# Social inequality and body mass differences in two post-Medieval Dutch populations

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Received: 23 October 2023 | Revised: 21 May 2024 | Accepted: 23 May 2024
DOI: 10.1002/oa.3320

RESEARCH ARTICLE

# Social inequality and body mass differences in two post-Medieval Dutch populations

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**Funding information**
This publication is part of the project Embodied Inequality: Transforming Archaeological Knowledge of State Formation, Social Disparity, and Health Inequality (with project number VI.Vidi.201.153), financed by the Dutch Research Council (NWO).

## Abstract

Adult body mass is largely related to nutrition levels, which can be affected by external stressors, such as diet, environment, and disease. High-status and low-status groups likely had very different nutrition and stress experiences, which might result in differences in population's body mass. Since inequality between social statuses prevailed in Europe in the post-Medieval period, did these differences result in body mass variations between high-status and low-status populations in the Netherlands? In order to answer this question, this research compared body size of two post-Medieval urban skeletal collections with different social statuses from the Eusebius cemetery of two cemeteries of the 17th–19th centuries: the Arnhem and the Broerenkerk church of Zwolle, the Netherlands. Social statuses of the two collections are estimated based on the burial locations, grave goods, and historical records. Body mass was estimated using both femoral head diameter method and stature/bi-iliac breadth method. Results have shown no statistically significant differences in body mass between the two samples. Therefore, this research suggests that inequality in post-Medieval Dutch society did not result in observable population body mass differences in the skeletal collections of different social status groups. It cannot, however, prove that social inequality in populations did not impact body size or health more broadly.

KEYWORDS
body mass reconstruction, interpopulation differences, post-Medieval Europe, socioeconomic inequality

## 1 | INTRODUCTION

Human body mass (BM) is a constantly changing measure that reflects the energy and nutrient balance over the course of an individual's life (Hill et al., 2012). Nutrients are transformed into energy through the thermic effect and consumed by the resting metabolic rate and physical activity. An imbalance in nutrient intake and consumption can lead to an increase or decrease in BM (Drewnowski & Specter, 2004; Hill et al., 2012). Various factors such as subsistence strategies, diet, disease, living conditions, social influences, and personal preference can impact an individual's nutrient levels throughout their life and, as a result, influence their BM.

In unequal societies, the allocation of property and resource are usually skewed to the high-status class, resulting in differences in living conditions and stresses between the high and the low statuses. Low social status usually means less income and resources. As a result, a range of living stresses, such as malnutrition, physical exertion, poor medical resources, and living conditions, often lead to worse health and nutrient conditions among the lower classes. Social inequality thus creates vastly different living conditions for people in different social statuses that can have varying degrees of impact on their physical features, including their BM (Robb et al., 2001). However, the actual relationship between population's average BM and social inequality would be more complex. In the pre-industrial period, because of low productivity, limited nutritious food and other related resources were usually sparser and difficult for the poor to access; hence, the socioeconomic status and population body size usually showed a positive correlation (Robb et al., 2001). Yet research on modern populations indicates that in high- and middle-income countries, socioeconomic status and population body mass are typically negatively correlated because of industrialized food production; this makes high-calorie foods more accessible than nutritionally balanced, healthy foods, leading to a higher risk of obesity among individuals of lower socioeconomic status (Claassen et al., 2019). Moreover, higher living stress along with negative psychological stress of low social status groups may facilitate individuals to consume more high-calorie foods (Vartanian & Porter, 2016). Research also suggests that obesity is usually more prevalent in countries with increased socioeconomic inequality, regardless of absolute income (Pickett et al., 2005). Therefore, BM can be used as an indirect indicator of an individual's access ability to resources throughout their life, and the differences in BM between groups of people can also be used as an indicator of differences in living stresses of varying social groups. Although such an indicator may represent entirely different situations in different social contexts.

Social inequality in post-Medieval Dutch societies intensified with industrialization, urbanization, and population growth (Bengtsson & Van Poppel, 2011). Starting from the 12th century, the Netherlands experienced rapid urbanization, with its productivity and labor force significantly increased compared with the earlier Medieval period (de Vries & van der Woude, 1997). The urban population in this period consisted of the upper class, the business class, the working class, and the propertyless impoverished class (Casna & Schrader, 2022; Wintle, 2000). Because of the lack of a traditional noble class, social and administrative power was mostly held by the wealthy merchants, whereas the middle classes were relatively more affluent than their counterparts in other European countries (Casna & Schrader, 2022; ten Hove, 2005). Therefore, social stratification and wealth allocation in the post-Medieval Dutch urban society were markedly consistent. Populations in low socioeconomic status were often subjected to poorer and harsher living conditions, long working hours, and poor hygiene (Hencock, 2000), which may have had an impact on their BM by low nutrient and health level (Bengtsson & Van Poppel, 2011; Mant & Roberts, 2015). Such patterns of post-Medieval Dutch society may have led to more complex trends in population BM.

The goal of this research is to examine the relationship between socioeconomic status and body mass in post-Medieval Dutch urban society, in order to further discuss the impact of social inequality on population's living and health conditions. Here, we analyze skeletal collections from Arnhem and Zwolle (Figure 1); the former reflects a working-class group, whereas the latter reflects a relatively wealthy group. Both collections consist of urban populations dated from the 15th century to the early 19th century (Aten, 1992; Baetsen et al., 2018).

