Demographic and sociocultural risk factors for adulthood weight gain in Hispanic/Latinos: results from the Hispanic Community Health Study / Study of Latinos (HCHS/SOL)

Lindsay Fernández-Rhodes1,2*, Nicole M. Butera3, Evans K. Lodge4,5, Nora Franceschini6, Maria M. Llabre6, Elva M. Arredondo7, Linda C. Gallo7, William Arguelles6,8, Frank J. Penedo6, Martha L. Davillius9, Carmen R. Isasi10, Paul Smokowski11,12, Penny Gordon-Larsen2,13, Allison E. Aiello2,4, Krista M. Perreira2,5, Daniela Sotres-Alvarez3 and Kari E. North4,14

Abstract

Background: United States (US) Hispanic/Latinos experience a disproportionate burden of obesity, which may in part be related to demographic or sociocultural factors, including acculturation to an US diet or inactive lifestyle. Therefore, we sought to describe the association between adulthood weight histories and demographic and sociocultural factors in a large diverse community-based cohort of US Hispanic/Latinos.

Methods: We estimated the effect of several factors on weight gain across adulthood, using multivariable linear mixed models to leverage 38,759 self-reported current body weights and weight histories recalled for 21, 45 and 65 years of age, from 15,203 adults at least 21 years of age at the baseline visit of the Hispanic Community Health Study/Study of Latinos (2008–2011).

Results: The average rate of weight gain was nearly 10 kg per decade in early adulthood, but slowed to < 5 kg a decade among individuals 60+ years of age. Birth cohort, gender, nativity or age at immigration, Hispanic/Latino background, and study site each significantly modified the form of the predicted adulthood weight trajectory. Among immigrants, weight gain during the 5 years post-migration was on average 0.88 kg (95% CI: 0.04, 1.72) greater than the weight gain during the 5 years prior. The rate of weight gain appeared to slow after 15 years post-migration.
Conclusions: Using self-reported and weight history data in a diverse sample of US Hispanic/Latinos, we revealed that both demographic and sociocultural factors were associated with the patterning of adulthood weight gain in this sample. Given the steep rate of weight gain in this population and the fact that many Hispanic/Latinos living in the US immigrated as adults, efforts to promote weight maintenance across the life course, including after immigration, should be a top priority for promoting Hispanic/Latino health and addressing US health disparities more broadly.

Keywords: Hispanic Americans, Latino health, Weight gain, Adults, Emigration and immigration

Background
Although obesity has been a problem in many Westernized countries like the United States (US) since the 1980s, many low to middle income countries like Mexico and other Latin American nations now rival or lead the US in adult or childhood obesity prevalence [1,2]. Moreover, studies in the US have shown that racial and ethnic minority populations like Hispanic/Latinos are disproportionally affected by obesity [3]. In 2014 43% of US Hispanic/Latino adults were living with obesity compared to 37% of their non-Hispanic/Latino White peers [4], albeit with variability in obesity across Hispanic/Latino backgrounds (or heritages) [5]. Although limited prospective data exist on the etiology of weight gain in this understudied population, it is thought that such within group differences may reflect differential exposures to either demographic or sociocultural risk factors (e.g. nativity, age at immigration, acculturative stress, etc.) for weight gain, or differential experiences with obesity-related health conditions later in adulthood [6–8].

Independent of childhood or young adult body mass, adulthood weight gain is a risk factor for all-cause morbidity and mortality later in life [9–11], and is more likely to lead to the deposition of extra weight in the abdomen where fat is most metabolically detrimental [12]. The most common long-term health risks of obesity include cardiovascular-related death, cardiometabolic diseases and several cancers [2, 13]. Hispanic/Latino morbidity and mortality represents an ever-growing share of US deaths and disability-adjusted life-years annually [2]. Therefore, weight maintenance for Hispanic/Latino adults or other US immigrant groups is a key target for public health interventions to combat the obesity epidemic and to mitigate worsening cardiovascular risk factors in this population [14, 15].

Roughly half of Hispanic/Latino adults are born outside of the US and its territories, first arriving to one of the 50 US states or the District of Columbia (DC) as adults, at which point many then go on to begin families in the US [16,17]. As of 2016, Hispanics/Latinos comprised more than 17.6% of the US population [18]. The importance of studying the health of this diverse and growing US minority group is further emphasized by the fact that between 2016 and 2017, Hispanics/Latinos contributed more than half of the total growth in the US population [19].

In light of the changing nature of US demographic trends [16] and the obesity epidemic in the Western Hemisphere [20], self-reported weight histories such as those collected in Hispanic Community Health Study/Study of Latinos (HCHS/SOL) may offer insights into the origins of, and potential intervention targets for, healthy weight promotion. Herein, we aimed to first summarize the key demographic (e.g. birth cohort, gender, city of residence) and sociocultural characteristics (e.g. Hispanic/Latino background, nativity, age at immigration) associated with adulthood body weight trajectories using baseline data from the diverse, community-based HCHS/SOL (2008–2011). In a second aim, among adult immigrants to the US, we assessed the impact that timing of immigration had on their adulthood weight trajectories, and how this timing of immigration interacted with the same demographic and sociocultural variables considered in the first aim.

