Do Feet Really Tell All? Comparing the Stature Estimation Method of Pablos et al. (2013) to the Established Fully Method and Trotter and Gleser Method with Skeletal Analysis of the Middenbeemster Collection from the 16th till 18th Century AD

Molenaar, Lara

Do Feet Really Tell All?

Comparing the Stature Estimation Method of Pablos et al. (2013) to the Established Fully Method and Trotter and Gleser Method with Skeletal Analysis of the Middenbeemster Collection from the 16th till 18th Century AD

Lara Molenaar

Do Feet Really Tell All?

Comparing the Stature Estimation Method of Pablos et al. (2013) to the Established Fully Method and Trotter and Gleser Method with Skeletal Analysis of the Middenbeemster Collection from the 16th till 18th Century AD.

Author, student number: Lara Molenaar

Course Bachelor Thesis, 1083VBTHEY_2223_HS

Supervisor: Dr R. Schats

Leiden University, Faculty of Archaeology

Schiedam, 15th of June 2023, Final Version

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

When human bones are found in an archaeological context, it is the osteologist's task to discover as much as possible about the individual's life. Things such as their sex, their age-at-death, and their stature are important facets to research, as these things can explain the development of people through time as well as give indications of their health. Though a lot more can be learned from skeletons, from information on pathological conditions to the diet of individuals (DeWitte and Stojanowski, 2015, p. 398). All that is needed is that the correct bones have survived, in the right conditions.

Stature, the final adult body height, which is part of the biological profile of an individual, is an important subject in the research of past individuals. Stature can give us information about the way people in the past evolved, as well as how people reacted to changes in their socioeconomic environment (Maat, 2005, p. 276-277; Schats, 2016, p. 53). Stature is also researched in a forensic context. When a human skeleton is found it can be an important indication for the identification of the individual (Christensen et al., 2014b, p. 285). For both these research foci, it is important to have reliable and easy-to-use methods.

1.1 Research Problem

Currently, two methods are most often applied in archaeological contexts. These are commonly known as the anatomical method and the mathematical method (Pablos et al., 2013, p. 299.e1). The anatomical method, more commonly known as the Fully method, was developed by G. Fully ((1956) as cited in Raxter et al. 2006, p. 375), and uses the majority of bones in the human body. It measures all the bones that contribute to the height of a person. These measurements are then added up, and a specific number, which is known as the soft tissue factor, is added to account for the soft tissue that is missing from the skeleton. From this formula, a stature with a standard error is calculated. More recently, there has been a revision of the Fully method (Raxter et al., 2006, p. 382-383), which created a new formula based on the Fully method, and specified the way all bones need to be measured.

The mathematical method, commonly known as the Trotter and Gleser method, was developed by Trotter and Gleser (1952; 1958). The method uses only one of the major long bones in the human skeleton to calculate stature. The method can be applied to (one of) the following five different long bones: humerus, ulna, radius, femur, and fibula. The bone's length is measured and then applied to a formula. There are different formulae for different sexes, as well as the ancestry of the individual.

Lundy (1985, p. 74-75) compared the Fully method and the Trotter and Gleser method to each other. He compared the measuring technique of the methods as well as the reality of the archaeological record. According to him, it is more likely to have at least one complete long bone in the archaeological record than it is to have the full skeletal remains of the individual. This is why the Trotter and Gleser method is more widespread in archaeological research, compared to the original Fully method. It also takes a lot more time to measure all the bones that contribute to a person's height, which makes the Fully method a lot more time-consuming. Therefore, it is more likely that an archaeologist would still choose for the Trotter and Gleser method than for the Fully method even when the full skeleton is available.

Lundy (1985) did not look at the difference in precision and accuracy between the two methods, nor how comparable the results were when both are applied on the same skeleton. The overall conclusion of his paper was that the preference should still go to the Fully method, as it is more likely to give an accurate height, as it measures the height of the bones connected to stature instead of calculating it from a single bone. He adds that if the skeleton is incomplete, the Trotter and Gleser method should be applied. However, the reality is that often the long bones are not complete either (CITE). And when that is the case neither of these methods can be applied.

Therefore, several methods have been created that use other bones to estimate stature. One of these is the method by Pablos et al. (2013). Their method uses a combination of footbones to estimate the living height of an individual. The method often uses two bones in the feet, a metatarsal and the calcaneus or talus. The combination of bones and the resulting formula depends on the sex of the individual. For an accurate estimation, there are separate formulas created for those of Afro-American or Euro-American ancestry, both differentiating in the male and the female individuals.

As the research of Pablos et al. (2013, p. 299.e1-299.e2) shows, it is more likely to find foot bones than a complete skeleton or complete long bones in the archaeological record. When excavating archaeological remains there is a big chance that the taphonomic processes have altered the bones in such a way that they are unusable. Parts that need to be used could be eroded, or the bones could have broken.

Therefore, this method, which would use components of the foot, could be a feasible alternative to the Fully method or the Trotter and Gleser method. However, so far there has not been any systematic review that investigates the usability of this method on the archaeological record. It is not clear how well this particular method compares to the two trusted methods, nor how well it works for the Dutch archaeological populations. The method itself was devised on a medical collection from America and therefore focused on Euroamericans and Afroamericans.

This identifies the importance of this thesis. The goal is to research how the Pablos et al. (2013) method compares to the more commonly used methods of Fully (1956) and Trotter and Gleser (1952, 1958) when using the Dutch Middenbeemster collection. The results would be helpful for both archaeologists as well as forensic anthropologists.

1.2 Research Questions

The main research question of this thesis is as follows: How do the statures obtained using the Pablos et al. (2013) method compare to the statures obtained with both the Fully and Trotter and Gleser method?

To answer this question there are several sub-questions formulated:

1. How do the statures obtained using the revised Fully method compare to those obtained by the Trotter and Gleser method and are there differences between males and females?
2. How do the statures obtained using the revised Fully method compare to those obtained using the Pablos et al. (2013) method and are there any differences between males and females?
3. How do the statures obtained using the Trotter and Gleser method compares to the statures obtained using the Pablos et al. (2013) method and are there differences between males and females?

1.3 Materials and Methods

To answer the research questions, 21 nearly complete adult skeletons were analysed. The chosen skeletons come from the Middenbeemster collection that is being stored in the depot at Leiden University. This collection consists of skeletons excavated in the cemetery of the Keyserkerk in Middenbeemster. Most of the skeletons of the collection date between 1829 and 1866, but the church has been used since 1623, and some of the skeletons come from this earlier time period (Hankvoort, 2013, p. 35).

Stature will be estimated for all the individuals using the revised Fully method (Raxter et al., 2006), the Trotter and Gleser regression equations (1952, 1958) and the Pablos et al. (2013) method. The focus will lie on both sides of the skeleton unless only one side is available. Then this shall be used.

1.4 Thesis Outline

The second chapter of this thesis will provide a background on past research done into stature estimation and will give more information about how these methods were created and when they can and should be used. The third chapter describes the materials and the methods that will be used for this research, with more information about the Middenbeemster collection as well as what criteria were applied. There will also be more information about the specific data collection as well as the data analysis of the results. The fourth chapter will contain the results of the research. The fifth chapter will give an interpretation of the results and will discuss the possible implications of these interpretations. The sixth, and last, chapter will give a conclusion, where the research questions will be answered, and possible future research will be mentioned.

Chapter 2: Background

This chapter will discuss the background of stature estimation. First, it will explain the types of stature estimation and the foundations of these methods. Afterwards there will be a brief history on the three methods that will be used in this thesis.

2.1 Anatomical Stature Estimation Versus Mathematical Stature Estimation

The methods that are used to estimate the stature of an individual can generally be divided into two different methods. The anatomical method and the mathematical method.

The anatomical method, such as the Fully method, uses the full body of the individual in its estimation (Raxter et al., 2006, p. 374). Because these methods rely on skeletal remains, the method uses all the bones that attribute to a person's height. This means the skull, the vertebral column, the upper and lower legs, and the ankle of the individual. The stature is estimated by adding the length or height of all these individual bones. This value is then put into a formula that takes the shrinkage of bone through time and the lack of soft tissue present in the skeletal remains into account. This is often described as the soft tissue factor. Different methods have different soft tissue correction factors (Bidmos & Manger, 2012, p. 212.e1).

The mathematical method is based on the concept of allometry. Allometry focuses on the relationship between the size of one body part to the size of others or the whole body. According to Allometry, each body part is relationally different to the others. With help of mathematical formulae, commonly known as regression formulae, these methods use the length or height of one or more bones in the body to estimate the height of the person itself (Pearson, 1899, p. 170-177). Ancestry and sex need to be kept in mind when mathematical methods are used to estimate the stature of an individual. This is because each population and each sex have different body ratios (i.e., body proportions) (Pearson, 1899, p. 177). For example, when taking two people of different ancestry with the same height and sex, the ratio of the length of their arm to the length of the entire body can be different. This needs to be taken into account with the mathematical formulae.

Many of the mathematical methods use long bones to estimate stature(femur, tibia, humerus, ulna, radius) (Trotter & Gleser, 1952, 1957; Trotter 1970). However, there are also mathematical methods that use the bones in the feet (e.g., Cordeiro et al., 2009, p. 131.e3; Karmalkar & Nikam, 2021, p. 156; Pablos et al., 2013, p. 299.e4-299.e5; Rodriguez et al., 2013, p. 297.e3). Others use the length of a clavicle (Torimitsu et al., 2017, p. 316.e4), cranial dimensions (Shrestha et al., 2015, p.187.e4-187.e5), or the length of cranial sutures (Jagadish Rao et al., 2009, p. 275).

For this thesis, the focus will be on three different methods; the revised Fully method, an anatomical method, the Trotter and Gleser method, a mathematical method that focuses on long bones, and the Pablos et al. (2013) method, a newer mathematical method that uses bones in the feet.

2.2 A Brief History of Skeletal Estimation Methods

2.2.1 The Anatomical Method of Stature Estimation

Throughout history many anatomical methods were developed for the estimation of stature. These methods have been worked on over the years, making them better, more accurate and easier to use.

One of the first times an anatomical approach was used to estimate stature of a skeletonised individual was in 1878 by T. Dwight (1878, p. 40-49). In this book, and later publications (Dwight, 1894, p. 293-294), he describes how one could estimate the height of the individual by placing the bones in a way they would be in a living body. He recreates this by placing the vertebrae in clay to create the spine and to leave room between them for the intervertebral disks. He subsequently places the rest of the bones around the spine, articulating them where possible. Measuring the height that was given by this placement, the stature was estimated.

Fully (1956, as cited in Raxter et al., 2006, p. 375) builds on Dwight's approach. Instead of placing the vertebrae in clay, each bone relating to stature is measured individually. These measurements include the height of the cranium, the height of the bodies of the vertebrae (except the first vertebra), the anterior height of the first sacral segment, the length of the femur and tibia, and the articulated height of the talus and the calcaneus. After measuring these bones, a soft tissue factor is added to estimate the living stature.

Fully's method (as cited in Raxter et al., 2006, p. 375) is based on individuals that Fully had previously identified on a Second World War battlefield of Mauthausen in Austria. With the identification, each soldier's living stature was known and could be tied to their skeletal remains. In total, he used 102 males to devise this method. All his individuals originated from France or other European countries. One of the drawbacks of this method was that the explanation of the measurement technique was not clear.

This is why Raxter et al. (2006) revised the method. They rework the method, specifying the way each bone should be measured, and rework the formula for the soft tissue factor. Raxter et al. (2006, p. 376) revised the method with the use of the Terry Collection of the National Museum of Natural History. They researched 119 skeletal remains, 54 of these were female, 65 were male, divided into those of Euro-American descent and of Afro-American descent. The age, ancestry, sex, and cadaveric statures were known for all the individuals, and they were all ranging from the age 21 to 85 years at time of death.