Despite the fact that estimating premortem BM based on human skeletal remains is a valuable subject in bioarchaeology research, the existing methods generally have limitations that cannot be disregarded. We applied the mechanical method and the morphometric method for BM estimation that are currently most commonly used and compared the results to reduce the limitations brought about by using a single method. As these methods were created from the skeletal materials, variations of BM that are caused by soft tissue changes are not considered in reconstruction. They are therefore applicable only to investigate the population's average BM rather than individual's BM (Lacoste Jeanson et al., 2017). In the mechanical estimation method, the BM of an individual is reconstructed according to the assumed biomechanical relationship between the weight-bearing bone and weight. The most common mechanical method is based on the diameter of femoral head (FHD), which is considered to be positively related to BM according to the adaptation of bone to the mechanical pressure of weight (Ruff et al., 1991, 2012). The morphometric method takes the human body as a cylinder and calculates its surface area by the stature and bi-iliac breadth (STBIB) and then estimates BM that positively related to the volume and size (Auerbach & Ruff, 2004; Ruff, 1994). It is not applicable to calculate the extreme BM of individuals (Auerbach & Ruff, 2004). The disparities between the reconstructed BM based on skeletal remains and the actual living BM will be conservatively considered, given these limitations (Berger et al., 2011). Moreover, early research generally believe that the femoral head size usually does not change after the closure of the proximal femoral growth plate; the FHD reflects the individual's BM during childhood and adolescence period rather than adult period (Niskanen et al., 2018; Ruff et al., 1991). Yet, more recent researches suggest that skeletal bi-iliac breadth and femoral head breadth would increase during life, resulting in higher estimated body mass in older individuals (Berger et al., 2011; Junno et al., 2018). These factors complicate the reconstruction of living body mass in skeletal collections.

The Trotter (1970) method was applied to estimate the individual's stature from maximum femur length, which contains the general set of equations that are suitable for the European population. In order to investigate the relative body size of populations, the body mass index (BMI) of individuals was calculated based on stature and the estimated BM of the FHD method (Burkhauser & Cawley, 2008). Since the STBIB method is developed based on population's average body size, it can only reflect the normal BMI (Lacoste Jeanson et al., 2017).

This study is the first of its kind to examine body mass in post-Medieval Dutch urban populations. Although other studies have indicated that there may have been embodied manifestations of social and economic inequality within post-Medieval Europe (Bengtsson & Van Poppel, 2011; Mant & Roberts, 2015; Schrader, 2022), we do not know whether body mass was significantly impacted by these disparate living conditions.

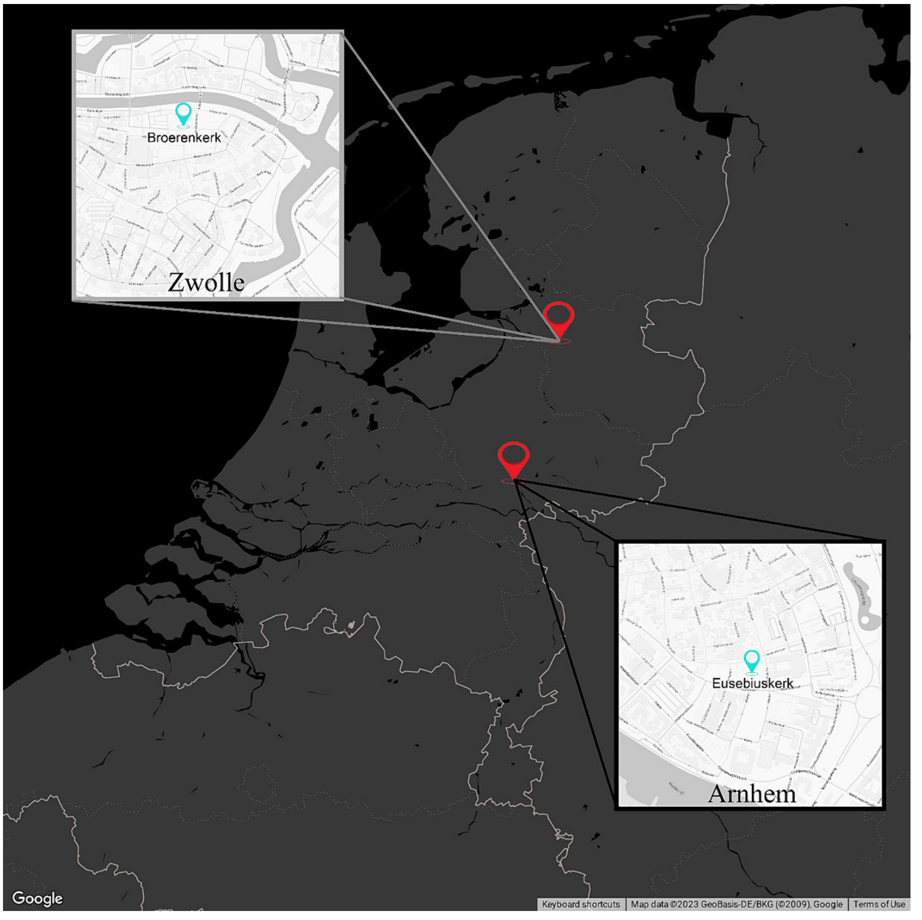


**FIGURE 1** Map that indicates the location of the Eusebius church in Arnhem and the Broeren church in Zwolle (edit from Google Map, 2023). [Colour figure can be viewed at wileyonlinelibrary.com]

## 2 | MATERIALS

Skeletal collections utilized in this research were excavated from two post-Medieval Dutch cemeteries: the Eusebius church cemetery in Arnhem and the Broeren church cemetery in Zwolle. Both collections are currently stored at the Laboratory for Human Osteoarchaeology at the Faculty of Archaeology, Leiden University.