Methods
Study population
The HCHS/SOL is a community-based cohort of 16,415 adults (18–76 years at baseline examination, 2008–2011) of diverse self-identified Hispanic/Latino backgrounds (Central or South American, Cuban, Dominican, Mexican, Puerto Rican, Other/Multiple) who were living in one of four US urban communities between 2008 and 2011 (Bronx, NY; Chicago, IL; Miami, FL; San Diego, CA, USA) [21, 22]. Based on a participant’s preference, centrally trained bilingual study personnel conducted screening and baseline questionnaires and examinations in either English or Spanish. Women who were pregnant during screening were rescheduled for their baseline examination approximately 3 months after delivery. Manuals of procedures and all administered baseline questions and forms can be found here: https://sites.csc.canci.edu/hchs/manuals-forms.

Study design and inclusion criteria
All analyses were restricted to participants > 21 years at the baseline examination (excluded n = 1013), and those
with no missing demographic or sociocultural covariates (excluded \( n = 106 \)). The resulting complete case analysis yielded a sample size of 15,203 individuals and a total of 38,759 reported weights (from either current age or the weight history). The number of possible observations in the weight history questionnaire was a function of an individual’s current age. For example, individuals < 45 years of age would be able to report a 21 year old and current body weight. Individuals, 45 years of age or older would be able to report up to two (at 21 and 45 years) or three body weights (at 21, 45, and currently). Lastly, individuals aged 65 years or older would be able to report up to three body weights (at 21, 45, 65 years) or four (21, 45, 65 years and currently). In sum, roughly 5 % of the sample reported a weight for one age, 41% reported for two ages, 48% reported for three ages, and 6% reported for four ages. Among the 813 individuals contributing only one body weight, only 84 (10.3%) did not provide a self-reported current weight from the anthropometry questionnaire (i.e. this single weight came from the weight history questionnaire for 21, 45, or 65 years of age).

Separately to address aim 2, we restricted to the sub-population of 8830 immigrants who came to the US first at \( > 21 \) years of age and their 23,518 self-reported weights (with an average of 13.5 years pre-immigration and 15.3 years post-immigration time; and a maximum of 52 years pre-immigration and 52 years post-immigration time). In this sub-sample, roughly 5% reported a weight for one time-point, 32% reported for two time-points, 55% reported a weight for three time-points, and 8% reported a weight for four time-points.

**Self-reported body weights and quality control**

As part of the anthropometric questionnaire, all participants (18–76 years) were asked to self-report their current body weight to the nearest lb. or kg, prior to a standardized measurement of body weight [22]. In addition, participants who were at least 21 years old were asked to complete a weight history questionnaire to provide ‘best guesses’ of their non-pregnant body weights (in whole lb. or kg.) for 21, 45, and 65 years of age.

Numerous previous studies have examined both the validity of self-reported weight [23–26] and weight histories [27–36] in various observational and clinical contexts, but most of these analyses have been conducted on smaller samples. Remarkably few studies have included US Hispanic/Latinos [29, 33, 35, 36]. Therefore, below we also discuss HCHS/SOL assessments of reliability and validity.

First, our previous work in HCHS/SOL has demonstrated good reliability in the current self-reported weights from the anthropometry questionnaire (mean difference between original and replicate = 0.46 kg; Coefficients of variation, CV = 6.3%; \( n = 560 \) participants during same visit) [37]. In addition, we have found good repeatability of the weight reported from the weight history questionnaire (mean difference = −1.34 to 0.23 kg; CVs = 3.7 to 7.7%; \( n \leq 52 \) participants a median of 40 days later) [38], similar to a separate work on the reproducibility of recalled body weight [39]. For purposes of informing the reliability of the self-reported weight history reports made during the same examination, and by participants of varying ages, we also examined the subset of 579 HCHS/SOL participants who were aged exactly 21, 45 or 65 years and who completed both the weight history and anthropometry questionnaires (Supplemental Fig. 1). Self-reported (current) weights from the weight history questionnaire were on average \( \leq 0.54 \) kg less than the anthropometric questionnaire for the same age, and the reliability between these reported weights was generally good (intra-class correlation coefficient \( \geq 0.86 \)). Nonetheless the mean differences between self-reported current weights were lowest for individuals at 21 years, followed by 45 years of age, suggesting that self-reports may be least reliable for older adults (e.g. 65 years of age) due to aging or other processes.

Second, we have previously described the accuracy of self-reported current weights relative to measured weight (self-reported versus measured mean difference of 0.23 kg, standard deviation of 4.29); only 4.8% of the observed differences were more extreme than the Bland Altman 95% Limits of Agreement (−8.18, 8.64 kg) [37]. In fact, 89.3 and 80.2% of the differences were within 5.5 kg of the mean (i.e. a 80% Limit of Agreement: −5.27, 5.73 kg) or within 5% of the measured weight, respectively. These observations were more accurate (based on any available difference-based metrics) than numerous previous reports on primarily non-Hispanic/Latino samples of smaller size [30–34]. This previous study identified a number of factors associated with mis-reporting of current weight including: age group, gender, body mass index categories, nativity (defined as 50 US states or DC, or elsewhere), a cross-classification between site and background, unit (lb or kg) as well as end digit preference (e.g. 0 s or 5 s, vs. 1–4, 6–9) of self-reported weight. Many of these same factors were of interest as potential correlates of adulthood weight change, and thus were included either as covariates or as effect measure modifiers (e.g. gender, nativity, background by site) in the current study’s statistical analyses. Among the 16,415 HCHS/SOL participants, 16,355 provided at least one self-reported weight. We have previously applied a staged-data quality control protocol that filtered on biologic plausibility, the magnitude of reported weight fluctuations, and body mass index (BMI) of 16–70 kg/m²; and excluded reports occurring during pregnancy or made by individuals with a limb
amputation [38]. This protocol has yielded a quality-controlled dataset of 39,984 self-reported weights from 16,322 HCHS/SOL individuals for this current study. Lastly, we rounded all weights to the whole kg. to minimize the impact of measurement error [37] based on the unit of self-report (lb. or kg).

