



# Time trend analysis of osteoporosis prevalence among adults 50 years of age and older in the USA, 2005–2018

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## Abstract

**Summary** Using data from NHANES for years 2005–2018, we examined temporal trends in osteoporosis prevalence and the proportion of undiagnosed osteoporosis in the United States of America. Our results suggested statistically significant increases in osteoporosis prevalence across several demographic groups. These findings carry profound implications for public health, given increased life expectancy and burden of chronic diseases.

**Introduction** This is the first study to assess osteoporosis prevalence trends over time and the proportion of undiagnosed osteoporosis across gender, ethnicity/race, and age groups.

**Methods** Observational time trend analyses were conducted using the 2005–2006, 2007–2008, 2009–2010, 2013–2014, and 2017–2018 National Health and Nutrition Examination Survey (NHANES) datasets, along with a descriptive analysis using the 2017–2018 NHANES dataset to capture the proportion of undiagnosed osteoporosis.

**Results** The findings showed a statistically significant increase in osteoporosis prevalence among women, non-Hispanic Whites, and all age groups (except for individuals 80 years of age and older) during the study period. A subsequent analysis examining individuals by both gender and ethnicity/race demonstrated a statistically significant increase among Other Hispanic men and non-Hispanic White women. Additional descriptive analyses found that 69.12% of individuals with osteoporosis went undiagnosed. Specifically, 86.88% of men and 84.77% of individuals 50–59 years of age with osteoporosis went undiagnosed, representing the two highest groups.

**Discussion and conclusion** The substantial and increasing prevalence among certain groups and sub-groups, along with the lack of diagnostic capture of osteoporosis, highlights existing gaps in public health efforts and care delivery infrastructure. This paper highlights high-risk groups and sub-groups that may benefit most from accelerated initiatives to reduce the burden of illness associated with osteoporosis.

**Keywords** Epidemiology · Osteoporosis · Public health · Social determinants of health · Prevalence

## Introduction

Osteoporosis is a major and growing public health issue. It has been estimated that among individuals 50 years of age and older, 10.2 million have osteoporosis, while another 43.4 million have low bone mass [1]. In a March 2021 data brief, the Centers for Disease Control and Prevention's National Center for Health Statistics in the United States of America (U.S.) found that the age-adjusted prevalence of osteoporosis

in women increased from 14.0 to 19.6% from the years 2007 to 2008 through 2017 to 2018, but there was no significant change in men [2]. Other publications have also assessed osteoporosis prevalence by ethnicity and race [3, 4]. Despite these recent estimates, there is a paucity of information that definitively quantifies any statistically significant changes in osteoporosis prevalence over time by gender, ethnicity/race, and specified age groups. Furthermore, it is known that there are specific subsets of the population that have a greater risk profile for developing osteoporosis [5]. The purpose of this study is to epidemiologically profile osteoporosis prevalence trends over time by gender, ethnicity/race, age group, and both gender and ethnicity/race using data for the years 2005–2006, 2007–2008, 2009–2010, 2013–2014, and 2017–2018. This includes descriptive analyses to

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capture the proportion of undiagnosed osteoporosis using years 2017–2018. Insights elucidated in this analysis should serve to enhance public health decision making, surveillance efforts, and initiatives focused on addressing osteoporosis among individuals at highest risk and with the greatest need.

## Methods

### Data source

Data from the publicly available, deidentified National Health and Nutrition Examination Survey (NHANES) dataset for the years 2005–2006, 2007–2008, 2009–2010, 2013–2014, and 2017–2018 were used for these analyses. NHANES is a cross-sectional survey designed to monitor the health and nutritional status of the non-institutionalized civilian U.S. population [6]. The NHANES sample is selected through a complex, multistage probability design. The sample design includes oversampling to obtain reliable estimates of health and nutritional estimates for various subpopulations. The survey consists of interviews conducted in participants' homes and standardized physical examinations conducted in mobile examination centers. Femur neck bone mineral density (BMD) scores were measured using a dual energy X-ray absorptiometry (DXA) scan on Hologic Discovery Model A Densitometers [7]. The sample was limited to individuals 50 years of age and older. This study was reviewed by an institutional review board and determined to be not research and therefore exempt, effective April 8, 2024.

### Demographic independent variables

Variables for gender (male and female); ethnicity/race (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Other Race — including multi-racial); age group (reclassified as 50–59 years of age; 60–69 years of age; 70–79 years of age; and 80 years of age and older); and gender and ethnicity/race (male Mexican American, male Other Hispanic, male non-Hispanic White, male non-Hispanic Black, male Other Race — including multi-racial, female Mexican American, female Other Hispanic, female non-Hispanic White, female non-Hispanic Black, and female Other Race — including multi-racial) were analyzed across NHANES years 2005–2006, 2007–2008, 2009–2010, 2013–2014, and 2017–2018 to determine if there was a statistically significant change across the time intervals.