The first collection, Arnhem, was excavated in 2017 in the northern cemetery of the Eusebius church by the RAAP Archeologie (archaeological research and advisors' company in the Netherlands). Approximately 350 individuals that dated from the mid-17th to early 19th century are included in this collection, covering all age groups with relatively even sex distribution (Zielman & Baetsen, 2020). Since the cemetery was completely closed by the government at the end of 1828 according to historical documents, the latest burials can be dated more precisely to 1829 (Zielman & Baetsen, 2020).

With the urbanization trend, Arnhem became a flourishing center of Gelderland province. Similar to most inland Dutch cities, the population of Arnhem steadily grew from the beginning of the 17th century, with several years of rapid decline due to the prevalence of epidemics in the mid-17th century (Paping, 2014). Starting in 1795, immigration intensified population growth in Arnhem, reaching 20,000 by the early 19th century. The majority of immigrants were workers and artisans from other regions of Gelderland (Casna & Schrader, 2022; Lourens & Lucassen, 1997).

The majority of the Arnhem population buried at Eusebius is considered to be of low socioeconomic status because of minimal grave goods and burial location in relation to the church. A few coins were found in some graves. However, because of their variable positions and minimal amount, it is hard to confirm whether these coins were intentionally selected as grave goods. In addition, a few fragments of clothing and ornaments were found, such as bronze buttons, a possible silver-plated ring, and a possible glass bead jewelry (Zielman & Baetsen, 2020).

The northern area of church was usually known as a less fortunate place for sinners and heathens in Medieval and post-Medieval Christian traditions, which made it the cheapest burial ground in this period. Thus, residents with a certain wealth preferred other areas of the cemetery, whereas those who did not have the choice were usually placed in the north (Baetsen et al., 2018). It has been suggested that the individuals from this collection are likely low-status workers of local industries (Baetsen et al., 2018). Since wealth and social status were strongly consistent in post-Medieval Dutch society, the burden of funeral expenses could be an indicator of the socioeconomic status of the buried population.

The Zwolle Broeren church was built in 1640 AD, according to historical records (Aten, 1992). About 500 skeletal individuals were excavated under the church floor, including all age and sex groups (Aten, 1992). The names, as well as date of birth and death, of some individuals were preserved on some of the tombstones (Hagedoorn, 1992). Based on the inscription of tombstones, the literature recordings of the church, and dating analysis on coin samples, individuals in the Broerenkerk collection dated from the 17th to 19th centuries (Hagedoorn, 1992).

Population development in Zwolle was similar to Arnhem. With the exception of several severe epidemics in the 17th and 18th centuries, the population remained relatively stable and slowly increased until policy-driven immigration (toward the end of the 18th century) led to rapid population growth in the 19th century (Habermehl, 1984).

Compared with the Arnhem collection from north Eusebius cemetery, the Zwolle individuals of the Broeren church are considered to be of higher social status, since there was a relatively high cost associated with burials and funerals inside the church. According to written records, the price of a burial inside a church in Zwolle ranged from 2.80 Dutch guilders to 16.80 guilders (Hagedoorn, 1992). For references, the annual salary of a laborer in the 17th century was only 200–250 guilders (Prak, 2005). Identified individuals include craftsmen, merchants, mill owners, inferior officers, school principals, and one former mayor. It is believed that the Broerenkerk collection consists of mainly urban high- and middle-class residents (Hagedoorn, 1992).

## 3 | METHODS

We applied the femoral head diameter equations provided in Ruff et al. (2012) for the mechanical approach (FHD = femoral head diameter, Figure 2):

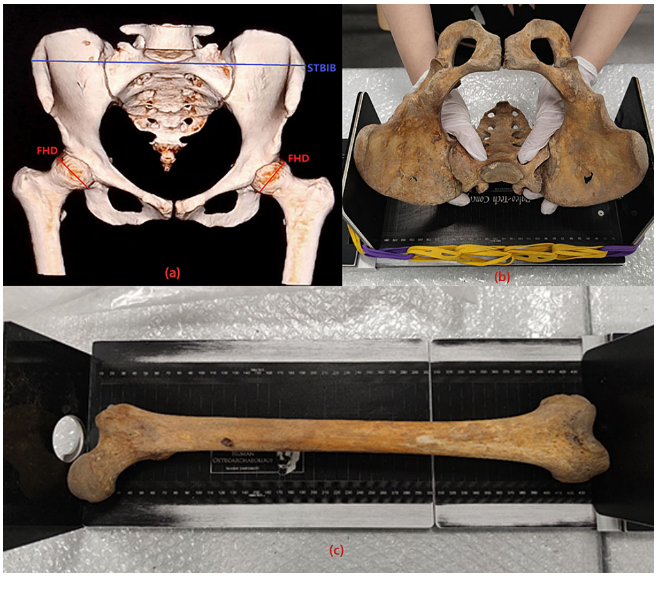


FIGURE 2 (a) Osteometric measurements of femur and pelvic breadth; (b) reconstruction of pelvic girdle and the measurement of bi-iliac breadth; (c) measurement of the maximum femur length (photo by Yuran Niu, 2022). [Colour figure can be viewed at wileyonlinelibrary.com]