**Statistical analyses**

In aim 1, we sought to use all of the available self-reported weight data to model weight trajectories across age using a linear mixed model to describe their interactions with demographic and sociocultural characteristics. The effects for the final linear mixed model for aim 1 (Model 1) are listed in Supplemental Table 1. Weight trajectories were modeled as quadratic in terms of the age for which the weight was reported (‘report age’). In addition, the following covariates were included in the models: age at baseline examination (to account for the amount of elapsed time between the recall and the participant’s current age), birth cohort (before 1980, or 1980 or after; to account for the temporal trends in obesity prevalence), self-identified gender, study site, Hispanic/Latino background, and a cross-classification of nativity (US 50 states/DC, or elsewhere) and age at immigration (first reported arrival to US at 0–11, 12–21, 22–34, 35–44, 45–54, 55–64, 65+ years, with the final categories determined by the availability of data in each model). Based on this coding, individuals born in Puerto Rico were considered to be ‘foreign-born’ and were categorized by the age at which they first moved to one of the 50 US states or DC. Based on previous work in HCHS/SOL [37], we also included an indicator of the self-reported weight end digit preference for zeros and fives as a covariate in the model to minimize the potential for measurement error in the reporting of body weights. The weight trajectory model allowed random intercepts for primary sampling unit, household, and the individual, and a random individual-specific linear slope for report age.

Weight trajectories across age were allowed to differ by birth cohort, gender, place of nativity/age at immigration, Hispanic/Latino background, and study site by including interaction terms with linear and quadratic age terms. We did a joint test for the interactions between the linear and the quadratic terms with report age using a Wald test in the Stata test command at an alpha of 0.05. Study site and Hispanic/Latino background were highly collinear in HCHS/SOL, and so study site was found to be interrelated with the association of Hispanic/Latino background with body weight trajectories. Therefore, a variable representing the cross-classification of study site and Hispanic/Latino background (‘background-by-study site’) was constructed and included in all models, where all combinations of Hispanic/Latino background and study site with inadequate sample size (n < 100) were pooled into an “other” category. As shown in Table 1, this cross-classification resulted in 13 categories representing a distinct combination of background and study site. To assess whether weight trajectories differed by background, the following nested testing procedure was used. First, we did an overall test for the interaction of linear and quadratic terms for report age with the 13 non-pooled categories of the background-by-study site variable at the 0.05 significance level. If the overall test was statistically significant, then within each study site we further tested the interaction of the linear and quadratic report-age terms with all backgrounds, using a Bonferroni correction for multiple comparisons.

In aim 2, we intended to leverage the large adult immigrant subpopulation of HCHS/SOL to describe the weight trajectories across time since immigration and their interactions with demographic and sociocultural characteristics. As shown in Supplemental Table 2, Model 2 contrasted weight trajectories pre/post immigration that were quadratic in terms of time since immigration for each reported weight, and included covariates for age at examination, immigration cohort (before 1980, or 1980 or after; to account for the temporal trends in obesity prevalence upon arrival to US), age at immigration, gender, Hispanic/Latino background, study site, and end digit preference for zeros and fives. This model allowed random intercepts for primary sampling unit, household, and the individual, and a random individual-specific slope for time since immigration. Again, weight trajectories across time since immigration were allowed to differ by immigration cohort, gender, age at immigration, and Hispanic/Latino background by study site. The pre-immigration trajectory was allowed to differ from the post-immigration trajectory, and this difference in the shape of the pre-immigration and post-immigration trajectories was tested at an alpha of 0.05. Specifically, we included (1) two-way interaction terms between time since immigration (linear and quadratic terms) and the demographic and sociocultural characteristics mentioned above, and (2) three-way interaction terms between time since immigration (linear and quadratic terms), demographic and sociocultural characteristics, and pre/post immigration. Similar to above, the weighted mean height for the adult immigrant subpopulation, or their corresponding stratum-specific weighted mean heights, were used to calculate the weight and time point at which an average height individual would first be at a body mass index \(\geq 30 \text{kg/m}^2\) and was signified with triangles in the figures.

