Activity Differences between Different Socioeconomic Status Populations of Arnhem and Zwolle in the Post-Medieval Netherlands

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Table of Contents

Chapter 1 Introduction

A recent study revealed the living conditions of the urban population at different socioeconomic levels affect the health of citizens by analyzing the prevalence of stress markers among persons of different socioeconomic levels (Casna & Schrader, 2022). Inspired by that study, this paper aims to examine differences in the functional status and mobility of the population's lower limbs between Arnhem and Zwolle, two cities with varying socioeconomic status (SES) in the post-medieval Netherlands. This paper is motivated by the need to understand the correlation between SES and the functional status and mobility of individuals' lower limbs in a historical urban environment and shed light on the lifestyles and labor practices of different SES populations in post-medieval cities.

The femur is one of the most critical indicators of locomotor activity in a population, and studying its functional state and mobility can assist in inferring survival strategies and behavioral patterns in different socioeconomic class groups. The Wolff hypothesis, which states that bones may adapt to mechanical loads by modifying their shape and structure, is the basis for this investigation.

The mechanical loads put on bones can be studied using skeletal biomechanics. Mechanical loads in this context refer to the loads applied to the skeleton by stretching and torsion. So, during the individual's lifetime, and with a multitude of repetitive movements, these accumulated loads cause changes in the morphology of the skeleton. A beam flow model of a building analyzed by civil and mechanical engineers was used to analyze the effects of loads imposed on the skeletal structure by specific human behavioral patterns to distinguish the different effects of different loads on skeletal morphology and thus relate the loads to the corresponding movements (Larsen & Ruff, 1994, p.21). The principle of this approach is to obtain cross-sections of bones located at different positions on the skeleton and to calculate the magnitude of the area, moment of inertia (I), and polar moment of inertia (J) data of the cross-sections to determine the different mechanical loads imposed during life. The area can be obtained from the outer surface or, in more detail, from the medullary area (MA) and the cortical area (CA); the larger the cortical area, the greater the compressive or tensile mechanical loads applied to the skeleton during the individual's prenatal period. Ix and Iy reflect anterior-posterior and internal-external bending strengths, respectively, and the value of Ix/Iy is commonly used in applications to evaluate an individual's or a population's activity level during the prenatal period. An individual's or a population's activity is determined. The polar moment of inertia (J) of the cross-section of the bone represents the ability of the bone to endure torsional loads, and the larger the value of the polar moment of inertia of the cross-section of the bone, the more activities conducted by the individual that results in femoral torsion. Although cross-sectional geometric data can be used to speculate on the mechanical loads placed on the bones of individuals or populations during their lifetime, it is difficult to directly relate these loads to specific movements or behaviors, and more accurate analyses require the use of archaeological materials and historical contexts.

In osteoarcheology, skeletal biomechanical methods offer a wide range of uses. A large amount of data was used in a comparative study between populations to determine the factors that generally affect the mechanical loading of bones, such as gender, age, and pathological conditions. A comparison of the activity level of populations was made to find that the numerical values of Ix/Iy in the lower extremities of populations with different livelihoods showed significant differences. The intrapopulation study can infer the population's activity level and livelihood by calculating the area of the lower limb cross-section, the moment of inertia (I), and the polar moment of inertia (J), among other things, and the population's activities can be further inferred by combining with historical documents or archaeological materials.

Skeletal biomechanical methods are employed in this research to more specifically expose differences in the pre-life behavioral activities of the Arnhem and Zwolle populations with various socioeconomic statuses. This research examines if there are distinct forms of labor linked with different SES by calculating the quantity of activity as well as differences in torsional loading in the different SES, taking a different approach than prior studies and incorporating historical literature. Samples with and without osteoarthritis were analyzed individually for their effects in this study to rule out the possibility that osteoarthritis affected individual activity.

The study's main question is whether there is a link between socioeconomic status, functional status, and lower-limb mobility in the Arnhem and Zwolle populations. We hypothesize that the Arnhem population with lower socioeconomic status would have higher functional status and mobility of the lower limbs, as evidenced by higher values of torsional load J and anterior-posterior load Ix/Iy in the mid-shaft cross-section, compared to the Zwolle population with higher socioeconomic status. This paper also analyses whether differing socioeconomic status affects the development of osteoarthritis and the effect of osteoarthritis development on the morphology of lower limb bone cross-section.

This paper achieves this goal by using bilateral femoral cross-sections as a sample of skeletal biomechanics in a lower SES Arnhem population and a higher SES Zwolle population dataset. J-values (torsional loading) and Ix/Iy (anterior-posterior loading) data from skeletal cross-sections are compared.

1.1 Thesis Structure

This research is divided into six major chapters. The theme, goal, and significance of this study, as well as the overall format of this work, are covered in the first section of Chapter 1. The background section in Chapter 2 comprises mostly a review of past studies on the research methodology of this work and how it connects to it. The material and method section of the third chapter focuses on the origins and composition of the materials used in this study and the research methods employed. The statistical results of the link between lower limb functional status and mobility within and between different SES populations are presented in Chapter 4. This study initially examines the differences in lower extremity functional status and mobility within and between the two SES populations in the discussion section of Chapter 5. Furthermore, because diseases such as lower extremity osteoarthritis can affect an individual's mobility, which in turn affects the functional status and mobility of the individual and the population's lower extremities, this paper examined the correlation between SES and lower extremity osteoarthritis to see if there is a difference in the prevalence of lower extremity osteoarthritis between the two populations of different SES and whether the presence of o Finally, the conclusion section in Chapter 6 summarizes the study's principal findings.

Chapter 2 Background

This chapter contains a review of the development of the skeletal biomechanics research methodology employed in this paper, as well as a review of past studies that have used this methodology to explore differences between different SES population.

2.1 Skeletal Biomechanical Methods and Population Activity

Although the entire process of bone remodeling is not completely understood, the influence of activity on bone is obvious (Ruff, 2018, p. 189). In current research, there are several methods for studying population activity patterns by reconstructing physical activity and habitual movement sequences, such as analysis of the development of musculoskeletal markers and attachments (Hawkey & Merbs, 1995, p. 324), bone measurements (Wanner et al., 2007, p. 253), pathological phenomena such as degenerative joint disease (Sofaer, 2000, p. 333) or osteoarthritis (Larsen, 1997, p. 161), and skeletal biomechanical methods.

Julius Wolff's research in the 19th century stated that bones are very sensitive to mechanical stimulation, that skeletal morphology and size change in response to external forces, and that skeletal tissues are constructed to reflect functional demands (Wolff, 1892). Wolff's predictions were validated in various animal tests carried out during this time period to evaluate the morphological changes of the skeleton in different loading states, as well as in the study of skeletal data from humans who had undertaken special activities for extended periods of time, such as athletes. Observations in both animal and human samples revealed that prolonged periods of increased loading increased cortical bone content, e.g., animals with the radius removed showed an increase in cortical bone (Chamay & Tschantz, 1972, p. 173), young pigs with increased exercise showed endosteal deposition (Woo et al., 1981), and human tennis players showed an increase in the cortical bone content of the humerus (Jones et al., 1977),

Beam flow models for civil and mechanical engineers analyzing buildings were utilized in various research studies in the 1980s and 1990s to analyze the effects of loading on the skeletal structure induced by certain patterns of human behavior (Larsen & Ruff, 1994, p. 21). The various ways in which the human body's bones are subjected to external forces during movement or labor are referred to as bone loading. Depending on how the stresses and moments are delivered, bone loading can be tension, compression, bending, shear, torsion, or mixed. Tension loading occurs when equal and opposite forces are applied outwardly from the surface of the section, bending loading produces tension, and compressive forces on the bone, and torsional loading refers to the twisting of the skeletal elements about their axes, resulting in combinations of tension, compressive, and shear forces. Bending and torsional pressures on long bones are the most common (Larsen & Ruff, 1994; Ruff, 2008, p. 192).

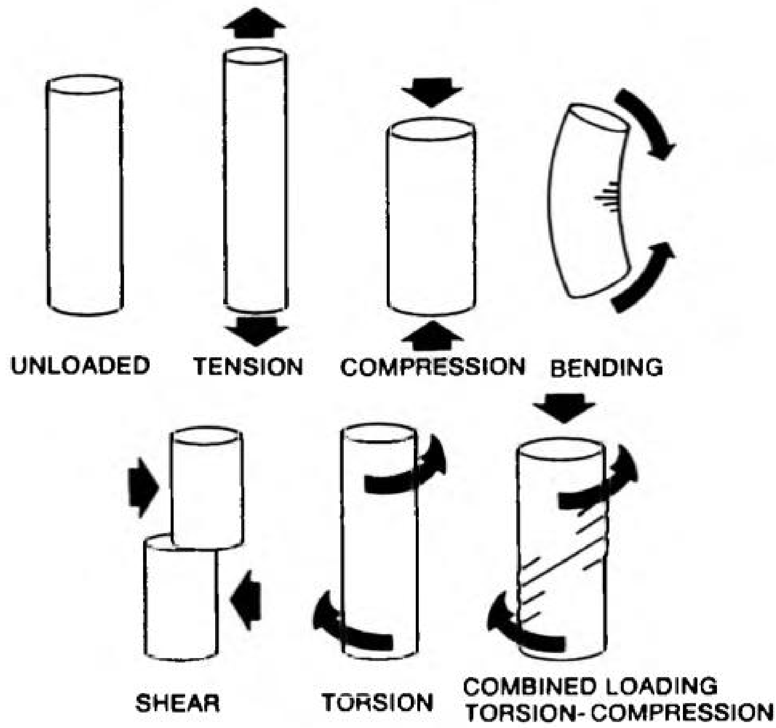

Figure2.1 Forces and Moments Applied on Bone. Including tension, compression, bending, shear, torsion, and combined. (Nordin & Frankel, 1980; Larsen, 1997, p. 197)

The distribution of skeletal tissues in the section, which includes a portion of the 'area' and a 'second portion of the area,' is measured by cross-sectional geometric characteristics. The total subperiosteal area (TA), medullary area (MA), and cortical area (CA) are all included in the area. The width of the medial-lateral (ml) and anterior-posterior (ap) long bone diaphyses was used to compute the area of the two planes, where T is the total external diameter, and M is the medullary diameter (Ruff & Jones, 1981, p. 72).

Resistance to pure compressive and tension loading is proportional to the quantity of cortical bone in the cross-section, which is estimated by subtracting the medullary area (MA) from the total subperiosteal area (TA) (Ruff, 2008; Larsen, 1997, p. 199). Expansion of the TA and MA suggests a larger distribution of skeletal tissues away from the bone's neutral axis. CA is a measurement of the cross-section of the cortical bone. It also reveals the strength of the long bone diaphysis under simple axial stress (similar to loading applied simultaneously to both ends of the bone) (Ruff, 1992, P. 193).

$$TA = \Pi(Tap / 2)(Tml / 2)$$

$$MA = \Pi(Map /2)(Mml / 2)$$

$$CA = TA - MA$$

The femoral diaphyseal is rarely subjected to axial stresses alone during human movement. It is, however, frequently accompanied by bending and torsional stresses caused by muscle contraction. The second moment of area, denoted by I, represents the anterior-posterior loading. It is proportional to the cross-sectional area and is controlled by the distribution of bone tissue around the neutral axis, i.e., the cross-sectional form. The greater the bending resistance in a given direction for the same cross-sectional area, the further the bone distribution is from the center point and the more the cross-section deviates from a circle (Ruff, 2008; Larsen, 1997, p. 199). Ix and Iy represent the cross-section's anterior-posterior and internal-external bending robustness, respectively. The parameter reflecting torsional loading of the cross-section is the polar moments of area, which suggests the magnitude of the bone's ability to withstand torsional loading and expressed in terms of J, the value of the polar moments of inertia (J) reacts to the strength of the bone's ability to withstand torsional loading, i.e., the larger the value, the more activities performed by an individual that resulted in femur torsion. The ratio of Ix/Iy represents the cross-section shape; the bigger the value, the more the cross-section shape deviates from a circular shape and becomes an asymmetric ellipse with a larger anterior-posterior diameter (Ruff, 2008; Larsen, 1997, p. 201).

2.2 Factors Affecting the Accuracy of Activity Levels

In addition to mechanical loading, many variables are thought to influence limb bones' cross-sectional geometry. Population behavioral patterns, topography, social context, sex, age, and laterality are among the characteristics considered.

Behavioral changes linked with survival strategies during human evolution may have long-term, albeit complex, implications on diaphyseal development. Different settings linked with different survival strategies have been found in studies to cause alterations in the geometry of diaphyseal cross-sections. Previous research on archaeological material from coastal Georgia, USA, discovered that the relative bone strength of the femur and humerus decreased from the pre-agricultural to the agricultural period, with this decline attributed to improved dentition and reduced workloads in agricultural populations (Ruff et al., 1984, P. 125). However, investigations of other indigenous North American groups that experienced changes in diverse subsistence strategies have produced conflicting results (Brock & Ruff, 1988, p. 113). Ruff (1999, p. 290) discovered no significant, consistent effect of survival strategy on femoral torsion loading in a joint examination of six separate prehistoric North American samples that controlled for physical topography variables. Another study of North American samples found comparable results, using only external long-bone data (Wescott, 2006, p. 201). This implies that changes in survival strategy may have varying consequences on diaphysis activity and mechanical loading but are also influenced by specific cultural and physical contexts. Meanwhile, previous research has discovered that the Ix/Iy values of the mid-femur cross-section can be used as an indicator of the population's activity level, as shown in Figure 2.2, where the population's livelihood mode in the transverse axis gradually overshoots from collection to agriculture from left to right, and the values of Ix/Iy show a clear downward trend (Larsen et al., 1995; Larsen, 1997, p. 205).

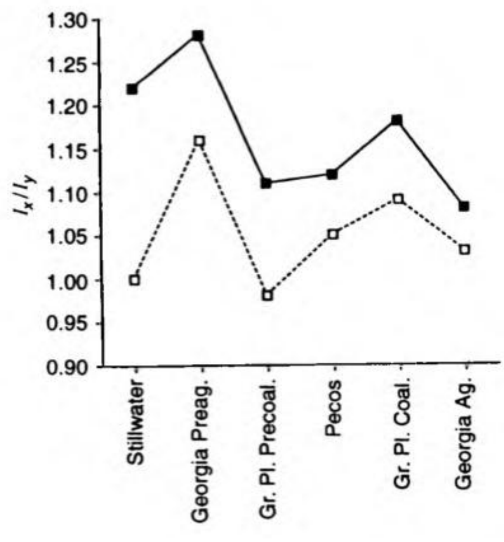

Figure 2.2 Differences in Ix/Iy values between populations with different livelihoods (Larsen et al., 1995; Larsen, 1997, p. 205)

Geographic terrain, in addition to survival strategy, has a substantial impact on limb bone mechanical loading. When statistically controlling for survival strategy and sex, population samples from mountainous locations had higher femur robustness than those from plains or coastal areas, which is consistent with mechanical results throughout rugged terrain (Ruff, 1999, p. 290). Recent research has used the European samples of approximately the same size from various archaeological sites to analyze the effect of geography on the relative strength of limb bones more quantitatively (Holt et al., 2018). Overall femur and tibia strength ratios (size-standardized Zp), as well as A-P (anterior-posterior) and M-L (medial-lateral) strength ratios (size-standardized Zx / Zy), were shown to be considerably greater in hilly terrain than in flat terrain. The A-P bending strength increased in the more rugged terrain samples, which suggests that greater extension forces are required during climbing (Holt et al., 2018, p. 117).