Raxter et al. (2006, p. 378) have devised two equations, one which incorporates the age of the individual and one that does not. The most accurate equation incorporates the individual's living age, but as Raxter et al. (2006, p. 378) acknowledge, for archaeological or forensic skeletal remains it is often not possible to estimate a specific age, only to estimate an age range. Therefore, they also devised an equation that does not need the specific age at death to work. For this method the sex nor the ancestry of the individual needs to be taken into account, as this is an actual sum of all bones that contribute to stature.

As the method made some important improvements to the anatomical method, the revised Fully method will be used in this thesis. This research works with skeletons from the Dutch population from Middenbeemster, and the revised Fully method from Raxter et al. (2006), and the revised Fully method can be applied here. It also has a clear method to measure each bone, which can be followed easily.

2.2.2 The Mathematical Method to Estimate Stature

2.2.2.1: Long bone Regression Model

As discussed, there are several mathematical methods available for the estimation of stature. Most commonly, the Trotter and Gleser method is applied, which used individual long bones to create regression formulae which are both population and sex-specific. However, this method was not the first of its kind.

According to Trotter and Gleser (1952, p. 463), the most important research into stature estimation through long bones came from Rollet's *De la Mensuration de Os Longs des Membres* (1888). Rollet measured 100 cadavers between the ages of 24 and 99 years approximately a week after their death. Afterwards, six long bones (humerus, radius, ulna, femur, tibia, and fibula) were extracted and measured for length. All were measured in wet condition when the bone was just extracted and still moist from the fluid in the body, and a part of them were measured in dry condition, after the bones had been laid to dry, leading to a shrinkage of about 2 cm (Trotter & Gleser, 1952, p. 463-464). Rollet (1888, as cited in Totter & Gleser, 1952, p. 464) created a Table with these measurements, where, for each stature, the average length of the six long bones were given. There were no regression formulae yet present in this method.

From Rollet's work, more research was done on long bone measurements and the estimation of stature. Two of these studies were done by Manouvrier and Peason. Manouvrier (1892; 1893, as cited in Trotter and Gleser, 1952, p. 464) used a similar technique, however, his Table gave an average range of statures connected to the measured long bones. The method of Manouvrier gave the cadaveric stature connected to the bone length, and 2 cm had to be taken away to account for living stature.

Pearson (1899, p. 192-196) devised 10 different formulae using the humerus, radius, femur, and tibia, as well as several combinations of these bones. Instead of measuring individuals himself, he used the datasets provided by other researchers, including Rollet and Manouvrier. An interesting aspect of his research is that Pearson (1899, p.198-216) is the first to use regression formulae to estimate the stature instead of creating a relative Table. Not only did he create formulae for individual populations, but he also used his formulae to estimate archaeological stature, such as neolithic, palaeolithic and protohistoric cases from European origin. Pearson (1899, p. 241) concludes that, although these formulae are likely the best method available so far, more research needs to be done, especially when taking population differences into account. A similar conclusion was also given by Stevenson (1929, p. 319) when he tried to use the formulae of Pearson on Northern Chinese people. This showed that these methods are indeed population specific.

Trotter and Gleser (1952; 1958) took their own stab at stature estimation, and it has since then been extensively used in anatomical research. They devised their method on the Terry Collection; this collection consists of American soldiers that died during the Second World War (Trotter & Gleser, 1958, p. 79). They have revised their own method several times. In their first article, they focused on Euroamerican and Afro-American skeletons (Trotter & Gleser, 1952, p. 468). Later they revisited their method by adding formulae for Mongoloid, Mexican and Puerto Rican males (Trotter & Gleser, 1958, p. 80).

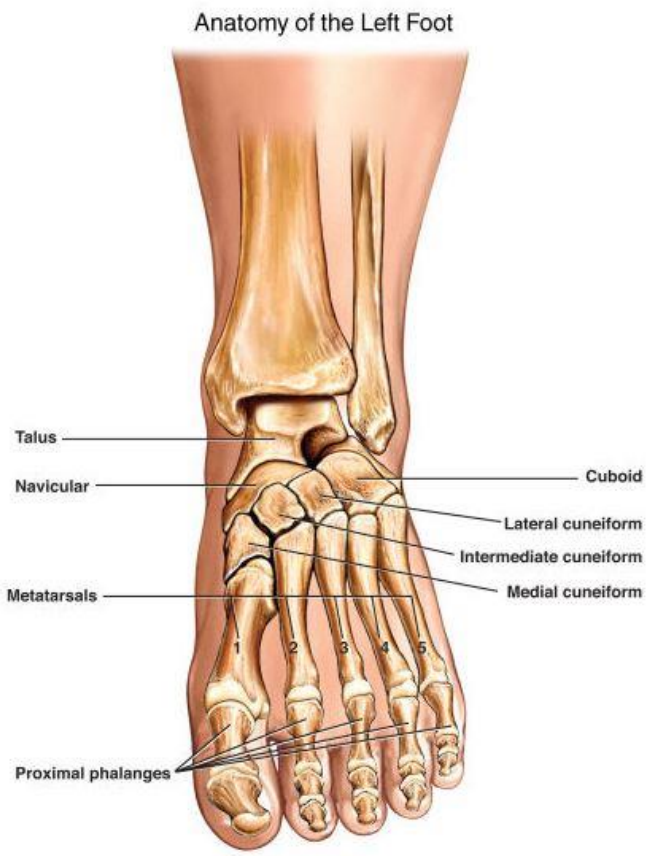
Trotter (1970, p. 72) reformulated the method again, while still using the same collections as the previous two articles. In this last reformulation, there were regression formulae created for the humerus, radius, ulna, femur, tibia, and fibula. Trotter created a formula for each long bone, all with their own standard error. For each population and sex, they made new formulae. When using the method, it is best to measure the complete bone that has the lowest standard error which can be found in the Table. When estimating stature for Euroamerican males, the femur has a preference, as this formula has the lowest standard (Trotter, 1970, p. 77). For females, the femur has the second lowest standard error. The fibula has the lowest standard error for Euroamerican females.

2.2.2.2 Talar bone regression models

Both the Fully method and the Trotter and Gleser method have been widely used because of their reliability, viability, and applicability (Christensen et al., 2014b, p. 285-287). In the context of archaeology, forensics, and palaeoanthropology it is not always possible to use one of these methods. As mentioned in the introduction, bones can often be found broken or too weathered for either method. Therefore, other methods that use different bones have been devised. Several of these methods focus on talar bones (see Figure 1). They use a combination of talar bones (Pablos et al., 2013, p. 299.e4-299.e5) or only one bone (Cordiero et al., 2009, p. 131.e3; Rodriquez et al., 2013, p. 297.e3) in their regression formulae.

Figure 1

The Anatomy of the Feet, Showing All Talar Bones Identified by Their Scientific Name



Note. From 4. Anatomy and physiology of the foot and nail learning outcomes. In *Basic Foot Care for RNs and RPNs*, by S. Lockbaum, n.b., Pressbooks (https://ecampusontario.pressbooks.pub/nrsghzpae/chapter/anatomy-and-physiology-of-the-foot/). CC BY 4.0.

Talar bones might be found intact more often than long bones, or the more fragile bones such as crania (Pablos et al., 2013, p. 299.e2). This has resulted in several methods being devised that use talar bones estimate stature. Feet and footprints have a correlation to stature as proven in several publications (e.g., Kanchan et al., 2008, p. 241.e4; Karmalkar & Nikam, 2021, p. 157; Krishan, 2008, p. 98; Reel et al., 2012, p. 283.e4).

Cordiero et al. (2009, p. 131.e3) devised a method of stature estimation based on metatarsal length. They used a Portuguese population for this specific method. Rodriguez et al. (2013, p. 297.e3) worked with the regression formulae of Cordiero et al. (2009), using radiographic imaging to establish the metatarsal length of Spanish individuals. Their research showed that, while it is possible to create formula based on one specific population, footbones are so population-specific, these formulae cannot be used on every similar population. Therefore, it is important to find a method that could be used on the Dutch population.

Pablos et al. (2013) stand out from this large group of stature estimation methods, as it focuses on more than one population and on more than one talar bone. They devised several formulae, based on regression analysis, using the talus, calcaneus, and metatarsals. They based formulae on singular bones as well as combining talar bones. Pablos et a. (2013, p. 299.e2) based their formulae on Euroamerican and Afroamerican males and females from the Hamann-Todd Osteological collection. They used 48 males, divided into 25 Euroamericans and 23 Afroamericans, and 46 females, divided into 21 Euroamericans and 25 Afroamericans.

They studied both the relation between the length of one individual footbone to the stature of the individual, as well as the relation of the combination of bones in the heel (talus and/or calcaneus) and the bones in the ball of the foot (the metacarpals) to stature. In their research, they found that the best method of estimation is not looking at a singular bone but combining the bone in the heel (calcaneus) to one of a bone in the ball of the foot. This way the formulae reflect both the posterior and anterior part of the foot, which is closer to the true foot length.

For each population and sex, as well as the pooled population and sex, two regression formulae were created. One formula uses one single talar bone, taking the bone which the tests from Pablos et al. (2013, p. 299.e5) show to have the highest significant relation to stature. The second formula uses a combination of one bone form the heel and one bone from the ball of the foot. The latter of the two formulae shows to be most accurate, as it has the lowest standard error, and the lowest p-value.

Each method has its drawbacks, and all are associated with a standard error, but they have not yet been compared to each other. Each method is important and can be used individually, but the question is if there is one method that is preferable to the other. Are anatomical methods more accurate than mathematical methods? And are the methods based on long bones, more accurate than those based on smaller bones?

To assess this, this thesis compares the three methods of Raxter et al. (2006), Trotter and Gleser (1952;1970) and Pablos et al. (2013).

Chapter 3: Methods and Materials

In this chapter, the materials and methods will be discussed. First there will be information on the Middenbeemster collection, followed by the selection criteria used in this thesis. In the second part the three methods that are used in this thesis are explained. Lastly the method of data analysis will be explained

3.1 Materials

3.1.1 The Middenbeemster Skeletal Collection

The Middenbeemster collection is an archaeological collection that was excavated in the Middenbeemster cemetery during the excavation near the Keyserkerk of Middenbeemster. In total the collection consists of more than 500 hundred skeletal remains of both adults and sub-adults. Not all of these are in a perfect condition, as the skeletons are from an archaeological excavation (Lemmers et al., 2013, p. 35).

In the report of the excavation 125 skeletons of the 500+ individuals were discussed. It showed that 64.8% were in good or even pristine condition. When looking at the individuals, 71 were described in the report, the division of male and female was nearly equal, 46.5% were men, and 52.1% were female (Lemmers et al., 2013, p. 41).

The age of the individuals can only be estimated in age brackets. Of the adults, the majority were in the 36-50 age bracket. The lengths of the individuals as measured through the Trotter and Gleser formulae were between 140 and 189 cm. With the peak for women being between 150-159 and for men between 160-169 (Lemmers et al., 2013, p. 42-43).

3.1.2 Selection Criteria

For the selection of the individuals, several things needed to be kept in mind. First, the individuals all had to be adults, as none of the three methods can be used on non-adults. Second, all bones that were used in each individual stature estimation method needed to be present. This means that the spine needed to be complete, with a focus on the bodies of the vertebrae. The skull needed to be complete enough that the cranial height was measurable. The femur, tibia, talus, and calcaneus needed to be present as well as the second metatarsal.

Preferably all these bones were present on both sides of the body as the revised Fully method calls for the mean length or height of the two sides (Raxter et al., 2006, p. 376). As the Pablos et al. (2013) method uses the right bones (Pablos et al., 2013, p. 299.e3), it is preferrable that the right talar bones are present.

To select the individuals, the previous criteria were used. In total, there were 65 skeletons that appeared complete enough to be included based on the skeletal forms that were available for each individual. However, upon closer inspection, not all were usable bringing the sample down to 37 individuals. When the siding of the talar bones was taken into account, six more individuals had to be removed, leaving 31 individuals, with all but one having the required talar bones on both sides. This was important because the talus and calcaneus are both used in the revised Fully method (Raxter et al., 2006, p. 376) and the Pablos et al. (2013) method.