$$\text{Female BM (kg)} = 2.18^{*}\ \text{FHD (mm)} - 35.8$$

$$\text{Male BM (kg)} = 2.8^{*}\ \text{FHD (mm)} - 66.7$$

The Trotter (1970) equations for European populations of maximum femur length were applied for stature estimation as follows (MFL = maximum femur length):

$$\text{Female Stature (cm)} = 2.47^{*}\ \text{MFL} + 54.10 \pm 3.72$$

$$\text{Male Stature (cm)} = 2.38^{*}\ \text{MFL} + 61.41 \pm 3.27$$

The BMI of individuals was calculated following the World Health Organization BMI classification, based on the FHD BM and stature (Sellen, 1995):

$$\text{BMIkg/m}^2) = \text{BM (kg)}/\text{Stature (m)}^2$$

The BMI result was then divided into four categories: underweight (BMI < 18.5 kg/m$^2$), normal (18.5 ≤ BMI ≤ 24.99), overweight (25 ≤ BMI ≤ 29.99), and obese (BMI ≥ 30) (Sellen, 1995).

For the morphometric approach, we applied the stature/bi-iliac breadth equations provided in Ruff et al. (1991). The measured skeletal bi-iliac breadth was first converted to the living bi-iliac breadth according to Ruff et al. (1991) (BIB = bi-iliac breadth, Figure 2):

$$\text{Living BIB} = 1.17^{*}\ \text{skeletal BIB} - 3$$

Then, the stature/bi-iliac breadth equations are as follows (LBIB = living bi-iliac breadth, ST = stature):

$$\text{Male BM (kg)} = 0.373^{*}\ \text{ST (cm)} + 3.033^{*}\ \text{LBIB (cm)} - 82.5$$

$$\text{Female BM (kg)} = 0.522^{*}\ \text{ST (cm)} + 1.809^{*}\ \text{LBIB (cm)} - 75.5$$

Samples selected from the two collections are limited to adult individuals who have at least one side of a complete ilium, a complete first segment of the sacrum that can be articulated to the ilium, and one complete femur. In addition, considering that the increased BIB and FHD of elderly individuals due to aging may affect the results and discussion of body mass reconstruction, adults over 50 years old are not included in this research. A total of 50 individuals from the Arnhem collection and 27 individuals from the Zwolle collection were selected (Table 1). Sex and age at death for each individual were estimated using skull and pelvic features (Buikstra & Ubelaker, 1994; WEA, 1980).

For each individual, the MFL, FHD, and BIB were measured. In the case where both femora are available, the mean value of both sides was applied to minimize possible deviations. For individuals with only one complete femur, a single side measurement was applied. The measurements of MFL and FHD were obtained using the osteometric board and digital caliper (Buikstra & Ubelaker, 1994; Figure 2).

**TABLE 1** Demographic composition of samples.

| | Arnhem | | | Zwolle | | |
|---|---|---|---|---|---|---|
| Age group | Female | Male | Total | Female | Male | Total |
| Young adult (18–35 years) | 13 | 10 | 23 | 3 | 5 | 8 |
| Middle adult (36–49 years) | 11 | 16 | 27 | 8 | 11 | 19 |
| Total | 24 | 26 | 50 | 11 | 16 | 27 |

**TABLE 2** Statistic results of BM and stature estimation.

| | | Site | Mean | Median | SD | Range | Normality | Welch's *t*-test *p* |
|---|---|---|---|---|---|---|---|---|
| Male | BM-FHD (kg) | Arnhem | 67.33 | 68.34 | 6.61 | 53.52–80.3 | 0.83 | 0.4018 |
| | | Zwolle | 65.41 | 67.35 | 7.9 | 51.05–78.63 | 0.7 | |
| | BM-STBIB (kg) | Arnhem | 68.67 | 68.44 | 5.23 | 59.79–78.29 | 0.6 | 0.8138 |
| | | Zwolle | 69.29 | 70.46 | 9.52 | 53.54–88.67 | 0.26 | |
| | Stature (cm) | Arnhem | 170.65 | 170.24 | 5.47 | 162.20–180.53 | 0.36 | 0.9303 |
| | | Zwolle | 170.48 | 169.64 | 6.67 | 156.97–182.67 | 0.74 | |
| Female | BM-FHD (kg) | Arnhem | 57.07 | 55.98 | 5.26 | 50.08–71.77 | 0.14 | 0.6825 |
| | | Zwolle | 57.88 | 55.67 | 5.75 | 52.13–69.41 | 0.12 | |
| | BM-STBIB (kg) | Arnhem | 58.88 | 59.13 | 4.56 | 50.00–72.58 | 0.24 | 0.3701 |
| | | Zwolle | 60.35 | 58.95 | 4.14 | 55.29–68.16 | 0.45 | |
| | Stature (cm) | Arnhem | 158.96 | 158.58 | 3.7 | 150.68–166.49 | 0.74 | 0.1547 |
| | | Zwolle | 161.79 | 160.93 | 5.72 | 155.37–175.38 | 0.17 | |

BIB was measured using the osteometric board with the reconstruction of pelvic girdle (Figure 2). For samples where only one ilium is preserved, the perpendicular distance from the lateral edge of the iliac crest to the midline of the sacrum was doubled.