Lastly as part of a sensitivity analysis, we conducted the same modeling as described above for Models 1 and 2, but restricted our analytic sample to the
Table 1 Descriptive Characteristics\(^a\) of the Target Population of HCHS/SOL, for the Entire Analytic Sample and the Adult Immigrant Subpopulation\(^b\)

| Characteristic\(^c\) | Overall (Unweighted n = 15,203) | Adult Immigrant Subpopulation\(^b\) (Unweighted n = 8830) | P-Value\(^c\) |
|----------------------|-------------------------------|---------------------------------|---------------|
| Male (%): Unweighted N | 6024 | 47.5 (46.4, 48.6) | 3302 | 45.3 (43.9, 46.8) | 0.0001 |
| Age (%): Overall | [57x685]22–29 years | 1628 | 18.4 (17.2, 19.6) | 212 | 4.8 (4.1, 5.6) | <0.0001 |
| | 30–39 years | 2360 | 23.6 (22.2, 24.9) | 1155 | 21.1 (19.5, 22.7) | <0.0001 |
| | 40–49 years | 4176 | 24.5 (23.5, 25.5) | 2571 | 28.5 (27.0, 29.9) | <0.0001 |
| | 50–59 years | 4286 | 18.0 (17.1, 18.9) | 2834 | 22.7 (21.4, 23.9) | <0.0001 |
| | 60–69 years | 2254 | 11.9 (11.1, 12.7) | 1660 | 17.1 (15.9, 18.4) | <0.0001 |
| | 70–76 years | 499 | 3.6 (3.1, 4.1) | 398 | 5.7 (4.9, 6.6) | <0.0001 |
| Study Site (%) Bronx: Unweighted N | 3729 | 28.4 (25.5, 31.5) | 1662 | 20.7 (17.8, 24.0) | <0.0001 |
| | Chicago: Unweighted N | 3876 | 15.8 (13.9, 17.8) | 2076 | 12.7 (10.9, 14.8) | <0.0001 |
| | Miami: Unweighted N | 3872 | 30.8 (26.6, 35.2) | 3141 | 44.8 (39.3, 50.3) | <0.0001 |
| | San Diego: Unweighted N | 3726 | 25.0 (21.8, 28.7) | 1951 | 21.8 (18.1, 26.0) | <0.0001 |
| Background (%): Central American: Unweighted N | 1639 | 7.6 (6.6, 8.8) | 1211 | 9.3 (8.0, 10.8) | <0.0001 |
| | Cuban: Unweighted N | 2243 | 21.1 (17.9, 24.7) | 1865 | 32.1 (27.4, 37.1) | <0.0001 |
| | Dominican: Unweighted N | 1332 | 9.5 (8.2, 10.9) | 910 | 10.2 (8.7, 12.0) | <0.0001 |
| | Mexican: Unweighted N | 5996 | 36.6 (33.4, 39.9) | 3291 | 32.7 (28.7, 36.9) | <0.0001 |
| | Puerto Rican: Unweighted N | 2554 | 16.3 (14.8, 18.0) | 596 | 6.5 (5.5, 7.6) | <0.0001 |
| | South American: Unweighted N | 1017 | 5.1 (4.5, 5.8) | 809 | 7.3 (6.4, 8.3) | <0.0001 |
| | Other/Multiple: Unweighted N | 422 | 3.8 (3.2, 4.4) | 148 | 2.0 (1.6, 2.5) | <0.0001 |
| Background (% within Site): Bronx Dominican: Unweighted N | 1245 | 31.4 (28.2, 34.7) | 847 | 46.0 (41.4, 50.6) | <0.0001 |
| | Central American: Unweighted N | 198 | 5.1 (4.0, 6.3) | 127 | 6.8 (5.2, 8.8) | <0.0001 |
| | Mexican: Unweighted N | 191 | 10.9 (8.5, 14.0) | 115 | 14.7 (11.0, 19.5) | <0.0001 |
| | Puerto Rican: Unweighted N | 1714 | 41.7 (38.4, 45.2) | 381 | 20.8 (17.7, 24.2) | <0.0001 |
| | South American: Unweighted N | 180 | 4.7 (3.7, 5.9) | 123 | 7.8 (6.1, 10.0) | <0.0001 |
| | Chicago Central American: Unweighted N | 406 | 7.1 (5.8, 8.6) | 286 | 9.9 (7.8, 12.4) | <0.0001 |
| | Mexican: Unweighted N | 2264 | 61.9 (58.5, 65.1) | 1304 | 68.7 (64.7, 72.4) | <0.0001 |
| | Puerto Rican: Unweighted N | 726 | 21.0 (17.8, 24.5) | 160 | 8.0 (6.1, 10.5) | <0.0001 |
| | South American: Unweighted N | 351 | 6.3 (5.0, 7.8) | 267 | 9.7 (7.8, 12.1) | <0.0001 |
| | Miami Central American: Unweighted N | 981 | 15.6 (12.8, 19.0) | 764 | 14.2 (11.5, 17.4) | <0.0001 |
| | Cuban: Unweighted N | 2171 | 67.0 (62.3, 71.3) | 1824 | 70.7 (66.1, 74.9) | <0.0001 |
| | South American: Unweighted N | 445 | 8.3 (6.9, 10.1) | 387 | 9.1 (7.3, 11.1) | <0.0001 |
| | San Diego Mexican: Unweighted N | 3506 | 93.2 (91.2, 94.8) | 1848 | 93.5 (90.8, 95.4) | <0.0001 |
| | Born in/after 1980 (%): Unweighted N | 1768 | 20.0 (18.8, 21.2) | 254 | 5.6 (4.9, 6.5) | <0.0001 |
| | Age at baseline exam (years): Unweighted N | 15,203 | 43.6 (43.2, 44.1) | 8830 | 48.8 (48.3, 49.3) | <0.0001 |
| | Nativity/age at immigration category (%): US-born | 2255 | 18.8 (17.4, 20.2) | – | – | – |
| | 0–11 yrs: Unweighted N | 1118 | 8.7 (7.9, 9.6) | – | – | – |
| | 12–21 yrs: Unweighted N | 3000 | 20.0 (18.7, 21.3) | – | – | – |
| | 22–34 yrs: Unweighted N | 4687 | 29.3 (28.2, 30.5) | 4687 | 55.9 (53.8, 57.9) | <0.0001 |
| | 35–44 yrs: Unweighted N | 2313 | 12.4 (11.5, 13.5) | 2313 | 23.7 (22.3, 25.1) | <0.0001 |
| | 45–74 yrs: Unweighted N | 1830 | 10.7 (9.7, 11.9) | 1830 | 20.4 (18.9, 22.0) | <0.0001 |
| | Age at immigration (years): Unweighted N | 12,948 | 22.6 (21.8, 23.4) | 8830 | 35.5 (35.0, 36.0) | <0.0001 |
subpopulation of HCHS/SOL who reported weights consistent with having a BMI < 30 kg/m² at 21 years of age. Given that we had already considered an individual’s 21 year old weight in the creation of this subpopulation, we only analyzed (Model 1 subsample: n = 13,125; Model 2 subsample: n = 7763) and estimated weight trajectories for those who reported at least one other weight between 22 and 74 years of age.

