globally, gestational diabetes affects 9.8 % of pregnancies in women aged 20-24 years; the prevalence dramatically increases for women of advanced age during pregnancy (45-49 years) to 45.1% (Cho et al., 2018). Furthermore, a meta-analysis of incidence of type 2 diabetes found that women with a history of gestational diabetes are at 7.43 times the risk than women who were normoglycemic during their pregnancies (Bellamy, Casas, Hingorani, & Williams, 2009). This makes insulin resistance during gestation a critical public health problem that deserves research attention.

### Gestational weight gain and Food intake

Weight gain is expected for a healthful pregnancy. The IOM recommended amount of weight to gain is based on pre-pregnancy body mass index (BMI) (CITE IOM 2009 Report). Since these recommendations were published, many studies have evaluated the prevalence of excessive gestational weight gain. This excessive gain of weight during gestation appears to be highly prevalent, with rates from 47% of sampled women (Goldstein et al., 2017; McClure, Catov, Ness, & Bodnar, 2013). Therefore, the prevalent and problematic excessive weight gain in pregnancy is an urgent public health problems that needs to be addressed to improve health indices of not only child health, but also maternal cardiometabolic health.

### Time-restricted feeding

Time restricted feeding is a feeding strategy that is known to affect insulin sensitivity, as well as other molecular markers of health (Halberg et al., 2005; Hatori et al., 2012; Kahleova, Lloren, Mashchak, Hill, & Fraser, 2017; Liu et al., 2019; n.d.; Ravussin, Beyl, Poggiogalle, Hsia, & Peterson, 2019; Sherman et al., 2012; Sutton et al., 2018; Woodie et al., 2018). Furthermore, many rodent models of TRF demonstrate metabolic improvements in insulin resistance without weight loss (Hatori et al., 2012; Liu et al., 2019; Sherman et al., 2012; Woodie et al., 2018), suggesting it may be a uniquely appropriate strategy for use in insulin resistant pregnant women. Although many things affected during pregnancy are also affected by TRF, to date, no study has evaluated time-restricted feeding of normal chow in mouse pregnancy. Only one study of time restricted feeding during gestation was completed, which utilized 60% high fat diet (HFD) and wistar rats(Upadhyay et al., 2019). This work demonstrated that HFD-TRF feeding led to a similar number of kcals consumed by both HFD-TRF and HFD-AL counterparts. With similar pre-pregnancy body weight gain between these groups. They failed to look at compartmentalization of the body weight before and during pregnancy, and did not asses maternal insulin sensitivity or glycemia. For this reason, I propose to study the effect of TRF in NCD fed mice before and during their pregnancy.

## Specific aim 2.1 Insulin sensitivity and glycemia

Studies of time restricted feeding have demonstrated improvements in insulin sensitivity in both animals ()and humans(Halberg et al., 2005; Sutton et al., 2018). However, this is usually not accompanied by drastic changes in glycemia (Halberg et al., 2005; Hatori et al., 2012; Liu et al., 2019; Sherman et al., 2012; Sutton et al., 2018; Woodie et al., 2018). In fact, reduction in glycemia was only apparent in 1 human study, and only detectable by the use of continuous glucose monitoring, where they found that night-time glucose was reduced whereas daytime glycemia was unchanged(Jamshed/Peterson, 2019). For this reason, I hypothesize that insulin sensitivity will be improved during gestation and that glycemia will not be greatly affected. To test insulin sensitivity, an insulin tolerance test (ITT) will be conducted, as it assesses both glycemic control and insulin production and is therefore more sensitive than a glucose tolerance test (GTT) (Kim, 2009) , and previous work has demonstrated that in pregnancy, insulin tolerance is affected, whereas glycemia is not (Musial et al., 2016). If the ITT demonstrates improved insulin sensitivity, I propose to conduct a hyperinsulinemic-euglycemic clamp during the early part of the last week of pregnancy, when insulin resistance is known to be greatest in mice(Musial et al., 2016). This will provide more information to further evaluate the mechanisms that underlie insulin sensitivity; such as contribution from hepatic glucose production, peripheral glucose disposal, and whole organ glucose utilization.

The specific mechanism of insulin sensitivity after treatment with eTRF in adult humans and animals is incompletely understood. One candidate mechanism could be hormonal; such as GDF15. ADD MORE ABOUT ORIGIN AND PROPOSED MECH OF GDF15. It is known to increase during gestation, and is associated with reduced food intake, and leanness, and improvements in glucose tolerance (Macia et al., 2012).

Sugulle and colleagues demonstrated that GDF15 is elevated in human pregnancies that are complicated by pre-eclampsia and diabetes (Sugulle et al., 2009). It has also been demonstrated that overexpression of GDF15 in adult mice fed both chow or high fat diet was able to reduce glycemic response to IPGTT challenge and had greater insulin sensitivity compared to WT controls (Macia et al., 2012).