The Trotter and Gleser Method, as well as the Pablos et al. (2013) method both have sex-specific formulae. For several of these skeletons, the sex had not been definitively established, categorising them as probable male or female. As it is unclear what influence this could have on the measurement and following estimations of stature, these individuals were removed from the sample as well. With all these very specific criteria, there were in total 10 female individuals and 11 male individuals left for this study.

As these skeletons are from an archaeological assemblage, the age of the individuals cannot be accurately determined and only an age group. The modal class for the female skeletons is late young adults, meaning between the ages of 26-35. For the males, the modal class is middle adult, meaning between the ages of 36 and 50 years of age.

3.2 Methods

3.2.1 The Methods for Stature Estimation

There are three methods that are compared in this thesis. The first is the revised Fully method and the measurements were taken as described by Raxter et al. (2006). The second method is the Trotter and Gleser method, in which measurements were taken as described by Trotter (1970). The last method is the Pablos et al. (2013) method, for which the measurements were taken as described in their paper.

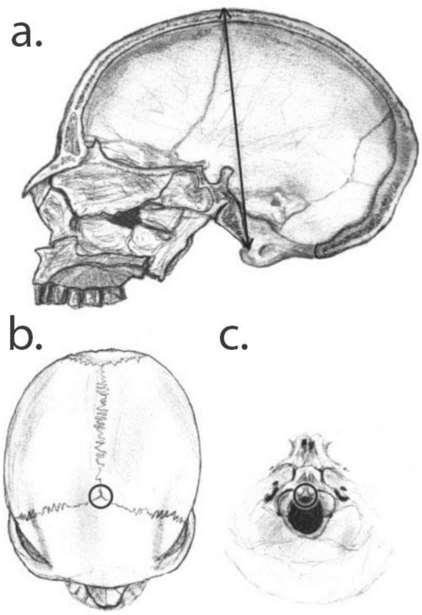
3.2.1.1 The Revised Fully Method

As mentioned in the background chapter the revised Fully Method uses the skull, vertebrae, femur, tibia, talus, and calcaneus. This section will explain the method of measurement and the formula will be given. The method followed the guidelines given by Raxter et al. (2006, p. 375).

When measuring the cranial height, the distance between bregma and basion was measured (see Figure 2a). The bregma can found where the coronal and sagittal sutures meet on the superior side of the skull (see Figure 2b). While the basion can be found between the occipital codyles on the anteroinferior margin of the foramen magnum (see Figure 2c) (Raxter et al., 2006, p. 382). This distance was measured with a spreading caliper in centimetres.

Figure 2

A Drawing Highlighting the Length Between the Bregma and Basion (a) as well as the Bregma (b) and the Basion (c)



Note. Adapted from “Revision of the Fully Technique for Estimating Statures,” by M. H. Raxter, B. M. Auerback and C. B. Ruff, 2006, *American Journal of Physical Anthropology, 130*(3), p. 382 (Doi/10.1002/ajpa.20361).

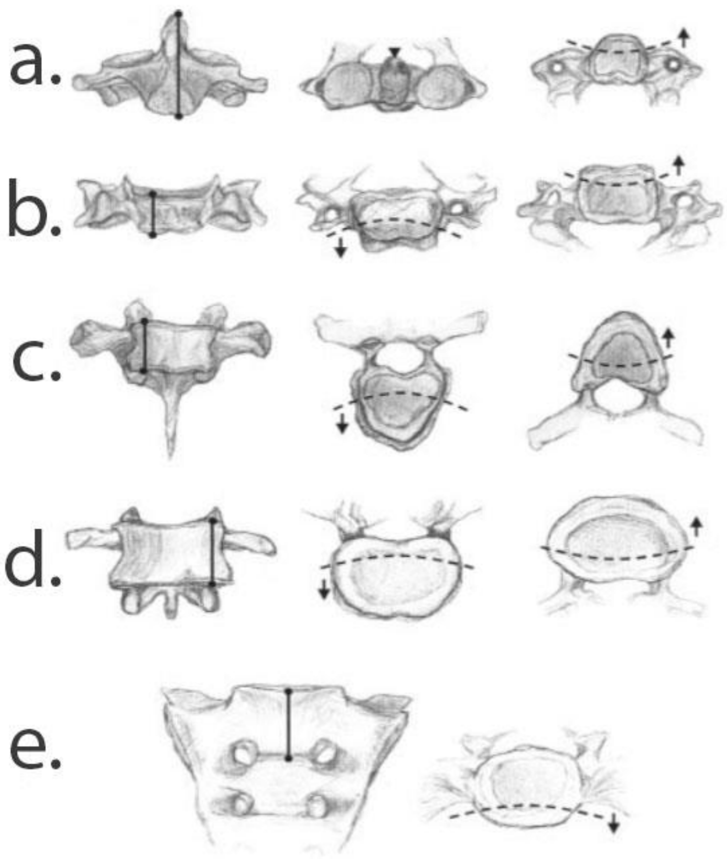
For the vertebrae (C2 – L5) and the first sacral vertebra, the maximum vertebral body height was measured as described by Raxter et al. (2006, p. 382-383) and all measurements were taken with a sliding caliper, noted in centimetres:

- For the axis, (second cervical vertebrae), the vertebral body height, including the dens, was measured from the most superior point of the dens to the most inferior point of the anteroinferior rim of the vertebral body (see Figure 3a).
- For the cervical vertebrae 3 to 7, their height was measured from the anterior medial to the curving edges of the centrum (see Figure 3b).
- For the thoracic vertebrae, the maximal height measurements were taken anterior to the rib articular facts on the body and the pedicles (see Figure 3c).
- For the lumbar vertebrae, the maximum height was measured anterior to the pedicles, not including any swelling of the centrum due to the pedicles (see Figure 3d).

- For the first sacral vertebra (S1), the maximum height was taken between the anterior surface of S1, measuring between anterior-superior rim of the body, and the point where the segment fuses and/or articulates with the second sacral vertebra (see Figure 3e).

Figure 3

A Drawing Highlighting how of Measure the First Cervical Vertebra (a), the Third to Seventh Cervical Vertebrae (b), the Thoracis Vertebrae (c), the Lumbar Vertebrae (d) and the 1st Sacral Vertebra (e) for the Revised Fully Method



Note. Adapted from "Revision of the Fully Technique for Estimating Statures," by M. H. Raxter, B. M. Auerback and C. B. Ruff, 2006, *American Journal of Physical Anthropology, 130*(3), p. 382 (Doi/10.1002/ajpa.20361).

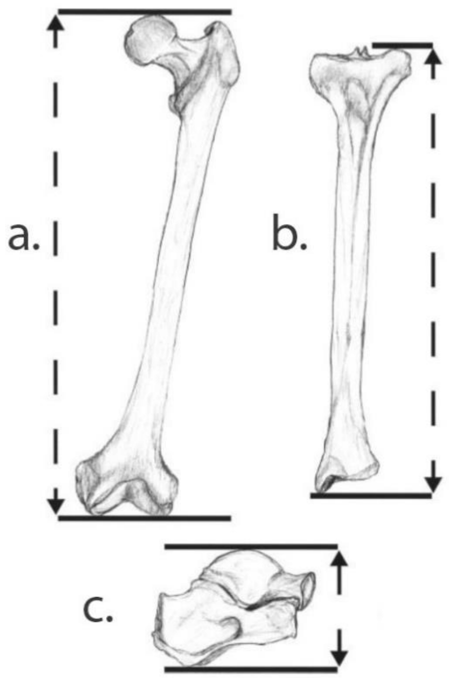
For both long bones and the talar bones, where possible, both sides were measured (in cm) and the average value of both sides was used in the formula. The bones are measured as follows, following the descriptions of Raxter et al. (2006, p. 382-383):

- The femur was measured for its physiological (bicondylar) length through the use of an osteometric board. To do so, both distal condyles were placed at the stationary end of the board, while the mobile end was set against the most superior aspect of the femoral head (see Figure 4a).

- The tibia was also measured on an osteometric board. To measure its length, the medial malleolus was placed against the stationary end, placing it so that the shaft was parallel to its longitudinal axis. The mobile part was set against the most superior aspect of the lateral condyle of the tibia (see Figure 4b).
- The calcaneus and talus were measured articulated together in the physiological position on an osteometric board (Raxter et al., 2006, p. 376), with the anterior of the calcaneus raised (see Figure 4). The height was measured by measuring the length between the midpoint of the trochlear surface of the talus and the most inferior point of the calcaneal tuber (see Figure 4c).

Figure 4

A Drawing of the Correct Placement and Measurements for the Femur (a), Tibia (b) and the Calcaneus and Talus (c) for the Revised Fully Method



Note. Adapted from "Revision of the Fully Technique for Estimating Statures," by M. H. Raxter, B. M. Auerback and C. B. Ruff, 2006, *American Journal of Physical Anthropology, 130*(3), p. 382 (Doi/10.1002/ajpa.20361).

All these measurements (taken in cm) were summed up, giving the skeletal height of the individual. Because the exact age of the individuals is unknown, the formulae Raxter et al. (2006, p. 383) gives for living stature without age is used. The formula applied goes as follows:

$$\text{Living stature (in cm)} = 0.996 \times \text{Skeletal height} + 11.7$$

According Raxter et al. (2013) the standard estimation of error for this formula is 2,23 cm for both male and female alike.

3.2.1.2 The Trotter and Gleser Method

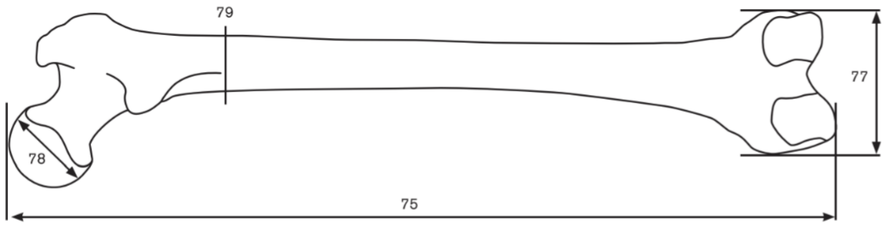
For this thesis the Trotter and Gleser method, follows the description of Trotter's latest additions (Trotter, 1970, p. 73-74). As described by Trotter (1970, p.74) for almost all individuals the bones were measured on either side and using the mean value in the formula. For three individuals only one bone could be measured.

For the males the femur has the lowest standard error, while for the female sex this is the fibula. The femur has the second lowest standard error for females (Trotter, 1970, p. 77). As the femur is already incorporated in the Fully method, this bone will be used in this thesis.

For this method, in contrast to the anatomical method, the maximum length of the femur was measured; to do so the medial condyle was put against the stationary end of an osteometric board, and the mobile end was pressed against the most proximal part of the femoral head (see Figure 5, 75) (Trotter, 1970, p. 73).

Figure 5

A Drawing Indicating the Maximum Femoral Length (75)



Note. From *Data Collection Procedures for Forensic Skeletal Material 2.0* (p. 79) by N.R. Langley, L. M. Jantz, S. D. Ousley, R.L. Jantz and G. Milner, 2016, Forensic Anthropology Center Department of Anthropology, The University of Tennessee.

The average value of the maximum femoral length of the left and right side (measured in cm) are used in the formulae for the living stature (Trotter, 1970, p. 77). The formula for Euroamerican females is:

Living stature (in cm) = 2.47 x maximum femoral length + 54.10

With a standard error of 3.72 cm.

For the Euroamerican males the formula is:

Living stature (in cm) = 2.38 x maximum femoral length + 61.41

With a standard error of 3.27 cm.

3.2.1.3 The Pablos et al. (2013) Method

For Pablos et al. (2013, p. 299.e3-299.e5) the formula that uses both the bones in the heel and the ball of the foot was used. Following the formulae for Euroamerican males and females, the talus and the second metatarsal were measured for each individual.