Sex dimorphism can also be seen in skeletal cross-section geometry. Previous research has indicated that men had better average upper limb skeletal strength because they have more upper body strength. However, this could be attributable to lifestyle factors (Weiss, 2003, p. 293). Moreover, due to the demands of childbearing, females often have larger hips and increased medial-lateral (M-L) bending strains on the proximal femur (Ruff, 1995, p. 527). Simultaneously, pregnancy and childbearing exert higher mechanical demands on females, which should be considered when interpreting the limb skeleton structure of sex dimorphism (Wall-Scheffler & Myers, 2013, p. 448). Additionally, sex dimorphism differs across subsistence strategy contexts. Hunter-gatherers often have high levels of sex dimorphism in mobility, whereas agricultural cultures have lower levels of sex dimorphism, and industrial societies have lower levels of sex dimorphism (Ruff, 1987, p. 402).

Individuals' skeletal cross-section geometry traits alter as they age. In adult individuals, there is a pattern of sex-differentiated behavior in juveniles. Previous research, for example, examined the structural characteristics of a sample of Pecos Pueblo youngsters' long bones and discovered that adolescents under the age of 15 could not be reliably sexed. On the other hand, those aged 15-19 demonstrated statistically significant sex differences in A-P/M-L bending resilience (p=0.05, inter-sex t-test). The mean percent difference between them was 12.7%, which was comparable to the difference between adults (13.3%) (Ruff, 1987, p. 396). This shows that sex-differentiated behavioral characteristics comparable to those observed in adults exist among older Pecos Pueblo adolescents. In addition, from childhood to early adulthood, the outer surface of the mid-femoral skeleton (TA) develops faster than the inner surface (MA), increasing relative cortical area (%CA) in the Pecos Pueblo population (4-55 years). However, at the age of 40, this pattern flips, with the MA increasing faster than the TA, resulting in a drop in %CA, bone mass, and cortical thinning. These patterns are comparable to those found in present living populations (Frisancho et al., 1970, p. 641). Thus, the geometric shape properties of a person's skeletal cross-section vary with age and are influenced by sex-differentiated behavioral tendencies and age.

Bilateral (left-right) asymmetry in long bone structure can reflect broad principles of functional skeletal adaptation and unique previous population practices. Studies have discovered a link between mechanical stress and bilateral bone strength asymmetry by comparing athletes with enhanced asymmetric upper limb use (Ruff et al., 2006, p. 484). Significant asymmetry in upper limb loading is observed in Neanderthal and Late Paleolithic samples, possibly attributable to upper limb activities such as throwing (Shaw & Stock, 2009, p. 163). Asymmetry of the humerus was found to be associated with war-related behaviors in a sample of medieval and Iron Age Europe, with people of different social status showing varying degrees of asymmetry, a pattern that disappeared in the later stages of general conscription (Sparacello et al., 2015, p. 309). Furthermore, multiple studies have found a link between the pellet-grinding technique and bilateral humeral asymmetry, with two-handed grinding in early agricultural samples resulting in low levels of asymmetry in females (Sparacello et al., 2015, p. 309). These findings imply that bilateral asymmetry can represent differences in activity among populations.

Pathologies of the skeleton, such as osteoarthritis, can also have an impact on an individual's activity, as evidenced by data on cross-sectional geometry (Palmer et al., 2016, p. 81; Schats, 2016, p. 42). Osteoarthritis is most likely to affect the body's synovial joints, and it begins by affecting the articular cartilage. As the disease progresses, more new bone proliferates at the edges of the joints, and porous surfaces can form in the joints until the joints form eburnation surfaces (Rogers, 2000, p. 163; Waldron, 2009, p. 26). Although osteoarthritis can be influenced by several factors such as body weight, living environment, or climate, exercise is required for the development of osteoarthritis (Waldron, 2009, p. 28), and past behavioral activities have been used to infer osteoarthritis formation in much previous research (Palmer et al., 2016, p. 84; Schats, 2016, p.42), and behavioral activities throughout an individual's and population's life can influence skeletal cross-section data.

2.3 Methods for Obtaining Bone Geometry Cross Sections

In the process of geometric analysis, a cross-sectional image prepared in a direction perpendicular to the longitudinal axis of the bone needs to be created. Direct cuts from the long bone diaphysis (Larsen & Ruff, 1994, p. 21) or non-intrusive imaging, such as computed tomography (CT) (Ruff, 1987, p. 396), multiplanar radiography (Trinkaus & Ruff, 1989b, p. 33), and photon absorption measurements (Martin & Burr, 1984, p. 195), can be used to obtain this image. One of the approaches is direct cuts from the long bone diaphysis. In the event that there are no incidental breaks or non-intrusive imaging facilities available, the endosteal of bone and/or the periosteal boundaries can be approximated using other non-intrusive methods. The ellipsoidal modelling method (EMM) and the latex casting method (LCM) (O'Neill & Ruff, 2004, p. 221) are two of the most common methods that are currently available.

When evaluating the bone's cross-sectional properties, biplane radiographs in the anteroposterior (A-P) and medial-lateral (M-L) planes are one of the most used diagnostic tools. With this approach, the cortex is described as two ellipses, and the widths of the subperiosteal and endosteal are assessed on radiographs taken in the A-P and M-L planes, respectively. According to Runestad et al. (1993, p. 208), it is possible to compute the cross-sectional properties by making use of basic geometric formulas. The center of mass of the internal ellipse is placed eccentrically within the exterior ellipse by utilizing the parallel axis theorem (Runestad et al., 1993, p. 208). This is a more difficult method of derivation. However, with the exception of certain particularly asymmetrical regions, such as the mandibular body (Biknevicius & Ruff, 1992, p. 157), the disparity in results between the concentric model and the eccentric ellipse model is quite minimal (Runestad et al., 1993, p. 210). When using the LCM (latex cast method), the subperiosteal shape is often produced using a mold constructed of silicone putty material. This mold is obtained by allowing the silicone putty material to cure and then removing (cutting) it. According to Wainwright et al. (1978, p. 243), when beams are subjected to bending and torsional loads, the material that is located furthest away from the center of mass of the cross-section is most associated with providing robustness and strength.

O'Neill MC and Ruff CB (2004, p. 226) published the results of a study in which they compared the accuracy of these two different approaches. The research demonstrated that ellipsoidal modelling and latex casting procedures strongly correlated with the cross-sectional properties of human femurs and tibiae. This was demonstrated by the findings of the study. While the random (absolute) estimation errors for LCM were between 3% and 8%, the estimation errors for EMM ranged from 5% to 14%. The EMM showed a consistent tendency to result in an exaggerated assessment of the cross-sectional characteristics. On the other hand, the directional bias for LCM was typically quite small (with the exception of certain areas of the MA), which means that LCM may be relied upon to accurately estimate cross-section properties (O'Neill & Ruff, 2004).

It is possible to analyze the amount of activity and prenatal forces of individuals and even groups of people, which can help to infer and analyze the prenatal behaviors of groups of people. However, the method of skeletal biomechanics at this stage of development is unable to relate the different changes in the morphology of skeletal cross-sections to the specific behavior of individuals during their lifetime. This is due to the fact that the morphology of skeletal cross-sections does not change during an individual's lifetime. In certain contexts, exercising extreme caution and accounting for the flaws introduced by the various approaches is required to arrive at an interpretation that is more all-encompassing of the findings.

Chapter 3 Material and Method

The content of this chapter concentrates on the profile of the Arnhem and Zwolle populations for which the text utilizes the material, covering elements such as region, year, socioeconomic status, and demography. Simultaneously, the method for obtaining femur cross-sections is provided.

3.1 Arnhem Collection

Arnhem is the capital of the province of Gelderland in the Netherlands' east. After 1950s, Arnhem's population had nearly doubled from 10,000 to almost 20,000. Prior to this period, Arnhem's working class was mostly engaged in small-scale manufacturing(van Laar, 1966). Both men and women engaged in manual labor, up to 20 hours per day (Wintle, 2000).

The material for this study came from Arnhem's Oude Kerkhof cemetery. The cemetery was utilized from 1444 until 1829 when burials were restricted in the city center due to population growth, and a new cemetery was created outside the city (Baetsen et al., 2018, p. 34). The excavated cemetery on the Eusebius Church. Workers from the local brewery, tannery, brick factory, and people involved in manual labor, food production, or textiles are buried there (Baetsen et al., 2018).

The research and consulting firm RAAP excavated the cemetery in 2017 as part of the Jansbeek project, which aims to revitalize deteriorating urban neighborhoods (Baetsen et al., 2018). During the excavations, walls, structures, water supply facilities, rubbish pits, and ancient relics such as metalwork, glass, animal bones, and ceramics were discovered. Approximately 350 relatively complete human skeletons representing diverse age and gender groups were discovered at the same time (Baetsen et al., 2018, p. 39). The collection is currently housed at Leiden University's Laboratory of Human Osteoarcheology.

The skeletal collections excavated from the northern part of the Eusebius church are assumed to be mostly of people with lower social status, the northern section of the church was often assigned for the interment of people from lower socioeconomic origins and those seen as outsiders (Zielman & Baetsen, 2020, p. 706). Wealthy individuals with sufficient wealth and social position selected the southern region for burial locations, but those without did not (Baetsen et al., 2018).

3.2 Zwolle Collection

The settlement of Zwolle, which dates back to the Middle Ages, its spectacular economic growth made the city very important, and it was officially designated as the capital of the province of Overijssel in 1798 (ten Hove, 2005). Zwolle's aristocracy swiftly acquired control of the city's governance after it became the capital. According to historical sources, Zwolle was the most affluent city in the Upper Overijssel region, with city coffers that were frequently double those of other Dutch cities (ten Hove, 2005).

The Zwolle skeleton collection was excavated from the Broerenkerk church in Zwolle, Overijssel province. Excavations started in 1987, as church restoration plans threatened to ruin the tombs beneath the church floor (Hagedoorn, 1992, p. 13). Around 500 bones were excavated from the church. Because many of the gravestones were well preserved, the inscriptions on some of the gravestones could be used to estimate the hierarchy and position of some of the burials. Individuals in the Broerenkerk collection can be traced back to the 17th-19th centuries based on inscriptions on gravestones, documentary chapel records, and coins found in graves (Hagedoorn, 1992, p. 23). The collection is currently housed at Leiden University's Laboratory of Human Osteoarcheology.

The Broerenkerk church was built in 1551 and was demolished and abandoned several times before being rebuilt as a church in 1640 A.D. Hagedoorn (1992, p. 41) describes the construction and sale of new tombs and gravestones. The prices for graves and burials in the Broerenkerk church were not the cheapest in Zwolle, implying that the people buried in the Broerenkerk church may not have had the highest social status (Hagedoorn, 1992, p. 38). According to 18th-century records, the cost of a burial at the church in Zwolle is up to 16.80 guilders (Hagedoorn, 1992, p. 38). The occupations of the identified grave owners included artisans, merchants, millers, junior officials, schoolmasters, and a former mayor, implying that the Zwolle collection at Broerenkerk was wealthier and with higher social status than those from the Arnhem cemetery on the north side of Eusebius Church (Hagedoorn, 1992, p. 43).

3.3 Sample Selection

The Arnhem population was chosen from 49 individuals with largely well-preserved femurs that could be identified by sex and age-at-death. The majority (39/49, 79.59%) had bilateral femur samples, with 7 samples having only the right femur and 3 samples having only the left femur. 9 of the 49 individuals were female, 15 were male, 12 were female-skewed, and 13 were male-skewed; for statistical purposes, female and female-biased and male and male-biased individuals were combined as a whole, i.e., 21 (21/49, 42.86%) female/female-biased individuals and 28 (28/49, 57.14%) male/male-biased individuals. The samples drawn from the Arnhem population were all adult samples, with the biggest age group being Middle Adults *n*=23 (23/49, 46.94%), followed by 18 young adults (18/49, 36.73%), and the fewest being Old Adults (8, 8/49, 16.33%).

The sample was drawn from a group of 45 people in Zwolle who had relatively well-preserved femurs. The majority of the samples (41/45, 91.11%) had bilateral femurs, with three having only the right femur and one having only the left femur. The 45 people included 19 females, 16 males, 3 female-biased people, and 7 male-biased people, and for data statistics, females, female-biased people, and male-biased people were combined. Females and female-biased individuals were merged, as were males and male-biased individuals, for a total of 22 (22/45, 48.89%) females/female-biased individuals and 23 (23/45, 51.11%) males/male-biased individuals. The samples drawn from the Arnhem population were all adult samples, with the most middle adult24 individuals (24/45, 53.33%), 12 (12/45, 26.67%) young adults, and 9 (9/45, 20.00%) old adults.

Table 3.1 Demographic composition of the total sample, divided by sex, age and side.

			Young adult (20-34 years)	Middle adult (35-49 years)	Old adult (50+ years)	Total
Arnhem	Female	Right	9	9	1	19
		Left	8	10	0	18
	Male	Right	8	12	7	27

		Left	7	13	5	25
Total			32	44	13	89
Zwolle	Female	Right	4	12	5	21
		Left	4	11	4	19
	Male	Right	7	12	4	23
		Left	7	12	4	23
Total			22	47	17	86

3.4 Method

3.4.2 Cross-sectional Properties

Through the use of skeletal biomechanics, this research's investigation of the activity resulted in the activity being broken down into two numerical data: anterior-posterior loading and torsional loading. The cross-sectional characteristics of this measurement include the anterior-posterior cross-sectional moment of inertia (Ix), which responds to anterior-posterior bending robustness; the internal and external cross-sectional moment of inertia (Iy), which responds to internal and external bending robustness; the polar moment of inertia (J), which responds to the bone's ability to withstand torsional loading; and the cross-section For purely axial stresses, the area of the cross-section of the backbone has the potential to respond to the bending rigidity of the femur, at least in theory. However, the cross-section area (TA) statistics are not utilized because of the naturally curved nature of the femur and the complicated musculoskeletal system that makes it difficult to generate complete axial forces in practice (Larsen, 1997, p. 196). This is because it is problematic to generate purely axial forces in practice.

Table 3.3 Definitions of cross-sectional geometric properties.

	Abbreviation	Units
Second moment of area about the ML (x) axis	Ix	mm^4
Second moment of area about the AP (y) axis	Iy	mm^4
Polar second moment of area	J	mm^4
Ratio of moments of inertia	Ix/Iy	

3.4.3 Preparation of Cross-sections

In this study, the non-invasive Latex Cast Method (LCM) was utilized. This technique makes use of dental impression silicone putty material to obtain the outer contour pattern of the mid-shaft femur cross-section. After the material has been allowed to air dry, the shaped material is cut off with a knife to obtain the outer contour line of the mid-shaft femur cross-section (O'Neill & Ruff, 2004, p. 223; Stock & Shaw, 2007). After obtaining the outside contour lines, they were scanned into a computer using a printer, and the resulting scanned PDF file was edited in Photoshop (2023) to provide a clear profile of the cross-section. In the end, the JPG file containing the cross-section profile was loaded into the Fiji software so that the RGB image could be converted into a grayscale image, and the scale of the pixels and the units of measurement could be determined. BoneJ, a plugin for the Fiji software, was used to do the calculations necessary to determine the biomechanical parameters of the resulting outer contour section (Domander et al., M[CP]. 2021).

