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Perceived weight discrimination and 10-year risk of allostatic load among US adults

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1 **Perceived weight discrimination and 10-year risk of allostatic load among US adults**

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28 **ABSTRACT**

29 **Background:** Discrimination promotes multi-system physiological dysregulation termed
30 allostatic load, which predicts morbidity and mortality. It remains unclear whether weight-
31 related discrimination influences **allostatic load**.

32 **Purpose:** To prospectively examine 10-year associations between weight discrimination,
33 **allostatic load**, and its components among adults 25-75y in the Midlife Development in the US
34 Biomarker Substudy.

35 **Methods:** Participants with information on weight discrimination were analyzed (n=986). At
36 both timepoints, participants self-reported the frequency of perceived weight discrimination
37 across nine scenarios as ‘never/rarely’ (scored as 0), ‘sometimes’ (1), or ‘often’ (2). The two
38 scores were averaged and then dichotomized as ‘experienced’ versus ‘not experienced’
39 discrimination. High **allostatic load** was defined as having ≥ 3 out of 7 dysregulated systems
40 (cardiovascular, sympathetic/parasympathetic nervous systems, hypothalamic pituitary axis,
41 inflammatory, lipid/metabolic, and glucose metabolism), which collectively included 24
42 biomarkers. Relative risks (RR) were estimated from multivariate models adjusted for socio-
43 demographic **and health** characteristics, **other forms of discrimination**, and BMI.

44 **Results:** Over 41% of the sample had obesity, and 6% reported weight discrimination at follow-
45 up. In multivariable-adjusted analyses, individuals who experienced (versus did not experience)
46 weight discrimination had twice the risk of high **allostatic load** (RR: 2.07, 95%CI: 1.21, 3.55 for
47 baseline discrimination; 2.16, 95%CI: 1.39, 3.36 for long-term discrimination). Weight
48 discrimination was associated with lipid/metabolic dysregulation (1.56, 95%CI: 1.02, 2.40),

49 glucose metabolism (1.99, 95% CI: 1.34, 2.95), and inflammation (1.76, 95% CI: 1.22, 2.54), but
50 no other systems.

51 **Conclusions:** Perceived weight discrimination doubles the 10-year risk of high **allostatic load**.
52 Eliminating weight stigma may reduce physiological dysregulation, **improving** obesity-related
53 morbidity and mortality.

54
55 **Word Count:** 250
56

57 **Key Words:** obesity stigma, weight discrimination, allostatic load, **allostasis**, dysregulation,
58 weight stigma

59

60 INTRODUCTION

61 Obesity is the leading contributor to disability-adjusted life-years in the US, at least partly
62 due to its adverse effects on multiple health outcomes (1). It is well-established that obesity
63 etiology is both complex and manifold (2), suggesting a need for integrated biopsychosocial and
64 biomedical approaches to address it (3). Despite this, predominant approaches to treat obesity
65 continue to accentuate the role of the individual (4), unintentionally contributing to a cycle that
66 further entrenches obesity and its related health consequences by promoting stigmatization of
67 this condition (3, 4).

68 Research suggests that pervasive individually-targeted health campaigns increase public
69 prejudice toward individuals with obesity by increasing the perception of obesity as a lifestyle
70 choice resulting from weakness of character (5). A downward consequence of this perception is
71 increased weight-related stigma, and often, discrimination (6, 7). Weight discrimination is the
72 fourth most prevalent form of discrimination among adults, after age, sex, and race-based
73 discrimination (8). Between 1995 and 2006, the absolute prevalence of weight discrimination
74 increased from 7% to 12% in the US, representing a 66% increase in prevalence and exceeding
75 the proportion that could be attributed to concomitant increases in obesity (9). Despite the lay
76 belief that weight stigma motivates positive behavioral change (10), most evidence demonstrates
77 that weight shaming promotes poorer dietary and exercise practices and health care avoidance
78 (11, 12), akin to how experienced racism correlates with negative health outcomes like cancer
79 risk (13, 14). As such, weight discrimination may contribute to obesity (3, 15) by discouraging
80 individuals from seeking treatment, reducing engagement with social support, or promoting
81 disordered eating patterns, less healthful food choices, and emotional dysregulation (12, 16-21).
82 Furthermore, weight stigma has been directly linked to overeating and physical inactivity in

83 randomized controlled trials (10), providing plausible mechanisms through which weight stigma
84 promotes physiologic dysregulation.

85 Discrimination also affects chronic stress, which could subsequently promote adverse
86 physiologic changes (3, 15, 22-24). For example, weight stigma has been associated with higher
87 glycemic parameters (24) and C-reactive protein (CRP) (15) in large, longitudinal studies. In
88 studies where weight stigma was experimentally manipulated, greater stigmatization resulted in
89 sustained cortisol secretion (22, 25). These findings echo existing research on the effects of
90 perceived discrimination on allostatic load (26, 27), suggesting that there may be a similar
91 connection between weight discrimination and physiologic dysregulation.

92 Allostatic load refers to the cumulative adverse adaptation of multiple physiological
93 systems (i.e. cardiovascular, sympathetic, parasympathetic, metabolic, etc.) in response to
94 chronic stressors, which has been more strongly associated with chronic disease morbidity and
95 mortality than traditional risk markers (28, 29). Although the operational definitions of **allostatic**
96 **load** vary across studies (28), the **allostatic load** metric is considered a robust estimator of multi-
97 system dysregulation in population studies (30). While it is valuable to examine **allostatic load** as
98 a composite score, examining dysregulation within the individual **allostatic load** systems can
99 help identify underlying pathways through which the **allostatic load** response is manifested,
100 according to the population's specific characteristics (30). As such, we examined whether the
101 chronic stress associated with weight discrimination impacts both **allostatic load** and seven
102 individual systems used to define **allostatic load** to elucidate the underlying pathways through
103 which weight discrimination promotes dysregulation.