The Shapiro–Wilk test has been applied to each group of variables separately to test the normality. Welch's two-sample *t*-test was applied to measure the difference of BM between two populations and sex groups. The null hypothesis was that there are no differences between the compared groups. When the *p*-value is less than or equal to 0.05, the null hypothesis cannot be rejected. In addition, the consistency between the estimated results of mechanical and morphometrical methods was analyzed with Pearson's correlation coefficient. All the statistical analyses were done with R programming language and RStudio version 4.1.2.

## 4 | RESULTS

Table 2 shows the results of calculated BM and stature for all groups that are normally distributed according to the Shapiro–Wilk test's results.

The mean and median BM and stature of Zwolle males are all slightly lower than the Arnhem males. The female groups, however, present the inverse result (Table 2 and Figures 3, 4, and 5). Results of the Zwolle samples show higher dispersion in both sex groups with higher standard deviation. Both methods showed a few remarkable outliers (Figures 3 and 4). However, the null hypothesis of the Welch's *t*-test cannot be rejected as the *p*-values are all higher than 0.05 (Table 2).

Table 3 shows that the BMI of the Arnhem population is slightly higher than that of the Zwolle population in either male or female groups, but still not statistically significant as *p*-values higher than 0.05. Table 4 lists the number of individuals assigned in BMI categories. Most of them were identified as normal BMI, with few overweight and two extreme BMI of obese or underweight.

The STBIB and FHD BM estimation methods generally presented similar trends of differences. Pearson's correlation coefficient analysis shows that the results of the two methods are positively correlated with $r(93) = .67$, $p < .001$ (Figure 6). Besides, Data of the measurements and body size reconstructions for each individual are available in Table S1.

## 5 | DISCUSSION AND CONCLUSION

Results above show that although the distribution of body size between high status, Zwolle, and low status, Arnhem, shows slight differences, no statistically significant differences in body mass are present. As methods for estimating BM based on skeletal remains generally have limitations, the estimated results are influenced by various factors, resulting in deviations from the actual living BM of populations. Despite the limitations of BM estimation, these results counter previous assumptions regarding the influences of social inequality on population body mass variation. These results suggest that the Arnhem and Zwolle populations, although having different socioeconomic backgrounds, might face similar external factors of post-Medieval Dutch society.

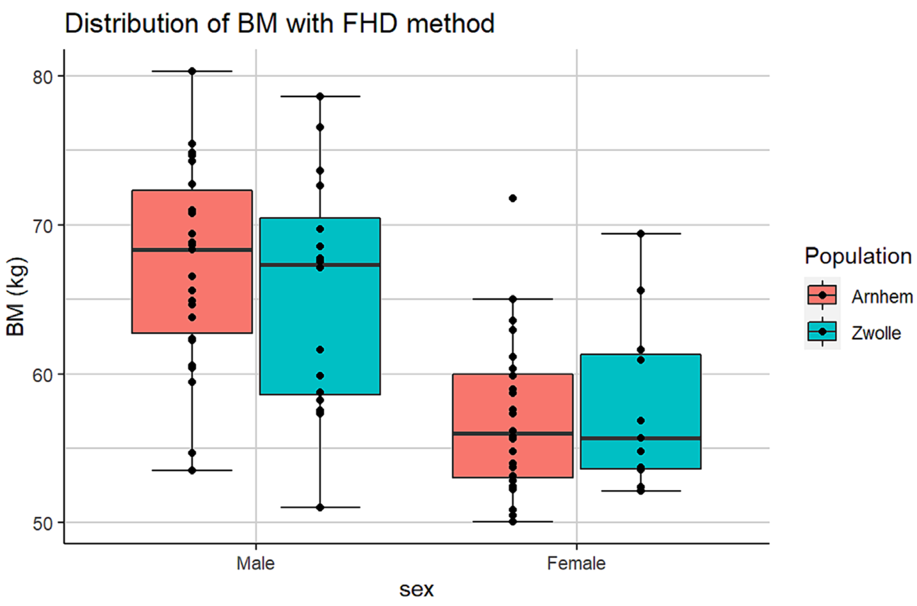


FIGURE 3 Distributions of BM (kg) with FHD method. [Colour figure can be viewed at wileyonlinelibrary.com]

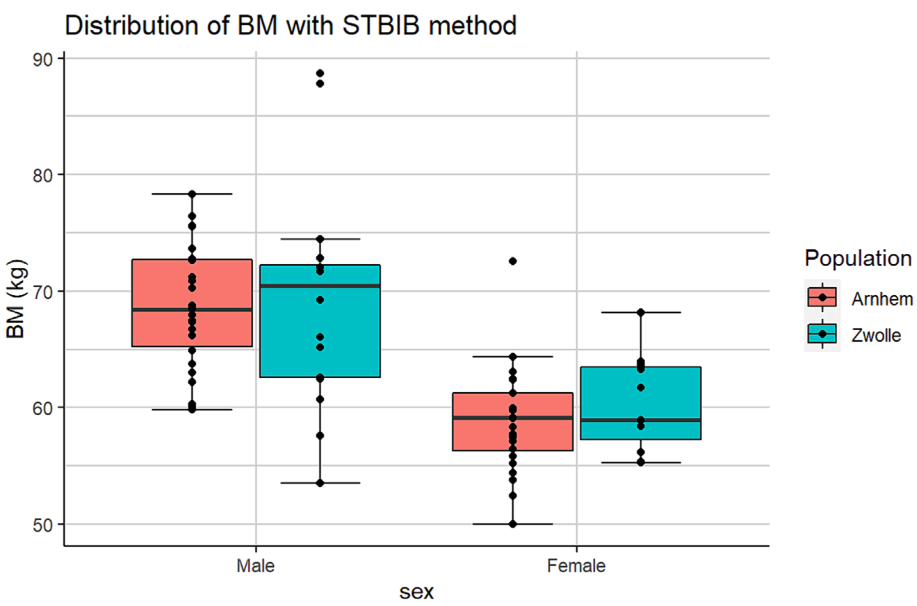


FIGURE 4 Distributions of BM (kg) with STBIB method. [Colour figure can be viewed at wileyonlinelibrary.com]