Figure3.1 Silicone putty material to obtain the outer contour pattern of the mid-shaft femur cross-section, Zwolle125R (Photo by Xuwen Yue, 2023)

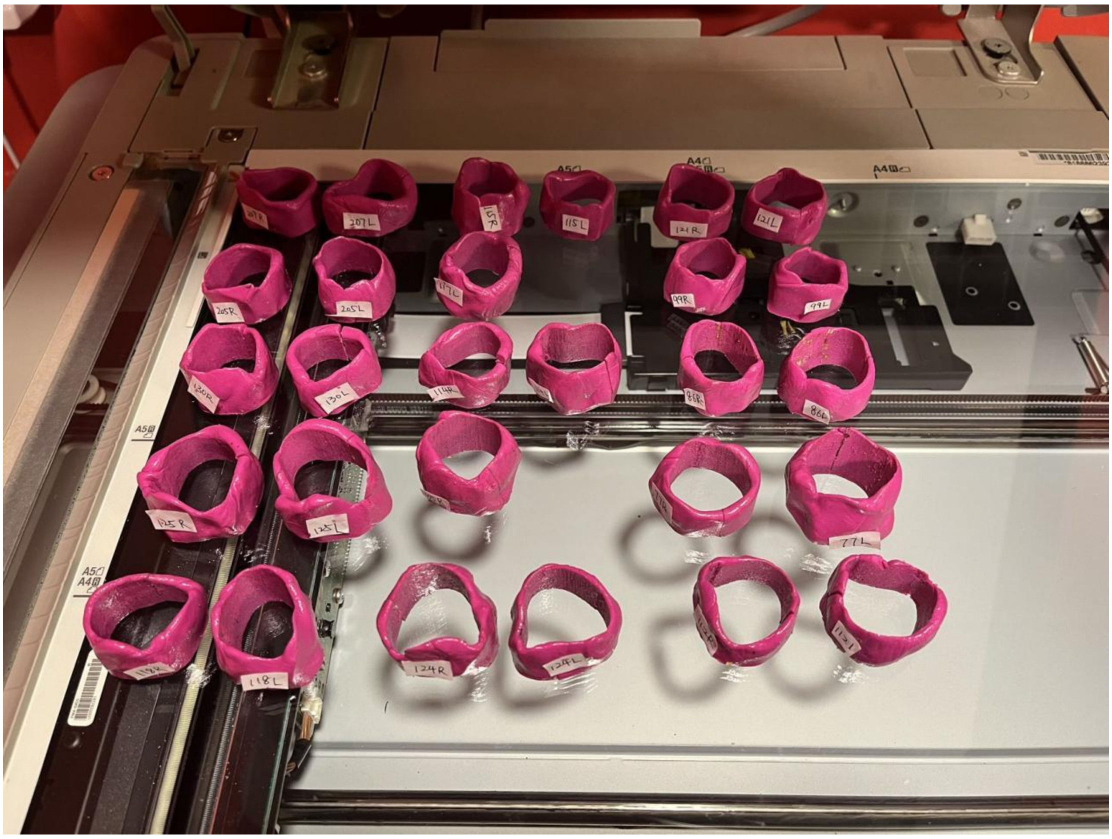

Figure3.2 Scan the outer contour lines of the cross-section (Photo by Xuwen Yue, 2023)

Figure3.3 The pdf of outer contour lines cross-section (Photo by Xuwen Yue, 2023)

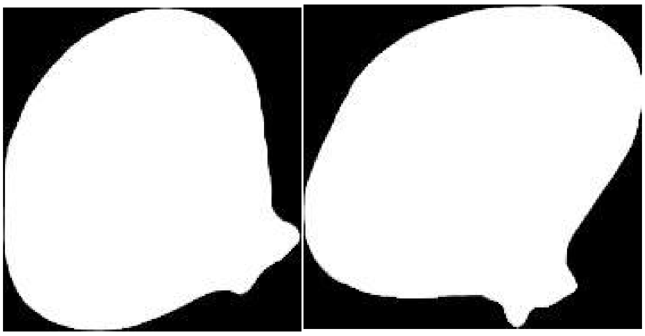

Figure3.4 grayscale image the pdf of outer contour lines cross-section, Zwolle125L(left) Zwolle125R(right) (Photo by Xuwen Yue, 2023)

3.4.3 Size Standardization

Because the carrying capacity of axial tension and compression loads on the long bones is related to the cross-sectional area of the diaphysis, the body weight creates axial loads on the femur. Therefore, the area of the cross-section needs to be standardized according to the total body weight. The amount of such loads is controlled by the length of the diaphysis and the body weight. Meanwhile, the cross-sectional moment of inertia shows the loading capacity for bending and torsion loads. As a result, it is essential that it be standardized in accordance with the body weight and the length of the femur through the utilization of Ruff's formula (Ruff, 2008, p. 197):

standardized moment of inertia = (moment of inertia/body weight * femur length^2)*10^5

There are three different estimation formulae for body weight that were used in this study. These formulas were developed by McHenry (McHenry, 1992, p. 421), Grine et al. (Grine et al., 1995, p. 178), and Ruff et al. (Ruff et al., 1991, p. 406). These three methods have been evaluated in previous studies, and the average of the three was found to be the most reliable for normal-sized individuals but not for those who are too small or too large; McHenry's method is suitable for extrapolating body weight for small-sized individuals, and Grine's method was derived from a study of medium- and large-sized individuals, and is therefore suitable for extrapolating body weight for medium- and large-sized individuals (Auerbach & Ruff, 2004, p. 334). Therefore, in order to estimate body weight, the McHenry formula was utilized whenever the femoral head diameter was less than 38 millimeters (which corresponded to a body weight of less than 50 kilograms); the average of the McHenry, Ruff, and Grine formulas was utilized whenever the femoral head diameter was between 38 and 47 millimeters (which corresponded to a body weight of approximately 50 to 70 kilograms); and the average of the Ruff and Gr According to the findings of Auerbach and Ruff (2004, p. 334), the average of the Ruff and Grine formulas was calculated.

Table 3.4 Body weight estimation

Ruff et al. (1991)	BM=(2.741*FH-54.9)*.90 (males) BM=(2.426*FH-35.1)*.90 (females) BM=(2.160*FH-24.8)*.90(combined sex)
McHenry (1992)	BM=2.239*FH-39.9
Grine et al. (1995)	BM=2.268*FH-36.5

Note 1): BM: body weight (kg)
Note 2): FH: anterior-posterior femoral head width (mm)

3.4.4 Statistical Analysis

Fiji software data CSV files were imported into Excel for basic descriptive statistics. SPSS (version 20) was used to analyze the relationships between categorical variables age, sex, side, and population and numerical variables J and Ix/Iy.

The independent samples t-test was used to compare the means of two groups of different numerical variables (J, Ix/Iy), with significance levels set at $p \leq 0.05$ and $p \leq 0.10$. The independent samples t-test was chosen since the data in this study were both qualitative and quantitative and because the data groups were independent of one another and the sample as a whole was normally distributed. The focus was on the interpretation and significance of the results in the context of the specific study rather than only considering the established criteria of "significance," so the criterion of p<=0.05 was not used (Valeggia & Fernández-Duque, 2022). In addition to reporting findings with p<=0.05, outcomes with p<=0.10 were also regarded as significantly different from the rest of the data when interpreting the results.

In the following chapter, the samples that were acquired were tallied separately according to the presence or absence of osteoarthritis. Additionally, the effect of osteoarthritis on the data obtained from the femur cross-section was analyzed. The data on the femur cross-section were analyzed independently both within and between populations of varying socioeconomic status for the samples that did not have osteoarthritis. This was done in order to deduce the effect that differences in socioeconomic status had on the prenatal activity of the population.

Chapter 4 Result

The functional state and mobility of the lower limbs are compared in this chapter between and within the populations of Arnhem and Zwolle, including differences according to the side, sex, and age of the subgroups being studied. In order to accomplish this objective, a group that did not have osteoarthritis was chosen and examined for changes in anterior-posterior and torsional stress. The functional state and mobility of the lower limbs are compared in this chapter between and within the populations of Arnhem and Zwolle, including differences according to the side, sex, and age of the subgroups being studied. In order to accomplish this objective, a group that did not have osteoarthritis was chosen and examined for changes in anterior-posterior and torsional stress.

4.1 Intrapopulation Comparison of Samples without Osteoarthritis

4.1.1 Arnhem

4.1.1.1 Side Difference

Torsional stresses on the right and left sides of the femur were studied in an osteoarthritic sample from the Arnhem community. To determine the significance of the differences, an independent samples t-test was employed, and the means and standard deviations of J (torsional load) and Ix/Iy (anterior-posterior load) are reported in Table 4.1. There was both unilateral and bilateral femoral presence in the sample. The comparison of J values between the left and right sides in the Arnhem population without osteoarthritis revealed a significant difference at the significance level of =0.050, t([df (26)]) = [value of t (-0.853)], p = [value of p (0.040)]. The left side of the femur (mean=963.2454) saw significantly more torsional loading than the right side (mean=884.2417). However, no significant differences in anterior-posterior loading were discovered, t([df (26)]) = [value of t (2.242)], p = [value of p (0.160)].

Table 4.1 Side difference of Arnhem population with independent sample t-test results.

	side	N	mean	Std. Deviation	Sig.
Ix	right	14	4527.789	93.19423	0.217

	left	14	4532.473	145.36364	
Iy	right	14	4314.628	89.07970	0.051
	left	14	5099.981	178.92849	
J	right	14	8842.417	159.72425	**0.040***
	left	14	9632.454	307.57125	
Ix/Iy	right	14	1.0657	0.20677	0.160
	left	14	0.9092	0.15946	
TA	right	14	1101.8822	109.65343	0.177
	left	14	1178.8757	161.92662	

4.1.1.2 Sex Difference

The researchers looked at male and female samples from the Arnhem community to see if there were any significant differences in the torsional and anterior-posterior loads that were placed on the femur. The significance of the differences was determined using t-tests on independent samples. Table 4.2 presents the means and standard deviations of J (torsional loading) and Ix/Iy (anterior-posterior loading), respectively. According to the findings, the statistical tests conducted at significance levels of =0.050 and =0.100 indicated no significant differences in torsional and anterior-posterior loads between the male and female sides of the sample that did not have osteoarthritis in the Arnhem population. These findings were based on the sample of those who did not have osteoarthritis. In particular, the significance levels (p-values) for both J and Ix/Iy were more significant than their respective significance levels, indicating that the observed differences were not statistically significant, with no difference in the total area of the outer contour of the cross-section. This was the case because both J and Ix/Iy had significance levels that were more significant than their respective significance levels.

Table 4.2 Sex difference with independent sample t-test results.

		Sex	N	mean	Std. Deviation	Sig.
Right	Ix	Female	5	4349.553	77.15141	0.423
		Male	9	4626.809	104.05944	
	Iy	Female	5	4518.255	128.65400	0.041
		Male	9	4201.502	64.92797	

	J	Female	5	8867.808	185.69021	0.633
		Male	9	8828.311	155.59575	
	Ix/Iy	Female	5	1.0041	0.25232	0.767
		Male	9	1.0999	0.18429	
	TA	Female	5	1146.4670	80.15338	0.176
		Male	9	1077.1128	119.97468	
Left	Ix	Female	4	5693.204	174.43567	0.415
		Male	10	4068.181	109.52711	
	Iy	Female	4	6550.89	170.77525	0.693
		Male	10	4519.617	153.05049	
	J	Female	4	12244.093	289.35823	0.478
		Male	10	8587.798	257.47912	
	Ix/Iy	Female	4	0.8843	0.23701	0.255
		Male	10	0.9192	0.13273	
	TA	Female	4	1303.0797	143.97791	0.867
		Male	10	1129.1942	146.16773	
Sum	Ix	Female	9	4946.731	139.28958	0.995
		Male	19	4332.794	107.85141	
	Iy	Female	9	5421.648	175.18327	0.209
		Male	19	4368.931	117.69517	
	J	Female	9	10368.379	283.37825	0.319
		Male	19	8701.725	209.90472	
	Ix/Iy	Female	9	0.9509	0.23852	0.600
		Male	19	1.0048	0.18026	
	TA	Female	9	1216.0726	133.41326	0.815
		Male	19	1104.5240	133.39269	

4.1.1.3 Age Difference

Next, I evaluated torsional and anterior-posterior femoral loading in different age categories (YA and MA) in an Arnhem population free of osteoarthritis. The data were then separated into left and right sides, and the significance of the differences was determined using independent sample t-tests. Table 4.3 displays the averages, standard deviations, and statistical significance of J (torsional load) and Ix/Iy (anterior-posterior load).

The comparison of Ix/Iy values for the YA and MA age groups for the left-sided sample revealed a significant difference between the samples without osteoarthritis in the Arnhem population at the =0.050 significance level, t([df (12)]) = [value of t (2.431)], p = [value of p (0.016)]. Specifically, anterior-posterior loading of the left femur differed across the YA and MA age groups (mean=0.9975). The YA age group had a considerably higher anterior-posterior load on the femur than the MA age group. However, no significant differences in torsional loading were identified, t([df (12)]) = [value of t (-0.209)], p = [value of p (0.315)].

The remaining tests indicated that the significance of the differences in torsional and anterior-posterior loads on the femur between the YA and MA age groups have p values that are lower than the reported statistically significant alpha levels, respectively, in the right side of the Arnhem population sample. These findings were based on the fact that the right side of the population sample was evaluated. As a result, no statistically significant differences in torsional and anterior-posterior loads were discovered to exist between the prenatal YA and MA age groups on the right side of the sample differences, and there was also no difference in the total area of the outer contour of the cross-section.

Table 4.3 Age difference with independent sample t-test results.

		Sex	N	mean	Std. Deviation	Sig.
Right	Ix	YA	9	4250.29	86.84951	0.921
		MA	5	5027.288	91.04803	
	Iy	YA	9	4281.037	96.88501	0.563
		MA	5	4375.091	83.33597	
	J	YA	9	8531.327	160.65131	0.775
		MA	5	9402.379	158.74141	
	Ix/Iy	YA	9	1.0137	0.21802	0.408
		MA	5	1.1593	0.16390	
	TA	YA	9	1105.4999	105.19443	0.425
		MA	5	1095.3703	129.85917	
Left	Ix	YA	7	4715.918	161.30263	0.930
		MA	7	4349.028	137.76496	
	Iy	YA	7	4738.002	124.98145	0.122
		MA	7	5461.96	225.14221	

	J	YA	7	9453.921	276.29559	0.315
		MA	7	9810.988	357.60851	
	Ix/Iy	YA	7	0.9975	0.16642	**0.016***
		MA	7	0.8209	0.09600	
	TA	YA	7	1158.1293	155.13849	0.718
		MA	7	1199.6221	178.15233	
Sum	Ix	YA	16	4454.002	122.47199	0.681
		MA	12	4631.636	120.77470	
	Iy	YA	16	4480.959	108.63946	0.140
		MA	12	5009.098	182.49975	
	J	YA	16	8934.962	215.71917	0.236
		MA	12	9640.734	281.71038	
	Ix/Iy	YA	16	1.0066	0.19105	0.936
		MA	12	0.9619	0.21248	
	TA	YA	16	1128.5253	127.49927	0.294
		MA	12	1156.1839	162.25199	

4.1.2 Zwolle

4.1.2.1 Side Difference

The samples from the Zwolle population that did not have osteoarthritis were clustered together on the side. A t-test for independent samples was used to examine the differences between the two groups. Tabulated below are the averages, standard deviations, and significance levels of both J and Ix/Iy, as determined by the statistical test findings (Table 4.4). It was discovered that if the p values were more than the reported statistically significant alpha levels, one could draw the conclusion that there was no difference between the torsional and anterior-posterior loads on both sides of the femur in the Zwolle population sample. This was the conclusion that was reached after looking at the results of the study.