104 We propose that weight-related discrimination triggers multi-system dysregulation that
105 adversely affects other health outcomes (e.g. cardiovascular disease) beyond the effects of

106 obesity alone (**Figure 1**). Similar to the cyclic obesity/weight-based stigma (COBWEBS) model
107 (3), weight-related discrimination is characterized as a stressor that triggers a downward cascade
108 of unfavorable psychosocial and behavioral processes that ultimately result in poor biological
109 outcomes across multiple systems (e.g. metabolic syndrome, cardiovascular disease) (31, 32). To
110 test this hypothesis, we used unique data from the national survey of Midlife Development in the
111 US (MIDUS) study to prospectively examine the 10-year associations between perceived weight
112 discrimination and **allostatic load** among adults ages 25-74y.

113

114 **METHODS**

115 *Participants*

116 We used data from the MIDUS I (1995-1996), MIDUS II (2004-2006), and MIDUS
117 Biomarker Substudy (2004-2009) to examine associations between perceived weight
118 discrimination, **allostatic load**, and the individual systems comprising **allostatic load**. Detailed
119 information about the study's sampling procedures have been previously published (33). Briefly,
120 7,108 non-institutionalized adults (including 950 siblings and 1,914 twins) aged 25-74y
121 participated in a telephone survey conducted via random digit dialing in 1995-1996. At follow-
122 up between 9 and 10 years later, approximately 4,900 members of the original cohort responded
123 to an additional phone survey; the mortality-adjusted longitudinal response rate at MIDUS II was
124 75%. During the 10-year follow-up, a subset of 1,255 adults who completed the phone interview
125 and questionnaires were randomly selected and invited to participate in a biomarker substudy.
126 The present analysis includes those in the biomarker sub-study with sufficient information to
127 compute **allostatic load** (n=1,233) or the individual **allostatic load** systems (n=1,158-1,254) and
128 who had information on perceived weight discrimination (n=986).

129 *Perceived Weight Discrimination*

130 Participants self-reported instances of perceived discrimination within interpersonal
131 relationships on a day-to-day basis at both the baseline and 10-year follow-up survey. Nine
132 scenarios about interpersonal discrimination were queried with the question ‘How often on a
133 day-to-day basis do you experience each of the following types of discrimination?’ The
134 scenarios included: ‘you are treated with less courtesy than other people’, ‘you are treated with
135 less respect than other people’, ‘you receive poorer service than other people at restaurants or
136 stores’, ‘people act as if they are afraid of you’, ‘people act as if they think you are dishonest’,
137 ‘people act as if they think you are not as good as they are’, ‘you are called names or insulted’,
138 and ‘you are threatened or harassed’. The frequency categories for these scenarios included
139 ‘Often’, ‘Sometimes’, ‘Rarely’, or ‘Never’. These questions were initially developed for a study
140 examining racial discrimination, and have been used widely since then (34).

141 **Similar to Puhl and others (8), only participants reporting discrimination ‘Sometimes’ or**
142 **‘Often’ were counted as instances of discrimination.** We constructed a continuous measure of
143 perceived discrimination that allocated 2 points for every instance that a discrimination scenario
144 was reported as ‘Often’, 1 point for every scenario reported as ‘Sometimes’, and 0 points for
145 those who reported discrimination ‘Rarely’ or ‘Never’. Separately, participants were asked to
146 select the primary reason(s) for discrimination, from among the following options: age, gender,
147 race, height or weight, ethnicity or nationality, physical disability, some aspect of appearance
148 other than weight or height, sexual orientation, religion, and other reason. Like previous studies,
149 we refer to the ‘height or weight’ variable as ‘weight discrimination’ throughout the manuscript
150 (8).

151 We constructed two variables for perceived weight discrimination at both baseline and
152 10-year follow-up. First, a continuous measure of perceived weight discrimination was
153 computed from the continuous perceived discrimination score for individuals who reported
154 ‘weight’ as a primary reason for discrimination. The observed range for this score was 0-10 at
155 baseline and 10-year follow-up. Secondly, a categorical indicator variable was created for
156 individuals who experienced any vs. no perceived weight discrimination.

157 Individuals who reported no instances of discrimination received a weight discrimination
158 score of 0 (n=126). We also carried baseline values forward for non-responders at the 10-year
159 follow-up who reported discrimination related to weight at baseline based on the correlation
160 between these two measures (n=215, $r=0.40$, $p<0.0001$). Individuals who refused to respond to
161 the question or whose responses were deemed ‘inappropriate’ by study administrators were
162 coded as missing (n=46). Complete information was available for 986 participants at baseline
163 and 940 at follow-up. The two exposures of interest were baseline weight discrimination and
164 long-term weight discrimination. Long-term discrimination was computed as the average value
165 of perceived discrimination at baseline and at 10-year follow-up or as discrimination at 10-years
166 for individuals with missing baseline data.

167 *Allostatic Load*

168 **Allostatic load** was comprehensively measured and defined in accordance with previous
169 studies conducted within this population using a score that captured dysregulation across seven
170 systems, including the sympathetic and parasympathetic nervous systems, hypothalamic pituitary
171 adrenal (HPA) axis, cardiovascular functioning, lipid and general metabolic activity, glucose
172 metabolism, and inflammatory system(31, 35, 36) (**Table 1**). All physiologic measures were

173 collected during the Biomarker Substudy visit, which corresponded with the timing of the 10-
174 year follow-up exam.