### Outcome variable

Prevalence was defined as the number of people in a given survey cycle with the presence of osteoporosis divided by

the total number of eligible people (age 50 years old and above) in our sample. NHANES sampling weights were used to generate nationally representative prevalence estimates. For the purpose of this study, the World Health Organization definition of osteoporosis as having a femoral neck BMD of 2.5 standard deviations or more below the young female adult mean (using normative data from the NHANES reference database on Caucasian women aged 20–29 years) was used to classify individuals with osteoporosis [8]. The narrow neck (NN) BMD ( $\text{g}/\text{cm}^2$ ) variable in the NHANES III dataset is the recommended metric for analysis [9] and is constructed from the Hip Structural Analysis (HSA) Program. The average BMD value for the NN site among Caucasian women aged 20–29 years was used to set the reference value against which standard deviation values were calculated for all individuals included in this study. If an individual's BMD value was 2.5 or more standard deviations below this reference value, that individual was classified as having osteoporosis; otherwise, they were classified as not having osteoporosis.

The presence of an osteoporosis diagnosis being made (yes; no) served as the secondary outcome variable and was assessed using descriptive statistics. This secondary outcome was used to determine and report the proportion of undiagnosed osteoporosis. In order to assess whether an individual was diagnosed with osteoporosis, self-reported NHANES questionnaire data was cross-referenced with NHANES examination data. If an individual responded to the NHANES survey question “Ever told had osteoporosis/brittle bones?” with “Yes” and DXA examination data showed the presence of osteoporosis, an individual was classified as being diagnosed with osteoporosis. Conversely, if an individual responded to that NHANES survey question “Ever told had osteoporosis/brittle bones?” with “No” and DXA examination data showed the presence of osteoporosis, an individual was classified as having undiagnosed osteoporosis.

### Statistical methodology

The NHANES survey creates primary sampling units (PSUs), which are typically single counties or may be groups of contiguous counties using probability proportional to a measure of size. Stratification parameters, which are defined by geography, metropolitan statistical area status, and various other population demographics, are applied to PSU creation to improve sample precision. The corresponding NHANES survey mobile examination center (MEC) sample strata and weights were applied for all descriptive and statistical calculations to ensure representativeness and generalizability to the U.S. civilian non-institutionalized population.

In the present study, we applied sampling weights to assess the temporal changes in the osteoporosis prevalence

between 2005 and 2018. Although NHANES response rates have been steadily falling since 2011, with more accelerated declines reported in recent years, efforts have been made to adjust biases and ensure comparability across survey years [9, 10]. Specifically, weights were adjusted for non-response to the in-home interview when creating the interview weights and further adjusted for non-response to the MEC exam when creating the exam weights. Also, the NHANES sample weights are post-stratified to match estimates of the U.S. civilian non-institutionalized population available from the U.S. Census Bureau [11]. Moreover, as declines in the response biased toward income and education in 2017–2018, a series of alternative weighting adjustments to reduce bias were explored. After the initial weighting process was applied, the weights were adjusted to education and

then further adjusted to income [12]. The intensive adjustments suggest that bias in the outcome statistics was mostly reduced through the enhanced weighting adjustments, and estimates in various NHANES cycles are comparable.

Descriptive analyses were conducted to capture osteoporosis prevalence estimates for gender, ethnicity/race, and age group (Table 1), and gender and ethnicity/race (Table 2) across NHANES survey years 2005 to 2018. The prevalence for the sub-group analyses was defined as the number of people in a sub-group with presence of osteoporosis divided by the total number of population at risk in that specific group. Sampling weights were used to generate nationally representative estimates of the prevalence. Descriptive analyses were also conducted using the NHANES weighting to capture osteoporosis prevalence estimates for diagnosed