Table 4.4 Side difference with independent sample t-test results.

	side	N	mean	Std.	Sig.

				Deviation	
Ix	right	13	4479.187	122.03204	0.419
	left	14	3816.198	98.40015	
Iy	right	13	4991.825	167.80775	0.157
	left	14	4311.096	116.18591	
J	right	13	9471.012	279.21671	0.172
	left	14	8127.293	200.75469	
Ix/Iy	right	13	0.9377	0.24590	0.669
	left	14	0.9008	0.16204	
TA	right	13	1143.9178	129.89676	0.892
	left	14	1096.5350	128.09316	

4.1.2.2 Sex Difference

The sample from the Zwolle population that did not have osteoarthritis was separated into groups according to gender and then further separated into groups based on whether the condition affected the left or right side of the body. Because this group did not contain any samples affected by osteoarthritis, we used a t-test for independent samples to analyze the data and look for differences between the sexes. A table containing the means, standard deviations, and statistical tests for the significance of J and Ix/Iy has been created, as shown in Table 4.5.

The significance result for the difference in Ix/Iy values between males and females in the right-hand sample was less than 0.100 when evaluated at the significance level =0.100, t([df (11)]) = [value of t (2.255)], p = [value of p (0.067)]. This demonstrates a substantial variation in the amplitude of anterior-posterior loads applied to the prenatal femur between males and females in the Zwolle population's right-hand sample. The female sample got considerably higher anterior-posterior loads (mean=1.1057) than the male sample (mean=0.8327). At the same time, there was no difference in the torsional loads of the male and female samples on the right side. Also, in the left side sample, the significance result for the difference in J-value between males and females was less than 0.100, t([df (12)]) = [value of t (-0.265)], p = [value of p (0.081)]. This demonstrates a substantial variation in the amplitude of torsional loads applied to the prenatal femur between males and females in the Zwolle population's left-side sample. The female sample (mean=774.5737) experienced considerably less torsional load than the male sample (mean=841.3461). In addition, there was no difference in anterior-posterior load between the male and female samples on the left side.

Notably, the significance results for the differences in J and Ix/Iy values for the male and female samples were more significant than 0.100 at the significance threshold of =0.100. This is an important finding. Therefore, it is possible to conclude that there were no significant differences in the torsional and anterior-posterior loads on the prenatal femur between the male and female samples of the Zwolle population as a whole and that there was also no difference in the total area of the outer contour of the cross-section.

Table 4.5 Sex difference with independent sample t-test results.

		Sex	N	mean	Std. Deviation	Sig.
Right	Ix	Female	5	4502.458	154.07465	0.401
		Male	8	4464.643	109.34993	
	Iy	Female	5	4353.178	206.68175	0.177
		Male	8	5390.979	138.30840	
	J	Female	5	8855.636	352.96162	0.206
		Male	8	9855.622	240.96462	
	Ix/Iy	Female	5	1.1057	0.32041	**0.067***
		Male	8	0.8327	0.11062	
	TA	Female	5	1121.4669	148.18574	0.572
		Male	8	1157.9497	125.66770	
Left	Ix	Female	6	3533.108	109.80512	0.298
		Male	8	4028.515	90.37474	
	Iy	Female	6	4212.629	162.99646	**0.081***
		Male	8	4384.946	77.11947	
	J	Female	6	7745.737	260.74632	0.087
		Male	8	8413.461	155.24271	
	Ix/Iy	Female	6	0.8741	0.17285	0.846
		Male	8	0.9209	0.16232	
	TA	Female	6	1059.3877	136.45552	0.395
		Male	8	1124.3955	122.88926	
Sum	Ix	Female	11	3973.721	134.48730	0.298

		Male	16	4246.579	99.49316	
	Iy	Female	11	4276.515	174.42688	**0.073***
		Male	16	4887.962	120.00569	
	J	Female	11	8250.236	295.27402	0.126
		Male	16	9134.542	209.49827	
	Ix/Iy	Female	11	0.9794	0.26578	0.290
		Male	16	0.8768	0.14170	
	TA	Female	11	1087.6055	138.36439	0.155
		Male	16	1141.1726	121.31571	

4.1.2.3 Age Difference

The sample taken from the Zwolle population that did not have osteoarthritis was separated into two groups: one for young adults (YA) and one for middle adults (MA). Only samples from the young adult group and the middle-aged adult group were analyzed because there was no sample available from the older age group (OA). Additionally, the samples were partitioned further into left and right groups for further analysis. The independent samples t-test was utilized to investigate any sex differences seen across the age spectrum. A table was created to organize the significance of the statistical test results as well as the means, standard deviations, and means of J and Ix/Iy (see Table 4.6 for more information).

It is interesting to observe that the p-value of the results was higher than the set that revealed statistically significant alpha levels. Therefore, we have come to the conclusion that there is not a significant difference between the torsional and anterior-posterior loads that were applied to the femur in the prenatal young adult and middle-aged adult groups of the Zwolle population sample. Moreover, there was also no difference in the total area of the outer contour of the cross-section.

Table 4.6 Age difference with statistical independent sample t-test results.

		Sex	N	mean	Std. Deviation	Sig.
Right	Ix	YA	6	4388.338	120.68437	0.904
		MA	7	4557.058	132.26146	
	Iy	YA	6	5336.883	166.22606	0.739
		MA	7	4696.06	176.30016	

	J	YA	6	9725.222	282.29749	0.846
		MA	7	9253.118	297.17657	
	Ix/Iy	YA	6	0.8343	0.12014	0.221
		MA	7	1.0264	0.29841	
	TA	YA	6	1162.9900	145.60825	0.705
		MA	7	1127.5702	124.10748	
Left	Ix	YA	7	3797.736	125.54640	**0.085**
		MA	7	3834.66	72.17405	
	Iy	YA	7	3974.122	116.40993	0.787
		MA	7	4648.07	114.22519	
	J	YA	7	7771.858	231.55520	0.394
		MA	7	8482.729	175.37488	
	Ix/Iy	YA	7	0.9607	0.18102	0.391
		MA	7	0.8409	0.12550	
	TA	YA	7	1079.4128	152.79112	0.262
		MA	7	1113.6572	107.33669	
Sum	Ix	YA	13	4070.321	122.01921	0.501
		MA	14	4195.859	109.00890	
	Iy	YA	13	4603.089	152.60579	0.968
		MA	14	4672.065	142.73575	
	J	YA	13	8673.41	265.11640	0.869
		MA	14	8867.924	237.80957	
	Ix/Iy	YA	13	0.9024	0.16340	0.898
		MA	14	0.9336	0.24006	
	TA	YA	13	1117.9869	149.62369	0.438
		MA	14	1120.6137	111.70720	

4.2 Interpopulation Comparison of Samples without Osteoarthritis

The sample was separated into two populations, Arnhem and Zwolle, and samples from each population were further divided into left and right sides. The independent samples t-test was used to examine population differences. The averages and standard deviations of J and Ix/Iy, as well as the statistical significance of the test results, were collated into a table (see Table 4.7).

The difference in J values for the right-hand samples was less than 0.050 when assessed at the significance level =0.050, t([df (25)]) = [value of t (-0.725)], p = [value of p (0.036)]. This demonstrates a significant variation in torsional load between the Arnhem and Zwolle populations' right-hand samples. The Zwolle population has a much higher torsional load (mean=947.1012) than the Arnhem population (mean=884.2417), but there is no difference in anterior-posterior load between the two populations.

The p-value of the remaining results was more than the statistically significant alpha levels given in the set. As a result, it was concluded that there was no significant difference in the torsional and anterior-posterior loads on the prenatal femur between the Zwolle and Arnhem populations, as well as no difference in the total area of the outer contour of the cross-section between the Zwolle and Arnhem populations.

Table 4.7 Population difference with independent sample t-test results.

		Project	N	mean	Std. Deviation	Sig.
Right	Ix	Arnhem	14	4527.789	93.19423	0.266
		Zwolle	13	4479.187	122.03204	
	Iy	Arnhem	14	4314.628	89.07970	**0.023***
		Zwolle	13	4991.825	167.80775	
	J	Arnhem	14	8842.417	159.72425	**0.036***
		Zwolle	13	9471.012	279.21671	
	Ix/Iy	Arnhem	14	1.0657	0.20677	0.784
		Zwolle	13	0.9377	0.24590	
	TA	Arnhem	14	1101.8822	109.65343	0.778
		Zwolle	13	1143.9178	129.89676	
Left	Ix	Arnhem	14	4532.473	145.36364	0.323
		Zwolle	14	3816.198	98.40015	
	Iy	Arnhem	14	5099.981	178.92849	0.222
		Zwolle	14	4311.096	116.18591	
	J	Arnhem	14	9632.454	307.57125	0.153
		Zwolle	14	8127.293	200.75469	
	Ix/Iy	Arnhem	14	0.9092	0.15946	0.616
		Zwolle	14	0.9008	0.16204	

	TA	Arnhem	14	1178.8757	161.92662	0.378
		Zwolle	14	1096.5350	128.09316	
Sum	Ix	Arnhem	28	4530.131	119.81565	0.929
		Zwolle	27	4135.415	113.37562	
	Iy	Arnhem	28	4707.304	144.34172	0.620
		Zwolle	27	4638.854	144.73297	
	J	Arnhem	28	9237.435	243.82340	0.657
		Zwolle	27	8774.269	246.60658	
	Ix/Iy	Arnhem	28	0.9874	0.19793	0.536
		Zwolle	27	0.9186	0.20345	
	TA	Arnhem	28	1140.3789	141.24702	0.488
		Zwolle	27	1119.3489	128.73855	

4.2.1 Sex Difference

The samples were separated into two groups based on population, Arnhem and Zwolle, and then further subdivided based on sex and left and right sides for various populations. The independent samples t-test was used to examine the differences between the sexes. Tables were created to organize the means and standard deviations of J and Ix/Iy, as well as the significance of the statistical test results (see Tables 4.8 and 4.9).

4.2.1.1 Female

The difference in J-values for the right-side samples was smaller than 0.100 when evaluated on females from the Arnhem and Zwolle populations, t([df (8)]) = [value of t (0.007)], p = [value of p (0.085)]. This demonstrates a substantial variation in torsional strain between the Arnhem and Zwolle populations' right-hand samples of women. The torsional load of suitable side samples in the Arnhem population is higher (mean=886.7808) than in the Zwolle population (mean=885.5636). At the same time, no variation in anterior-posterior load exists between the two populations of women.

The p-value of the remaining results was more than the statistically significant alpha levels given in the set. As a result, there was no significant difference in the torsional and anterior-posterior loads to the femur during life between the Zwolle population and the Arnhem population females, and no difference in the total area of the outer contour of the cross-section between the Zwolle population left female sample.

Table 4.8 Population female difference with independent sample t-test results.

		Project	N	mean	Std. Deviation	Sig.
Right	Ix	Arnhem	5	4349.553	77.15141	0.152
		Zwolle	5	4502.458	154.07465	
	Iy	Arnhem	5	4518.255	128.65400	0.155
		Zwolle	5	4353.178	206.68175	
	J	Arnhem	5	8867.808	185.69021	**0.085***
		Zwolle	5	8855.636	352.96162	
	Ix/Iy	Arnhem	5	1.0041	0.25232	0.635
		Zwolle	5	1.1057	0.32041	
	TA	Arnhem	5	1146.4670	80.15338	0.151
		Zwolle	5	1121.4669	148.18574	
Left	Ix	Arnhem	4	5693.204	174.43567	0.574
		Zwolle	6	3533.108	109.80512	
	Iy	Arnhem	4	6550.89	170.77525	0.986
		Zwolle	6	4212.629	162.99646	
	J	Arnhem	4	12244.093	289.35823	0.681
		Zwolle	6	7745.737	260.74632	
	Ix/Iy	Arnhem	4	0.8843	0.23701	0.672
		Zwolle	6	0.8741	0.17285	
	TA	Arnhem	4	1303.0797	143.97791	0.801
		Zwolle	6	1059.3877	136.45552	
Sum	Ix	Arnhem	9	4946.731	139.28958	0.685
		Zwolle	11	3973.721	134.48730	
	Iy	Arnhem	9	5421.648	175.18327	0.619
		Zwolle	11	4276.515	174.42688	
	J	Arnhem	9	10368.379	283.37825	0.662
		Zwolle	11	8250.236	295.27402	
	Ix/Iy	Arnhem	9	0.9509	0.23852	0.922

		Zwolle	11	0.9794	0.26578	
	TA	Arnhem	9	1216.0726	133.41326	0.466
		Zwolle	11	1087.6055	138.36439	

4.2.1.2 Male

The difference in Ix/Iy values for the right-hand sample was smaller than 0.100 when evaluated on males from the Arnhem and Zwolle populations, t([df (15)]) = [value of t (3.562)], p = [value of p (0.090)]. This implies that the p-value in the anterior-posterior load between the right-hand samples of males in the Arnhem and Zwolle populations is slightly lower than the established alpha level. Males in the Arnhem population have a higher anterior-posterior load of right-side samples (mean=1.0999) than males in the Zwolle community (mean=0.8327). At the same time, there is no difference in torsional load between the two populations of guys.

The p-value of the remaining results was more than the statistically significant alpha levels given in the set. As a result, there was no significant difference in the torsional and anterior-posterior loads on the prenatal femur between males from the Zwolle and Arnhem populations and no difference in the total area of the outer contour of the cross-section between males from the Zwolle and Arnhem populations.

Table 4.9 Population male difference with independent sample t-test results.