175 **Sympathetic nervous system** functioning was measured with 12-hour overnight urinary
176 measurements of epinephrine and norepinephrine via high-pressure liquid chromatography, and
177 levels were reported per level of creatinine (g). **Parasympathetic nervous system** activity was
178 measured by four heart rate variability parameters during an 11-minute seated rest period using
179 an electrocardiograph: low frequency spectral power, high frequency spectral power, the
180 **standard deviation of heartbeat to heartbeat intervals**, and the **root mean square of successive**
181 **differences**. Overnight urinary cortisol and serum dehydroepiandrosterone sulfate (DHEA-S)
182 were used as markers of HPA activity. Markers of cardiovascular functioning included resting
183 systolic blood pressure (SBP), heart rate, and pulse pressure. Lipid/fat metabolism markers
184 included high-density lipoprotein (HDL), low-density lipoprotein (LDL), triglycerides, body
185 mass index (BMI), and waist-to-hip ratio (WHR). Glycosylated hemoglobin (HbA1c), fasting
186 glucose, and the homeostasis model of insulin resistance (HOMA-IR) were used to assess
187 glucose metabolism. Inflammation was measured with plasma **CRP**, fibrinogen, serum
188 interleukin-6 (IL6), the soluble adhesion molecule E-selectin, and intracellular adhesion
189 molecule-1. All blood, urine, saliva, cardiovascular, and heart rate variability measurements were
190 collected during an overnight stay at one of three University General Clinical Research **Centers**.
191 Detailed collection protocols for each biomarker have been previously published (31, 37).
192 Consistent with previous studies (36), we computed a system risk score for each of the seven
193 systems that was in the upper or lower quartile of the biomarker population-specific distribution,
194 based on whether high or low values of the parameter were generally associated with higher
195 health risk. Additionally, consistent with previous research (35, 38-40), participants who

196 reported using medications to treat dysregulated parameters were categorized as high risk for that
197 parameter to account for pre-existing dysregulation. These medications included
198 antihypertensive medications for high SBP; heart rate-reducing medications (e.g. beta-blockers
199 and atrio-ventricular nodal blockers) for high resting heart rate; hypoglycemic agents for
200 dysregulated fasting glucose and HbA1c; statins, cholesterol absorption inhibitors, niacin and/or
201 bile acid sequestrants for dysregulated LDL; fibrates for elevated serum triglycerides;
202 testosterone for dysregulated DHEA-S, and anti-inflammatory medications (including non-
203 steroidal anti-inflammatory medications) for dysregulated CRP and IL-6. The number of
204 participants with dysregulated parameters including and excluding medication data in the
205 definition of **allostatic load** is shown on **Supplemental Table 1**. In sensitivity analyses, we
206 examined all associations excluding the use of medications in the definitions of system
207 dysregulation.

208 System risk scores were continuous and computed by calculating the proportion of
209 individual biomarkers within the system that were dysregulated. Scores could range from 0 to 1
210 (corresponding with 0-100% of system biomarkers in high-risk range). We only computed
211 system risk scores for participants with values for at least half of the system's biomarkers. Over
212 90% of participants had information for all 7 systems, and most participants (98%) had complete
213 data for all systems excluding the parasympathetic measures; 106 participants (8%) were missing
214 information on the parasympathetic parameters due to instrumentation failures and/or
215 measurement difficulties.

216 The **allostatic load** variable was computed for participants with data on at least six of the
217 seven systems by summing the seven system risk scores; total **allostatic load** scores ranged from
218 0 to 7, with higher scores indicative of more dysregulation. An indicator variable for high versus

219 low **allostatic load** was created: **allostatic load** summary scores ≥ 3 were considered “high” and
220 scores < 3 were considered “low.” Although the median **allostatic load** score in this population
221 was 2, using a higher cut-point allowed us to capture individuals at higher disease risk (39).

222 *Covariates*

223 Potential confounding variables were selected based on their relevance from prior
224 literature. We used self-reported information collected during the follow-up period for these
225 variables: age, race (white, black, other), household income ($> \$100,000/\text{year}$), educational
226 attainment ($<$ high school, high school graduate, some college, college graduate or more),
227 smoking status (never, former, current) and physical activity (engagement in regular exercise at
228 least 20 minutes 3 times per week). Baseline rather than follow-up values were used for BMI
229 and for perceived discrimination related to age, race, and/or sex (the three most common forms
230 of discrimination (8)) because prolonged stress is more strongly related to **allostatic load** (28).
231 These variables were computed in the same manner as weight discrimination.

232 *Statistical Methods*

233 Mixed linear models with maximum likelihood estimation and family membership as a
234 random effect were used to examine the continuous associations between perceived weight
235 discrimination and **allostatic load**. Family membership was incorporated as a random effect to
236 account for clustering since the sample included participants from the sibling/twin subsamples of
237 the main MIDUS study (31). A generalized linear model procedure was used to estimate relative
238 risks (RR) using Poisson regression with robust error variance (41), as this method produces
239 95% confidence intervals with the correct coverage. Base models were adjusted for age and sex.
240 The first multivariable adjusted model (Model 1) further adjusted for race, household income,
241 smoking status, and educational attainment. Model 2 further incorporated physical activity, and

242 Model 3 was further adjusted for baseline perceived race, sex, and age discrimination. Our final
243 model (Model 4) also adjusted for baseline BMI. We tested for the presence of interactions
244 between perceived weight discrimination and sex, BMI, physical activity, smoking status, and
245 race, sex, or age discrimination using a p-value<0.05 to establish significance. We also used
246 Baron and Kenny criteria (42) to examine whether health behaviors like smoking and physical
247 activity mediated the association between weight discrimination and **allostatic load**.
248 Additionally, we examined the associations between perceived weight discrimination and
249 individual system dysregulation in order to provide insight into the biological pathways
250 underlying any observed associations. Finally, in sensitivity analyses, we excluded BMI and
251 WHR from the definition of lipid/metabolic dysregulation in the calculation of **allostatic load**.
252 All analyses were conducted with SAS v 9.4 (SAS Institute Inc., Cary, NC, USA).