All linear mixed models accounted for the complex sampling design by including random intercepts for primary sampling units, household, and individual, and applying sampling weights to the level of the model corresponding to the individual. All linear mixed models were estimated using the mixed command in Stata 14 using an independent correlation matrix for all random effects and independent residuals (StataCorp LP, College Station, TX, USA). Trajectories were plotted based on the covariate distribution of the analytic sample, unless otherwise noted in the footnote of each main and supplemental figure. Therefore, within a given panel the plotted differences in trajectories should due to the specific demographic or sociocultural strata that are being plotted. The overall weighted mean height in our HCHS/SOL analytic sample, or in the case of trajectories by demographic/sociocultural characteristics the stratum-specific weighted mean heights, were used to calculate the weight and age at which an average height individual would first be at a body mass index ≥30 kg/m². Triangles were placed on the resulting figures to indicate this transition point(s).

Results
Table 1 describes the characteristics among all adults, as well as the immigrant subpopulation who first arrived to the 50 US states/DC at > 21 years of age (n = 8830). Differences were seen between the adult immigrant subpopulation versus all others across characteristics (p ≤ 0.009). For example, the adult subpopulation appeared to have more females and be older than the overall population. Weighted frequencies and means revealed that the target population of HCHS/SOL was mainly Mexican American, followed by Cuban and Puerto Rican. As compared to the overall population, the adult immigrant subpopulation included proportionally more Cubans and less Puerto Ricans. The majority of the overall population, and adult immigrant subpopulation, was born before 1980, and first immigrated to the US in 1980 or after—most often between the ages of 22–34 years. In the entire target population, this was 21 years prior to the baseline examination on average, and among the adult immigrant sub-population this was 13 years prior to baseline. Lastly, the amount of time that participants were asked to recall back varied as a function of their own age at baseline and the requested age of report, and was greatest on average for 21-year-old reports (weighted mean of 22.6 years past) and least for 65-year-old reports (3.7 years). Nonetheless, the majority of the self-reported weight data (57.9%, unweighted frequency) was reported within 10 years of the participant’s current age.

The weight trajectory analysis suggested that independent of covariates (see model coefficients and example calculation in Supplemental Table 3), adults in this cohort gained weight at an average rate of 9.5 kg per decade (95% CI: 6.8, 12.3; Table 2) between 22 to 29 years of age, but this rate appeared to slow across time (Fig. 1A). The average rate of weight gain between 30 and 39 years of age was nearly 8.5 kg per decade (95% CI:...
average age at the time of the HCHS/SOL baseline exami-
nation, this turning point was expected to occur even
earlier—in their 30s. Whereas for those 45 years of age
or older at baseline, this was expected to happen in their
50s. Among the adult immigrants, the apparent slowing
of weight gain ~ 15 years post-migration also appeared
around the same time when an average adult immigrant
would have been expected to develop obesity (Supple-
mental Table 5; Fig. 1B).

Adjusted weight trajectories in adulthood varied across
a number of demographic and sociocultural risk factors
(Fig. 2A–E). For example as shown in Fig. 2A, individuals
born in or after 1980 appeared to have a greater average
weight gain in their 20s compared to individuals born
before 1980. This cohort difference represents an esti-
mated 5.7 ± 1.13 kg of extra body weight by the age of
30 years. Further, in Fig. 2B, we observe a greater post-
immigration trajectory of average weight gain and earlier
estimated time at which these adult immigrants on aver-
age are expected to develop obesity (i.e. by 21 years post
immigration versus 27 years for those who came to the
US before 1980).

As shown in Fig. 2C–D, gender shifted the estimated
intercept (i.e. at 21 years of age) for men upwards by ap-
proximately 12.6 kg (SE: 0.33) as compared to women in
Fig. 2C and 11.6 kg (SE: 0.47) in Fig. 2D. The form of
the trajectories across age and time since immigration
varied less dramatically. When taking the weighted aver-
age height differences between the genders into account,
females were predicted to acquire obesity before their
male counterparts; however, this was more dramatic for
estimated trajectories across time since immigration
than for age, which indicates that female adult immi-
grants to the US may experience greater immigration-
related weight gain than men on average (Fig. 2D).