		Project	N	mean	Std. Deviation	Sig.
Right	Ix	Arnhem	9	4626.809	104.05944	0.854
		Zwolle	8	4464.643	109.34993	
	Iy	Arnhem	9	4201.502	64.92797	**0.056***
		Zwolle	8	5390.979	138.30840	
	J	Arnhem	9	8828.311	155.59575	0.270
		Zwolle	8	9855.622	240.96462	
	Ix/Iy	Arnhem	9	1.0999	0.18429	**0.090***
		Zwolle	8	0.8327	0.11062	

	TA	Arnhem	9	1077.1128	119.97468	0.807
		Zwolle	8	1157.9497	125.66770	
Left	Ix	Arnhem	10	4068.181	109.52711	0.549
		Zwolle	8	4028.515	90.37474	
	Iy	Arnhem	10	4519.617	153.05049	0.389
		Zwolle	8	4384.946	77.11947	
	J	Arnhem	10	8587.798	257.47912	0.411
		Zwolle	8	8413.461	155.24271	
	Ix/Iy	Arnhem	10	0.9192	0.13273	0.458
		Zwolle	8	0.9209	0.16232	
	TA	Arnhem	10	1129.1942	146.16773	0.375
		Zwolle	8	1124.3955	122.88926	
Sum	Ix	Arnhem	19	4332.794	107.85141	0.563
		Zwolle	16	4246.579	99.49316	
	Iy	Arnhem	19	4368.931	117.69517	0.565
		Zwolle	16	4887.962	120.00569	
	J	Arnhem	19	8701.725	209.90472	0.839
		Zwolle	16	9134.542	209.49827	
	Ix/Iy	Arnhem	19	1.0048	0.18026	0.133
		Zwolle	16	0.8768	0.14170	
	TA	Arnhem	19	1104.5240	133.39269	0.284
		Zwolle	16	1141.1726	121.31571	

4.2.2 Age Difference

According to the populations, the samples were divided into two groups, Arnhem and Zwolle, and the samples from each population were further divided into age groups and left and right sides. The independent samples t-test was used to examine differences across populations of different ages. The mean and standard deviation of J and Ix/Iy, as well as the significance of the statistical test results, were arranged into tables (see Tables 4.9 and 4.10.

4.2.2.1 Young Age

When examined at the significance threshold of = 0.100, tests on the YA age group samples from the Arnhem and Zwolle populations produced findings larger than 0.100. This implies that there is no statistically significant difference between the YA age group samples from the two populations, Arnhem and Zwolle. It can be concluded that there is no significant difference in the torsional and anterior-posterior loads applied to the prenatal femur, as well as no difference in the total area of the outer contour of the cross-section between the Zwolle and Arnhem YA age groups.

Table 4.9 Population YA difference with independent sample t-test results.

		Project	N	mean	Std. Deviation	Sig.
Right	Ix	Arnhem	9	4250.2899	868.49512	0.399
		Zwolle	6	4388.3381	1206.84366	
	Iy	Arnhem	9	4281.0372	968.85010	0.210
		Zwolle	6	5336.8835	1662.26056	
	J	Arnhem	9	8531.3272	1606.51310	0.154
		Zwolle	6	9725.2216	2822.97492	
	Ix/Iy	Arnhem	9	1.0137	0.21802	0.128
		Zwolle	6	0.8343	0.12014	
	TA	Arnhem	9	1105.4999	105.19443	0.454
		Zwolle	6	1162.9900	145.60825	
Left	Ix	Arnhem	7	4715.9184	1613.02626	0.955
		Zwolle	7	3797.7356	1255.46397	
	Iy	Arnhem	7	4738.0021	1249.81445	0.841
		Zwolle	7	3974.1222	1164.09926	
	J	Arnhem	7	9453.9205	2762.95591	0.966
		Zwolle	7	7771.8578	2315.55204	
	Ix/Iy	Arnhem	7	0.9975	0.16642	0.753
		Zwolle	7	0.9607	0.18102	
	TA	Arnhem	7	1158.1293	155.13849	0.912
		Zwolle	7	1079.4128	152.79112	
Sum	Ix	Arnhem	16	4454.0024	1224.71987	0.650
		Zwolle	13	4070.3214	1220.19212	
	Iy	Arnhem	16	4480.9594	1086.39458	0.270

		Zwolle	13	4603.0890	1526.05793	
	J	Arnhem	16	8934.9618	2157.19173	0.384
		Zwolle	13	8673.4104	2651.16397	
	Ix/Iy	Arnhem	16	1.0066	0.19105	0.509
		Zwolle	13	0.9024	0.16340	
	TA	Arnhem	16	1128.5253	127.49927	0.714
		Zwolle	13	1117.9869	149.62369	

4.2.2.2 Middle Age

The difference in J-values of the left side samples was less than 0.100 when the Middle Age group samples of Arnhem and Zwolle populations were examined at the significance level α=0.100, t([df (12)]) = [value of t (0.882)], p = [value of p (0.061)]. This shows a substantial difference in the torsional loads of the left-hand side MA samples for both the Arnhem and Zwolle populations. Torsional loads were greater in the MA group of the Arnhem population (mean=9810.9875) than in the MA group of the Zwolle population (mean=8482.7291). In contrast, there was no difference in anterior-posterior loads between the two populations' MA groups.

The p-value of the remaining results was more than the statistically significant alpha levels given in the set. As a result, there was no significant difference in the torsional and anterior-posterior loads placed on the prenatal femur and no difference in the total area of the outer contour of the cross-section between the MA samples from the Zwolle population's right side.

Table 4.10 Population OA difference with statistical independent sample t-test results.

		Project	N	mean	Std. Deviation	Sig.
Right	Ix	Arnhem	5	5027.2878	910.48027	0.465
		Zwolle	7	4557.0581	1322.61461	
	Iy	Arnhem	5	4375.0907	833.35965	**0.079***

		Zwolle	7	4696.0601	1763.00156	
	J	Arnhem	5	9402.3786	1587.41407	0.159
		Zwolle	7	9253.1183	2971.76572	
	Ix/Iy	Arnhem	5	1.1593	0.16390	0.445
		Zwolle	7	1.0264	0.29841	
	TA	Arnhem	5	1095.3703	129.85917	0.723
		Zwolle	7	1127.5702	124.10748	
Left	Ix	Arnhem	7	4349.0277	1377.64957	**0.083***
		Zwolle	7	3834.6595	721.74054	
	Iy	Arnhem	7	5461.9598	2251.42207	0.101
		Zwolle	7	4648.0696	1142.25189	
	J	Arnhem	7	9810.9875	3576.08511	**0.061***
		Zwolle	7	8482.7291	1753.74880	
	Ix/Iy	Arnhem	7	0.8209	0.09600	0.638
		Zwolle	7	0.8409	0.12550	
	TA	Arnhem	7	1199.6221	178.15233	0.231
		Zwolle	7	1113.6572	107.33669	
Sum	Ix	Arnhem	12	4631.6361	1207.74701	0.531
		Zwolle	14	4195.8588	1090.08899	
	Iy	Arnhem	12	5009.0977	1824.99749	0.593
		Zwolle	14	4672.0649	1427.35754	
	J	Arnhem	12	9640.7338	2817.10381	0.607
		Zwolle	14	8867.9237	2378.09565	
	Ix/Iy	Arnhem	12	0.9619	0.21248	0.783
		Zwolle	14	0.9336	0.24006	
	TA	Arnhem	12	1156.1839	162.25199	0.136
		Zwolle	14	1120.6137	111.70720	

4.3 Sample Statistics for the Presence of OA

The prevalence of OA in Arnhem and Zwolle populations with different SES was first counted in this study; additionally, the correlation between other factors, including SES, gender, and age, and the onset of OA was tested using the chi-square test of four-compartmental tabulated data with a completely randomized design to confirm the effect of different factors on the onset of OA; at the same time, differences in functional status of the lower limbs and mobility were

The prevalence of OA was determined in the Arnhem and Zwolle populations with varying socioeconomic statuses. In both the Arnhem and Zwolle populations, the number of people with OA was significantly higher than the number of people without OA. At the same time, the prevalence of OA was slightly more significant in the Zwolle population than in the Arnhem population. The findings revealed that, whereas the SES in the Zwolle community was higher than in the Arnhem population, the higher SES did not result in a decreased incidence of OA.

Table 5.1 Prevalence of OA among different SES populations

		OA（%）	Without OA （%）	Total
Arnhem	Right	32（65.30）	14（28.57）	46
	Left	29（59.18）	14（28.57）	43
Zwolle	Right	31（68.89）	13（28.89）	44
	Left	28（62.22）	14（31.11）	42

4.3.1 Correlation between Different Factors and the Prevalence of OA

Meanwhile, in a completely randomized design of four-compartmental table information, a chi-square test for correlation between multiple parameters, including SES, gender, and age, and the prevalence of OA was performed to confirm the effect of different factors on the start of OA.

The statistical results of the chi-square test for four-compartmental table information of a completely randomized design revealed that in the Arnhem and Zwolle populations (Tables 5.2 to 5.13), only the age of the samples and the incidence of OA were significantly less than 0.05 at $p \leq 0.05$, indicating that the incidence of OA was not affected by gender or side of the sample, but only by age.

Table 5.2 sex * OA Crosstabulation of Arnhem

		OA/withoutOA		Total
		OA	withoutOA	
sex	Female	28	9	37
	Male	33	19	52
Total		61	28	89

Table 5.3 Chi-Square Tests of sex * OA of Arnhem

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.496[a]	1	0.221		
Continuity Correction[b]	0.983	1	0.321		
Likelihood Ratio	1.522	1	0.217		
Fisher's Exact Test				0.254	0.161
Linear-by-Linear Association	1.479	1	0.224		
N of Valid Cases	89				

Table 5.4 side * OA Crosstabulation of Arnhem

		OA/withoutOA		Total
		OA	withoutOA	
side	Right	32	14	46
	Left	29	14	43
Total		61	28	89

Table 5.5 Chi-Square Tests of side * OA of Arnhem

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.046[a]	1	0.829		
Continuity Correction[b]	0.000	1	1.000		
Likelihood Ratio	0.046	1	0.829		
Fisher's Exact Test				1.000	0.505
Linear-by-Linear Association	0.046	1	0.830		
N of Valid Cases	89				

Table 5.6 age * OA Crosstabulation of Arnhem

		OA/without OA		Total
		OA	Without OA	
age	YA	16	16	32
	MA	32	12	44
	OA	13	0	13
Total		61	28	89

Table 5.7 Chi-Square Tests of age * OA of Arnhem

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.426[a]	2	0.003
Likelihood Ratio	14.922	2	0.001
Linear-by-Linear Association	11.250	1	0.001
N of Valid Cases	89		

Table 5.8 sex * OA Crosstabulation of Zwolle

		OA/withoutOA		Total
		OA	withoutOA	
sex	Female	29	11	40
	Male	30	16	46
Total		59	27	86

Table 5.9 Chi-Square Tests sex * OA of Zwolle

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.527[a]	1	0.468		
Continuity Correction[b]	0.243	1	0.622		
Likelihood Ratio	0.529	1	0.467		
Fisher's Exact Test				0.495	0.312

Linear-by-Linear Association	0.521	1	0.471		
N of Valid Cases	86				

Table 5.10 side * OA Crosstabulation of Zwolle

		OA/withoutOA		Total
		OA	withoutOA	
side	Right	31	13	44
	Left	28	14	42
Total		59	27	86

Table 5.11 Chi-Square Tests side * OA of Zwolle

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.143[a]	1	0.705		
Continuity Correction[b]	0.021	1	0.884		
Likelihood Ratio	0.143	1	0.705		
Fisher's Exact Test				0.817	0.442
Linear-by-Linear Association	0.141	1	0.707		
N of Valid Cases	86				

Table 5.12 age * OA Crosstabulation of Zwolle

		OA/withoutOA		Total
		OA	withoutOA	
age	YA	9	13	22
	MA	33	14	47
	OA	17	0	17
Total		59	27	86

Table 5.13 Chi-Square Tests age * OA of Zwolle

	Value	df	Asymp. Sig. (2-sided)

Pearson Chi-Square	15.671[a]	2	0.000
Likelihood Ratio	20.005	2	0.000
Linear-by-Linear Association	15.488	1	0.000
N of Valid Cases	86		

4.3.2 the Correlation of SES and the OA

Because the incidence of OA can be altered by the sample's age, the chi-square test was used to compare various SES populations for samples of the same age. The test results showed that at a significance of p≤0.05, the significance of the results of the samples with different SES age groups and the incidence of OA was more significant than 0.05 in the YA and MA age groups, indicating that the SES of the samples in the Arnhem and Zwolle populations had no effect on the incidence of OA.

Table 5.14 project * OA Crosstabulation of YA

		OA/withoutOA		Total
		OA	withoutOA	
project	Arnhem	16	16	32
	Zwolle	9	13	22
Total		25	29	54

Table 5.15 Chi-Square Tests project * OA of YA

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.433[a]	1	0.510		
Continuity Correction[b]	0.145	1	0.704		
Likelihood Ratio	0.435	1	0.510		
Fisher's Exact Test				0.585	0.352
Linear-by-Linear Association	0.425	1	0.514		
N of Valid Cases	54				

Table 5.16 project * OA Crosstabulation of MA

		OA/withoutOA		Total
		OA	withoutOA	
project	Arnhem	32	12	44
	Zwolle	33	14	47
Total		65	26	91

Table 5.15 Chi-Square Tests project * OA of MA

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.070[a]	1	0.791		
Continuity Correction[b]	0.001	1	0.974		
Likelihood Ratio	0.070	1	0.791		
Fisher's Exact Test				0.820	0.487
Linear-by-Linear Association	0.070	1	0.792		
N of Valid Cases	91				

4.2.3 the Correlation of Lower Extremity Functional Status and Mobility with the Presence of OA

Furthermore, lower limb functional status and mobility changes were counted individually between samples with and without OA in different socioeconomic groupings.
The test results for the Arnhem population showed that at a significance of p0.05, the difference between the J and Ix/Iy values of the samples in the YA age group in the presence and absence of OA was more significant than 0.05, indicating that there was no torsional versus anterior-posterior loading difference between the samples in the YA age group in the presence and absence of OA. Only the J values of the samples with and without OA on the left side were less than 0.10 at the significance level of p0.10, indicating that there is a difference between torsional load and forward load for the samples with and without OA in the MA age group of the Arnhem population.

Only the left side of the samples with the presence and absence of OA had J values less than 0.10 in the YA age group, according to the test results for the Zwolle population, with a significance of $p \leq 0.10$. As a result, there was a difference in torsional loading between samples with and without OA in the Zwolle population's YA age group. The difference in J and Ix/Iy values between samples with and without OA in the MA age group samples is more significant than 0.05 at the significance level of p≤0.05. Therefore, there is no difference in torsional and forward and backward loading for samples with and without OA in the Zwolle population's MA age group.