253

254 **RESULTS**

255 The study sample was predominately comprised of white (93%), female (57%), middle-
256 aged adults (mean age=57y) with high educational attainment (47% with a college education or
257 higher) (**Table 2**). More than 75% of participants reported engaging in regular physical activity,
258 15% were current smokers, and more than 75% were classified with either overweight or obesity.
259 At baseline, nearly 4% of participants reported experiencing weight-related discrimination, with
260 an average discrimination score of 0.13 (0.76). At follow-up, this percentage increased to
261 approximately 6% with average discrimination values of 0.22 (1.09). When medication was
262 included in the definition of high **allostatic load**, 18% of participants met the criteria, while only
263 13% met the criteria when medication usage was excluded.

264 No significant interactions between perceived weight discrimination and relevant
265 covariates were detected (data not shown). Results were similar regardless of whether we used
266 medications to operationalize **allostatic load**; thus, those presented hereafter include medication
267 information to capture already-deregulated parameters. Compared to individuals who did not
268 experience weight discrimination, both baseline and long-term perceived weight discrimination
269 were associated with more than double the risk of high **allostatic load** in final multivariable
270 models (RR: 2.07, 95%CI: 1.21, 3.55 for baseline discrimination and RR: 2.16, 95%CI: 1.39,
271 3.36 for long-term discrimination) (**Table 3**). Similar associations were observed when these
272 associations were examined using the continuous weight discrimination score and **allostatic load**
273 variables ($\beta=0.11$, $p=0.01$ for baseline discrimination and $\beta=0.19$, $p=0.0001$ for long-term
274 discrimination). Additionally, the effect of weight discrimination on **allostatic load** was partly
275 mediated (~5%) through decreased physical activity among those who experienced versus did
276 not experience weight discrimination (data not shown). Perceived race, sex, and age
277 discrimination were not significantly associated with **allostatic load** in final models (data not
278 shown). In sensitivity analyses, when BMI and WHR were excluded from the definition of
279 **allostatic load**, baseline perceived weight discrimination was not significantly associated with
280 **allostatic load**, but long-term weight discrimination remained associated with **allostatic load** after
281 controlling for baseline BMI (RR:1.62, 95%CI: 1.01, 2.62; $p=0.047$).

282 Overall, compared to individuals reporting no weight-related discrimination, long-term
283 weight discrimination was most strongly associated with metabolic/lipid dysregulation (RR:
284 1.56, 95%CI: 1.02, 2.40), glucose metabolism (RR:1.99, 95% CI: 1.34, 2.95), and inflammatory
285 parameters (RR: 1.76. 95% CI: 1.22, 2.54) after adjustment for other confounding variables
286 including baseline BMI (**Table 4**). Weight discrimination was not significantly associated with

287 CVD function, **sympathetic or parasympathetic nervous system** dysregulation, or HPA
288 dysfunction.

289

290 **DISCUSSION**

291 Perceived baseline and long-term weight discrimination were associated with more than
292 twice the risk of high **allostatic load** in this sample. The detrimental effects of weight
293 discrimination on **allostatic load** persisted following adjustment for BMI, suggesting that
294 perceived weight-related discrimination adversely affects overall physiological regulation
295 beyond what can be attributed to excess weight alone. Further support for the independent
296 associations between weight discrimination and **allostatic load** were observed when BMI and
297 WHR were excluded from the operationalization of **allostatic load**, and the long-term
298 associations remained significant. When the individual systems comprising **allostatic load** were
299 examined separately, perceived weight discrimination was most strongly associated with
300 lipid/metabolic dysregulation, glucose metabolism, and markers of inflammation. Taken
301 together, these results suggest that the stigma associated with having excess weight adversely
302 influences **allostatic load**, and potentially chronic disease morbidity and mortality, highlighting a
303 need for prevention efforts to reduce weight-related stigma in diverse settings.

304 While limited, empirical studies demonstrate that reducing weight-related stigma
305 favorably affects weight-loss self-efficacy and attitudes toward exercise. In an experimental
306 study, Pearl and Lebowitz (2014) demonstrated that overweight and obese participants who read
307 passages that implicate the food environment vs. personal responsibility in obesity etiology had
308 greater self-efficacy to lose weight and no increase in weight stigmatizing attitudes that
309 adversely affect weight control (5). Similarly, US women exposed to neutral vs. stereotypical

310 images of a woman with obesity exercising had more favorable attitudes toward exercise
311 engagement and lower weight-based stigma (43).

312 Our results suggest that perceiving weight discrimination can adversely affect multiple
313 biological systems and are consistent with research examining individual biomarkers. In
314 MIDUS, Tsenkova and others (24) noted that experiencing weight discrimination amplified the
315 adverse effects of elevated WHR on HbA1c. Among community-dwelling adults with diabetes,
316 researchers found that participants experienced worse glycemic outcomes if they had
317 experienced weight-based discrimination (11). Similar to the present study, the changes in
318 glycemic markers persisted even after accounting for body weight and other forms of
319 discrimination (11). Moreover, the participants from the study conducted by Potter and others
320 also reported worse diabetes self-care practices related to diet, exercise, and blood glucose
321 monitoring, providing insight into the pathways by which weight discrimination adversely
322 impacts physiologic parameters. These observed negative behavioral adaptations support the
323 pathways proposed in our conceptual model relating weight discrimination to **allostatic load**.
324 Another study noted that weight-related discrimination was associated with inflammatory
325 markers like CRP among overweight but not obese individuals (15), and also suggested that
326 worse self-care practices may underlie the associations between weight-related discrimination
327 and health outcomes. The significant findings in overweight rather than obese individuals
328 implied that that weight discrimination may support the development and maintenance of obesity
329 by activating inflammatory pathways (15).