**Table 1** Trends in U.S. prevalence of osteoporosis among older adults, 2005–2018

| Demographics                        | Older adults with osteoporosis, % (95% <i>CI</i> ) |                                 |                                 |                                 |                                 |                         | <i>p</i> -trend (linear) | <i>p</i> -trend (quadratic) |
|-------------------------------------|----------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|-------------------------|--------------------------|-----------------------------|
|                                     | 2005–2006<br>( <i>n</i> = 1614)                    | 2007–2008<br>( <i>n</i> = 2403) | 2009–2010<br>( <i>n</i> = 2448) | 2013–2014<br>( <i>n</i> = 2230) | 2017–2018<br>( <i>n</i> = 2286) |                         |                          |                             |
| No. with osteoporosis <sup>a</sup>  | 291                                                | 418                             | 461                             | 487                             | 490                             |                         |                          |                             |
| Gender <sup>b</sup>                 |                                                    |                                 |                                 |                                 |                                 |                         |                          |                             |
| Men                                 | 8.48%<br>(6.56–10.89)                              | 8.93%<br>(6.73–11.75)           | 9.27%<br>(7.14–11.95)           | 10.69%<br>(8.98–12.68)          | 10.73%<br>(7.81–14.56)          | <i>p</i> = 0.158        | <i>p</i> = 0.979         |                             |
| Women                               | 26.91%<br>(22.81–31.45)                            | 25.10%<br>(21.50–29.08)         | 26.47%<br>(23.28–29.92)         | 30.64%<br>(27.48–34.00)         | 35.61%<br>(30.95–40.56)         | <b><i>p</i> = 0.001</b> | <b><i>p</i> = 0.041</b>  |                             |
| Ethnicity/race <sup>b</sup>         |                                                    |                                 |                                 |                                 |                                 |                         |                          |                             |
| Mexican American                    | 11.55%<br>(8.92–14.83)                             | 13.37%<br>(8.22–21.01)          | 14.92%<br>(10.28–21.15)         | 19.28%<br>(16.77–22.07)         | 15.16%<br>(11.51–19.71)         | <i>p</i> = 0.084        | <i>p</i> = 0.236         |                             |
| Other Hispanic                      | 11.40%<br>(3.25–32.99)                             | 17.38%<br>(10.61–27.16)         | 21.77%<br>(16.79–27.73)         | 12.48%<br>(8.45–18.06)          | 16.48%<br>(11.81–22.52)         | <i>p</i> = 0.938        | <i>P</i> = 0.477         |                             |
| Non-Hispanic White                  | 19.11%<br>(15.82–22.90)                            | 18.56%<br>(16.52–20.80)         | 18.77%<br>(16.03–21.87)         | 21.99%<br>(19.41–24.81)         | 26.99%<br>(23.05–31.33)         | <b><i>p</i> = 0.001</b> | <b><i>p</i> = 0.032</b>  |                             |
| Non-Hispanic Black                  | 8.06%<br>(5.67–11.33)                              | 7.39%<br>(5.41–10.04)           | 7.22%<br>(4.99–10.33)           | 9.42%<br>(6.47–13.51)           | 9.54%<br>(6.94–12.97)           | <i>p</i> = 0.247        | <i>p</i> = 0.517         |                             |
| Other race (Including multi-racial) | 23.00%<br>(13.74–35.91)                            | 21.03%<br>(13.63–31.01)         | 28.69%<br>(18.67–41.34)         | 31.18%<br>(25.48–37.51)         | 21.20%<br>(16.42–26.92)         | <i>p</i> = 0.981        | <i>p</i> = 0.117         |                             |
| Age group <sup>b</sup>              |                                                    |                                 |                                 |                                 |                                 |                         |                          |                             |
| 50–59 years of age                  | 10.39%<br>(7.31–14.55)                             | 10.73%<br>(8.25–13.86)          | 9.22%<br>(7.04–11.99)           | 13.09%<br>(9.71–17.41)          | 14.41%<br>(11.46–17.96)         | <b><i>p</i> = 0.049</b> | <i>p</i> = 0.227         |                             |
| 60–69 years of age                  | 12.84%<br>(10.18–16.06)                            | 16.79%<br>(13.10–21.28)         | 20.66%<br>(16.31–25.82)         | 18.99%<br>(15.14–23.53)         | 22.97%<br>(17.51–29.52)         | <b><i>p</i> = 0.007</b> | <i>p</i> = 0.627         |                             |
| 70–79 years of age                  | 30.40%<br>(24.80–36.66)                            | 24.58%<br>(21.37–28.10)         | 22.33%<br>(18.74–26.38)         | 31.61%<br>(27.47–36.05)         | 35.12%<br>(30.08–40.52)         | <b><i>p</i> = 0.029</b> | <b><i>p</i> = 0.003</b>  |                             |
| 80 years of age and older           | 46.43%<br>(39.67–53.33)                            | 39.77%<br>(33.61–46.27)         | 44.16%<br>(37.57–50.96)         | 46.93%<br>(41.13–52.80)         | 44.59%<br>(36.06–53.46)         | <i>p</i> = 0.717        | <i>p</i> = 0.657         |                             |
| Total                               | 17.84%<br>(15.03–21.05)                            | 17.47%<br>(15.79–19.28)         | 18.13%<br>(15.65–20.91)         | 20.88%<br>(18.98–22.91)         | 23.49%<br>(20.59–26.65)         | <b><i>p</i> = 0.001</b> | <i>p</i> = 0.133         |                             |