Table 5.16 Arnhem population YA age group numerical data Ix/Iy with J descriptive statistics and t-test results

		OA	N	mean	Std. Deviation	Sig.
Right	Ix	OA	8	4753.0676	1676.57655	0.339
		WithoutOA	9	4250.2899	868.49512	
	Iy	OA	8	5406.3301	1710.44454	0.121
		WithoutOA	9	4281.0372	968.85010	
	J	OA	8	10159.3977	3068.03525	0.276
		WithoutOA	9	8531.3272	1606.51310	
	Ix/Iy	OA	8	0.9207	0.27117	0.549
		WithoutOA	9	1.0137	0.21802	
Left	Ix	OA	8	4155.9022	929.56058	0.466
		WithoutOA	7	4715.9184	1613.02626	
	Iy	OA	8	4512.5297	697.39106	0.206
		WithoutOA	7	4738.0021	1249.81445	
	J	OA	8	8668.4319	1343.04754	0.197
		WithoutOA	7	9453.9205	2762.95591	
	Ix/Iy	OA	8	0.9344	0.22877	0.445
		WithoutOA	7	0.9975	0.16642	
Sum	Ix	OA	16	4454.4849	1345.39632	0.916
		WithoutOA	16	4454.0024	1224.71987	
	Iy	OA	16	4959.4299	1343.61056	0.646
		WithoutOA	16	4480.9594	1086.39458	
	J	OA	16	9413.9148	2413.96264	0.767
		WithoutOA	16	8934.9618	2157.19173	
	Ix/Iy	OA	16	0.9275	0.24246	0.357
		WithoutOA	16	1.0066	0.19105	

Table 5.17 Arnhem population MA age group numerical data Ix/Iy with J descriptive statistics and t-test results

		OA	N	mean	Std. Deviation	Sig.
Right	Ix	OA	16	4648.0366	1095.15117	0.749
		WithoutOA	5	5027.2878	910.48027	
	Iy	OA	16	4971.2490	669.05138	0.984
		WithoutOA	5	4375.0907	833.35965	
	J	OA	16	9619.2856	1560.21382	0.972
		WithoutOA	5	9402.3786	1587.41407	
	Ix/Iy	OA	16	0.9367	0.18561	0.651
		WithoutOA	5	1.1593	0.16390	
Left	Ix	OA	16	5207.3222	1408.14861	0.794
		WithoutOA	7	4349.0277	1377.64957	
	Iy	OA	16	5729.9690	997.63666	0.011
		WithoutOA	7	5461.9598	2251.42207	
	J	OA	16	10937.2912	2238.48095	**0.086***
		WithoutOA	7	9810.9875	3576.08511	
	Ix/Iy	OA	16	0.9043	0.17073	0.225
		WithoutOA	7	0.8209	0.09600	
Sum	Ix	OA	32	4927.6794	1272.99471	0.980
		WithoutOA	12	4631.6361	1207.74701	
	Iy	OA	32	5350.6090	920.18369	0.015
		WithoutOA	12	5009.0977	1824.99749	
	J	OA	32	10278.2884	2012.64609	0.182
		WithoutOA	12	9640.7338	2817.10381	
	Ix/Iy	OA	32	0.9205	0.17620	0.450
		WithoutOA	12	0.9619	0.21248	

Table 5.18 Zwolle population YA age group numerical data Ix/Iy with J descriptive statistics and t-test results

		OA	N	mean	Std. Deviation	Sig.

Right	Ix	OA	5	4132.1682	1510.75039	0.908
		WithoutOA	6	4388.3381	1206.84366	
	Iy	OA	5	4044.6004	1291.63235	0.603
		WithoutOA	6	5336.8835	1662.26056	
	J	OA	5	8176.7685	2618.72092	0.808
		WithoutOA	6	9725.2216	2822.97492	
	Ix/Iy	OA	5	1.0344	0.20138	0.294
		WithoutOA	6	0.8343	0.12014	
Left	Ix	OA	4	4627.5881	493.13311	0.049
		WithoutOA	7	3797.7356	1255.46397	
	Iy	OA	4	4632.7636	834.88470	0.715
		WithoutOA	7	3974.1222	1164.09926	
	J	OA	4	9260.3517	793.83550	**0.063***
		WithoutOA	7	7771.8578	2315.55204	
	Ix/Iy	OA	4	1.0287	0.24335	0.231
		WithoutOA	7	0.9607	0.18102	
Sum	Ix	OA	9	4352.3548	1140.41835	0.532
		WithoutOA	13	4070.3214	1220.19212	
	Iy	OA	9	4306.0063	1091.62153	0.370
		WithoutOA	13	4603.0890	1526.05793	
	J	OA	9	8658.3611	1997.82848	0.447
		WithoutOA	13	8673.4104	2651.16397	
	Ix/Iy	OA	9	1.0319	0.20614	0.335
		WithoutOA	13	0.9024	0.16340	

Table 5.19 Zwolle population MA age group numerical data Ix/Iy with J descriptive statistics and t-test result

		OA	N	mean	Std. Deviation	Sig.
Right	Ix	OA	17	4485.5961	1363.05968	0.750
		WithoutOA	7	4557.0581	1322.61461	
	Iy	OA	17	4594.7640	1443.41796	0.410
		WithoutOA	7	4696.0601	1763.00156	
	J	OA	17	9080.3601	2716.74182	0.689
		WithoutOA	7	9253.1183	2971.76572	

	Ix/Iy	OA	17	0.9905	0.18203	0.356
		WithoutOA	7	1.0264	0.29841	
Left	Ix	OA	16	4872.3999	1652.48104	0.027
		WithoutOA	7	3834.6595	721.74054	
	Iy	OA	16	5033.9166	1435.93466	0.527
		WithoutOA	7	4648.0696	1142.25189	
	J	OA	16	9906.3165	2910.34697	0.141
		WithoutOA	7	8482.7291	1753.74880	
	Ix/Iy	OA	16	0.9741	0.19787	0.293
		WithoutOA	7	0.8409	0.12550	
Sum	Ix	OA	33	4673.1373	1499.17184	0.096
		WithoutOA	14	4195.8588	1090.08899	
	Iy	OA	33	4807.6865	1434.54593	0.911
		WithoutOA	14	4672.0649	1427.35754	
	J	OA	33	9480.8238	2799.36256	0.481
		WithoutOA	14	8867.9237	2378.09565	
	Ix/Iy	OA	33	0.9825	0.18705	0.895
		WithoutOA	14	0.9336	0.24006	

4.2.4 Summary

Torsional load differed between the left and right samples in the Arnhem population. The torsional load on the left side sample (mean=963.2454) was substantially higher than on the right (mean=884.2417). Moreover, anterior-posterior loads differed in the Arnhem community's left-side samples from different age groups (YA, MA). The torsional load was substantially higher in the YA age group (mean=0.9975) compared to the MA age group (mean=0.8209). In the Arnhem population, however, there were no sex differences, nor were there variations in anterior-posterior and torsional loads in the different age groups (YA, MA) samples on the right side.

The Zwolle population had anterior-posterior load variations in the sex samples on the right side. The female sample had a substantially higher anterior-posterior load (mean=1.1057) than the male sample (mean=0.8327). In addition, the torsional load in the left side sample differed by gender, with the female sample (mean=774.5737) having a considerably lower torsional load than the male sample (mean=841.3461). In the Zwolle population, however, there were no changes in anterior-posterior and torsional loads between side and age groups, nor was there a difference in the total area of the cross-section's outer contour.

The right side sample exhibited a substantial difference in torsional load when compared to the left side sample. The torsional load in the Zwolle population's right-side sample (mean=947.1012) was substantially higher than in the Arnhem population's right-side sample (mean=884.2417). Moreover, the female right-side samples from Arnhem and Zwolle exhibited statistically significant differences in torsional load. The torsional load in the female right-side sample from Arnhem (mean=886.7808) was higher than in the female right-side sample from Zwolle (mean=885.5636). There was a substantial variation in anterior-posterior load between the Arnhem and Zwolle populations for the male right-side sample. The anterior-posterior load was higher in the male right-side sample from Arnhem (mean=1.0999) than in the male right-side sample from Zwolle (mean=0.8327). The anterior-posterior burden, however, did not differ between the two populations. In the left-side sample, there was no inter-population difference in anterior-posterior load amongst females. At the same time, no variation in torsional load was seen between males in the two populations.

Chapter 5 Discussion

In Chapter 4, the statistical findings on differences in femoral functional status and activity levels among different socioeconomic status populations are discussed. It covers the study's weaknesses as well as potential future research possibilities.

5.1 Differences in Lower Extremity Functional Status and Mobility Between SES Populations

The findings revealed that the torsional load on the right side of the femur was greater in the high SES population than in the low SES population, contrary to the hypothesis that the torsional load would be greater in the lower SES population than in the higher SES population in this study. In this study, there was no significant difference in anterior-posterior load on the femur between the high and low SES populations, which contradicted the hypothesis that anterior-posterior load would be larger in the low SES population than in the high SES population. This conclusion, however, may also represent the influence of SES on the population's behavioral activities.

The J value represents the skeleton's overall loading capacity to torsional stress. Previous research has demonstrated that, in addition to movement or behavioral patterns, topography can influence sample J-values (Stock, 2006, p. 198; Larsen et al., 1995; Ruff, 1987, p. 405). Torsional loading of the femur was found to have a clear correlation with topography in a female sample in a study of a North American sample, with female samples from populations living in mountainous terrain having significantly higher J-values than those from plains areas and lower J-values from more low-lying coastal areas compared to the former two (Ruff, 1987, p. 405). However, the influence of topography does not apply to the case of the current study and contradicts the findings. Arnhem has more low hills, as illustrated in Figure 5.1, and the terrain has more relief than the Zwolle region. As a result, torsional loads in Arnhem remain lower than in Zwolle. This shows that the difference in femoral torsional stresses between the Arnhem and Zwolle populations is not related to topographic variations. At the same time, the findings reveal a side-by-side asymmetry within the Arnhem population. Torsional loads on the left side of the femur are substantially higher in this population than on the right. This may be because the Arnhem population with low SES had a single repeated movement posture slanted to the left side in their work, according to the subsequent study (section 5.2). This scenario may also have an impact on the differential in torsional loading on the right side of the femur between the two groups.

The Ix/Iy ratio reflects the intensity of anterior-posterior femoral motion, which may be used to predict a person's mobility and running behavior over time. The findings of this study revealed no significant difference in Ix/Iy between the Arnhem and Zwolle populations with different SES, which contradicts the study's hypothesis, which suggested that the Arnhem population with a low SES would have a higher overall activity level than the Zwolle population because the Arnhem population with a low SES consisted of more workers, who would have performed more labor during their lifetime, resulting in a higher overall activity level. The current study's findings, on the other hand, reveal that the two populations had comparable levels of activity in metropolitan areas.

In terms of living conditions, the Arnhem population with lower socioeconomic status faced poorer living conditions, such as expensive housing, which resulted in workers living in housing units shared by two or more families (van Laar, 1966); thus, the Arnhem population, despite engaging in heavier physical labor than the Zwolle population, lived in a more confined existence, which may be one of the reasons why their lower limbs were not as active as the Zwolle population. Additionally, there was no strict spatial division of different socioeconomic neighborhoods in Dutch cities during this period, and residents of various socioeconomic statuses had similar spatial activities and scopes in the city (van der Woud, 2010), which may have contributed to the similarity in the amount of activity of the two populations.

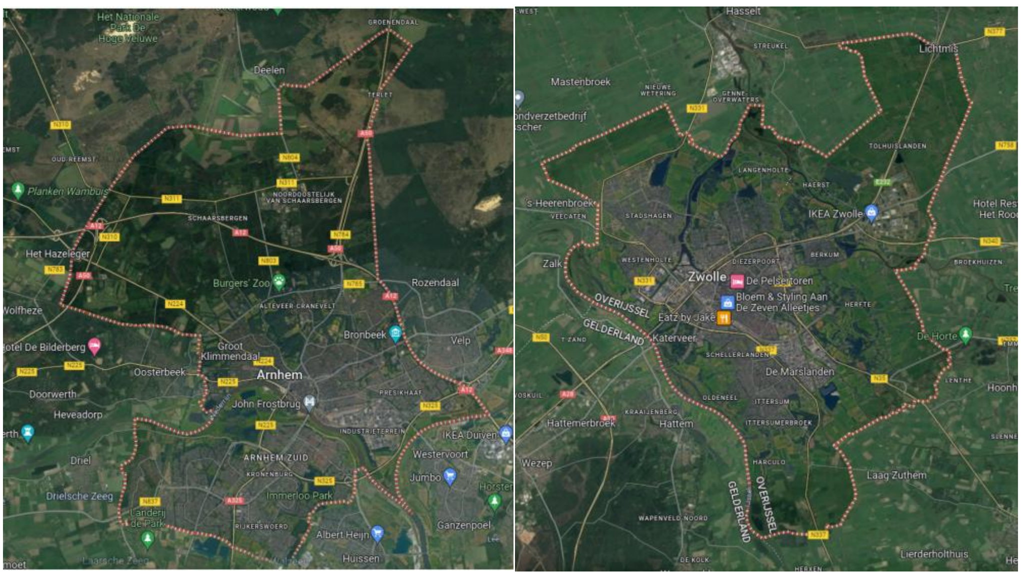

Figure 5.1 Topography of Arnhem and Zwolle. Imagery 2023 Google, Imagery 2023 TerraMetrics, Arnhem(left), Zwolle(right).

5.2 Asymmetry of the Lower Limbs

Torsional loading of the lower limb among the lower SES group (Arnhem) was substantially greater on the left than on the right in independent comparisons between the two individuals. In the higher SES population (Zwolle), there were no side-by-side differences.

Previous research has discovered a left-right lateral asymmetry in human limb bones, with the upper limb bones showing a predominantly right-sided predominance due to human habits of use and genetics (Stirland, 1993, p. 109; Auerbach, 2008, p. 667), and the lower limb bones as a whole showing left-right lateral differences with fluctuating asymmetry (Hallgrmsson, 1999, p. 125). Fluctuating asymmetry is a tiny random departure from a symmetrical feature on both sides, with a standard or spiky distribution. It can reflect the impact of environmental stress on an organism population (Hallgrmsson, 1999, p. 125).

As a result, the distinct left-right asymmetries demonstrated by the femur samples from the various SES communities in the current study may represent the effect of environmental pressures to which the people are subjected. This might be connected to the vocational and survival situations in which people of different socioeconomic backgrounds work. The Arnhem population, a lower SES sample, is primarily engaged in small-scale manufacturing industries such as tobacco, shoe-making, and printing, and there is a great deal of repetitive physical demand in these industrial labors, and individuals engaged in them may be affeacted by specific work postures that bias them towards certain movement patterns or positions at work that result in more torsional loading on the left femur. This lateral asymmetry was not present in the Zwolle population with higher SES because the Zwolle sample in this study was mainly engaged in occupations such as businessmen and municipal officials and were middle to upper socio-economic members of society (Aten, 1992), which are occupations that are not physically demanding and do not require individuals to repeat specific movement patterns or postures, thus not showing left-right laterality.

It is worth noting that there was a difference in torsional or anterior-posterior loading only in the right-side samples and not in the left-side samples in any significant way, a result that may reflect the same phenomenon of fluctuating asymmetry of the femur, i.e., the cause of this difference is more likely to be the specific suture.

5.3 Differences in Sexual Division of Labor between SES Populations

There were no significant variations between the sexes in the lower limb torsional load, the anterior-posterior load, or the total area in the analysis of differences between sexes within the groups. This was the case for the lower SES community (Arnhem). In contrast, within the group with a better socioeconomic status (Zwolle), the anterior-posterior load was higher for females in the sample taken from the right side, while the torsional load was higher for men in the sample taken from the left side. Torsional loads were significantly more significant in the right femur of the Arnhem population than in the Zwolle population among females, and anterior-posterior and anterior in the right femur of the Arnhem population among males, which is a result that is partially in line with the hypothesis of this study, which stated that the Arnhem population would have significantly greater functional status and mobility of the lower extremity than the Zwolle population.