330 Although **allostatic load** should primarily be evaluated as a matrix of dysregulated
331 systems, investigating the individual systems informs our understanding of the biological
332 underpinnings of an important risk marker. This study primarily implicated 3 of the 7 systems in

333 the association between weight discrimination and **allostatic load**, potentially identifying relevant
334 treatment priorities. However, additional research into all systems remains necessary because
335 the time course of metabolic dysregulation and the duration and mechanism of action of the
336 biomarkers is not well understood. For example, it remains unclear whether obesity precedes
337 HPA axis dysregulation or vice versa, and whether it results in hypo- or hyperactivity or
338 volatility (44). In the present study, many of the primary markers of HPA axis and CVD
339 dysregulation associated with **allostatic load** were not affected by perceived weight
340 discrimination, potentially suggesting that obesity precedes HPA axis dysregulation and induces
341 some volatility (44). However, because adrenal cortisol and adipose tissue cortisol may be
342 differentially affected by obesity (44) and because biomarkers were only measured once during
343 the follow-up period, we may have been unable to discern the critical window and/or site where
344 HPA dysregulation would occur.

345 Experiencing weight discrimination appears to promote many of the pathologic features
346 of obesity, such as inflammation, lipid/metabolic imbalances, glycemic dysregulation, and more
347 holistically, **allostatic load**. Although the pathways through which weight discrimination
348 influences **allostatic load** may be interconnected and multifactorial, this complexity provides
349 promising opportunities for further research. It may be informative to investigate how
350 discrimination relates to **allostatic load** parameters in more diverse populations where being
351 overweight is less stigmatized, and whether factors like healthcare access can also modulate the
352 effect of weight discrimination on health. While we did not detect any significant interactions
353 between perceived weight discrimination and physical activity or smoking, and detected minimal
354 mediation through physical activity, other research has found that health behaviors during
355 adulthood partly explain the association between adverse events in early life and subsequent

356 **allostatic load** (45). For example, research in MIDUS has established a link between positive
357 coping strategies and social support on **allostatic load** (36) that warrants additional exploration in
358 individuals who experience weight discrimination. Physical activity also deserves further
359 attention as it is possible that a more precise measure would more strongly mediate the
360 association between weight discrimination and **allostatic load**.

361 In addition, while the associations between weight discrimination and **allostatic load** were
362 robust in this study, 10-years of follow-up may provide only an indication of the potential full
363 effect that weight discrimination could have on cumulative physiological dysregulation
364 throughout longer periods of time or at different lifecycles. More longitudinal research with
365 longer follow-up periods and repeated measurements would enhance our understanding of the
366 time course of weight discrimination related to **allostatic load** development as well as critical
367 windows when risk can be modified (28). Finally, it may be important to establish confluence
368 between clinical-cut points and population-based cut-points for the various biomarkers
369 encompassing **allostatic load** to more accurately determine risk estimates.

370 Some limitations of the present analysis must be noted. Dietary information was not
371 collected in the MIDUS study, which may be an important confounding or mediating variable in
372 the association between perceived weight discrimination and **allostatic load** – particularly
373 because poor dietary choices have been related to the effects of discrimination on glycemic
374 control (46). Participant non-response rates on the questions about perceived discrimination also
375 reduced the final sample size. Because non-response was higher among smoking, younger,
376 women with lower self-reported physical activity, and higher BMI at baseline (data not shown),
377 we expect that our risk estimates were attenuated and that the associations between weight
378 discrimination and **allostatic load** are actually stronger than what we were able to observe.

379 Finally, because participants could select multiple primary reasons for discrimination, it is
380 possible that individuals who reported multiple forms of discrimination differed from individuals
381 who only reported weight discrimination. However, associations did not change after controlling
382 for other forms of reported discrimination, which improves the robustness of our findings.

383 The present study has several strengths that warrant mention. First, this study utilizes
384 data from a large US national sample. Additionally, much research to date examining **allostatic**
385 **load** have used limited markers or have been cross-sectional despite a call for more longitudinal
386 research (28); our study precisely measured multiple biomarkers across 7 systems, and the nearly
387 10 years of follow-up provide important insight into the cumulative effects of weight
388 discrimination as a stressor on multi-system dysregulation. By accounting for family
389 relationships within the cohort, we reduced bias related to shared genetic or environmental
390 factors that contribute to weight and metabolic dysregulation. The present study also builds upon
391 existing evidence that self-reported weight discrimination adversely influences biochemical
392 parameters beyond the effect of actual weight (11). Given the established connection between
393 personal responsibility campaigns and increased obesity stigma (5), the results from this study
394 have important policy implications with respect to framing obesity prevention campaigns as well
395 as treatment implications for clinicians working with clients with obesity.

396 The adverse health effects of obesity are well documented and require concerted efforts
397 to treat. The emphasis on personal responsibility in the US has had the effect of further
398 stigmatizing obesity, resulting in less favorable health outcomes within this vulnerable
399 population (4). Weight discrimination was recently associated with a nearly 60% increase in
400 overall mortality risk among MIDUS participants (47), and it is plausible that this hazard is at
401 least partly mediated by **allostatic load**. The magnitude of risk observed between weight

402 discrimination and **allostatic load** is greater than what has been observed for poor quality dietary
403 patterns and **allostatic load** (40), and comparable to physical inactivity (48), drawing attention to
404 weight discrimination as a significant **allostatic load** risk factor. Given that high **allostatic load**
405 has been shown to be robustly associated with type 2 diabetes, hypertension, cardiovascular
406 disease, and mortality (39, 49), targeted efforts to reduce weight discrimination are warranted.
407 From a disease prevention standpoint, it is imperative to develop less stigmatizing public health
408 campaigns and clinical approaches to reduce physiological dysregulation and long-term chronic
409 disease risk among individuals with obesity or at risk for obesity. Simultaneously, directed
410 efforts to better understand the pathways through which weight discrimination influences
411 **allostatic load** can improve treatment targets and health outcomes among the substantial
412 proportion of the population with weight-related comorbidities.