Ethnicity and race were determined by self-reporting of study participants. The non-Hispanic Asian category was not available before 2011 due to the survey study design and thus estimates could not be reported separately

<sup>a</sup>Unweighted number of individuals with osteoporosis

<sup>b</sup>All prevalence estimates were adjusted using the NHANES weighting methodology to ensure generalizability to the national U.S. population

**Table 2** Trends in U.S. prevalence of osteoporosis among older adults, 2005–2018

| By gender and ethnicity/race, % (95% CI) |                  |                         |     |                         |     |                         |     |                         |     |                         |                     |                        |
|------------------------------------------|------------------|-------------------------|-----|-------------------------|-----|-------------------------|-----|-------------------------|-----|-------------------------|---------------------|------------------------|
| Demographics                             | No. <sup>a</sup> | 2005–2006<br>(n = 1614) | No  | 2007–2008<br>(n = 2403) | No  | 2009–2010<br>(n = 2448) | No  | 2013–2014<br>(n = 2230) | No  | 2017–2018<br>(n = 2286) | p-trend<br>(linear) | p-trend<br>(quadratic) |
| Men <sup>b</sup>                         |                  |                         |     |                         |     |                         |     |                         |     |                         |                     |                        |
| Mexican American                         | 130              | 3.44%<br>(1.26–9.03)    | 160 | 7.76%<br>(3.67–15.68)   | 208 | 6.49%<br>(3.18–12.80)   | 143 | 7.40%<br>(4.74–11.37)   | 132 | 6.75%<br>(4.79–9.43)    | p = 0.332           | p = 0.320              |
| Other Hispanic                           | 14               | 8.40%<br>(2.66–23.51)   | 136 | 8.65%<br>(4.48–16.06)   | 101 | 11.90%<br>(5.94–22.44)  | 90  | 7.14%<br>(3.42–14.30)   | 117 | 3.42%<br>(1.49–7.69)    | <b>p = 0.049</b>    | p = 0.197              |
| Non-Hispanic White                       | 530              | 9.14%<br>(6.97–11.90)   | 664 | 9.86%<br>(7.08–13.58)   | 675 | 9.54%<br>(7.31–12.36)   | 495 | 11.64%<br>(9.47–14.22)  | 454 | 13.00%<br>(8.70–19.00)  | p = 0.113           | p = 0.574              |
| Non-Hispanic Black                       | 179              | 2.40%<br>(0.99–5.71)    | 229 | 2.47%<br>(0.91–6.51)    | 235 | 4.38%<br>(2.68–7.09)    | 250 | 3.52%<br>(1.77–6.89)    | 282 | 3.61%<br>(1.96–6.58)    | p = 0.367           | p = 0.497              |
| Other race<br>(including multi-racial)   | 21               | 13.34%<br>(3.32–40.81)  | 48  | 6.57%<br>(1.94–20.02)   | 54  | 15.82%<br>(5.20–39.20)  | 133 | 15.14%<br>(7.68–27.67)  | 214 | 8.52%<br>(5.26–13.52)   | p = 0.787           | p = 0.528              |
| Women <sup>b</sup>                       |                  |                         |     |                         |     |                         |     |                         |     |                         |                     |                        |
| Mexican American                         | 120              | 19.99%<br>(14.82–26.40) | 168 | 18.93%<br>(11.61–29.32) | 205 | 23.88%<br>(16.82–32.74) | 122 | 32.72%<br>(27.16–38.81) | 123 | 24.38%<br>(17.22–33.32) | p = 0.085           | p = 0.353              |
| Other Hispanic                           | 12               | 13.28%<br>(2.65–46.26)  | 125 | 27.52%<br>(18.65–38.60) | 118 | 30.79%<br>(21.60–41.81) | 106 | 16.89%<br>(10.05–27.01) | 127 | 27.69%<br>(19.63–37.51) | p = 0.490           | p = 0.677              |
| Non-Hispanic White                       | 437              | 28.87%<br>(24.21–34.03) | 605 | 26.37%<br>(21.81–31.51) | 615 | 27.54%<br>(23.50–31.97) | 534 | 32.01%<br>(27.86–36.48) | 392 | 39.90%<br>(34.31–45.77) | <b>p = 0.001</b>    | <b>p = 0.012</b>       |
| Non-Hispanic Black                       | 146              | 13.38%<br>(8.92–19.59)  | 226 | 11.21%<br>(7.48–16.46)  | 182 | 9.85%<br>(6.30–15.06)   | 214 | 14.92%<br>(10.37–20.99) | 250 | 14.86%<br>(10.53–20.56) | p = 0.325           | p = 0.295              |
| Other race (including<br>multi-racial)   | 25               | 32.05%<br>(15.16–55.46) | 42  | 33.12%<br>(19.03–51.05) | 55  | 38.21%<br>(25.16–53.22) | 143 | 44.79%<br>(36.40–53.48) | 195 | 36.79%<br>(27.40–47.30) | p = 0.477           | p = 0.433              |