### 5.1 | Food supply and diet

The Netherlands went through a period of rapid economic growth and prosperity during the post-Medieval period, specifically from the 16th to the end of the 17th century (de Vries & van der Woude, 1997; Prak, 2005). The development of food products in this period shows a relatively ample supply of basic food resources, which could ensure a basic level of nutrition and energy acquisition for parts of the low-status population (de Vries & van der Woude, 1997; Hartog, 2004; Prak, 2005). The commercialized and industrialized intensive agriculture has brought a relatively cheap and stable supply of staple food to the post-Medieval Dutch people (Prak, 2005). The stability and ample supply of potatoes as starchy resources that were introduced from South America around 1550 kept their prices within reach for the poor populations and provided a fundamental guarantee of carbohydrate intake, vital vitamins, and minerals for people of low socioeconomic status (Wintle, 2000).

Post-Medieval Dutch people also had more high-quality protein food in their diet. As the results of thriving dairy product industry, even the poorest households in the 19th century could sometimes include dairy products in their daily diet (Wintle, 2000). Moreover, the growth of the shipping industry during the 17th century led to the increased production and yields in fishing. Fish have provided substantial protein supplement for the urban low-status groups (de Vries & van der Woude, 1997). Isotope analyses of $\delta^{13}C$ and $\delta^{15}N$ on dental samples from the Arnhem collection show that although their consumption of high-nutrient meat was limited, they had a higher consumption of marine fish with high nutritional values, resulting in a higher overall protein intake (Zielman & Baetsen, 2020). This supports the hypothesis that the gap in protein intake between the

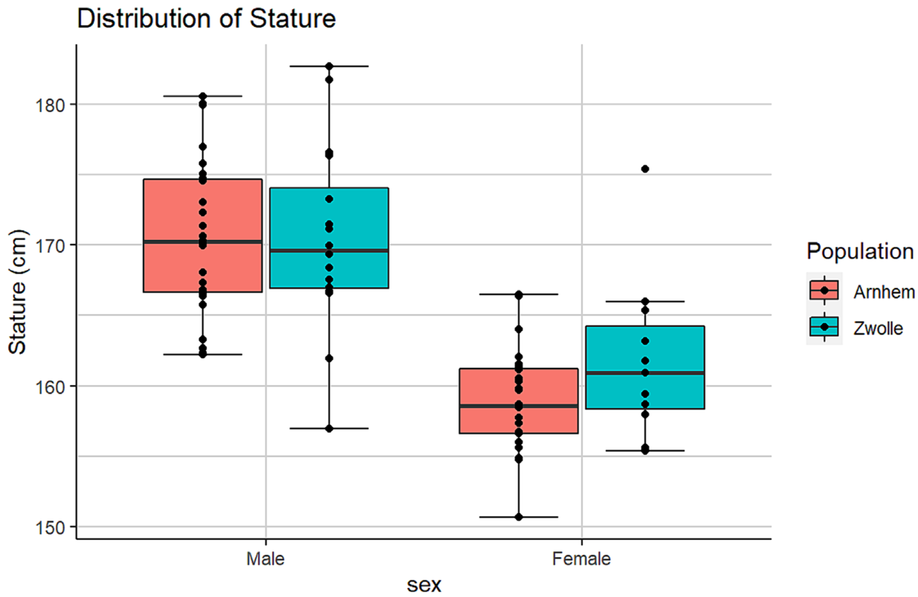


**FIGURE 5** Distributions of stature (cm). [Colour figure can be viewed at wileyonlinelibrary.com]

**TABLE 3** Statistic results of BMI calculated from FHD BM and stature.

| | Site | Mean BMI (kg/m$^2$) | Median BMI (kg/m$^2$) | SD | Range (kg/m$^2$) | Welch's *t*-test *p* |
|---|---|---|---|---|---|---|
| **Male** | **Arnhem** | 23.14 | 22.43 | 2.31 | 18.95–27.73 | 0.3232 |
| | **Zwolle** | 22.46 | 22.11 | 1.89 | 19.65–25.32 | |
| **Female** | **Arnhem** | 22.61 | 22.2 | 2.35 | 18.86–30 | 0.555 |
| | **Zwolle** | 22.12 | 21.95 | 2.08 | 19.06–27.17 | |

**TABLE 4** Number of individuals assigned in BMI categories.

| | Site | Underweight | Normal | Overweight | Obese |
|---|---|---|---|---|---|
| **Male** | Arnhem ($n = 32$) | 0 | 24 | 8 | 0 |
| | Zwolle ($n = 21$) | 1 | 17 | 3 | 0 |
| **Female** | Arnhem ($n = 28$) | 0 | 25 | 2 | 1 |
| | Zwolle ($n = 14$) | 0 | 13 | 1 | 0 |