413

414 **ACKNOWLEDGEMENTS**

415

416

417 **References**

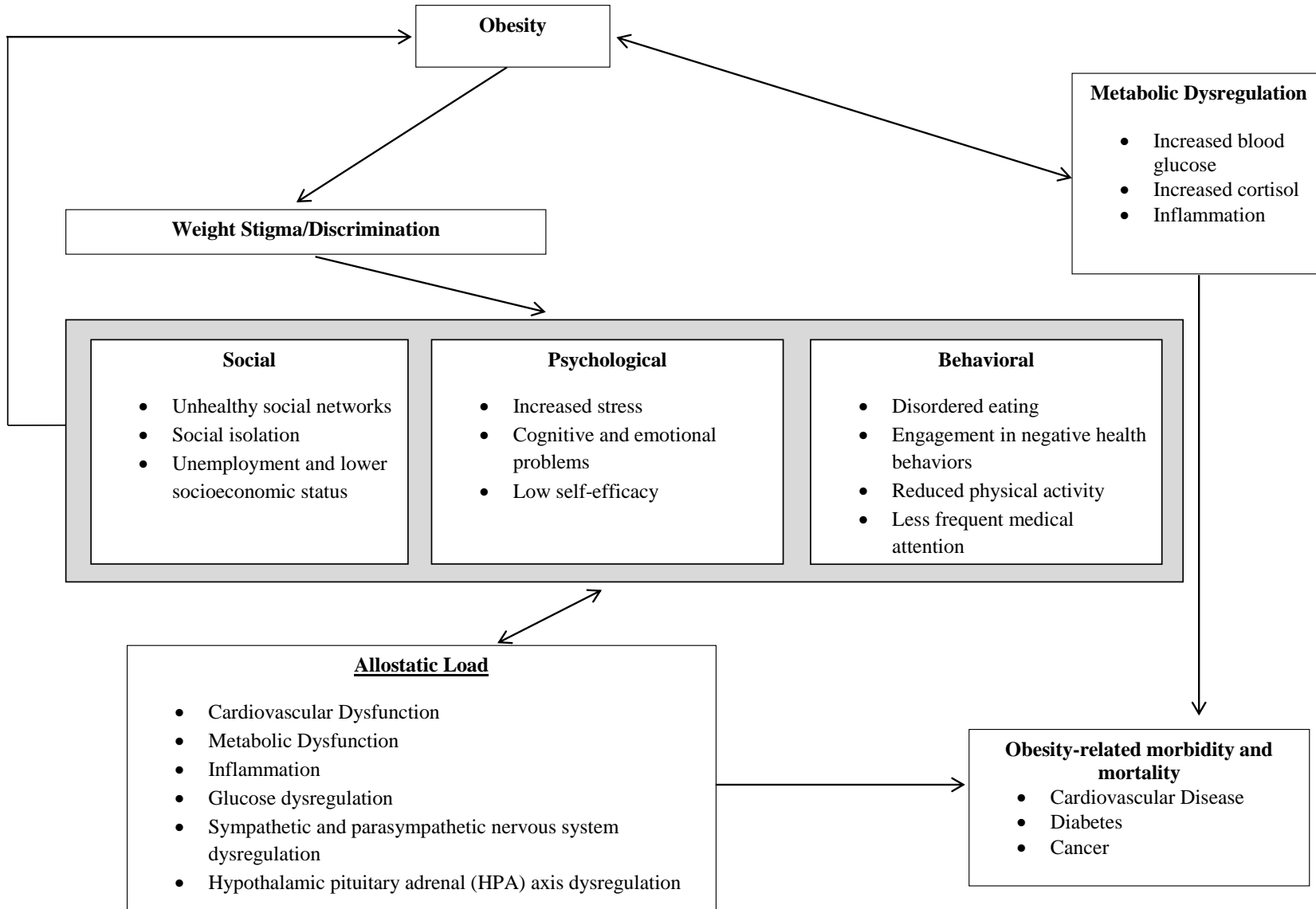
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591 **Figure 1:** Conceptual model of potential pathways through which obesity and weight discrimination are associated with allostatic load
 592 (Adapted from Gruenwald et al, 2012(31) and Tomiyama et al. 2014(3))
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594 **Table 1: Mean values and population-specific high-risk cutpoints for allostatic load parameters in**
595 **the MIDUS Biomarker Substudy**

System and Representative Biomarkers	N	Mean	SD	Min	Max	High-risk cutpoint by population-specific quartile
<i>Cardiovascular</i>						
Resting SBP (mmHg)	1254	131.5	18.3	83.0	222.0	≥144.0 (n=309)
Resting heart rate (bpm)	1253	71.1	11.2	36.0	111.0	≥79.0 (n=314)
Resting pulse pressure (mmHg)	1254	55.8	14.7	24.0	114.0	≥65.0 (n=312)
<i>Metabolic- lipids</i>						
BMI (kg/m ²)	1254	29.8	6.63	15.0	65.1	≥33.1 (n=313)
WHR	1253	0.89	0.10	0.62	1.72	≥0.97 (n=316)
Triglycerides (mg/dL)	1244	132.5	131.8	25.0	3299.0	≥156.0 (n=312)
HDL Cholesterol (mg/dL)	1242	55.4	18.0	19.0	121.0	≤42.0 (n=310)
LDL Cholesterol (mg/dL)	1242	105.5	35.4	6.00	283.0	≥128.0 (n=310)
<i>Metabolic- glucose metabolism</i>						
Glycosylated hemoglobin (%)	1235	6.10	1.16	3.58	19.7	≥6.24 (n=314)
Fasting glucose (mg/dL)	1236	102.1	28.4	5.00	418.0	≥105.0 (n=314)
Insulin resistance (HOMA-IR)	1236	3.58	3.98	0.04	53.7	≥4.36 (n=310)
<i>Inflammation</i>						
CRP (mg/L)	1235	3.02	4.78	0.14	61.7	≥3.66 (n=309)
IL6 (pg/mL)	1243	3.04	3.04	0.16	23.0	≥3.48 (n=310)
Fibrinogen (mg/dL)	1235	348.9	87.8	45.0	857.0	≥399.0 (n=313)
sE-Selectin (ng/MI)	1242	43.4	22.7	0.09	178.1	≥51.9 (n=310)
sICAM-1 (ng/MI)	1242	288.5	115.6	44.0	1076.6	≥335.8 (n=310)
<i>Sympathetic Nervous System</i>						
Urine Epinephrine (ug/g creatine)	1233	1.96	1.28	0.09	10.6	≥2.47 (n=308)
Urine Norepinephrine (ug/g creatine)	1243	27.4	13.9	3.50	187.1	≥33.0 (n=311)
<i>Hypothalamic Pituitary Adrenal Axis</i>						
Urine Cortisol (ug/g creatine)	1252	15.8	24.6	0.40	725.0	≥20.0 (n=308)
Blood DHEA-S (ug/dL)	1239	105.1	77.0	0.90	685.0	≤51.0 (n=313)
<i>Parasympathetic Nervous System</i>						
SDRR (msec)	1148	35.6	17.2	5.56	138.8	≤23.7 (n=287)