Ethnicity and race were determined by self-reporting of study participants. The non-Hispanic Asian category was not available before 2011 due to the survey study design and thus estimates could not be reported separately

<sup>a</sup>Unweighted number of individuals in the sample (inclusive of those with and without osteoporosis)

<sup>b</sup>All prevalence estimates were adjusted using the NHANES weighting methodology to ensure generalizability to the national U.S. population

and undiagnosed osteoporosis among gender, ethnicity/race, and age group (Table 3) for NHANES years 2017 to 2018, in addition to a descriptive assessment of the proportion of undiagnosed osteoporosis.

Temporal trend analyses were conducted utilizing linear probability models (LPMs) to assess for changes in prevalence across all included NHANES cycles. LPMs are preferred over logistic regression in such cases because of the intuitive and easily interpretable estimates [13]. Appropriate sampling weights were applied in the trend analysis. These results are listed in Tables 1 and 2, and a two-sided  $p$ -value less than 0.05 was considered statistically significant.

Analyses were conducted using the STATA statistical software package [14].

## Results

Among all U.S. civilian non-institutionalized individuals 50 years of age and older (Table 1), there was a statistically significant (linear,  $p=0.001$ ) increase in the prevalence of osteoporosis over time. Specific prevalence estimates across survey years included 17.84% (2005–2006), 17.47% (2007–2008), 18.13% (2009–2010), 20.88% (2013–2014),

**Table 3** U.S. prevalence of osteoporosis among older adults, 2017–2018

| Demographics                           | Total no. <sup>a</sup> | Diagnosed osteoporosis <sup>b</sup> |                                         | Undiagnosed Osteoporosis <sup>b</sup> |                                         |                                                                | Osteoporosis |                                         |
|----------------------------------------|------------------------|-------------------------------------|-----------------------------------------|---------------------------------------|-----------------------------------------|----------------------------------------------------------------|--------------|-----------------------------------------|
|                                        |                        | no. <sup>c</sup>                    | Prevalence <sup>d</sup> , %<br>(95% CI) | No. <sup>c</sup>                      | Prevalence <sup>d</sup> , %<br>(95% CI) | % of Individuals<br>with osteoporosis <sup>e</sup><br>(95% CI) | No           | Prevalence <sup>d</sup> , %<br>(95% CI) |
| Overall prevalence                     | Total sample<br>(2158) | 144                                 | 7.55%<br>(05.93–09.57)                  | 341                                   | 16.90%<br>(14.17–20.03)                 | 69.12%<br>(62.14–75.32)                                        | 485          | 24.45%<br>(21.33–27.87)                 |
| Gender                                 |                        |                                     |                                         |                                       |                                         |                                                                |              |                                         |
| Men                                    | 1167                   | 19                                  | 1.43%<br>(0.85–2.37)                    | 120                                   | 9.44%<br>(6.56–13.40)                   | 86.88%<br>(79.53–91.86)                                        | 139          | 10.86%<br>(7.72–15.08)                  |
| Women                                  | 991                    | 125                                 | 13.68%<br>(10.58–17.49)                 | 221                                   | 24.36%<br>(20.66–28.50)                 | 64.05%<br>(56.87–70.65)                                        | 346          | 38.04%<br>(33.02–43.33)                 |
| Ethnicity/race                         |                        |                                     |                                         |                                       |                                         |                                                                |              |                                         |
| Mexican American                       | 242                    | 10                                  | 3.57%<br>(1.78–7.03)                    | 30                                    | 12.03%<br>(8.84–16.16)                  | 77.13%<br>(61.65–87.62)                                        | 40           | 15.59%<br>(11.62–20.61)                 |
| Other Hispanic                         | 229                    | 14                                  | 5.91%<br>(2.34–14.15)                   | 27                                    | 11.75%<br>(8.69–15.72)                  | 66.54%<br>(42.66–84.17)                                        | 41           | 17.66%<br>(12.36–24.60)                 |
| Non-Hispanic White                     | 801                    | 78                                  | 8.73%<br>(6.86–11.06)                   | 172                                   | 19.16%<br>(14.98–24.18)                 | 68.69%<br>(59.97–76.27)                                        | 250          | 27.89%<br>(23.61–32.61)                 |
| Non-Hispanic Black                     | 500                    | 15                                  | 3.28%<br>(1.61–6.58)                    | 38                                    | 6.90%<br>(5.01–9.42)                    | 67.79%<br>(50.97–80.99)                                        | 53           | 10.18%<br>(7.15–14.28)                  |
| Other race (including<br>multi-racial) | 386                    | 27                                  | 6.31%<br>(4.00–9.82)                    | 74                                    | 16.14%<br>(11.94–21.47)                 | 71.90%<br>(60.48–81.05)                                        | 101          | 22.45%<br>(17.22–28.72)                 |
| Age group                              |                        |                                     |                                         |                                       |                                         |                                                                |              |                                         |
| 50–59 years of age                     | 686                    | 13                                  | 2.27%<br>(0.94–5.41)                    | 71                                    | 12.65%<br>(9.11–17.32)                  | 84.77%<br>(65.42–94.25)                                        | 84           | 14.93%<br>(11.74–18.80)                 |
| 60–69 years of age                     | 824                    | 49                                  | 8.82%<br>(6.56–11.76)                   | 117                                   | 14.93%<br>(9.89–21.90)                  | 62.86%<br>(50.11–74.03)                                        | 166          | 23.75%<br>(18.11–30.49)                 |
| 70–79 years of age                     | 412                    | 46                                  | 12.36%<br>(8.13–18.36)                  | 84                                    | 25.12%<br>(19.62–31.55)                 | 67.02%<br>(54.05–77.82)                                        | 130          | 37.48%<br>(31.55–43.81)                 |
| 80 years of age and<br>older           | 236                    | 36                                  | 18.35%<br>(13.10–25.08)                 | 69                                    | 28.84%<br>(19.88–39.81)                 | 61.12%<br>(47.18–73.45)                                        | 105          | 47.18%<br>(37.99–56.56)                 |