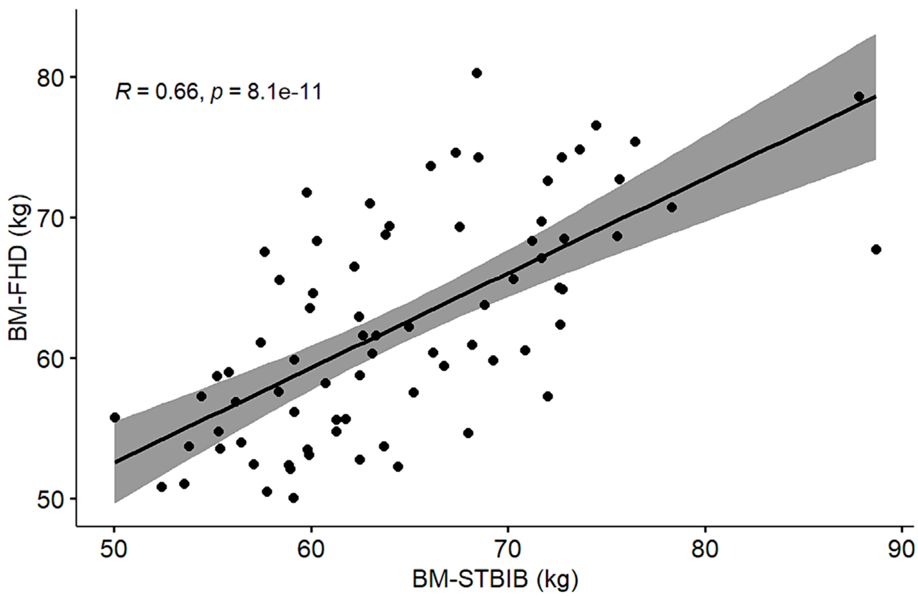


**FIGURE 6** Pearson's correlation coefficient. [Colour figure can be viewed at wileyonlinelibrary.com]

high- and low-status populations was narrowed because of the availability of a sufficient fish supply.

In addition, the production boom in refined sugar transformed it from a luxury item reserved for the wealthy to a widely available commodity (de Vries & van der Woude, 1997). The widespread availability of inexpensive sugar meant that the low-status populations likely experienced the effects of the additional energy intake from consuming extra refined sugar leading to changes in body mass increase.

Recent research on skeletal non-specific stress indicators shows significant differences: the prevalence of cribra orbitalia is higher in Arnhem samples than in Zwolle samples, yet the linear enamel hypoplasia is more common in Zwolle samples than in Arnhem samples. Porotic hyperostosis and chronic maxillary sinusitis, however, show no significant differences (Casna & Schrader, 2022). It can be considered as evidence of similar nutrition and life stress between the two populations. However, the results presented here also corresponded with the osteological paradox hypothesis, which suggests that deviations in population mortality might lead to different presents of skeletal stress indicators. For example, the more severe living conditions faced by low-status children could lead to higher child mortality. Thus, only people with relatively better nutritional status and health conditions could survive to adulthood. Although the higher classes experienced similar risks of disease and malnutrition in childhood, they might have the opportunity to get better treatment, food, and care and therefore had a greater chance of survival (Casna & Schrader, 2022; DeWitte & Stojanowski, 2015).

## 5.2 | Urban environment and infectious diseases

During the Republic period in the 17th century, the Netherlands saw a significant expansion of urbanization in cities. By the 18th century, the Low Countries region had become the most urbanized in Europe (Prak, 2005). This era also presented specific environmental risks to urban residents in the Netherlands.

Post-Medieval Dutch cities generally faced water salinization and pollution as a result of offshore dams, marshy conditions, high groundwater levels, poor drainage of water management systems, and industrial pollution. This resulted in a poor public hygiene situation (Wintle, 2000). In the 19th century, historical reports describe the existence of fetid open sewers and cesspools in cities that were overflowing with waste and industrial pollutants and a lack of proper separation from clean water sources (Wintle, 2000). Contaminated water sources in cities increased the risk of diarrhea and the spread of malaria through mosquito larvae (van Poppel et al., 2005; Wintle, 2000). Malaria became widespread in the Netherlands and resulted in a high death rate from the 17th century until the widespread use of quinine in the 20th century (Wintle, 2000).

Furthermore, the urbanization in the Netherlands led to population growth and urban expansion, resulting in densely populated and overcrowded living conditions (Prak, 2005). Characterized by close human contact and inadequate ventilation, the urban living conditions were conducive to the spread of respiratory infections, such as tuberculosis, pneumonia, and sinusitis (Casna et al., 2021; Schats, 2016). Previous research shows no significant difference between the prevalence rate of chronic maxillary sinusitis of the Arnhem and Zwolle samples (Casna & Schrader, 2022). Research on social status and chronic maxillary sinusitis in Dutch post-Medieval samples has also shown similar results (Casna et al., 2021). Such results indicate that urban living conditions, including indoor heating and factory pollution, have brought similar health stresses to people of different social statuses (Casna & Schrader, 2022). However, since patients with severe health problems who die in hospitals were usually buried in hospital cemeteries rather than churchyards, discussions about the differences in disease prevalence rates across social statuses also have biases. Similar to many Dutch cities, residents of Arnhem and Zwolle suffered greatly from bubonic plague in the mid-17th century, resulting in thousands of deaths (Habermehl, 1984; Hagedoorn, 1992). Several epidemics of dysentery and smallpox were also recorded in both Arnhem and Zwolle during the 18th century (Hagedoorn, 1992; Zielman & Baetsen, 2020).