For each bone only the right side of the body was measured (Pablos et al., 2013, p. 299.e3). For one individual the left bones were measured as the right bones were not complete enough. The maximum length of the talus is measured with a sliding caliper in mm. The measurements were taken from the posterior medial tubercle to the most anterior point of the head (see Figure 6a). The maximum length of the second metatarsal was also measured with a sliding caliper in mm. The measurements were taken from the apex of the capitulum, to the most posterior point of the base, parallel to the longitudinal axis of the bone (see Figure 6b).

With the maximum length of the talus and the second metatarsal (measured in mm) the living stature of the individuals was estimated with the following equations from Pablos et al. (2013, p. 299.e5). For the living stature of white female individuals, the following formula was used:

Living stature (in mm) = 425,213 + 10,480 x length talus + 8,683 x length second metatarsal

With a standard error of 13.13 mm.

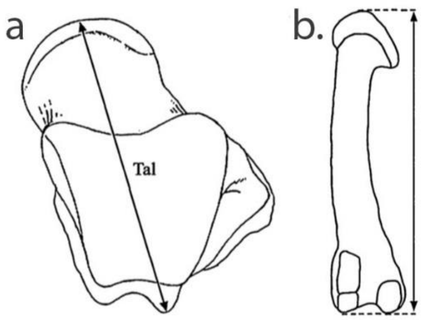
For the living stature of white male individuals, the formula goes as follows:

Living stature (in mm) = 953.636 + 5.427 x length talus + 5.711 x length second metatarsal

With a standard error of 36.83 mm.

Figure 6

Drawings of the Placement and Measurements of the (a) Talus and the Second Metatarsals (b)



Note. Adapted from “From Toe to Head: Use of Robust Regression Methods in Stature Estimation Based on Foot Remains,” by A. Raxter, A. Gómez-Olivencia, A. García-Pérez, I. Martínez, C. Lorenzo and J. L. Arsuaga, 2013, *Forensic Science International, 226*(1), p. 299.e3 (doi.org/10.1016/j.forsciint.2013.01.009).

3.2.2 Data Analysis

All measurements and subsequent estimations of stature were recorded in Microsoft Excel. The Pablos et al. (2013) method was converted into centimetres to make it possible to compare the three methods.

The three methods were statistically compared in the programme JASP 0.17.1.0, where first the female and males were compared through the Mann-Whitney U test, with the significance set at $p<.05$. Comparing the three methods to each other was done with sex separated when there was a significant difference. For this analysis, two methods were compared in a paired t-test, as the two methods were applied to the same subjects. Because the results were not normally distributed the Wilcoxon signed-rank test was used, with a significance of $p<.05$.

The Wilcoxon signed-rank test was used with the hypothesis that the two methods were not alike, which meant that when $p<.05$ there was a significant difference, and the two methods did not compare. While if $p>.05$ was measured the two methods did compare. This was done for all three combinations and divided in both sexes.

Chapter 4: Results

In this chapter, first the descriptive statistics of the methods are given. To compare the sexes the Mann-Whitney U test is applied. Afterward the Wilcoxon signed-rank test that compare two methods together will be discussed. As only two methods can be compared against each other at the same time, the Fully method will first be tested against the Trotter and Gleser method. Then the Fully method will be compared to the Pablos et al. (2013) method, after which the Trotter and Gleser method will be compared to the Pablos et al. (2013) method. Lastly the three methods will be compared to each other using descriptives.

4.1 Individual Methods

4.1.1 The Fully Method

When looking at the Fully methods of stature estimation, a division was made between the male and the female sex. The mean of the male sex (n=11) as gained through this method was at 165.42 cm, with a standard deviation of 4.73 cm. The mean of the female sex (n=10) was at 158.41 cm, with a standard deviation of 5.65 cm (see Table 1 and Figure 7).

Table 1: Descriptive statistics of the estimated statures gathered through the Fully method, divided by sex.

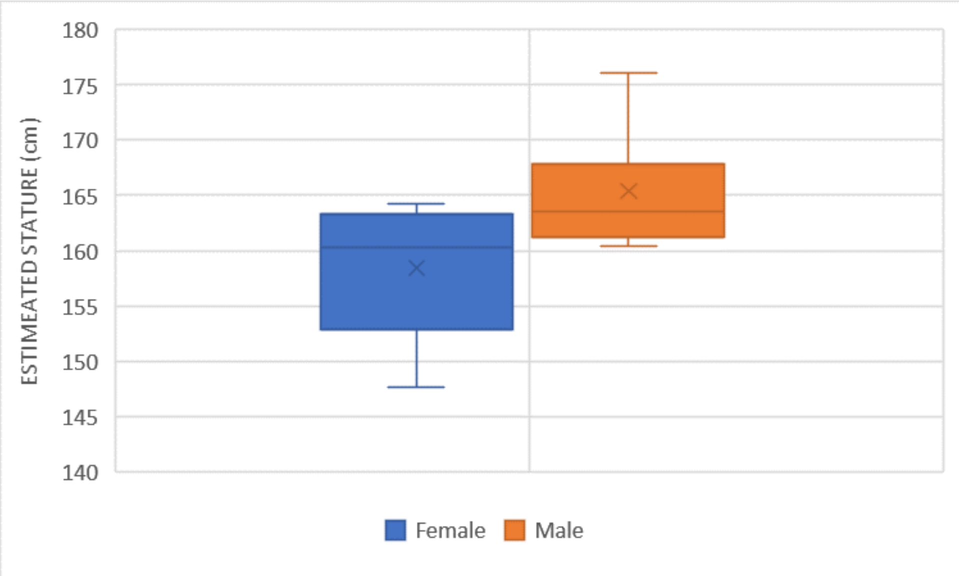
Table 1

Descriptive Statistics of the Estimated Statures Gathered Through the Fully Method, Divided by Sex

	The Fully Method	
	F	M
n	10	11
Mean	158.409	165.418
Std. Deviation	5.646	4.727
Minimum	147.684	160.385
Maximum	164.292	176.050

Figure 7

Box and Whiskers Plot of the Estimated Statures Gathered Through the Revised Fully Method, Divided by the Individuals Sex



A Mann-Whitney U test was done comparing the mean statures of the individuals with male sex to the individuals with female sex. The results (see Table 2) showed that there was a significant difference between the two sexes (p=.013). Therefore, from here on out, the comparisons between methods were done divided by sex. Seeing as a pooled sample would have no significant worth.

Table 2

The Results of the Mann-Whitney U Test Comparing the Estimated Statures of the Individuals of Male sex to the Individuals of Female sex for the Results of the Revised Fully Methods.

Method	Group	Mean	SD	SE	W	p	n
Fully	Female	158.409	5.646	1.785	20.000	.013	11
	Male	165.418	4.727	1.425			10

Note. Mann-Whitney U test.

4.1.2 The Trotter and Gleser Method

When looking at the Trotter and Gleser methods of stature estimation, a division was made between the male and the female sex. The mean of the male sex (n=11) as gained through this method was at 167.65 cm, with a standard deviation of 3.75 cm. For the female sex (n=10) the mean was at 159.27 cm, with a standard deviation of 7.44 cm (see Table 3 and Figure 8).

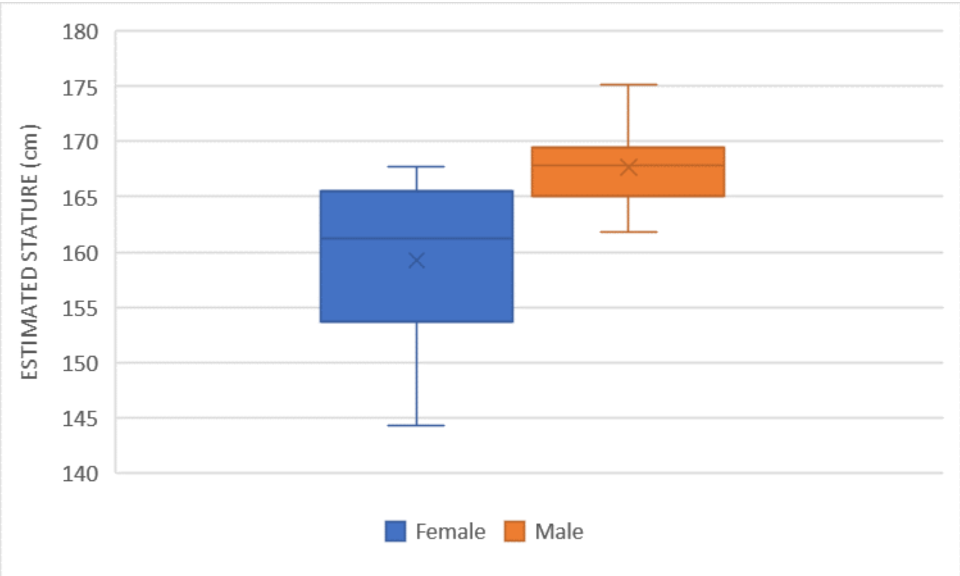
Table 3

Descriptive Statistics of the Estimated Statures Gathered Through the Trotter and Gleser Method Divided by Sex

	Trotter and Gleser Method	
	F	M
n	10	11
Mean	159.265	167.650
Std. Deviation	7.443	3.749
Minimum	144.280	161.846
Maximum	167.677	175.174

Figure 8

Box and Whiskers Plot of the Estimated Statures Gathered Through the Trotter and Gleser Method, Divided by the Individual's sex



A Mann-Whitney U test was done comparing the mean statures of the individuals with male sex to the individuals with female sex. The results (see Table 4) showed that there was a significant difference between the two sexes (p=.004). Therefore, from here on out, the comparisons were done divided by sex. Seeing as a pooled sample would have no significant worth.

Table 4

Results of the Mann-Whitney U Test comparing the estimates statures of the individuals of male sex to the individuals of female sex for the Trotter and Gleser method

Method	Group	Mean	SD	SE	W	p	n
Trotter and Gleser Method	Female	159.265	7.443	2.354	14.000	.004	11
	Male	167.650	3.749	1.130			10

Note. Mann-Whitney U test.

4.1.3 The Pablos et al. (2013) Method

When looking at the Pablos et al. (2013) methods of stature estimation, a division was made between the male and the female sex. The mean of the male sex (n=11) as gained through this method was at 171.90 cm, with a standard deviation of 4.47 cm. the mean of the female sex (n=10) was at 162.56 cm, with a standard deviation of 7.62 cm (see Table 5 and Figure 9).

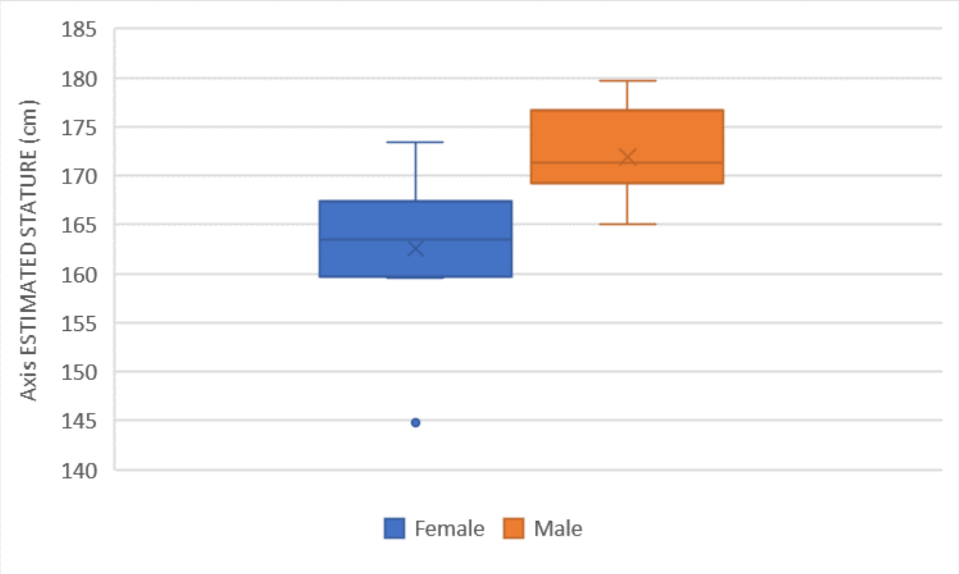
Table 5

Descriptive Statistics of the Estimated Statures Gathered with the Pablos et al. (2013) Method, Divided by Sex

	Average Pablos et al. (2013) Method	
	F	M
n	10	11
Mean	162.558	171.904
Std. Deviation	7.623	4.470
Minimum	144.826	165.071
Maximum	173.378	179.703

Figure 9

Box and Whiskers Plot of the Estimated Stature Gathered Through the Pablos et al. (2013) Method, Divided by Sex



A Mann-Whitney U test was done comparing the mean statures of the individuals with male sex to the individuals with female sex. The results (see Table 6) showed that there was a significant difference between the two sexes (p=.002). Therefore, from here on out, the comparisons were done divided by sex. Seeing as a pooled sample would have no significant worth.