116 individuals were removed because the individual did not have osteoporosis as examined through the NHANES DXA examination data but answered the survey question “Ever told had osteoporosis/brittle bones?” with “Yes”

<sup>a</sup>Unweighted sample size

<sup>b</sup>Diagnosed and undiagnosed figures are based on matching of NHANES experimental examination data with self-reported questionnaire responses

<sup>c</sup>Unweighted number of individuals in the sample within the respective category

<sup>d</sup>All prevalence estimates were adjusted using the NHANES weighting methodology to ensure generalizability to the national U.S. population

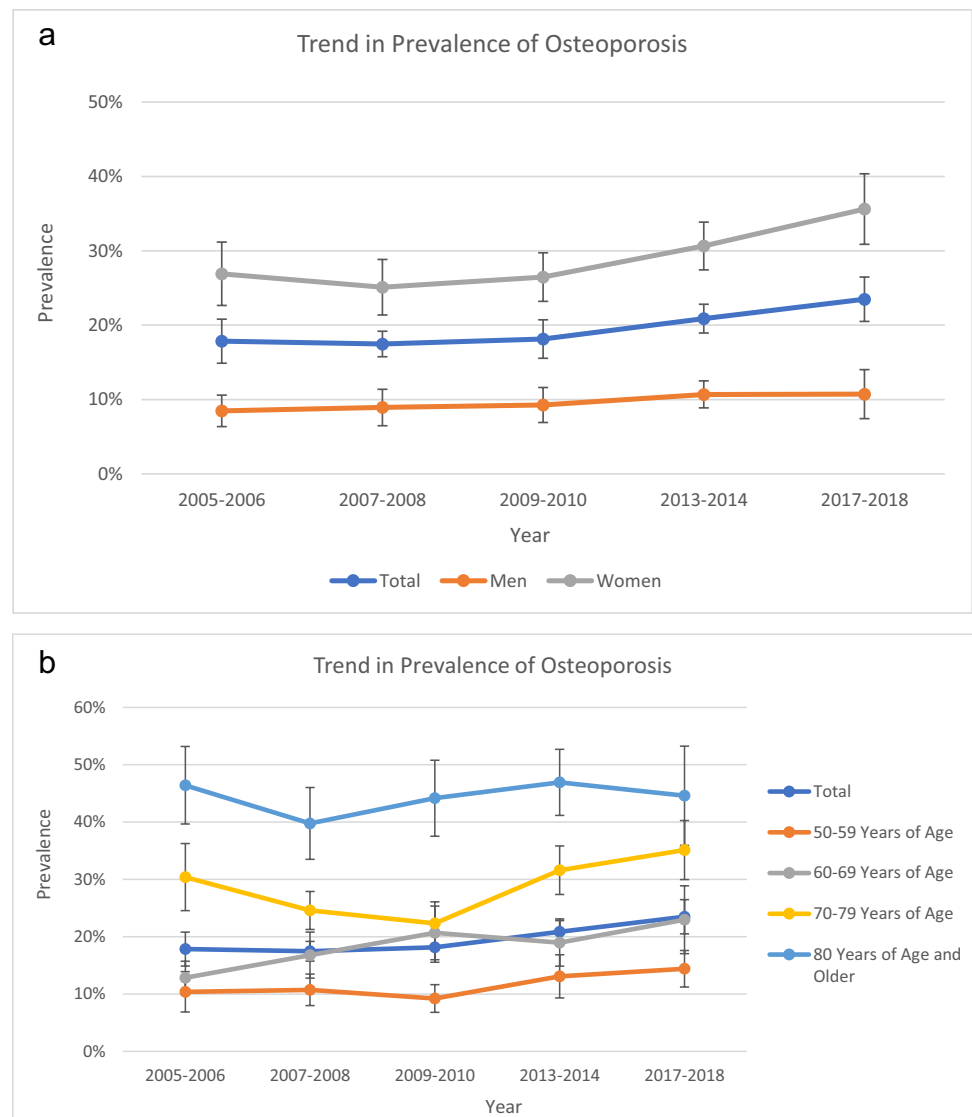
<sup>e</sup>The proportion of undiagnosed osteoporosis, among those with osteoporosis was adjusted using the NHANES methodology to ensure generalizability to the national U.S. population