Research by Ruff (1987, 1999, 2008; Ruff & Larsen 2001, p. 113) has demonstrated that the degree of sexual dimorphism (SD) in the morphology of the femoral stem becomes less pronounced in hunter-gatherer communities, agricultural populations, and modern industrial civilizations in that order. According to research conducted on the skeletal remains of people who lived in North America, changes in living circumstances and the intensification of agricultural practices did not reflect consistent biological reactions. Instead, they are a reflection of variations in local culture as well as gender roles (Bridges, 1989, p. 385; Panter-Brick, 2002, p. 633). Therefore, the standard deviation (SD) in the cross-sectional shape of the long bone axis that was detected in the industrial activity patterns chosen by the sample may reflect the one-of-a-kind social division of labor that was represented by the sample rather than the macroscopic changes that occurred in the general human social activity patterns.

When analyzed in conjunction with the results of the current study, there were differences in functional status and mobility between sexes within the Zwolle population at higher SES. These differences were not present in the Arnhem population at lower SES. This suggests that the sexed division of labor, as reflected in lower limb behavioral patterns, was more pronounced within the Zwolle population at higher SES. This result can be analyzed in terms of differences in access to survival resources across SES populations. More adequate survival resources exist in higher SES Zwolle populations compared to Arnhem populations, and adequate resources can be distributed relatively equally to men and women in populations with higher social status. However, in the population of Arnhem, since there are not enough resources for sustenance, both men and women are likely to participate in industrialized labor, which results in minimal variations between the sexual division of labor (Schmidt, 2009, p. 177). At the same time, the torsional load or activity of the lower extremities was found to be considerably higher in the Arnhem community than it was in the Zwolle population for individuals of the same sex in both populations. This finding confirms the hypothesis that the population of Arnhem with a lower socioeconomic status in this study has larger lower extremity loads and activity due to substantially heavier workloads.

5.4 Age Differences

When differences between age groups within populations were compared, it was found that individuals in the YA age group in the lower socioeconomic status population (Arnhem) had considerably larger forward and backward loadings on the left side than those in the MA age group. In contrast, there were no differences found between the YA and MA age groups in terms of forward, backwards, or torsional loadings among the population with a better socioeconomic status in Zwolle. In spite of the fact that the two groups of young adults were evaluated independently with regard to their sexual orientation, there was not a discernible difference between the two groups. On the other hand, there was a distinction in the MA age group; specifically, the torsional loads were much more significant in the Arnhem population than they were in the Zwolle population in the sample from the left-hand side. This finding is consistent, if only to a limited extent, with the notion that the torsional loads were of greater significance in the Arnhem population than in the Zwolle group over the course of the current investigation.

In the Arnhem population, people in the YA age group had considerably higher anterior thoracic burdens on the left side than those in the MA age group, probably because of the occurrence of selective mortality in the bone paradox. This phenomenon relates to the fact that the group that dies as a sample is simply a subset of the live group, and sick people may die sooner than healthy people in the same group (DeWitte & Stojanowski, 2015). The more difficult living conditions experienced by low-status communities may result in more YA-aged persons dying, and the sample results from this study support this assumption, with 32

YA-aged individuals dying in the Arnhem community, much higher than the 22 in the Zwolle population. This finding implies that persons in the YA age group in the Arnhem community had lower health than those in the MA age group, which may impact the anterior-posterior loadings results. On the contrary, torsional loading was more significant in the Arnhem population than in the Zwolle population in the left sample, which partially supports the current study's hypothesis that torsional loading is more significant in the low SES population than in the high SES population due to the high amount of repetitive fixed-posture work in industrial labor.

5.5 Presence of Osteoarthritis

The prevalence of OA was found to be somewhat greater in the Zwolle population than in the Arnhem population. In contrast, the prevalence of OA was altered by age within the different communities, and there was no statistically significant association between the incidence of OA and SES amongst the different populations. Torsional loads were significantly greater in samples with OA present than in samples without OA in the left-hand side samples of the MA age group of the Arnhem population; Torsional loads were significantly greater in samples with OA present than in samples without OA in the left sample of the YA age group of the Zwolle population.

There are numerous risk factors for the development of OA, including mechanical stress (Waldron, 2009, p. 26), and historical data suggests that access to life resources, such as food and healthcare, and opportunity varies significantly across the different SES populations in this study (Wintle, 2000). In a socioeconomic setting of plentiful food supply, high-status groups may have more flexibility in food choice foods, and high SES Zwolle residents are more prone to have finicky eating behaviors. As a result, the health quality of high-income populations may contribute to problems such as weight increase, influencing the prevalence of OA. This conclusion may possibly be attributed to the osteological paradox that all persons with OA are elderly, and the Arnhem population's low socioeconomic status may result in early mortality. In contrast, the Zwolle population may have a longer survival age due to greater SES and a better surviving environment. As a result, the findings indicate a greater prevalence of OA in the Zwolle population. Meanwhile, there is a link between OA incidence and torsional loading in the Arnhem and Zwolle populations in samples on the left side of a specified age range, suggesting that OA is linked to increased torsional loading in both populations.

5.6 Limitations

This study has several drawbacks. For starters, the sample size utilized in this investigation may have been insufficient; the incidence of osteoarthritis (OA) is high in both the Arnhem and Zwolle populations, and all of the older samples in this study had OA, and the small sample size may have hampered the generalizability of the findings. Second, the usage of Ix/Iy and J values may not adequately reflect specific differences in activity among socioeconomically diverse populations. Although Ix/Iy and J values can reflect the degree of anterior-posterior and torsional stress in a sample, there is no clear evidence linking these values to specific activities. In addition, while the LCM approach gives faster and less expensive access to bone cross-sections than non-invasive procedures such as CT, it does not provide information on medullary cavity cross-sections and hence cannot calculate %CA values. Moreover, the bone paradox may restrict the statistical findings of this study because they only represent the combined mortality of the two groups. These limitations emphasize the need for more research with larger and more varied samples to better understand the unique biomechanical variations and functional consequences between people of varying socioeconomic positions and exercise levels. Furthermore, most skeletal cross-sectional mechanics investigations have employed CT scans to produce cross-sections, and the method of LCM used in this study made it impossible to compare the results gained from the other studies. Future research can employ formulae to calculate the medullary cavity area for comparison. However, this can lead to erroneous results. Additionally, when obtaining the contour of the femur's outer surface, mistakes owing to manipulation may occur. First and foremost, due to the uneven shape of the bone, a little inaccuracy in establishing the position of the mid-femur may occur. Second, because sampling requires cutting the mold and then pasting at the break, misalignment in pasting or not securely pasting may result in contour variation. Finally, while removing the inner surface, the Photoshop program may make erroneous mistakes.

5.7 Directions for Future Research

Future research might give significant information regarding the functional state and activity levels of the upper extremity in different socioeconomic status groups by analysing humeral samples from the same study population. This study may give a more detailed knowledge of activity differences amongst persons of different socioeconomic backgrounds. Moreover, increasing the sample size and integrating people from varied socioeconomic backgrounds will increase the statistical results' reliability and generalizability. Furthermore, future research examining activity differences in groups of varying socioeconomic positions should look into the effects of various illnesses that may affect individual activity. A more thorough knowledge of the link between SES and activity patterns might also be gained by considering a broader variety of characteristics. Other technologies, such as CT scanning, might be used to analyze cross-sectional characteristics and %CA values to offer a more precise assessment of bone strength in order to gather more thorough data on bone structure. A comparison of findings from several approaches might aid in understanding the consistency and dependability of various procedures.

Chapter 6 Conclusion

This study used skeletal biomechanics to investigate differences in lower limb functional status and mobility of populations in two different socioeconomic status (SES) cities in the post-medieval Netherlands, Arnhem and Zwolle, in order to gain a deeper understanding of the lifestyles and labor practices of populations with different SES in a post-medieval urban environment, and to investigate the effects of socioeconomic status on the individual's locomotor ability and activity level. The findings of the study indicate that different socioeconomic statuses affect the population's activity patterns and correlate with lower limb functional status and mobility. However, it is not as often assumed that the high SES Zwolle population did not always exhibit higher torsional load J and anterior-posterior load Ix/Iy values than the low SES Arnhem sample, and the real results are more complicated.

The torsional load J and anterior-posterior load Ix/Iy values differed between SES groups. Low-income Arnhem residents faced several repeated physical pressures at work and tended to repeat particular movement patterns or postures. In contrast, professions in the Zwolle community with a high SES demand less physical effort, and individuals do not need to repeat specific movement patterns or postures, resulting in no left-right lateral asymmetry. Simultaneously, the gender division of labor is increasingly prominent. Furthermore, the Zwolle population has a narrower survival area, which may contribute to their lower levels of extremity activity. However, the two SES populations showed similar activity levels, presumably because individuals of various socioeconomic statuses had similar geographical activity and range of motion in the city.

This study employed skeletal biomechanics to investigate the functional status and activity level of different populations' lower limbs over the course of their lives. Although it addressed the effect of osteoarthritis on individual lower limb function, other contributing factors, such as other pathological disorders and individual lifestyles, may still influence the outcomes. These factors may have an effect on the structural and mechanical qualities of the lower limb skeleton; thus, interpret the results with caution. Future research should take a more detailed look at the consequences of various clinical illnesses and individual lifestyles to better explain population differences. Additionally, we employed the LCM method for sample collection, which is a non-invasive, easy, and low-cost procedure. The LCM approach, on the other hand, cannot adequately evaluate the morphology of the medullary cavity in the skeletal cross-section, which might alter the interpretation and accuracy of the results in some circumstances. As a result, alternative approaches, such as CT scanning, may be employed in future research to get more extensive skeletal information and to analyze the differences between different methods, therefore improving the study's reliability and validity. Moreover, despite the fact that some findings were obtained, the sample size of this study still has certain limitations. In future studies, the sample size may be raised to include more people from various socioeconomic backgrounds and age groups, allowing researchers to better understand the variations and trends across diverse populations.

In conclusion, while this study has made important advances in understanding the functional status and activity level of diverse populations' lower limbs across their lifespan, there are still some limitations. Future studies will use more comprehensive measurements and larger sample sizes to gain a better understanding of lower limb function and activity levels in populations, as well as the effects of socioeconomic status on individual lifestyles and exercise capacity.

Abstract

In the setting of the Dutch population in the post-medieval period, this thesis investigates the patterns and differences in the activities of two different urban groups, one with higher social status (Zwolle) and the other with lower social status (Arnhem). The study aims to uncover how socioeconomic status affects everyday activities and labor division in these post-medieval urban centers. This study used human remains from archaeological excavations in Arnhem and Zwolle as samples, functional mechanics of bones to determine the functional status and mobility of the two populations' lower limbs, and a meticulous study of historical documents and records to learn about the cities' socioeconomic status in the post-medieval period. Higher J and Ix/Iy ratios showing lower limb functional status and mobility would occur in the lower SES Arnhem population due to more manufacturing employment, according to the study's hypothesis. The study's findings indicate that torsional load (J) and anterior-posterior bending (Ix/Iy) values varied significantly among socioeconomic groups. However, contrary to the initial premise, J and Ix/Iy were not considerably greater in Arnhem than in Zwolle. In general, individuals with lower socioeconomic status in Arnhem are compelled to engage in repetitive manual labor, which leads to a preference for particular repetitive movement patterns or postures, whereas those with higher socioeconomic status in Zwolle perform less physical labor. As a result, the left-right asymmetry is not significant, and the two socioeconomic groups have a similar degree of activity, which might be because individuals of various socioeconomic statuses move in urban centers at similar rates and in similar spatial and movement patterns. Although the study focused on the impact of osteoarthritis on lower limb function, other variables may still alter the skeletal structure and mechanical characteristics of the lower limbs. Therefore, the findings should be interpreted with caution. To more precisely explain differences across urban populations, future research should fully evaluate the effects of various clinical diseases and other variables.

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Appendix

Label	Project	Age	Sex	Side	Ix(s)	Iy(s)	J(s)	Ix/Iy(s)	OA
481R	Arnhem	MA	M	R	5144.99325	4564.567429	9709.560679	1.127158998	OA
2053L	Arnhem	MA	F	L	5226.458398	4336.506767	9562.965165	1.205223162	OA
2053R	Arnhem	MA	F	R	5905.830762	5621.538757	11527.36952	1.050571919	OA
1259L	Arnhem	MA	M	L	7290.297006	6687.743912	13978.04092	1.090098111	OA
814R	Arnhem	OA	F	R	4330.963826	5416.475118	9747.438944	0.799590828	OA
1259R	Arnhem	MA	M	R	4693.016402	4360.27504	9053.291442	1.076312012	OA
863L	Arnhem	OA	M	L	3844.835627	5447.681964	9292.51759	0.705774612	OA
863R	Arnhem	OA	M	R	5551.206251	3953.708552	9504.914803	1.404050445	OA
1253L	Arnhem	YA	M	L	3531.233821	4680.615907	8211.849728	0.754437854	OA
1375L	Arnhem	MA	M	L	6211.425073	6383.580885	12595.00596	0.973031467	OA
1375R	Arnhem	MA	M	R	3032.957071	4100.381411	7133.338482	0.739676817	OA
1253R	Arnhem	YA	M	R	3950.549456	4838.377646	8788.927102	0.816502916	OA
1298R	Arnhem	OA	M	R	3333.466854	4810.148208	8143.615062	0.693007099	OA
1299R	Arnhem	OA	M	R	7180.054276	8843.355642	16023.40992	0.811915133	OA
1043L	Arnhem	OA	M	L	3743.716087	5823.761479	9567.477566	0.642834721	OA
1043R	Arnhem	OA	M	R	7953.95096	6835.081681	14789.03264	1.163695085	OA
1596R	Arnhem	YA	M	R	3494.556888	6865.585032	10360.14192	0.508996228	OA
1247L	Arnhem	YA	F	L	4510.756343	3727.424895	8238.181238	1.210153516	OA
1530L	Arnhem	YA	F	L	3288.030775	4682.67944	7970.710215	0.702168666	OA
1530R	Arnhem	YA	F	R	8673.841081	7980.063388	16653.90447	1.08693887	OA
1655L	Arnhem	MA	F	L	4243.720455	5120.285598	9364.006053	0.82880542	OA
1655R	Arnhem	MA	F	R	5010.525286	5643.079465	10653.60475	0.887906207	OA
1727L	Arnhem	YA	F	L	4310.686549	4692.426464	9003.113013	0.918647651	OA
1727R	Arnhem	YA	F	R	4289.700683	5006.999586	9296.700269	0.85674077	OA
1752L	Arnhem	MA	F	L	8272.244721	7274.647813	15546.89253	1.137133361	OA
1752R	Arnhem	MA	F	R	4219.071373	4533.87443	8752.945803	0.930566437	OA
1840L	Arnhem	MA	F	L	4233.62594	5313.741311	9547.367251	0.796731661	OA
1802L	Arnhem	MA	M	L	4587.54834	7422.272794	12009.82113	0.618078649	OA
1802R	Arnhem	MA	M	R	5533.670743	5627.96642	11161.63716	0.98324516	OA
1840R	Arnhem	MA	F	R	4524.965046	4641.567668	9166.532715	0.974878612	OA