Table 6

Results of the Mann-Whitney U Test Comparing the Estimated Statures of the Individuals of Male Sex to the Individuals of Female Sex for the Results of the Pablos et al. (2013) Method

Method	Group	Mean	SD	SE	W	p	n
Pablos et al. (2013) method	Female	162.558	7.623	2.411	12.000	.002	11
	Male	171.904	4.470	1.348			10

Note. Mann-Whitney U test.

4.2 Comparison of The Methods

4.2.1 The Fully Method Versus the Trotter and Gleser Method

Firstly, the means of the Fully method were compared against the Trotter and Gleser method. This was done through the Wilcoxon signed-rank. One test was run on the individuals with male sex (Table 7) and another test was held against the individuals with female sex (see Table 8). These tests showed that for the male sex there was a significant difference between the means of the two tests (p=.032). However, for the female sex there was a non-significant difference (p=.232), meaning that they were comparable.

Table 7

Results of the Wilcoxon Signed-Rank Test Comparing the Fully Method to the Trotter and Gleser Method

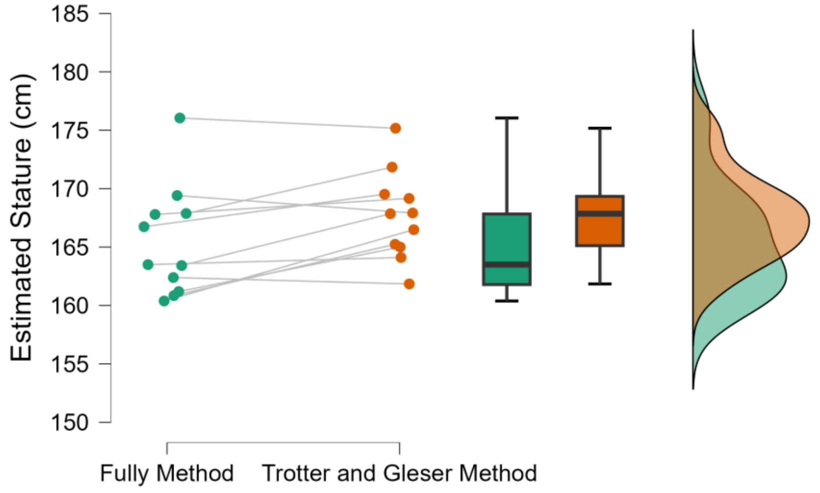
Methods	Group	Mean	SD	W	z	p	n
Fully method	Male	165.418	4.727	9.000	-2.134	.032	11
Trotter and Gleser method		167.760	3.749				
Fully method	Female	158.409	5.646	15.000	-1.274	.232	11
Trotter and Gleser method		159.265	7.443				

Note. Wilcoxon signed-rank test.

For both groups a raincloud plot was made to visualise the distribution. The graph shows all individuals measures of both methods. With a line connecting the dots that represent the same individual. Next to the graph there is also a box and whiskers plot and a distribution plot on the far right. The raincloud plot of the male sex (see Figure 10) shows that the Pablos et al. (2013) method estimates similar for a lot of individuals, but a significant amount measures a higher stature through the Trotter and Gleser method. This is also visible in the distribution plot. The raincloud plot of the female sex (see Figure 11) shows that for most individuals the methods estimate quite along the same lines, but for two individuals the Trotter and Gleser method measures lower than the Fully method does.

Figure 10

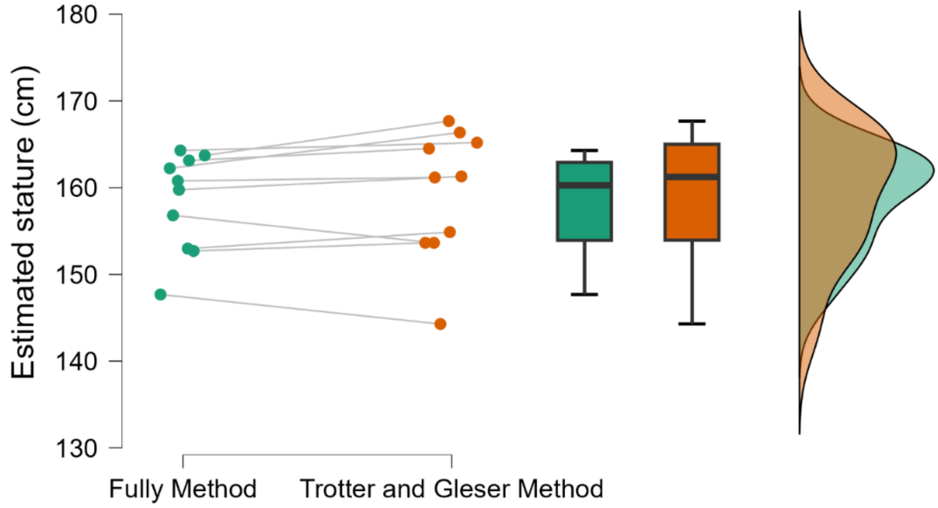
Raincloud Plot of the Fully Method Compared to the Trotter and Gleser Method



Note. Male sex only

Figure 11

Raincloud Plot of the Fully Method Compared to the Trotter and Gleser Method



Note. Female sex only

4.2.2 The Fully Method Versus the Pablos et al (2013) Method

The mean of the Fully method was also compared against the means of the Pablos et al. (2013) method. This was also done through the Wilcoxon signed-rank. These tests (see Table 8) showed that for the male sex there was a significant difference between the means of the two methods (p=.002), Which was also the case for the female sex (p=.010)

Table 8

Results of the Wilcoxon Signed-Rank Test Comparing the Fully Method to the Pablos et al. (2013) method

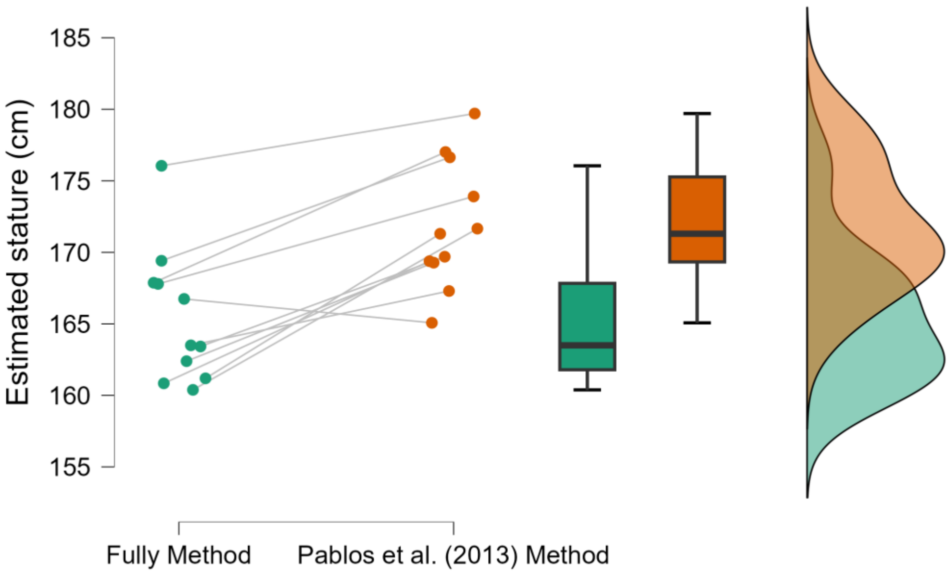
Methods	Group	Mean	SD	W	z	p	n
Fully method	Male	165.418	4.727	1.000	-2.845	.002	11
Pablos et al. (2013) method		171.904	4.470				
Fully method	Female	158.409	5.646	3.000	-2.497	.010	10
Pablos et al. (2013) method		162.558	7.623				

Note. Wilcoxon signed-rank test.

For these two sexes raincloud plots were also made. Figure 12 shows that for male sex the Pablos et al. (2013) method measures notably higher. While for one individual the Pablos et al. (2013) method measures quite lower. The fact that the Pablos et al. (2013) method measures higher for most individuals is also seen in the distribution plot. While the distribution plot shows a lot of overlap, the Wilcoxon signed-rank test shows that it's significant (p=.002). This means that the two methods statistically count as unequal to each other. Figure 13 shows that for the female sex there is one individual that estimates much lower than most individuals, which was also indicated as an outlier in the box and whiskers from Figure 8. This individual also measures much lower in the Pablos et al. (2013) method than it does in the Fully method, which is remarkable as for all others the Pablos et al. (2013) method measures higher than the Fully method.

Figure 12

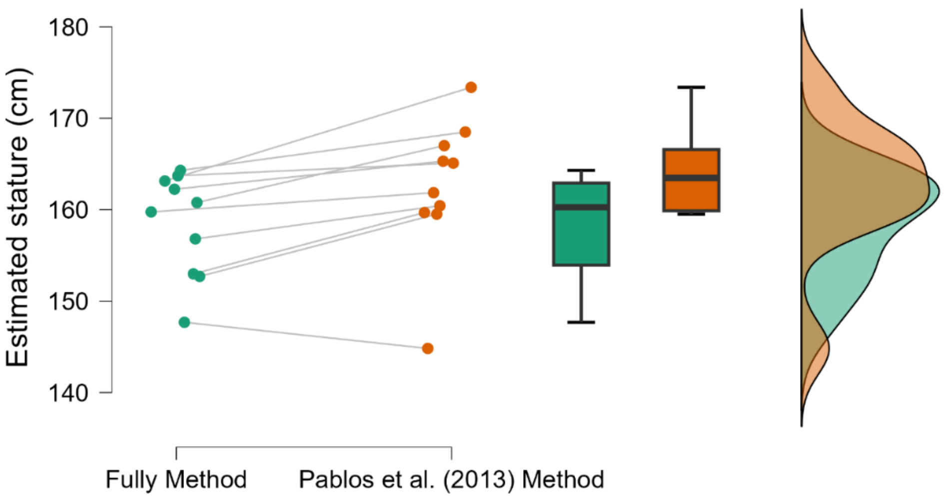
Raincloud Plot of the Fully Method Compared to the Pablos et al. (2013) Method



Note. Male sex only

Figure 13

Raincloud Plot of the Fully Method Compared to the Pablos et al. (2013) Method



Note. Female sex only

4.2.3 The Trotter and Gleser Method Versus the Pablos et al. (2013) Method

To compare the Trotter and Gleser method to the Pablos et al. (2013) method, the means of both methods were compared through a Wilcoxon signed-rank test. This was divided by sex as the Mann-Whitney U test showed a significant difference between the sexes. These two tests (see Table 9) showed that for the male sex there was a significant difference between the two methods (p=.007). This was also the case for the female sex (p=.037).

