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Effects of carbohydrate restriction and dietary cholesterol provided by eggs on clinical risk factors in metabolic syndrome

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BACKGROUND: There are a limited number of clinical interventions evaluating the effects of dietary cholesterol in individuals at elevated risk for type 2 diabetes and cardiovascular disease.

OBJECTIVE: To investigate the effects of whole egg intake in adults with metabolic syndrome (MetS).

METHODS: Men (n = 12) and women (n = 25) with MetS were instructed to follow a moderate carbohydrate-restricted diet (<30% energy) and randomly assigned to consume either three whole eggs (EGG, n = 20) or egg substitute (SUB, n = 17)/d for 12 weeks. Dietary intake, MetS parameters, and body composition were assessed at baseline and post-intervention.

RESULTS: Total carbohydrate ($P < .001$) intake decreased in all participants over time. The EGG group consumed more dietary cholesterol ($P < .001$) and choline ($P < .001$) than the SUB group. MetS was reduced in both groups, with improvements noted in dyslipidemia and decreases in waist circumference ($P < .01$), weight ($P < .001$), and percent body fat ($P < .001$). Reductions in plasma tumor necrosis factor-α ($P < .001$) and serum amyloid A ($P < .05$) were seen in the EGG group only. Notably, increases in dietary cholesterol were associated with reductions in plasma tumor necrosis factor-α (r = −0.340, $P = .04$). Plasma C-reactive protein, adiponectin, interleukin-6 interleukin-10, and cell adhesion molecules were unaffected by the intervention.

CONCLUSIONS: These results demonstrate that on a moderate carbohydrate background diet, accompanied by weight loss, the inclusion of whole eggs improves inflammation to a greater extent than yolk-free egg substitute in those with MetS.

In tandem with increases in obesity and an aging population, the prevalence of metabolic syndrome (MetS) has increased dramatically in recent decades.[1] The clinical presentation of MetS is characterized by abdominal adiposity, insulin resistance, atherogenic dyslipidemia, and chronic low-grade inflammation.[2] Simultaneous presentation of underlying, major and emerging risk factors for disease results in approximate 2-fold and 5-fold increased risks for cardiovascular disease (CVD) and type 2 diabetes, respectively.[3,4] Individuals identified as having MetS are recommended to pursue intensive lifestyle changes such as increasing physical activity, weight loss,

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and dietary modification to reduce underlying causes and treat associated risk factors.[5] Therefore, dietary considerations should aim to improve MetS-associated metabolic risk factors and facilitate weight loss. One particular dietary strategy that is highly effective at managing and even reversing characteristics of MetS is carbohydrate restriction.[6] Carbohydrate-restricted diets (CRDs) have been extensively used as an effective means to achieve weight loss.[7] Carbohydrate restriction can improve markers of MetS even in the absence of weight loss.[8] In addition, following a dietary pattern aimed at carbohydrate restriction fares better than dietary fat restriction in those with MetS.[6] Thus, carbohydrate restriction is considered an ideal dietary strategy to ameliorate MetS.

In addition to dietary patterns aimed at restricting carbohydrate intake, there may be specific food choices within a CRD that further improve MetS. Daily egg consumption can be easily incorporated into carbohydrate-restricted weight-loss diets because eggs are low in calories and essentially absent in carbohydrates. Eggs may also facilitate weight loss as the result of their effects on increasing satiety.[9,10] Furthermore, a previous study conducted in our laboratory demonstrated that daily egg consumption, as part of a CRD, improved lipid and nonlipid CVD and type 2 diabetes risk factors in overweight men.[11–13] Importantly, compared with yolk-free egg substitute, daily egg intake resulted in reductions in plasma adiponectin and C-reactive protein after 12 weeks.[13]

We have previously reported greater improvements in atherogenic dyslipidemia with whole egg intake compared with yolk-free egg substitute in adults with MetS.[14] As an extension of these findings, we investigated whether egg intake would influence abdominal adiposity and inflammation in those with MetS. In contrast to the anti-inflammatory effects of whole egg consumption observed previously,[13] there is some evidence that dietary cholesterol may exacerbate inflammation and induce serum amyloid A (SAA) in both animals[15–17] and humans.[18] In addition, several epidemiological studies suggest that those with insulin resistance may be at greater risk for CVD with daily egg consumption,[19,20] which is in contrast to what has been reported with healthy populations.[19,21,22]

We investigated the effects of including 3 eggs per day (additional 534 mg of cholesterol) in combination with moderate carbohydrate restriction in adults with MetS. We hypothesized that whole egg consumption would not exacerbate but rather improve risk factors associated with MetS compared to yolk-free egg substitute.

Materials and methods

Experimental design

The dietary intervention study used a randomized, single-blind, placebo-controlled parallel design and has been previously reported.[14] All participants were asked to follow a CRD throughout the 12-week intervention. In addition, participants were randomly allocated to consume either three whole eggs per day (EGG; additional 534 mg of dietary cholesterol) or the equivalent amount of egg substitute (SUB; 0 additional mg of dietary cholesterol) throughout the intervention.

Forty male and female participants (30−70 years) classified with MetS according to National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults−Adult Treatment Panel III guidelines[23] were recruited and enrolled in a 12-week diet intervention. Participants (n = 37) completed the 12-week diet intervention and their data set was used in the analyses. This study was approved by the University of Connecticut-Storrs Institutional Review Board, and all participants signed the written, informed consent form.

Diet and physical activity assessment

Participants were instructed to consume specific low-carbohydrate food choices to meet the targeted macronutrient distribution ranges (25%–30% of energy from carbohydrates, 25%–30% of energy from protein, and 45%–50% of energy from fat). Individualized dietary counseling, nutrition education materials, and sample menus and recipes were provided by trained personnel. The dietary instructions consisted of the following: unlimited amounts of beef, cheese, poultry, fish, and soy products; moderate amounts of nonstarchy vegetables, unsweetened dairy, fruits, 2-3 ounces of nuts/seeds; and limited amounts starchy vegetables, legumes, and whole grains. Volunteers were instructed to avoid high-carbohydrate food choices such as sweets, refined sugars, sweetened beverages, syrups, fruit juices, refined grains, breads, rice, cereals, and pasta. Dietary intake for participants was *ad libitum*, with no specific guidelines on caloric restriction. Participants were asked to complete a 5-day food record at baseline, week 6, and week 12 of the intervention to assess dietary intake and compliance. Dietary records were analyzed with the Nutrition Data System for Research (Nutrition Coordinating Center, University of Minnesota) nutrient analysis software.

Liquid whole eggs (EGG group) and cholesterol/fat-free eggs (SUB group; both from the Sysco Corporation, Houston, TX) were provided biweekly to volunteers. Both products were equal in consistency and color. The composition of the egg products provided was as follows: three whole eggs contain 0 g carbohydrate, 16 g protein, 12 g fat, and equivalent to 186 kcal; and cholesterol/fat-free eggs contain 2 g carbohydrate, 14 g protein, 0 g fat, and equivalent to 60 kcal. Participants were asked to maintain their current physical activity and refrain from eating additional eggs outside of the study allocation. Physical activity and egg product compliance were assessed with weekly questionnaires and collection of empty egg containers. Physical activity was expressed as the amount of