According to Peterson and colleagues, non-pathological excursions in glycemia may be evident in participants undergoing TRF, and the only way to catch these MAGE events is through constant transmission of blood or interstitial glucose (ravussin/Peterson 2019).

## Specific aim 2.2 Gestational weight gain and maternal body composition

Although only one study has been done in TRF in pregnancy, there have been many studies in non-pregnant adults in humans and in mice that evaluate body weight, body composition, and BMI after treatment with eTRF. The literature is divergent in humans and animals. In most studies with humans employing different models of intermittent fasting, there is a moderate reduction of body weight when isocaloric/eucaloric feeding is not employed as part of the study (stote, 2017; Gabel 2018). In rodent models; however, TRF of chow diet usually does not impart weight loss (Liu et al., 2019; Woodie et al., 2018). When High fat diet is given, TRF stimulates body weight loss (Hatori et al., 2012; Liu et al., 2019; Sherman et al., 2012).

## Specific aim 2.3 Feeding

Food intake increases during pregnancy to allow enough substrate to continue maternal healthful living and to provide materials for the developing fetuses(Ladyman, Carter, & Grattan, 2018). This increase in food intake is usually transient, and most pronounced during the last two weeks of gestation(Ladyman et al., 2018); followed by a sharp uptick during lactation.

## Specific aim 2.4 Energy Expenditure

Works in TRF of humans and animals have demonstrated mixed results with respect to energy expenditure. In some, energy expenditure is increased using this feeding strategy (Halberg, 2005; Gabel, 2018 ), while many more fail to detect any significant increase in daily energy expenditure(Ravussin et al., 2019). Based on preliminary results, the food intake and body composition levels are unchanged; however,, these are only proxy measurements of actual energy expenditure. It is possible that while food intake and body weight do not have detectable differences, that there is an increase in energy expenditure to balance food intake and body weight. This may manifest itself in many ways. It could be through physical activity, thermogenesis, or even by differences in absorptive capacity of food.

Although significant differences in total daily energy expenditure is not often seen, there are often periods where RER is distinct from ad lib controls. Namely, during the night, the RER/RQ lowers, resulting in greater fat utilization, and during the day, a high RER?RQ predominates – demonstrating greater metabolic capacity for flexibility in those exposed to TRF(. 2016; 14: 290.

* Increase in the postprandial period which compensates for the extra absorption and does not manifest as additional weight gain

## Specific aim 2.5 Digestive efficiency

Although digestion and nutrient utilization are active areas of research in pregnant animals and humans, the physical and physiological changes of the alimentary canal in pregnancy are not well characterized. The vast majority of work that has been done in both humans and in animals focuses on micronutrient transport and utilization during gestation; especially of iron and calcium (CITE). The little work done has demonstrated in animal models that there is hypertrophy of the absorptive surfaces in pregnant animals compared to their non-pregnant counterparts (histology paper). Still further, none of these studies have evaluated the effect of 8-hour eTRF on the digestive tract. However, circadian rhythms and food restriction have been found to entrain nutrient transporters to anticipate caloric intake in animals with intact CLOCK(Pan, 2009). In the case of macronutrient transport, food was found to be a more potent entrainment tool than even light/dark cycle manipulation in mice (Pan, 2009). For this reason, I believe that energy absorption will be more complete in dams fed eTRF. of These changes may be especially useful in shift working pregnant mothers as shift workers are heavy GI complainers ().

* Fasting is also known to induce remodeling of GI nerve activity (doi 1007/s10237-019-01185-7.)
* Fasting may therefore be one of the ways we can aid women with GI symptoms in pregnancy experience relief ()highly prevalent – may not go down this route.

## Methods:

### Animals:

C57Black6/J mice were previously used in the insulin resistance of pregnancy experiment were used in this experiment. At 134 days of age, age matched females were randomized to either *ad libitum* (AL) or early time-restricted eating (eTRF). Dams randomized to AL feeding had 24-hour access to chow (5% fat, 24% protein, 3.7% sucrose, 32% starch). Dams randomized to eTRF feeding were allowed *ad libitum* access to chow during 6 hours of the dark cycle (8pm-2am). At 2 am, all dams were moved to clean cages to standardize stress and handling between feeding regimens (Hatori, 2012). Animals were held in a 12:12 light dark cycle, in a temperature and humidity-controlled facility. Food intake was monitored daily, with 6 hour and 24-hour intake calculated as total grams of food consumed per day multiplied by utilizable energy in the provided diet. Dams were switched to AL feeding upon parturition.