Table 9

Results of the Wilcoxon Signed-Rank Test Comparing the Trotter and Gleser Method to the Pablos et al. (2013) Method

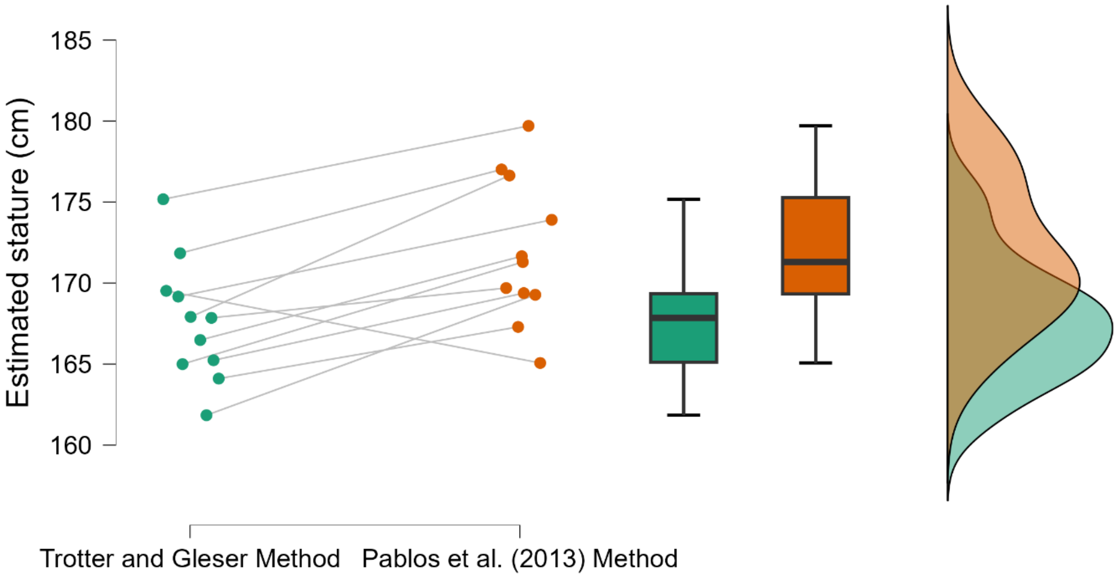
Methods	Group	Mean	SD	W	z	p	n
Trotter and Gleser method	Male	167.650	3.749	4.000	-2.578	.007	11
Pablos et al. (2013) method		171.904	4.470				
Trotter and Gleser method	Female	159.265	7.443	7.000	-2.090	.037	10
Pablos et al. (2013) method		162.558	7.623				

Note. Wilcoxon signed-rank test.

In the Raincloud plots it is visible that for the male sex (see Figure 14) the Pablos et al. (2013) method estimates higher compared to the Trotter and Gleser method for all but one individual. The distribution plots shows that the Pablos et al. (2013) measures higher, though there is quite an overlap, it is not enough for the methods to significantly compare. For the female sex (see Figure 15) the difference is a little more scattered. For some individuals the methods estimate similar to each other, while for others the Pablos et al. (2013) method measure both higher and lower. It was more common for the Pablos et al. (2013) method to estimate higher than the Trotter and Gleser method. The distribution plot does overlap, but according to the Wilcoxon signed-rank not enough to be significant (p=.037). Therefore, they do not statistically compare.

Figure 14

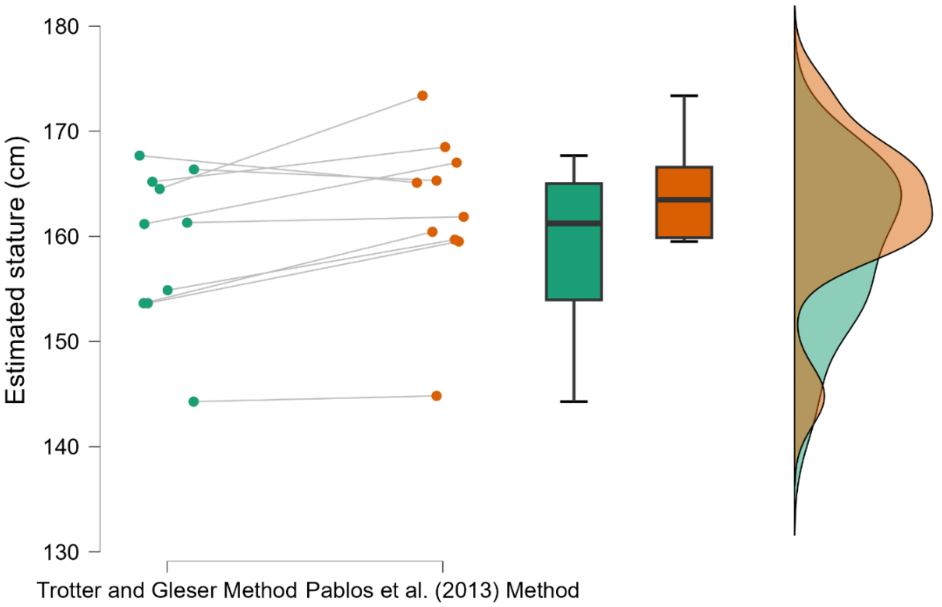
Raincloud Plot of the Trotter and Gleser Method Compared to the Pablos et al. (2013) Method



Note. Male sex only

Figure 15

Raincloud Plot of the Trotter and Gleser Method Compared to the Pablos et al. (2013) Method



Note. Female sex only

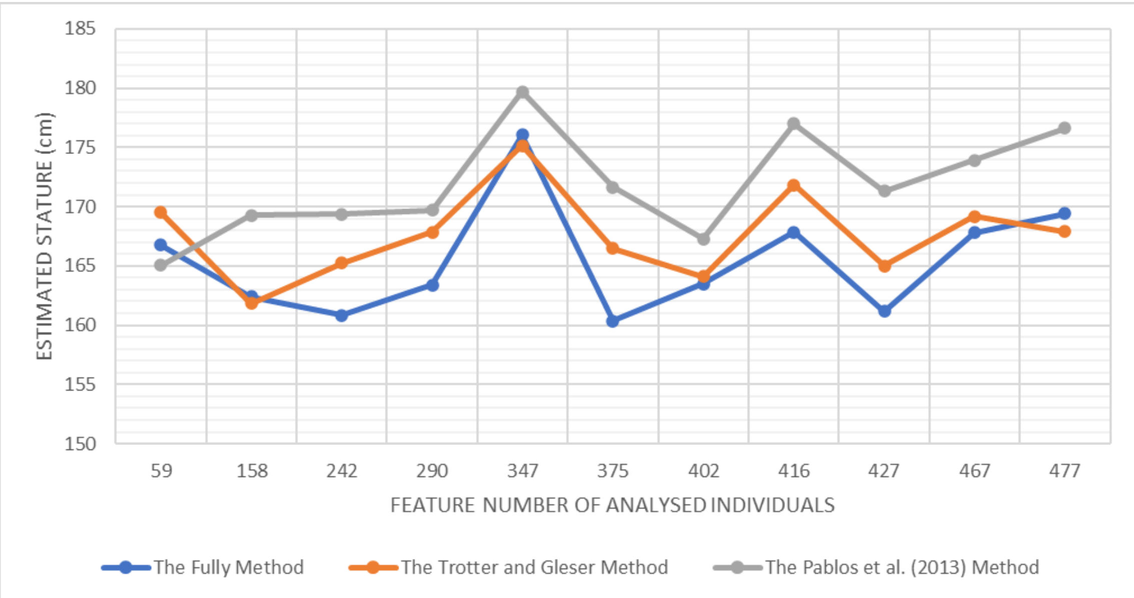
4.2.4 The Three Compared to Each Other

The three methods cannot be compared within one statistical test. To compare the three methods together two types of descriptive plots were used, divided by sex.

The scatterplot for the male sex (see Figure 16) shows that the three methods do not often overlap. Only four times does the Fully method fall close with the Trotter and Gleser method, while not once does the Pablos et al. (2013) method fall close to the Fully or the Trotter and Gleser method. When the methods do not overlap the Pablos et al. (2013) method estimates the highest of the three, with the Trotter and Gleser method often falling in the middle. Only once does the Pablos et al. (2013) method estimate lower than both the Fully method and the Trotter and Gleser method.

Figure 16

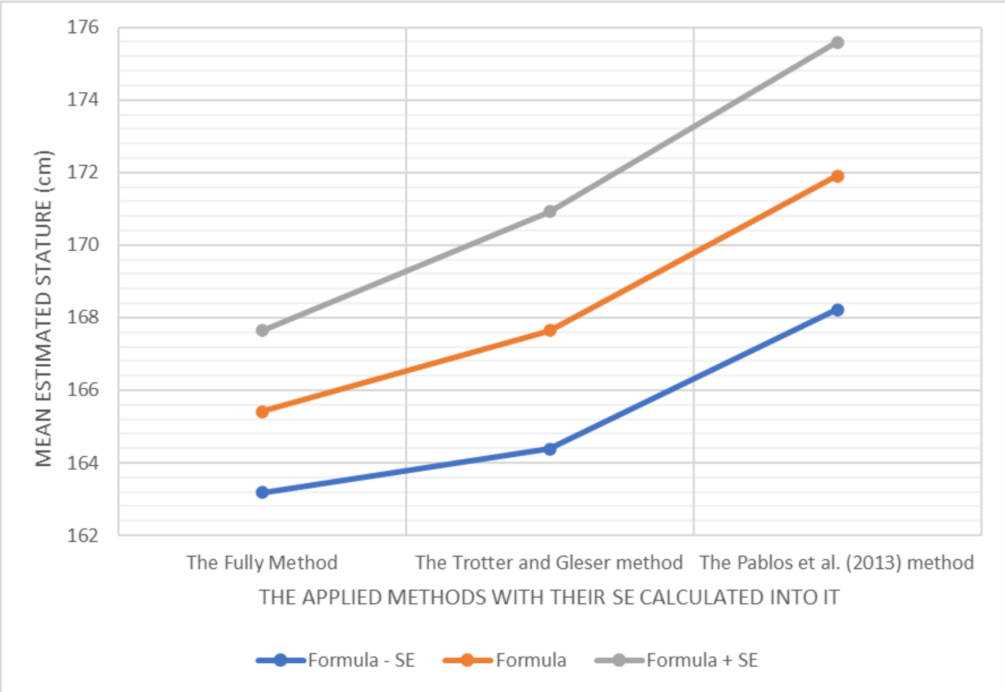
Scatterplot Divided by all Individuals of the Male Sex, Each method Outline Individually



But as said before the methods all have their own standard error, which gives a range in which each individual can fall. To account for this, two graphs were made to show the ranges of the three estimation methods. These graphs were made by taking the means of the three methods (the orange line), afterwards adding the standard error to the mean (the grey line), and then subtracting the standard error from the mean (the blue line). Left shows the range of the Fully method, the middle shows the range of Trotter and Gleser method, and the right shows the range of the Pablos et al. (2013) method. For the male sex (see Figure 17) the graph shows that when looking at the Pablos et al. (2013) method does not overlap the Fully method. This is shown by the minimum of the Pablos et al. (2013) method falling above the maximum of the Fully method. The Trotter and Gleser method overlaps with both the Fully method and the Pablos et al. (2013) method. Where the Fully method estimates the stature lower, the Pablos et al. (2013) method estimates stature higher compared to the Trotter and Gleser method.