	RMSSD	1148	22.9	17.7	2.64	209.7	≤12.1 (n=287)
	Low frequency spectral power	1148	424.3	607.5	1.60	10943.6	≤114.6 (n=287)
	High frequency spectral power	1148	316.5	729.4	2.45	15731.7	≤58.8 (n=287)
	<i>Allostatic Load</i>	1233	1.72	1.03	0	5.03	
	<i>Allostatic Load (with medication data)</i>	1233	1.94	1.10	0	5.37	

596 Abbreviations: BMI: body mass index; CRP: C-reactive protein; DHEA-S: dehydroepiandrosterone sulfate;
597 PNS: parasympathetic nervous system; HPA: hypothalamic pituitary axis; IL6: interleukin-6; RMSSD: root
598 mean square of successive differences; SBP: systolic blood pressure, SDRR: the standard deviation of R-R
599 (heartbeat to heartbeat) intervals; sE-selectin: soluble adhesion molecule E-selectin; sICAM: soluble
600 intracellular adhesion molecule-1; SNS: sympathetic nervous system

601 Allostatic Load was defined in accordance with previous studies conducted within this population using a score
602 that captured dysregulation across seven systems, including multiple markers of cardiovascular pathways,
603 **Sympathetic Nervous System, Parasympathetic Nervous System**, HPA axis, inflammation, lipid and general
604 metabolic activity, and glucose metabolism, and could range from 0 to 7.

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607 **Table 2:** Descriptive characteristics of the MIDUS participants at 10-year follow-up, (n=932-1,255)^a

Age		57.3 (11.5)
Sex (% female)		56.8
Race		
	White	93.1
	Black	2.6
	Other	4.4
Educational attainment (%)		
	Less than high school	4.3
	High school	19.9
	Some college	29.2
	College and above	46.6
Household income (>\$100,000/year)		21.4
Regular physical activity (%) ^b		76.5
Smoking status (%)		
	Never	52.4
	Past	32.6
	Current	14.9
Body Mass Index		29.8 (6.6)
Weight category (%)		
	Overweight	35.1
	Obesity	41.2
Perceived weight discrimination (%) ^c		
	Baseline	3.96
	10-year follow-up	6.17
Perceived weight discrimination score ^c		
	Baseline	0.13 (0.76)
	10-year follow-up	0.22 (1.09)
High allostatic load ^d		18.3
High allostatic load (excluding medication) ^d		12.9

608 ^aContinuous variables are expressed as mean (SD) and categorical variables as percentages

609 ^bPhysical activity was defined as the percentage who regularly exercised at least 20 min 3 times per week.

610 ^cPerceived weight discrimination measured how often participants experienced discrimination due to their weight in
 611 nine situations on a daily basis. For the categorical measure, anyone who reported any weight discrimination
 612 (“often” or “sometimes”) was counted. For the continuous score measure, we summed the number of instances a
 613 person reported discrimination “sometimes” (assigned as 1 point) or “often” (assigned as 2 points). Individuals who
 614 reported discrimination “never” or “rarely” received a score of 0. Baseline values were carried forward for
 615 individuals who reported weight discrimination at baseline, but had missing data at follow-up.

616 ^dHigh allostatic load was defined as greater than or equal to 3 dysregulated systems and low allostatic load was
 617 defined as less than 3. Allostatic load was measured at follow-up.

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620 **Table 3:** Relative Risk of High Allostatic Load based on Perceived Baseline and Long-Term Weight Discrimination
 621 in the MIDUS Study