Nativity and age at immigration were also associated
with age and immigration-related weight trajectories
(Fig. 2E–F). For example as shown in Fig. 2E, being ei-
ther born in the US or brought to the US as a child (0–
11 years), during adolescence, or young adulthood (12–
21 years) resulted in greater age-related weight gain and
an earlier average age of obesity onset—between 34 and
38 years of age. Fig. 2E shows that the intercept of the
estimated weight trajectories for most adult immigrant
groups were shifted downwards, and this, in part, re-
sulted in an older average age of obesity onset, in their
40s instead of their 30s. Fig. 2F shows a similar trend
through the perspective of time since immigration; a
similar dose-response pattern appeared wherein immi-
grants, who arrived to the US in early or mid-adulthood
(22–44 years), arrived prior to developing obesity. Yet,
their this potential advantage appeared to erode with

Cl: 6.2, 10.7), and continued to slow to 7.3 kg per decade
(95% CI: 5.0, 9.6) by mid-adulthood (i.e. 40s), and to 5.0
kg per decade (95% CI: 2.6, 7.3) by 60 to 69 years of age
(Table 2).

Figure 1B shows the weight trajectory among the 8830
adult immigrants by time since first migration to the US.
As described above, we allowed the shape of the weight
trajectory to differ before and after immigration by in-
cluding interactions for the linear and quadratic terms
for time since immigration with an indicator for post-
immigration. We tested whether the shape of the trajec-
tory differed during the pre/post-immigration periods
(i.e. before and after the zero in the x-axis, see Supple-
mental Table 4 for an example). After accounting for co-
variates, there was an average weight gain of 3.5 kg in
the five years before immigration, in contrast to 4.4 kg in
the five years after immigration, resulting in an increase
of 0.88 kg (95% CI: 0.04, 1.72) weight gain across this
combined 10 year period. Yet, the rate of weight gain ap-
ppeared to begin to slow after 15 years post-migration
(Fig. 1B). This slowing post-immigration weight trajec-
tory resulted in an apparent leveling off of weight gain
between 15 and 40 years post immigration.

Based on the weighted mean height per subgroup, we
estimated the age at which individuals from the HCHS/
SOL communities/subgroups would begin living with
obesity and the estimates are overlaid on Figs. 1, 2, 3
and provided in Supplemental Table 5. Although this
transition occurred for the overall trajectory between 38
and 39 years of age, for those adults who were < 45 years
of age at the time of the HCHS/SOL baseline exami-
nation, this turning point was expected to occur even
earlier—in their 30s. Whereas for those 45 years of age
or older at baseline, this was expected to happen in their
50s. Among the adult immigrants, the apparent slowing
of weight gain ~ 15 years post-migration also appeared
around the same time when an average adult immigrant
would have been expected to develop obesity (Supple-
mental Table 5; Fig. 1B).

### Table.2 Average Weight Gain per Age Range and 95% Confidence Intervals (CIs) Based on Mixed Effects Modeling

| Age Range   | Average Weight Gain Per Age Range | Lower 95% CI Limit | Upper 95% CI Limit |
|-------------|-----------------------------------|--------------------|--------------------|
| 22–29 years | 9.52634                           | 6.76798            | 12.2847            |
| 30–39 years | 8.47104                           | 6.24663            | 10.6955            |
| 40–49 years | 7.29849                           | 5.04409            | 9.5529             |
| 50–59 years | 6.12593                           | 3.83046            | 8.4214             |
| 60–69 years | 4.95338                           | 2.60634            | 7.3004             |
| 70–76 years | 4.01533                           | 0.16987            | 7.8608             |

*Average weight gain per decade of age is calculated as the fitted value from the model for the end of the age range minus the fitted value for the beginning of
the age range, standardized to 10 years (i.e., divided by the length of the age range, and then multiplied by 10 years). The fitted values were adjusted to weighted
age at clinic visit, proportion male, proportion born before 1980, distribution of age at immigration, proportion for each site-background combination, and
proportion preferring 5 s and 10s.
time spent in the US as their weight trajectories converged within 20 years to those of mid-adult immigrants (45–54 years). In contrast, adult immigrants who arrived to the US first in later adulthood, e.g. 55 years or older, on average were living with obesity prior to immigration, which may reflect age-related trends in obesity in Latin America or other correlates of an individual immigrating in late adulthood to the US (e.g. family reunification, accumulated wealth, retirement/employment status, and health status, etc.).

Trajectories of weight gain in adulthood differed by both HCHS/SOL study site and self-identified Hispanic/Latino background (Fig. 3A-H). Because study site was found to be related to Hispanic/Latino background and body weight trajectories, our weight trajectories are presented for each background within each study site. The test for differences in the weight trajectories by background was not significant within the Chicago study site, this slowing of weight gain in late adulthood may in part be related to the duration of obesity and its cardiometabolic sequelae, or survival biases.