and 23.49% (2017–2018). The analyses (Table 1) found a statistically significant increase over time among women (Fig. 1a) (linear,  $p=0.001$ ; quadratic,  $p=0.041$ ) with 26.91% (2005–2006), 25.10% (2007–2008), 26.47% (2009–2010), 30.64% (2013–2014), and 35.61% (2017–2018) prevalence estimates across survey year time intervals; a statistically significant increase from over time among individuals identifying as non-Hispanic White (linear,  $p=0.001$ ; quadratic,  $p=0.032$ ), with 19.11% (2005–2006), 18.56% (2007–2008), 18.77% (2009–2010), 21.99% (2013–2014), and 26.99% (2017–2018) prevalence estimates across survey year time intervals; and a statistically significant increase over time across individuals 50–59 years of age (Fig. 1b) (linear,  $p=0.049$ ), individuals 60–69 years of age (linear,  $p=0.007$ ), and individuals 70–79 years of age (linear,  $p=0.029$ ; quadratic,  $p=0.003$ ). Among groups where there was a statistically significant quadratic finding, there tended to be a

reduction in the prevalence of osteoporosis from 2005 to 2006, with a subsequent increase across the remaining survey years. Figure 1a includes a line graph with survey interval point estimates among gender, and Fig. 1b includes a line graph with survey interval point estimates among age groups.

The sub-analysis (Table 2) focusing on both gender and ethnicity/race found that individuals identifying as non-Hispanic White women had the highest prevalence of osteoporosis at 39.90%, with individuals identifying as Other Race (including Multi-racial) women having the second highest prevalence of osteoporosis at 36.79% for 2017–2018. Additionally, there was a statistically significant change over time among individuals identifying as Other Hispanic men (linear,  $p=0.049$ ), with 8.40% (2005–2006), 8.65% (2007–2008), 11.90% (2009–2010), 7.14% (2013–2014), and 3.42% (2017–2018) prevalence estimates across survey

**Fig. 1** Gender and age differences in temporal trends of in U.S. prevalence of osteoporosis 2005–2018. **a** Gender difference in temporal trends of in U.S. prevalence of osteoporosis 2005–2018. Note: Error bars represent 95% confidence intervals. **b** Age difference in temporal trends of in U.S. prevalence of osteoporosis 2005–2018. Note: Error bars represent 95% confidence intervals



year time intervals; and a statistically significant increase over time among individuals identifying as non-Hispanic White women from 2007 to 2018 (linear,  $p=0.001$ ; quadratic,  $p=0.012$ ), with 28.87% (2005–2006), 26.37% (2007–2008), 27.54% (2009–2010), 32.01% (2013–2014), and 39.90% (2017–2018) prevalence estimates across survey year time intervals.

The analyses (Table 3) examining the proportion of undiagnosed osteoporosis found that 69.12% of individuals with osteoporosis went undiagnosed. Within gender, men had the highest proportion of undiagnosed osteoporosis at 86.88%, with a diagnosed prevalence estimate of 1.43% and an undiagnosed prevalence estimate of 9.44%; within ethnicity/race, individuals identifying as Mexican American had the highest proportion of undiagnosed osteoporosis at 77.13%, with a diagnosed prevalence estimate of 3.57% and an undiagnosed prevalence estimate of 12.03%; and within age groups, individuals 50–59 years of age had the highest proportion of undiagnosed osteoporosis at 84.77%, with a diagnosed prevalence estimate of 2.27% and an undiagnosed prevalence estimate of 12.65%.