	High Allostatic Load ^a			Continuous Allostatic Load ^b			High Allostatic Load (excluding BMI and WHR)		
	RR	95% CI	p-value	β	SE	p-value	RR	95% CI	p-value
Baseline perceived weight discrimination^c									
Age- and sex-adjusted	2.60	1.60, 4.23	0.0001	0.15	0.04	0.0005	1.92	1.14, 3.23	0.01
Multivariable-adjusted Model 1 ^d	2.42	1.44, 4.04	0.0008	0.14	0.04	0.001	1.78	1.02, 3.11	0.04
Multivariable-adjusted Model 2 ^e	2.31	1.38, 3.84	0.001	0.13	0.04	0.002	1.71	0.99, 2.97	0.05
Multivariable-adjusted Model 3 ^f	2.23	1.28, 3.87	0.004	0.13	0.04	0.005	1.61	0.90, 2.87	0.11
Multivariable-adjusted Model 4 ^g	2.07	1.21, 3.55	0.008	0.11	0.04	0.01	1.55	0.87, 2.75	0.13
Long-term perceived weight discrimination^{c,h}									
Age- and sex-adjusted	2.50	1.72, 3.63	<0.0001	0.21	0.04	<0.0001	1.87	1.25, 2.79	0.002
Multivariable-adjusted Model 1 ^d	2.47	1.65, 3.69	<0.0001	0.21	0.04	<0.0001	1.79	1.15, 2.78	0.01
Multivariable-adjusted Model 2 ^e	2.37	1.58, 3.56	<0.0001	0.20	0.04	<0.0001	1.73	1.11, 2.69	0.02
Multivariable-adjusted Model 3 ^f	2.27	1.45, 3.56	0.0003	0.21	0.05	<0.0001	1.66	1.03, 2.69	0.04
Multivariable-adjusted Model 4 ^g	2.16	1.39, 3.36	0.0007	0.19	0.05	0.0001	1.62	1.01, 2.62	0.047

622 ^aHigh allostatic load was defined as greater than or equal to 3 dysregulated systems, and low allostatic load was defined as less
 623 than 3. Allostatic load was measured at follow-up, and medication usage was included in the definition.

624 ^bFamily status was added to the continuous models as a random effect.

625 ^cOnly individuals who reported discrimination “sometimes” or “often” were coded as having experienced discrimination.

626 ^dModel 1 includes age, sex, race (white, black, other), household income (>\$100,000/year), smoking status (never, former,
 627 current), educational attainment (< high school, high school graduate, some college, college graduate or more)

628 ^eModel 2 includes covariates in Model 1 plus engagement in regular exercise at least 20 min 3 times per week

629 ^fModel 3 includes covariates in Models 1-2 plus perceived race, sex, and age discrimination at baseline

630 ^gModel 4 includes covariates in Models 1-3 plus baseline BMI

631 ^hLong-term weight discrimination was computed as the average value of perceived discrimination at baseline and at 10-year
 632 follow-up for those who had both measures. For individuals with no baseline measure, but with a measure at 10-years, long-term
 633 discrimination was computed as their reported discrimination at 10-years.

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635 **Table 4:** Relative Risk of High Allostatic Load System Parameters based on Perceived Long-Term Weight
 636 Discrimination in the MIDUS Study^a

	Percent with dysregulated system	RR	95% CI	p-value
Cardiovascular	38.6			
Age and sex-adjusted		1.37	1.03, 1.81	0.03
Model 1 ^b		1.26	0.92, 1.72	0.15
Model 2 ^c		1.20	0.89, 1.65	0.23
Model 3 ^d		1.24	0.89, 1.72	0.20
Model 4 ^e		1.23	0.89, 1.72	0.21
Metabolic	18.3			
Age and sex-adjusted		2.07	1.49, 2.88	<0.0001
Model 1 ^b		2.07	1.45, 2.97	<0.0001
Model 2 ^c		1.96	1.35, 2.82	0.0003
Model 3 ^d		1.66	1.07, 2.57	0.02
Model 4 ^e		1.56	1.02, 2.40	0.04
Glucose Metabolism	23.5			
Age and sex-adjusted		2.29	1.62, 3.24	<0.0001
Model 1 ^b		2.29	1.43, 3.67	0.0006
Model 2 ^c		2.26	1.59, 3.22	<0.0001
Model 3 ^d		2.10	1.40, 3.15	0.0003
Model 4 ^e		1.99	1.34, 2.95	0.0006
Inflammation	26.6			
Age and sex-adjusted		1.89	1.37, 2.61	<0.0001
Model 1 ^b		1.99	1.44, 2.76	<0.0001
Model 2 ^c		1.91	1.37, 2.67	0.0001
Model 3 ^d		1.83	1.27, 2.64	0.001
Model 4 ^e		1.76	1.22, 2.54	0.003
Sympathetic Nervous System^f	12.4			
Age and sex-adjusted		1.27	0.70, 2.32	0.43
Model 1 ^b		1.26	0.67, 2.35	0.47
Model 2 ^c		1.24	0.66, 2.32	0.50

	Model 3 ^d	1.31	0.64, 2.68	0.46
	Model 4 ^e	1.44	0.70, 2.96	0.32
Hypothalamic Pituitary Axis	43.6			
	Age and sex-adjusted	0.94	0.71, 1.24	0.66
	Model 1 ^b	0.96	0.71, 1.28	0.77
	Model 2 ^c	0.97	0.72, 1.30	0.84
	Model 3 ^d	0.94	0.69, 1.30	0.72
	Model 4 ^e	0.95	0.69, 1.31	0.77
Parasympathetic Nervous System^f	19.6			
	Age and sex-adjusted	1.42	0.90, 2.23	0.13
	Model 1 ^b	1.42	0.86, 2.33	0.17
	Model 2 ^c	1.38	0.83, 2.29	0.21
	Model 3 ^d	1.28	0.75, 2.21	0.36
	Model 4 ^e	1.29	0.75, 2.21	0.37

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^aLong-term perceived weight discrimination represents the average value of perceived discrimination at baseline and at follow-up for those who had both measures. For individuals with only one measure, long-term discrimination represents their reported discrimination at that time point

^bModel 1 includes age, sex, race (white, black, other), household income (>\$100,000/year), smoking status (never, former, current), educational attainment (< high school, high school graduate, some college, college graduate or more)

^cModel 2 includes covariates in Model 1 plus engagement in regular exercise at least 20 min 3 times per week

^dModel 3 includes covariates in Models 1-2 plus perceived race, sex, and age discrimination at baseline

^eModel 4 includes covariates in Models 1-3 plus baseline BMI

^fMedication usage was not considered in the diagnosis of **Parasympathetic Nervous System** or **Sympathetic Nervous System** dysregulation.