Figure 17

Descriptive Comparison of the Means of the Three Stature Estimation Methods with the Standard Error Calculated in

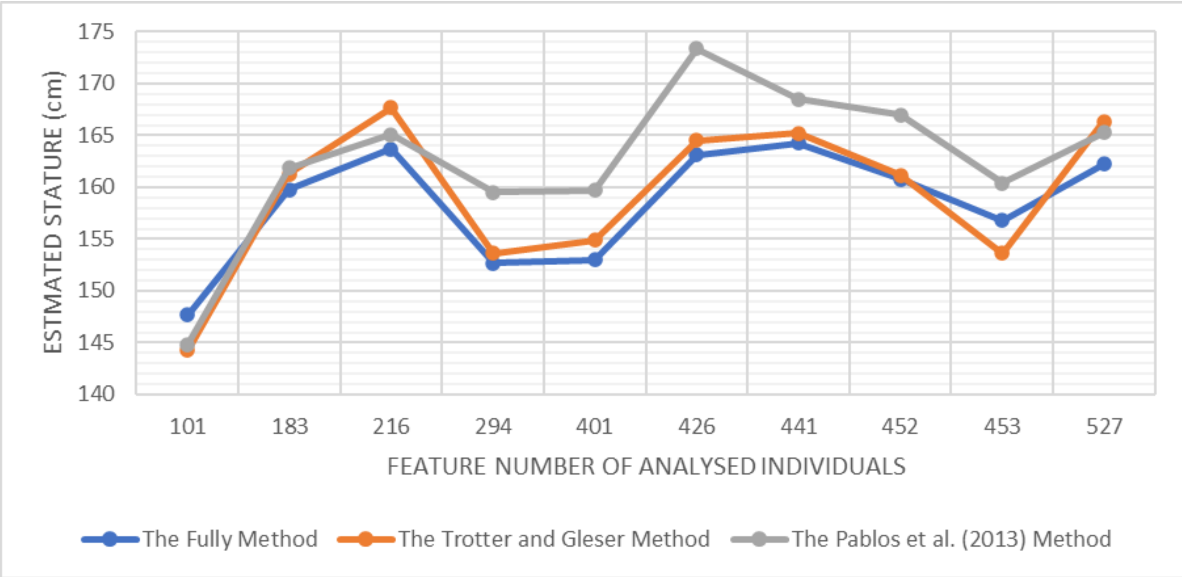


Note. Male sex only

Similar graphs were made for the female sex. The scatterplot (see Figure 18) shows that the Fully method and the Trotter and Gleser method are quite close to each other for almost all individual. This cannot be said for the Pablos et al. (2013) method. There are a few individuals where the Pablos et al. (2013) method estimates similar to the Fully and Trotter and Gleser method, but for the majority it measures visibly higher. Where the Pablos et al. (2013) method estimates similar, it follows the Trotter and Gleser method closer than the Fully method.

Figure 18

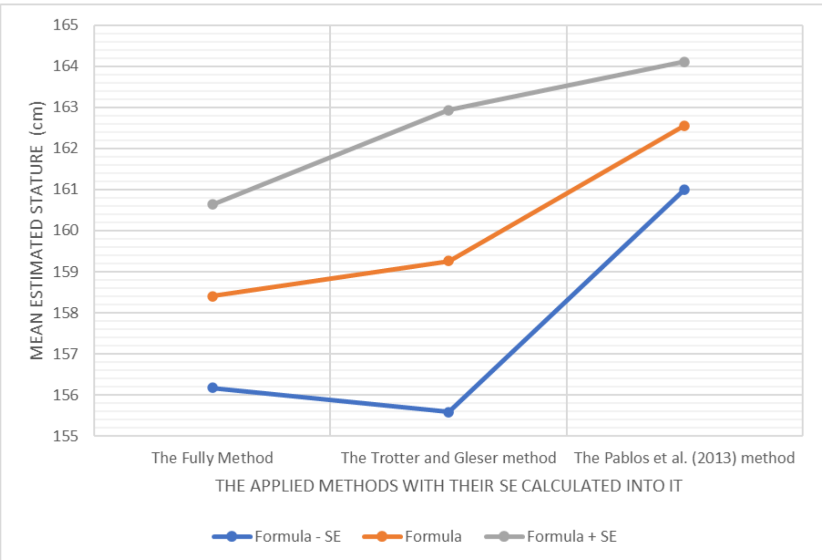
Scatterplot Divided by all Individuals of the Female Sex, Each method Outline Individually



When looking at the graph depiction the standard error range for the female sex (see Figure 19) it shows that the Fully method and the Pablos et al. (2013) method do not overlap. Interestingly the range of the Fully method falls inside the range of the Trotter and Gleser method. The Pablos et al. (2013) method overlaps with the higher range of the Trotter and Gleser method.

Figure 19

Descriptive Comparison of the Means of the Three Stature Estimation Methods with the Standard Error Calculated in



Note. Female sex only

Chapter 5: Discussion

This chapter first describes the individual stature estimation methods and their application to the Middenbeemster population and the Dutch population. First the focus will be on the male sex and then on the female sex. Subsequently the results of the Wilcoxon-signed rank tests are analysed and evaluated with the descriptive comparison. Finally, some possible explanations for the results are discussed together with a broader application of the compared methods.

5.1 Stature and the Middenbeemster Population

The majority of Middenbeemster collection was analysed through the use of Trotter and Gleser method. This analysis showed that the average stature of the male individuals in the Middenbeemster collection was 171.64 cm with a standard deviation of 3.28 cm. However, the majority of the individuals analysed in the Middenbeemster collection estimated between the height of 160 and 169 cm (Lemmers et al., 2013, p. 43). In this thesis only eleven individuals of male sex had their stature estimated. Using the Fully method the mean stature falls 6 cm below the average of Lemmers et al. at 165.42 cm with a standard deviation of 4.72 cm. While the mean of the Trotter and Gleser method falls slightly higher, at 167,65 cm with a standard deviation of 3.75 cm it is still lower than the mean of the Middenbeemster collection. The Pablos et al. (2013) method falls closest to the collection, with the mean of 171.90 cm and a standard deviation of 4.47 cm. Notable is that the Fully method and the Trotter and Gleser method measure quite lower than the collection, falling outside the standard deviation, while the Pablos et al. (2013) method estimates close to the collection.

When looking at the female sex, the Middenbeemster collection estimates a mean of 160.71 cm with a standard deviation of 3.69 cm. Most female sex individuals in the collection fell between the statures of 150 and 159 cm (Lemmers et al., 2013, p. 43). When looking at the ten individuals of this thesis the mean stature estimated with the Fully method is 158.40 cm, with a standard deviation of 5.65 cm. This falls within the model measures but is lower than the mean of the collection. When looking at the Trotter and Gleser method, the mean stature estimates closer to the collection, at 159.26 cm with a standard deviation of 7.44 cm. The Pablos et al. (2013) method estimates a mean higher than the collection with 162.56 cm with a standard deviation of 7.62 cm. While the means are not identical, they all fall close to the estimation of the collection, with a maximum of 2 cm difference, which falls within the standard deviation of the collection. Notable is that the Pablos et al. (2013) method estimates the mean above the model measurements of the collection.

The individuals of the Middenbeemster collection all lived around the 1650-1800 (Hankvoort, 2013, p. 29). Maat (2005, p. 278) compiled the average stature of Dutch male individuals through time. When looking at the individuals living around the same time frame, there were two averages given.

Individuals excavated in Leiden (n=102) estimated an average stature of 166,7 cm. Individuals excavated in Breda (n=19) estimated an average stature of 171.3 cm. When looking at the measurements taken for this thesis, the Fully method and Trotter and Gleser method fall close to the Leiden individuals. The Pablos et al. (2013) method falls closer to the means of the average stature of Breda. When looking at a more modern time period, Maat (2005, p. 278), gives an average height of 184 cm in 1997. This is an even higher than the maximum stature estimated for this thesis.

De Beer (2004, p. 47) shows that for the female sex, the average stature in Leiden during the 1650-1800 estimated at 156.7 cm. This average falls lower to all three means estimated in this thesis. The average height of females in 1976 fell around 170 cm, this height was only reached by individuals measured with the Pablos et al. (2013) method.

5.2 Comparing the Three Stature Methods

Each individual stature estimation method gives a range in which the individuals stature is supposed to fall. This range is calculated with the standard error, as discussed in the methods chapter. However, because only means can be used in the statistical analysis, the standard error has been left aside when comparing the three methods. For the male sex, when looking at the Wilcoxon signed-rank test, the Fully method does not compare to either the Trotter and Gleser method or the Pablos et al. (2013) method. These latter two methods also do not compare to each other. However, when looking at the Figures in chapter 4.2.4 the ranges give a very different perspective. Figure 17 shows that for the male sex the range of the Fully method, overlaps with the range of the Trotter and Gleser method. The range of the Fully method and the range Pablos et al. (2013) method do not overlap. The Trotter and Gleser method does overlap with the Pablos et al. (2013) method, even if the latter seems to measure quite higher than the former. It is important to consider that each individual mean on this graph also has a standard deviation on its own, which means that for individual cases the ranges might overlap more.

When looking at the comparison of the female stature estimation methods, focussing only on the means that we can compare through the Wilcoxon signed-rank test, it shows that the Fully method compares to the Trotter and Gleser method. The Pablos et al. (2013) method does not compare with the Fully method nor the Trotter and Gleser method. Looking at the ranges (see Figure 19) the picture is similar to the male sex. The Fully method falls within the range of the Trotter and Gleser method. The range of the Pablos et al. (2013) method falls above the Fully method range. Similar to the male sex, the range of the Pablos et al. (2013) method falls over the Trotter and Gleser method, estimating a higher stature.

In conclusion, when looking at the three methods and keep in mind that the Fully method is generally seen as the most accurate method of stature estimation, it seems that the Trotter and Gleser method should still be the preferred method of stature estimation after this. However, if no long bones are present or whole, the Pablos et al. (2013) method may be a good alternative. As long as one keeps in mind that this method often estimates higher than the other two.

5.3 Possible Causes

A possible explanation for the Pablos et al. (2013) method estimating could be the difference between body proportions between populations. The body proportion of the Middenbeemster population could be different to the proportions of Americans. As the Hamann-Todd Osteological collection that was used to establish this method has American origins (Pablos et al., 2013, p. 299.e2). Another reason could be that body proportions changed more over time. The individuals from the collection that Pablos et al. (2013) used were born between 1825 and 1910 (Pablos et al., 2013, p. 299.e2), while the individuals of the Middenbeemster collection lived 1600-1850. In Dutch population alone the average height between these time periods is quite different. As even between 1955 and 1997 alone the average male stature grew with 8.5 cm. Whatever the cause may be, the feet for this particular population are larger than the formulae created by Pablos et al. (2013) anticipated.

The ancestry of this population could also explain why the Trotter and Gleser method and the Pablos et al. (2013) method were different in their stature estimation compared to the Fully method. When looking at all these individuals it was resumed in this thesis that they were all from a European ancestry. However, this might not be the case. The individuals could have been from mixed backgrounds, or even from a whole different background altogether. This too could influence the estimated stature through both the Trotter and Gleser method and the Pablos et al. (2013) method. Both methods are population specific, while the Fully method is not.

Something that should be mentioned is that all these measurements were done on an archaeological sample. In archaeology taphonomic processes can lead to a spreading of the bones, or even the fracturing of bones before or during an excavation (Christensen et al., 2014a, p. 133-134). The talus and the metacarpals are dense bones that have a higher likelihood of remaining intact through taphonomic processes or excavation (CITE). Which makes the Pablos et al. (2013) method so valuable. Even the Middenbeemster collection shows this, as with over four hundred skeletons of both adult and non-adult individuals, there were only 21 skeletons that could be used for all three methods. More individuals could have been used when only comparing the Trotter and Gleser method to the Pablos et al. (2013) method. However, there were more than a few skeletons that had to be dismissed because, for example, the head of the femur was too deteriorated for it to be properly measured. This shows that not only fracturing but also the deterioration and erosion of bones can impact the skeleton and therefore which method can be used.

Not only for osteoarchaeology is the Pablos et al. (2013) method important, it could also be very useful in the forensic context. While it is uncertain yet if the method is comparable to the Fully method, it is comparable to the Trotter and Gleser method. This latter method is now often employed in forensic context (Christensen et al., 2014a, p. 285). But as in archaeology, in a forensic context it is possible, and even likely for many long bones to be fractured, or for the individual's bones to be spread out. A good alternative such as the Pablos et al. (2013) method might be detrimental. Hight can, after all, tell us more about a victim, which in turn can help identifying an individual (Christensen et al., 2014, p. 285).