1856L	Arnhem	MA	F	L	3431.858033	4274.068175	7705.926207	0.802948828	OA
1856R	Arnhem	MA	F	R	4546.761358	4997.561692	9544.32305	0.909795944	OA
1862L	Arnhem	OA	M	L	6700.654244	4308.520282	11009.17453	1.555210097	OA
1862R	Arnhem	OA	M	R	5831.511542	6951.109818	12782.62136	0.838932443	OA
1873L	Arnhem	MA	M	L	2344.920048	4113.51592	6458.435967	0.570052503	OA
1873R	Arnhem	MA	M	R	3264.57244	5066.893609	8331.466049	0.644294649	OA
1881L	Arnhem	YA	M	L	5957.2994	5883.768353	11841.06775	1.012497271	OA
1881R	Arnhem	YA	M	R	5382.005181	6753.788158	12135.79334	0.796886881	OA
1889L	Arnhem	MA	M	L	4744.350812	5295.423379	10039.77419	0.895934182	OA
1901L	Arnhem	YA	M	L	4805.915796	3640.044679	8445.960475	1.320290332	OA
1901R	Arnhem	YA	M	R	4035.974156	5202.550001	9238.524157	0.775768451	OA
1967L	Arnhem	OA	M	L	2622.318502	1933.555407	4555.873909	1.356215856	OA
1967R	Arnhem	OA	M	R	5189.773178	4646.854351	9836.627529	1.116835775	OA
1633L	Arnhem	MA	F	L	5757.032134	5489.601189	11246.63332	1.048715915	OA
1633R	Arnhem	MA	F	R	7247.055883	5593.231854	12840.28774	1.295683081	OA
973L	Arnhem	MA	M	L	5326.821973	5632.366823	10959.1888	0.945751962	OA
973R	Arnhem	MA	M	R	4056.811594	4932.93611	8989.747704	0.822392892	OA
2120L	Arnhem	MA	M	L	4803.116355	5929.633128	10732.74948	0.810019145	OA
2120R	Arnhem	MA	M	R	5573.89898	6068.176595	11642.07558	0.918545941	OA
1754L	Arnhem	MA	F	L	5801.840797	6373.479702	12175.3205	0.910309763	OA
1754R	Arnhem	MA	F	R	4523.407164	3762.246261	8285.653425	1.202315545	OA
2L	Zwolle	MA	M	L	3522.657243	3725.80624	7248.463483	0.945475158	OA
2R	Zwolle	MA	M	R	5770.78894	6219.997815	11990.78676	0.927779898	OA
3L	Zwolle	OA	M	L	5498.74343	3823.719284	9322.462715	1.438061485	OA
3R	Zwolle	OA	M	R	4310.637607	3857.784249	8168.421855	1.117386906	OA
12L	Zwolle	MA	F	L	6159.565161	6079.681852	12239.24701	1.01313939	OA
12R	Zwolle	MA	F	R	4073.974351	3282.379121	7356.353472	1.241165082	OA
13L	Zwolle	MA	M	L	5801.893801	5666.622079	11468.51588	1.023871668	OA
13R	Zwolle	MA	M	R	7196.300604	7883.119878	15079.42048	0.912874689	OA
14L	Zwolle	OA	M	L	5666.687738	6238.181744	11904.86948	0.908387727	OA
14R	Zwolle	OA	M	R	5442.297538	4921.98518	10364.28272	1.105711891	OA
15L	Zwolle	MA	F	L	8081.717207	7557.269175	15638.98638	1.0693965	OA
15R	Zwolle	MA	F	R	5552.41131	5274.428816	10826.84013	1.05270381	OA
20L	Zwolle	MA	M	L	3357.727182	3886.238937	7243.966119	0.864004308	OA

20R	Zwolle	MA	M	R	4759.170758	3272.19195	8031.362707	1.454428967	OA
26L	Zwolle	YA	M	L	4537.466654	5617.390794	10154.85745	0.807753425	OA
26R	Zwolle	YA	M	R	4203.645463	5487.059003	9690.704466	0.766101742	OA
29L	Zwolle	MA	F	L	2622.24831	4521.736958	7143.985268	0.579920578	OA
29R	Zwolle	MA	F	R	2694.60363	3801.447357	6496.050987	0.708836235	OA
31L	Zwolle	MA	M	L	5179.425393	4845.104509	10024.5299	1.06900179	OA
31R	Zwolle	MA	M	R	3872.313911	4924.470014	8796.783925	0.786341251	OA
32L	Zwolle	MA	F	L	2582.618384	2829.135867	5411.754251	0.912864742	OA
32R	Zwolle	MA	F	R	2333.634764	2321.15191	4654.786673	1.00537787	OA
2451L	Arnhem	OA	M	L	5823.916148	5216.096749	11040.0129	1.116527631	OA
2451R	Arnhem	OA	M	R	4046.141447	3897.027625	7943.169072	1.038263476	OA
36L	Zwolle	MA	F	L	6682.262259	5000.284848	11682.54711	1.336376319	OA
36R	Zwolle	MA	F	R	5000.239188	5303.83252	10304.07171	0.942759631	OA
2484L(2)	Arnhem	YA	F	L	3490.493927	4519.392548	8009.886476	0.772336966	OA
2484R(2)	Arnhem	YA	F	R	4317.813759	3815.038089	8132.851848	1.131787851	OA
45R	Zwolle	OA	F	R	12962.0751	8833.111206	21795.1863	1.467441629	OA
2168L	Arnhem	MA	F	L	5245.808347	5668.930691	10914.73904	0.925361172	OA
2168R	Arnhem	MA	F	R	3318.123319	4402.396491	7720.51981	0.753708424	OA
50L	Zwolle	MA	M	L	4986.245709	4058.998193	9045.243902	1.228442456	OA
50R	Zwolle	MA	M	R	3413.343634	3413.343634	6826.687267	1	OA
2433L	Arnhem	MA	F	L	5796.086609	6363.70639	12159.793	0.910803587	OA
2433R	Arnhem	MA	F	R	3772.925452	5623.290508	9396.215961	0.67094621	OA
1883L	Arnhem	YA	F	L	3352.801137	4273.885526	7626.686664	0.78448548	OA
1883R	Arnhem	YA	F	R	3880.099662	2788.239017	6668.338679	1.391595067	OA
53L	Zwolle	MA	M	L	6917.174887	6357.78635	13274.96124	1.087984796	OA
53R	Zwolle	MA	M	R	6714.724777	7150.596063	13865.32084	0.939044063	OA
55R	Zwolle	YA	F	R	3767.708629	4032.719063	7800.427692	0.934284926	OA
68L	Zwolle	MA	F	L	4505.273197	5096.104897	9601.378095	0.8840621	OA
68R	Zwolle	MA	F	R	5184.797344	4578.806458	9763.603802	1.13234691	OA
69L	Zwolle	OA	F	L	4786.683379	5984.968313	10771.65169	0.799784248	OA
69R	Zwolle	OA	F	R	6125.944211	4940.217512	11066.16172	1.240015079	OA
70L	Zwolle	OA	M	L	7252.494565	7569.422419	14821.91698	0.95813051	OA
70R	Zwolle	OA	M	R	5768.659625	6400.123447	12168.78307	0.901335681	OA
77L	Zwolle	MA	M	L	2983.341472	2642.717675	5626.059147	1.128891482	OA

77R	Zwolle	MA	M	R	3055.645857	3483.422336	6539.068193	0.877196493	OA
86L	Zwolle	YA	M	L	4476.573671	3765.818038	8242.39171	1.188738709	OA
86R	Zwolle	YA	M	R	6594.580541	5045.876747	11640.45729	1.306924618	OA
87L	Zwolle	YA	F	L	5326.749327	4147.84325	9474.592577	1.284221463	OA
87R	Zwolle	YA	F	R	3583.568324	3391.220364	6974.788688	1.056719393	OA
90L	Zwolle	OA	M	L	2092.106922	2744.23347	4836.340392	0.762364771	OA
90R	Zwolle	OA	M	R	6033.362108	4447.64122	10481.00333	1.356530756	OA
105R	Zwolle	MA	F	R	3468.809381	4179.736166	7648.545547	0.829911086	OA
112L	Zwolle	OA	F	L	4218.839393	4155.909076	8374.748469	1.015142371	OA
112R	Zwolle	OA	F	R	3725.53691	4722.735487	8448.272397	0.788851487	OA
118L	Zwolle	OA	F	L	6613.038265	4938.127964	11551.16623	1.339179202	OA
118R	Zwolle	OA	F	R	5049.486347	7609.409981	12658.89633	0.663584478	OA
121L	Zwolle	OA	F	L	6299.529924	7508.292448	13807.82237	0.839009664	OA
121R	Zwolle	OA	F	R	3928.159164	4093.144057	8021.30322	0.959692381	OA
125L	Zwolle	MA	M	L	6118.02825	6793.43997	12911.46822	0.900578834	OA
125R	Zwolle	MA	M	R	4970.308739	4383.959208	9354.267947	1.133748857	OA
130L	Zwolle	YA	F	L	4169.562856	5000.002361	9169.565217	0.833912177	OA
130R	Zwolle	YA	F	R	2511.337911	2266.126697	4777.464608	1.108207195	OA
205L	Zwolle	MA	M	L	4417.686863	4654.911332	9072.598196	0.949037811	OA
205R	Zwolle	MA	M	R	3530.381222	4269.617557	7799.998779	0.826861229	OA
207L	Zwolle	MA	F	L	4040.532902	6826.827066	10867.35997	0.59186103	OA
207R	Zwolle	MA	F	R	4663.68533	4368.487862	9032.173192	1.06757429	OA
492L	Arnhem	MA	M	L	4028.096027	4427.874766	8455.970793	0.909713178	non-OA
560L	Arnhem	MA	M	L	2824.251384	3350.58041	6174.831794	0.842914074	non-OA
560R	Arnhem	MA	M	R	4832.330277	4009.987465	8842.317742	1.205073662	non-OA
855R	Arnhem	YA	F	R	3053.734125	3133.996814	6187.730939	0.974389671	non-OA
1432L	Arnhem	YA	M	L	3324.347056	2827.175271	6151.522327	1.175854603	non-OA
1432R	Arnhem	YA	M	R	4901.767918	4277.193307	9178.961225	1.146024406	non-OA
1434R	Arnhem	YA	F	R	4243.661627	5240.783641	9484.445268	0.809737993	non-OA
1495L	Arnhem	YA	M	L	4671.648457	4105.911413	8777.559871	1.137785984	non-OA
1495R	Arnhem	YA	M	R	5214.415827	4184.812248	9399.228075	1.246033398	non-OA
1500L	Arnhem	YA	M	L	4317.227373	4790.373202	9107.600575	0.901229861	non-OA
1500R	Arnhem	YA	M	R	3294.33867	3673.722501	6968.061171	0.896730406	non-OA
1506L	Arnhem	MA	F	L	5617.039895	8859.400353	14476.44025	0.634020325	non-OA

1561L	Arnhem	MA	M	L	6335.623362	8232.625016	14568.24838	0.769575117	non-OA
1561R	Arnhem	MA	M	R	5602.306241	5636.730451	11239.03669	0.993892876	non-OA
1585L	Arnhem	YA	F	L	5068.590123	5601.024255	10669.61438	0.904939863	non-OA
1585R	Arnhem	YA	F	R	4860.483189	4824.958331	9685.44152	1.007362728	non-OA
1638L	Arnhem	YA	F	L	8103.550053	6764.549066	14868.09912	1.197943865	non-OA
1638R	Arnhem	YA	F	R	4922.970657	6114.470059	11037.44072	0.805134478	non-OA
1864L	Arnhem	MA	M	L	4990.723486	5546.66388	10537.38737	0.899770311	non-OA
1864R	Arnhem	MA	M	R	6237.453925	4437.216557	10674.67048	1.405713209	non-OA
2062L(1)	Arnhem	YA	M	L	3542.431613	4098.395931	7640.827544	0.864345874	non-OA
2062R(1)	Arnhem	YA	M	R	3094.321482	3802.333219	6896.654701	0.813795452	non-OA
2064L(1)	Arnhem	MA	M	L	2656.306493	3263.30904	5919.615534	0.813991706	non-OA
2064R(1)	Arnhem	MA	M	R	4562.575514	4438.687685	9001.263199	1.027910914	non-OA
2107L	Arnhem	MA	M	L	3991.153129	4553.265478	8544.418606	0.876547425	non-OA
2107R	Arnhem	MA	M	R	3901.773226	3352.831531	7254.604756	1.163724807	non-OA
2114L	Arnhem	YA	F	L	3983.63405	4978.585858	8962.219908	0.800153731	non-OA
2114R	Arnhem	YA	F	R	4666.915849	3277.06492	7943.980769	1.424114555	non-OA
34L	Zwolle	YA	M	L	4565.835294	5384.446231	9950.281525	0.847967478	non-OA
34R	Zwolle	YA	M	R	5373.141304	6328.160562	11701.30187	0.849084225	non-OA
35L	Zwolle	YA	M	L	4388.515418	3943.681334	8332.196752	1.11279666	non-OA
35R	Zwolle	YA	M	R	3879.692388	4830.635424	8710.327812	0.803143282	non-OA
39L	Zwolle	YA	M	L	3469.903876	3359.815778	6829.719654	1.032766112	non-OA
39R	Zwolle	YA	M	R	2749.060173	3932.115364	6681.175538	0.699130091	non-OA
44L	Zwolle	YA	M	L	2219.843789	3673.375665	5893.219454	0.604306227	non-OA
44R	Zwolle	YA	M	R	4595.630893	5413.064431	10008.69532	0.848988766	non-OA
49L	Zwolle	MA	M	L	4159.233796	3961.951254	8121.18505	1.049794288	non-OA
49R	Zwolle	MA	M	R	4853.50838	4506.560424	9360.068804	1.076987308	non-OA
51L	Zwolle	MA	F	L	4831.176861	6007.594999	10838.77186	0.804178188	non-OA
51R	Zwolle	MA	F	R	5344.177411	5680.928554	11025.10597	0.940722518	non-OA
52L	Zwolle	YA	F	L	2059.158848	2029.153239	4088.312087	1.014787257	non-OA
52R	Zwolle	YA	F	R	3669.006362	3495.737334	7164.743697	1.049565803	non-OA
54L	Zwolle	MA	M	L	4179.112617	4936.637356	9115.749973	0.846550458	non-OA
54R	Zwolle	MA	M	R	3304.223152	4015.474126	7319.697278	0.82287248	non-OA
63L	Zwolle	YA	M	L	5319.062742	5344.545226	10663.60797	0.995232057	non-OA
63R	Zwolle	YA	M	R	6063.497709	8021.587808	14085.08552	0.755897443	non-OA

94L	Zwolle	MA	M	L	3926.612487	4475.115218	8401.727705	0.877432713	non-OA
94R	Zwolle	MA	M	R	4898.393016	6080.233574	10978.62659	0.805625796	non-OA
99L	Zwolle	MA	F	L	2936.742723	3265.67466	6202.417383	0.899275962	non-OA
99R	Zwolle	MA	F	R	2652.878491	2770.560062	5423.438553	0.957524266	non-OA
114L	Zwolle	MA	F	L	4006.643137	6231.05416	10237.6973	0.643012087	non-OA
114R	Zwolle	MA	F	R	6643.012622	7303.650018	13946.66264	0.909546953	non-OA
115L	Zwolle	MA	F	L	2803.095181	3658.459497	6461.554678	0.766195494	non-OA
115R	Zwolle	MA	F	R	4203.213919	2515.014022	6718.227941	1.671248702	non-OA
117L	Zwolle	YA	F	L	4561.829308	4083.838161	8645.667469	1.117044586	non-OA