Our time since immigration analysis (Fig. 3E-H) showed that most background and study site groups being living with obesity 10–20 years after immigration and that this onset was earliest for Puerto Ricans living in the Bronx and Central Americans living in Miami, and latest for South Americans living in both locations (Fig. 3E and G). The estimated pre/post immigration trajectory for the Mexicans living in the Bronx was statistically different compared to all other background groups at the same site, this slowing of weight gain in late adulthood may in part be related to the duration of obesity and its cardiometabolic sequelae, or survival biases.
Lastly as a sensitivity analysis, we plotted the population-level trajectories between 22 and 74 years of age within the subgroup of HCHS/SOL (n = 13,125; 59% whom were adult immigrants) who reported body weights consistent with having a BMI < 30 kg/m² at 21 years of age. Although Fig. 1A-B and Supplemental Figs. 2A-B are not directly comparable, we observed substantively similar population-level trends in weight gain (Supplemental Fig. 2A-B). We noted that even though the non-obese subgroup started at a lower weight in early adulthood, they continued to gain weight throughout adulthood, ending up at a similar estimated weight by 70 years of age (~ 100 kg), as what was seen in Fig. 1A-B for the overall sample. This sensitivity analysis
A. Predicted Weight Trajectory by Age- The Bronx, NY

B. Predicted Weight Trajectory by Age- Chicago, IL

C. Predicted Weight Trajectory by Age- Miami, FL

D. Predicted Weight Trajectory by Age- San Diego, CA

E. Predicted Weight Trajectory by Time- The Bronx, NY

F. Predicted Weight Trajectory by Time- Chicago, IL

G. Predicted Weight Trajectory by Time- Miami, FL

H. Predicted Weight Trajectory by Time- San Diego, CA

Fig. 3 (See legend on next page.)
indicated that the relatively small group of individuals who were living with obesity at 21 years of age did not appear to be driving our overall findings.

**Discussion**

Hispanic/Latino adults comprise the largest racial/ethnic minority group in the US [18] and face a higher prevalence of overweight and obesity than their non-Hispanic/Latino peers [4]. Thus, understanding of the correlates and magnitude of adult weight gain in this population is critical. This is particularly challenging for Hispanic/Latino immigrants, who may be difficult to follow using traditional longitudinal studies and who often receive medical care across borders, from non-traditional providers or go periods of time without health services or insurance [5]. Based on the estimated weight trajectories, the average adult, from one of the four communities studied as part of HCHS/SOL, began living with obesity (≥30 kg/m²) before their 40s; however, we observe notable heterogeneity in individual trajectories and timing of obesity onset. Despite the potential for self-report bias, we demonstrate how repeated measures/reports of body weight can help provide insights into the correlates of weight gain, in understudied or marginalized populations, like US Hispanic/Latinos.

Past studies of US Hispanics/Latinos have noted substantial heterogeneity in obesity burden across Hispanic/Latino backgrounds [6]. Others have described the cross-sectional association between obesity prevalence and sociocultural measures, including proxy measures of acculturation—the dynamic process of adaptation to aspects of a new culture and its associated lifestyle and dietary habits [6, 40, 41]. This body of cross-sectional evidence has supported the ‘unhealthy assimilation’ hypothesis that we would expect immigrant body weights to ‘converge’ to levels seen among US-born Hispanics/Latinos with increasing acculturation to obesogenic US lifestyles. Emerging results from repeated cross-sectional and longitudinal investigations of this hypothesis are mixed, however, indicating that obesity-protective exposures in early and middle life of some immigrants persist across the life course and may lead to ‘divergent’ weight trajectories between foreign and US-born adults [40, 42–45].

In this current study of diverse Hispanic/Latino adults, we focused on describing the form of the relationship between body weight and the demographic and sociocultural factors, which we expected would be relatively constant across time. We observed strong evidence for poor weight maintenance across a wide range of adulthood (21–76 years of age), which is supported by documented epidemiologic trends in this population [3, 4]. By leveraging repeated measures of body weight—occurring both prior to and after immigration—we were able to link the timing of one’s first immigration to the US with increases in weight gain. We found that, while HCHS/SOL participants did experience a statistically significant acceleration in weight gain during the first five years post-immigration, albeit modestly by <1 kg. The overall predicted trajectory leveled off and therefore did not support ‘convergence’ with US-born Hispanics/Latinos similar to previous findings [40, 42–45]. Furthermore, post-immigration weight gain was buffered by being male, arriving to the US before 1980, or arriving to the US in mid/late adulthood, when one’s lifestyle may be less permeable to obesogenic environments. Although the overall acceleration of weight gain post-immigration was modest (<1 kg), it may have greater public health significance when considered in conjunction with other obesogenic factors. For example, female adult immigrants developed obesity on ~8 years before their male peers (Fig. 2B), or select backgrounds were estimated to develop obesity 5 or more
years earlier than other backgrounds living in the same community (Fig. 3E-G).

Even though individuals born in 1980 or after were younger at baseline on average, they may have grown up amidst the US obesity epidemic and had greater exposure to obesogenic environments earlier in life. The trajectory of early adulthood weight gain observed for those born in 1980 or after is particularly concerning as it indicates that this group may experience an earlier transition to obesity—estimated on average to occur in their earlier 30s. Although previous scholarship has studied the association between weight trajectories and a number of risk factors [42, 43, 45–48], to our knowledge this is the first work to describe these weight trajectories in such a large and diverse sample of Hispanic/Latinos across such a wide time span in adulthood, and across borders.