### Mating:

Dams were singly housed for the course of the experiment. After a one-week acclimation period, males were added to the cages in monogamous pairs. Males were allowed to remain in cages until copulatory plug appeared, which was noted as day 0.5 of pregnancy. At gestation day 19, males were removed to prevent second pregnancies after delivering. During the course of the birth and post-natal period until PND 21, dams were singly housed with their litters.

### Body Composition:

Once a week, Dams weight was measured weekly using an electronic scale (Mettler Toledo). Body composition including fat mass, lean mass, and free water was assessed indirectly via magnetic resonance imaging (EchoMRI).

### Insulin Sensitivity:

*Insulin tolerance test:*

Insulin sensitivity was assessed by insulin tolerance test 16 days after mating began. Gestational age during ITT was determined using plug data, body weight gain, and date of delivery. As a result, most dams were in the 1st or 3rd week of gestation during this time. After 6-hour fast, blood glucose was taken using a glucometer and tail clip. Females were given insulin injections (0.75 units/kg body weight; Humulin U100 in cold sterile, filtered Phosphate buffered saline (PBS)) and blood glucose was tested using a glucometer at 15-minute intervals for 2 hours. If animals began to exhibit moribund behaviors, 300 units of 10% glucose in cold sterile filtered PBS was administered and subsequent BG measurements were omitted from the ITT.

*Hyperinsulinemic-euglycemic clamp:*

After mating and confirmation of pregnancy by weight gain of 1.75g signaling 7 days of pregnancy(Heyne et al., 2015), animals will be placed singly housed into a special cage unit. Dams will be cannulated and exogenous insulin will be administered, inducing a state of hyperinsulinemia(Kim, 2009) and thereby suppressing hepatic glucose production. Glucose is infused to maintain blood sugar, with the amount infused correlating to the ability of that animal to utilize insulin to dispose of glucose. Greater glucose infusion rates represent more insulin sensitive animals. This method also allows for understanding of tissue-specific glucose disposal. 2-deoxy-glucose is given as a bolus75 minutes after initiation of the clamp. Sample and tissues are taken for analysis of glucose content

Radiolabeled [3H] glucose HGP= whole body glucose turnover – GIR.

This was already done in Musial, as well as hepatic vs adipose vs skeletal muscle insulin signaling and then also fetal vs placental vs maternal tissue use of radiolabeled glucose.

### Glycemia:

### Energy Expenditure:

CLAMS

### Digestive Physiology:

*Energy Absorption*

To determine if there exist any differences in the amounts of energy consumed from food consumed between eTRF dams and ad libitum fed dams, fecal calorimetry will be performed. Full 24-hour fecal samples will be collected from dams individually and dried. Dried fecal matter will be assessed by a bomb calorimeter to determine total energy content in the stool as described by Murphy and colleagues (Murphy et al., 2010). Results will be expressed as total energy intake for that day – energy found in stool.

*Macronutrient absorption*

macronutrient absorption

## Expected Results and Potential Pitfalls:

### Aim 2.1 Are dams exposed to eTRF more insulin sensitive than ad libitum fed, age-matched counterparts?

One of the few fairly consistent findings of time-restricted feeding trials in both humans and animals is an improvement of insulin resistance. This is usually accompanied by a reduction in insulin levels, and no changes in glycemia. However, based on Peterson and colleagues’ recent findings about eTRF reducing nocturnal glucose excursions, static fasting blood glucose during the light cycle is likely insufficient to fully capture the effects to eTRF on glycemia (Peterson, 2019; )

### Aim 2.2 Do dams exposed to eTRF demonstrate altered energy balance?

### Aim 2.3 Are dams exposed to eTRF nutrient restricted?

One such concern about the use of TRF in gestation is that the narrow eating window would provide too little time to consume sufficient calories to support maternal needs and fetal growth. This is especially a concern based on data available from human trials of TRF. In adult humans, when TRF/IF is employed, there is often a reduction in total kcal intake which then leads to weight loss. However, this is often not seen in animal studies even in studies of HFD feeding with TRF, food intake is similar. ().Furthermore, Upadhyay and colleagues found that TRF of a high fat diet in gestation yielded offspring growth similar to AL chow fed control pups(Upadhyay et al., 2019). For this reason, I do not expect that dams assigned to eTRF treatment to be unable to consume necessary calories to continue a healthful pregnancy. Preliminary data suggests that with the eating window of 6 hours, there are no differences in total 24-hour energy intake in the preliminary cohort.

### Aim 2.4 Energy Expenditure

Pitfalls in general:

* Restriction may affect implantation- see that paper from INSS?
* May lead to dams being hungry/eating pups- perhaps, but share data
* May be growth restricted pups- evidence against it – Detrick’s pediatrics paper

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