The harsh conditions and widespread disease have a substantial effect on the body mass of the population. Diseases can drain the body of essential nutrients, hindering the uptake and distribution of nutrients, leading to nutrient deficiencies and heightened metabolic needs, disrupting an individual's energy balance and resulting in body mass reduction and wasting (King & Ulijaszek, 1999; Perkins et al., 2016). Despite the fact that low-status population may experience worse conditions, there was no rigid division of living areas based on social class in Dutch cities. Elites' servants had access to multiple dwellings and lived alongside individuals of lower status, and contaminated water sources were not isolated from the living environment of the upper class (van der Woud, 2010). As a result, in urban areas, residents of different social classes may be equally exposed to the negative impacts of spreading infectious diseases (van der Woud, 2010; van Poppel et al., 2005).

## 5.3 | Social welfare

Charity has been a prominent value in Dutch society since the 14th century, with the influence of Christianity playing a significant role (Boele, 2013). During the post-Medieval period, the Dutch cities had implemented poverty alleviation programs as part of their public works. This was achieved through the provision of basic necessities such as food, shelter, and medical care to the poor through the use of church institutions (Boele, 2013). The growth of the Dutch economy also allowed for relatively stable funding of social welfare initiatives (Prak, 2005). During this period, a number of almshouses for the sick and elderly were established, which to some extent ensured decent living conditions for citizens, although the residents of these almshouses included both middle and low statuses rather than only poor citizens (Goose & Looijesteijn, 2012). These institutions have helped to improve the living conditions of those in low-income groups, providing them with additional resources that can improve their living conditions.

### 5.4 | Limitations

It should be noted that both methods of BM estimation have their inherent limitations; hence, there are deviations between the estimated skeletal BM and the actual living BM of the population. BM estimation methods based on skeletal measurements are often limited in detecting minor fluctuations and extremes in BM (Lacoste Jeanson et al., 2017). Several previous studies state that FHD reflects the individual's BM during childhood and adolescence rather than adulthood (e.g., Niskanen et al., 2018; Ruff et al., 1991). Despite differing viewpoints in some recent studies, more evidence still indicate that adult BM is still greatly influenced by the development and growth of non-adult period (Berger et al., 2011; Gluckman & Hanson, 2006; Junno et al., 2018). Meanwhile, both the BMI results and the STBIB BM results are directly correlated with stature estimation; the accuracy of Trotter (1970) stature equations, however, has been questioned in more recent studies, which could also potentially influence the results of BM estimation (Mays, 2016; Ruff et al., 2012). Although the biases resulting from the stature equations may not necessarily affect the observation of inter-population differences in this research, it is not advisable to apply the body size results of this study to compare with the body size of other populations that are estimated from different equations.

On the other hand, in this study, the social statuses of the two collections were determined based on burial location, grave goods, and cemetery historical records. As mortuary practices usually reflect complex social, political, and economic conditions, the assessment of socioeconomic status based only on mortuary practices might deviate from the actual situation (Pearson, 1982). Also, since both include the middle classes, the actual difference in social status between the two collections may be smaller.

In addition, as the osteological paradox suggests that the research samples represent only a subset of the living populations, the absence of subadult samples may exacerbate the bias of selective mortality (DeWitte & Stojanowski, 2015; Katzenberg & Saunders, 2008; Wood et al., 1992). Harsh living conditions may lead to increased child mortality rates, with children in the poorest health being less likely to survive into adulthood. The death risks of the Arnhem population resulting from the more severe living conditions experienced by low-status populations cannot be overlooked. Adults in the Arnhem population were probably selected through early-life death, resulting in a biased sample of "survivors" who may have had advantages in survival and adaptation and, consequently, larger body size. Those who were affected by harsher living conditions and had no survival advantages may have died prematurely and thus not be represented in the research results.

## 6 | CONCLUSIONS

Results of all estimated BM are not significantly different between different socioeconomic groups in this research. Further investigation into the correlations between social inequality and body mass variations during the post-Medieval period is warranted. Increasing the sample size and including more diverse samples can enhance the research on this topic. One potential approach is to expand the sample size by incorporating skeletal collections from other Dutch urban cemeteries from the same period to compare regional differences. The sufficient sample size may support more detailed analyses and discussions in age groups and therefore reduce the impact of age factors on BM reconstruction.

Moreover, ongoing testing and research on various body mass estimation methods are essential. Specific attention should be given to examining the biases caused by different estimation methods. Although reconstructing actual population body mass from skeletal remains is challenging, comparing different methods could offer more comprehensive results. Therefore, future research on this topic should continue to explore and refine the different methods of body mass estimation to improve the accuracy and reliability of the result.

## ACKNOWLEDGMENTS

This publication is part of the project Embodied Inequality: Transforming Archaeological Knowledge of State Formation, Social Disparity, and Health Inequality (with project number VI.Vidi.201.153), which is financed by the Dutch Research Council (NWO). Thanks to the communities of Arnhem and Zwolle that provided the samples used in this research. Thanks to the RAAP Archeologie and the municipality of Zwolle who organized the excavation projects. And finally, thanks to the Laboratory for Human Osteoarchaeology, Faculty of Archaeology, Leiden University for providing all resources in research.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Niu, Y., & Schrader, S. (2024). Social inequality and body mass differences in two post-Medieval Dutch populations. *International Journal of Osteoarchaeology*, *34*(5), e3320. https://doi.org/10.1002/oa.3320