Our finding that immigrant women in the HCHS/SOL on average began living with obesity earlier after arriving to the US as compared to their male peers may point to unique stressors and vulnerabilities faced by immigrant women in the US. Differences in expectations regarding work, remittances, childcare, or experiences of immigration-related trauma may underlie this gender disparity. We also uncovered important differences in adult weight trajectories across the HCHS/SOL study sites and the diverse background groups living there. Such individual and community-level differences deserve additional investigation to fully understand how demographic and sociocultural characteristics may interact to exacerbate or mitigate adult weight gain in this diverse US populations.

There are important limitations of this work to discuss. First, given that we rely on repeated measures of self-reported weights, recall bias may shape our data, increasing either as a function of time that is recalled or with less socially desirable weight statuses [33]. We have previously reported good accuracy (validity) of self-reported weights in the HCHS/SOL, and we consider many of these predictors of misreporting in our modeling [37]. Given the relative dearth of studies in Hispanic/Latino or immigrants populations, we are unsure the exact nature of recall bias relates to these same factors, or if this bias scales linearly with time since recall, as suggested previously [33]. Herein, we adjusted for age at examination as a linear indicator of the time between the reported weight and the baseline observations in our linear mixed modeling.

Furthermore, weight change itself may alter one’s ability to accurately recall weight [31, 32, 34], but this differential bias has not been observed consistently in all US-based nationally-representative samples [29, 33] or for recalled body weights within 10 years [30]. We note that the majority of the self-reported weight data in HCHS/SOL was reported within 10 years of the participant’s current age. Although we may not have the data to directly validate our recalled weights during a time when the majority of our Hispanic/Latino adult participants were preparing/immigrating to the US, we would expect that if self-report and recall biases were to be present, it would most likely result in an attenuation of the estimated weight trajectories by encouraging more moderate reporting of extreme weight values. This assumption is supported by previous observations of differential mis-reporting towards more socially desirable norms in validity studies of non-US populations [32, 34]. Nonetheless, we cannot rule out the role of residual measurement error in the body weights used in this current study.

Due to the complex structure of our data collection, the majority of the weight measurements are recalled at 21, 45, or 65 years of age with the rest being self-reported for a participants current age, which could have ranged from 22 to 76 years. Therefore, there are more early- versus late-adulthood weights, and depending on when immigration occurred in adulthood, we may have had an unbalanced number of observations during the pre versus post-immigration periods. We also cannot rule out the role of selection or survival biases in shaping the type of community-dwelling individuals living within the HCHS/SOL communities and thus the weight trajectories described herein. Lastly, overweight and obese low-income Hispanic mothers from Houston, Texas who reported poor health, were more likely to accurately categorize their body mass than their peers of better self-rated health [49]. This current study did not have access to pre-baseline measures (e.g. health care access, diet quality, physical activity, stress, socioeconomic factors), which could drive changes in health behaviors, ethnic identity, acculturative processes, migration-related/psychosocial stressors or residential mobility, in order to further explore their impact on weight trajectories.

Conclusions

In this large community-based study of diverse Hispanic/Latino adults, on average individuals reported weights that correspond to a substantial amount of adulthood weight gain. Participant gender was associated with differences in the estimated weight intercept in early adulthood, and greater average weight gain for women post-migration. Several other socio-demographic factors patterned differences in early to mid-adulthood (e.g. birth and immigration cohort, nativity/age at immigration, study site by Hispanic/Latino background). Despite its limitations, this work represents an important first step towards understanding the risk factors for age and migration-related weight gain in this population,
and may inform windows of intervention for future studies or initiatives to promote health in US Hispanic/Latino communities.

Abbreviations
CI: Confidence Interval; BMI: Body mass index; DC: District of Columbia; HCHS/SOL: Hispanic Community Health Study/Study of Latinos; US: United States

Supplementary Information
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Additional file 1. Supplementary Information.

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Authors’ contributions
LFR and KEN conceived of the aims of this study. LFR cleaned the data under the guidance of NF, PS, PGL, DSA, and KEN. LFR and NMB analyzed and interpreted data under the guidance of DSA. All authors read and approved the final manuscript.

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Availability of data and materials
The Hispanic Community Health Study/Study of Latinos (HCHS/SOL) data used in this manuscript are publicly available following an approved manuscript proposal. The investigators’ website can be found here. http://www.cscc.unc.edu/hchs/

Declarations
Ethics approval and consent to participate
All participants provided informed written consent. The Institutional Review Boards of the study sites (San Diego State University, University of Miami, Albert Einstein College of Medicine, University of Illinois at Chicago) and coordinating center (University of North Carolina-Chapel Hill) each approved the study procedures. All research activities were conducted in accordance with the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
1Department of Biobehavioral Health, College of Health and Human Development, The Pennsylvania State University, University Park, PA, Pennsylvania, USA. 2Carolina Population Center, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 3Collaborative Studies Coordinating Center, Department of Biostatistics, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 4Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 5School of Medicine, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 6University of Miami, Miami, FL, USA. 7Department of Psychology, San Diego State University, CA, San Diego, USA. 8Baptist Health South Florida, Coral Gables, FL, USA. 9Institute for Minority Health Research, University of Illinois at Chicago, Chicago, IL, USA. 10Albert Einstein College of Medicine, Bronx, NY, USA. 11School of Social Work, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 12School of Social Welfare, The University of Kansas, Lawrence, KS, USA. 13Department of Nutrition, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA. 14Carolina Center for Genome Sciences, University of North Carolina at Chapel Hill, NC, Chapel Hill, USA.

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