## Discussion

While previous studies have assessed the prevalence of osteoporosis among gender, ethnicity/race, and specified age groups [1–4], to our knowledge, this is the first study to determine whether there have been statistically significant changes over time across these groups. The ability to track these changes over time is one of the primary strengths of this paper, particularly with an aging population that comprises a greater total share of the US population. In part due to this dynamic, annual fracture rates are projected to increase from 1.9 to 3.2 million (68%) from 2018 to 2040, with related costs rising from \$57 to over \$95 billion [15].

The increasing prevalence of osteoporosis finding is particularly important given recent trends tracking the incidence of hip fracture, a deadly and frequent adverse health outcome associated with osteoporosis. From 2002 to 2012, hip fracture rates had been declining for women 65 years of age or older each year until 2013–2015 when rates began plateauing at levels higher than projected from 2013 to 2015 [16]. The increasing prevalence among specific groups and sub-groups, such as individuals identifying as non-Hispanic White women and individuals from 50 to 79 years of age suggest that there may be specific socio-demographic, cultural, environmental, and other factors impacting these populations. As such, it is both important and worthwhile to develop tailored public health strategies to prevent potential future adverse health outcomes associated with osteoporosis, such as hip fracture.

An additional strength of this paper is its ability to quantify the issue of undiagnosed osteoporosis. Previous studies have reported on the underdiagnosis of osteoporosis [17, 18]. However, the proportion of undiagnosed osteoporosis present in this study suggests a potentially more drastic gap in the U.S. health system's preventive activities for bone health than may be previously thought, with 69.12% of individuals with osteoporosis not receiving a diagnosis when osteoporosis was present. The two groups with the highest proportion of undiagnosed osteoporosis were men at 86.88% and individuals 50–59 years of age at 84.77%, with lower proportions across other age groups (60–69 years of age at 62.86%; 70–79 years of age at 67.02%; and 80 years of age and older at 61.12%), suggesting that existing guidance on screening for osteoporosis and efforts to address stigmatization may be insufficient. Since the NHANES survey cycle process conducts BMD assessments irrespective of risk for osteoporosis and is nationally representative, these undiagnosed osteoporosis rates may be more rigorous than previously reported numbers.

Additional policy considerations have been postulated to be a contributor to low diagnostic capture of osteoporosis. For instance, in 2007 Medicare cut reimbursement rates for office-based imaging services, to include DXA scans, which have traditionally been viewed as a gold standard for diagnosing osteoporosis. One study examining the impact of this change found that screening did not decrease at a rate relative to reimbursement reductions as anticipated in 2007 and 2008 [19]. However, another analysis affirmed this trend of plateauing DXA scan testing from 2007 to 2009, with a subsequent decline in 2010 when reimbursement relief was delayed [20]. This also coincided with a shift from office-based settings to more costly hospital-based settings [21], which may also have implications related to osteoporosis prevention efforts and access-to-care challenges.

Future research should continue exploring socio-demographic, environmental, health system, and policy factors that may contribute to the increasing prevalence over time of osteoporosis among high-risk individuals and widespread gaps in diagnosing osteoporosis in the U.S.

## Limitations

There are several limitations that should be acknowledged. First, self-reported data was used to determine whether or not an individual was diagnosed with osteoporosis. With self-reported data, there is the possibility of recall bias, which can lead to potential overestimation or underestimation. Validation and calibration of NHANES estimates is beyond the scope of this study. Future national research based on measured data is thus warranted. Second, due to small sample size, we were not able to examine the differences and temporal trends between gender-race-age specific

groups, i.e., we were not able to interact gender, age, and race/ethnicity to conduct stratified analyses. This limitation restricts the detailed information this study can provide for these sub-populations.

## Conclusion

Time trends analyses of osteoporosis prevalence among adults 50 years of age and older in the U.S. found a statistically significant increase over time among women, non-Hispanic Whites, and all age groups (except for individuals 80 years of age and older) from 2005 to 2018. The proportion of undiagnosed osteoporosis remains very high, with roughly 69.12% of individuals going undiagnosed. This was particularly acute for men and individuals 50–59 years of age and older, with 86.88 and 84.77% among these respective groups having undiagnosed osteoporosis. Additional efforts remain to tackle the growing burden of illness associated with osteoporosis.

**Data availability** Data used for this study is publicly available via the National Health and Nutrition Examination Survey (NHANES).

## Declarations

**Conflict of interest** Mr. Naso is an employee of and stockholder in Baxter International. Dr. Lin, Ms. Song, and Dr. Xue have no financial disclosures.

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