While the Pablos et al. (2013) method might have a lot of applications, it is still not preferrable over the methods of Trotter and Gleser. The Fully method is seen as the most accurate method of estimating stature. The Trotter and Gleser method is more comparable to this method than the Pablos et al. (2013) method. Therefore, the latter should only be used as a last resort or an additional measurement.

Chapter 6: Conclusion

This research attempts to answer the main question 'How do the statures obtained using the Pablos et al. (2013) method compare to the statures obtained with both the Fully and Trotter and Gleser method?' through an analysis of 21 skeletons, 10 of female sex and 11 of male sex.

To give a proper answer to the main research question, first the three sub-questions need to be addressed.

6.1 Answering the Sub-Questions

6.1.1 Sub-Question 1: The Method of Fully vs. Trotter and Gleser

The first sub-question 'How do the statures obtained using the revised Fully method compare to those obtained by the Trotter and Gleser method?' can be answered statistically and descriptively. When looking at the Wilcoxon signed-rank tests, it shows that the Fully method is only comparable to the Trotter and Gleser method when estimating stature for individuals with female sex. For the male sex the statistics show a significant difference and is therefore not comparable. When taking the ranges into account, while not a statistical analysis, it seems that the Trotter and Gleser method estimates similar to the Fully method for the male sex too, estimating higher. Looking at the ranges for the female, the Fully method falls within the ranges of the Trotter and Gleser method.

6.1.2 Sub-Question 2: The Method of Fully vs. Pablos et al. (2013)

Fir the second sub-question 'How do the statures obtained using the revised Fully method compare to those obtained using the Pablos et al. (2013) method and are there any differences between males and females?' there is a significant difference between the means of both methods for both the male and the female sex. When looking at the ranges this too shows that the Pablos et al. (2013) method estimates the stature higher than the Fully method does, the ranges not overlapping.

6.1.3 Sub-Question 3: The Method of Trotter and Gelser vs. Pablos et al. (2013)

The third sub-question is 'How do the statures obtained using the Trotter and Gleser method compares to the statures obtained using the Pablos et al. (2013) method and what are the differences between males and females?'. For both the male and the female sex there is a significant difference between the Trotter and Gleser method and the Pablos et al. (2013) method. However, when looking at the ranges the Pablos et al. (2013) method overlaps with the Trotter and Gleser method, estimating higher, but comparable in range. This is the case for both the male and the female sex.

6.2 Answering the Main Research Question

The three sub-questions help answer the main question of this thesis. Statistically the answer is that they do not compare. The statures from the Pablos et al. (2013) method estimate higher than both the statures from the Fully and Trotter and Gleser method. When looking at the ranges, which cannot be statistically compared, it shows that the Pablos et al. (2013) method estimates at a higher range, where the Pablos et al. (2013) method only overlaps with the Trotter and Gleser method.

6.3 Future Research

The method of statistical analysis is a big drawback for this thesis. It is only possible to compare the means and not ranges, while stature estimation formulae give a range. A more accurate method of statistical analysis might help with giving a more secure answer than can be given in this thesis. Even so, more research should be done into body proportions in different populations. Especially because feet have been found to be so population-specific (Cordeiro et al., 2009; Karmalka & Nikam, 2021; Rodriguez et al., 2013). Knowing more about the different body proportions of different people even through time can help with establishing a method that can be accurate through all eras and all populations. Or it can help with establishing edited formulae for the Pablos et al. (2013) method that is applicable for the multiple populations.

Future research analysing these three methods on a larger number of individuals can help with answering the questions of this thesis. But overall, it is clear that more research needs to be done. With what we now know it can be said that, presuming the Fully method to be the most accurate stature estimation method, the Trotter and Gleser method is still the preferred alternative. If that method is inapplicable the Pablos et al. (2013) method might give a close estimation of stature.

Abstract

Estimation of stature is important because it can indicate health trends, diet, and evolution. Pablos et al. (2013) devised a new method using talar bones but has yet to be compared to the well-used method of Trotter and Gleser or the Fully method. This thesis compares these three methods using a Wilcoxon-signed rank test and descriptive analysis. The comparison shows that the Fully method statistically compares to the Trotter and Gleser method for the female sex, while not for the male sex. When comparing the Pablos et al. (2013) method test shows that the method does not compare statistically to the Trotter and Gleser method or the Fully method. When looking at the standard error range for both sexes the Trotter and Gleser method overlaps with both the Fully method and the Pablos et al. (2013). But the Pablos et al. (2013) method and the Fully method do not overlap.

Bibliography

de Beer, H. (2004). Observations on the history of Dutch physical stature from the late-Middle Ages to the present. *Economics & Human Biology*, *2*(1), 45–55. https://doi.org/10.1016/j.ehb.2003.11.001

Bidmos, M. A., & Manger, P. R. (2012). New soft tissue correction factors for stature estimation: Results from magnetic resonance imaging. *Forensic Science International*, *214*(1–3), 212.e1-212.e7. https://doi.org/10.1016/j.forsciint.2011.08.020

Christensen, A. M., Passalacqua, N. V., & Bartelink, E. J. (2014a). Forensic taphonomy. In *Forensic anthropology: Current methods and practice* (pp. 119–147). Academic Press.

Christensen, A. M., Passalacqua, N. V., & Bartelink, E. J. (2014b). Stature Estimation. In *Forensic anthropology: Current methods and practice* (pp. 285–300). Academic Press.

Cordeiro, C., Muñoz-Barús, J. I., Wasterlain, S., Cunha, E., & Vieira, D. N. (2009). Predicting adult stature from metatarsal length in a Portuguese population. *Forensic Science International*, *193*(1), 131.e1-131.e4. https://doi.org/10.1016/j.forsciint.2009.09.017

DeWitte, S. N., & Stojanowski, C. M. (2015). The Osteological Paradox 20 Years Later: Past Perspectives, Future Directions. *Journal of Archaeological Research*, *23*(4), 397–450. https://doi.org/10.1007/s10814-015-9084-1

Dwight, T. (1878). *The Identification of the human skeleton*. David Clapp & Son, printers.

Dwight, T. (1894). Methods of estimating the height from parts of the skeleton. *Medical Record: A Weekly Journal of Medicine and Surgery*, *46*(10), 293–297.

Hankvoort, A. (2013). *De begravingen bij de Keyserkerk te Middenbeemster*. Hollandia-rapport 464. Hollandia Archeologen.

Jagadish Rao, P. P., Sowmya, J., Yoganarasimha, K., Menezes, R. G., Kanchan, T., & Aswinidutt, R. (2009). Estimation of stature from cranial sutures in a South Indian male population. *International Journal of Legal Medicine*, *123*(3), 271–276. https://doi.org/10.1007/s00414-008-0316-5

Kanchan, T., Menezes, R. G., Moudgil, R., Kaur, R., Kotian, M. S., & Garg, R. K. (2008). Stature estimation from foot dimensions. *Forensic Science International*, *179*(2–3), 241.e1-241.e5. https://doi.org/10.1016/j.forsciint.2008.04.029

Karmalkar, A. S., & Nikam, V. R. (2021). Prediction of stature from long bones versus hand and foot measurements: A comparative study of the Kolhapur population. *The National Medical Journal of India*, *34*(3), 154–157. https://doi.org/10.25259/NMJI_79_20

Krishan, K. (2008). Estimation of stature from footprint and foot outline dimensions in Gujjars of North India. *Forensic Science International*, *175*(2–3), 93–101. https://doi.org/10.1016/j.forsciint.2007.05.014

Lemmers, S., Schats, R., Hoogland, M., & Waters-Rist, A. (2013). De begravingen bij de Keyserkerk te Middenbeemster. In A. Hankvoort (Ed.), *De begravingen bij de Keyserkerk te Middenbeemster (pp. 35-60)*. Hollandia Rapport-464. Hollandia Archeologen.

Langley, N. R., Jantz, L. M., Ousley, S. D., Jantz, R. L., & Milner, G. (2016). *Data collection procedures for forensic skeletal material 2.0*. Forensic Anthropology Center Department of Anthropology, The University of Tennessee.

Lockbaum, S. (n.d.). 4. Anatomy and physiology of the foot and nail learning outcomes. In *Basic foot Care for RNs and RPNs*. Pressbooks. https://ecampusontario.pressbooks.pub/nrsghzpae/chapter/anatomy-and-physiology-of-the-foot/

Lundy, J. K. (1985). The mathematical versus anatomical methods of stature estimate from long bones. *The American Journal of Forensic Medicine and Pathology*, *6*(1), 73–76.

Maat, G. J. R. (2005). Two millennia of male stature development and population health and wealth in the Low Countries. *International Journal of Osteoarchaeology*, *15*(4), 276–290.

Pablos, A., Gómez-Olivencia, A., García-Pérez, A., Martínez, I., Lorenzo, C., & Arsuaga, J. L. (2013). From toe to head: Use of robust regression methods in stature estimation based on foot remains. *Forensic Science International*, *226*(1), 299.e1-299.e7. https://doi.org/doi.org/10.1016/j.forsciint.2013.01.009

Pearson, K. (1899). IV. Matematical contributions to the theory of evolution. V. On the reconstruction of the stature of prehistoric races. *Philosopical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physcial Character*, *192*, 169–244. https://doi.org/10.1098/sta.1899.0004

Raxter, M. H., Auerbach, B. M., & Ruff, C. B. (2006). Revision of the Fully technique for estimating statures. *American Journal of Physical Anthropology*, *130*(3), 374–384. https://doi.org/doi/10.1002/ajpa.20361

Reel, S., Rouse, S., Vernon Obe, W., & Doherty, P. (2012). Estimation of stature from static and dynamic footprints. *Forensic Science International*, *219*(1–3), 283.e1-283.e5. https://doi.org/10.1016/j.forsciint.2011.11.018

Rodriguez, S., Miguens, X., Rodriguez-Calvo, M. S., Febrero-Bande, M., & Munoz-Barus, J. I. (2013). Estimating adult stature from radiographically determined metatarsal length in a Spanish population. *Forensic Science International*, *226*(1), 297.e1-297.e4. https://doi.org/10.1016/j.forsciint.2012.12.006

Schats, R. (2016). *Life in transition: An osteoarchaeological perspective of the consequences of mediëval socioeconomic developments in Holland and Zeeland (AD 1000-1600)*.

Shrestha, R., Shrestha, P. K., Wasti, H., Kadel, T., Kanchan, T., & Krishan, K. (2015). Craniometric analysis for estimation of stature in Nepalese population—A study on an autopsy sample. *Forensic Science International*, *248*, 187.e1-187.e6. https://doi.org/10.1016/j.forsciint.2014.12.014

Stevenson, P. H. (1929). On racial differences in stature long bone regression formulae, with special reference to stature reconstruction formulae for the Chinese. *Biometrika*, *21*(1/4), 303–321. https://doi.org/10.2307/2332563

Torimitsu, S., Makino, Y., Saitoh, H., Sakuma, A., Ishii, N., Yajima, D., Inokuchi, G., Motomura, A., Chiba, F., Yamaguchi, R., Hashimoto, M., Hoshioka, Y., & Iwase, H. (2017). Stature estimation in a contemporary Japanese population based on clavicular measurements using multidetector computed tomography. *Forensic Science International*, *275*, 316.e1-316.e6. https://doi.org/10.1016/j.forsciint.2017.02.037

Trotter, M. (1970). Estimation of stature from intact long limb bones. In T. D. Stewart (Ed.), *Personal identification in mass disasters* (pp. 71–84). National museum of Natural History, Smithsonian Institution.

Trotter, M., & Gleser, G. C. (1952). Estimation of stature from long bones of American Whites and Negroes. *American Journal of Physical Anthropology*, *10*(4), 463–514.

Trotter, M., & Gleser, G. C. (1958). A re-evaluation of estimation of stature based on measurements of stature taken during life and of long bones after death. *American Journal of Physical Anthropology*, *16*(1), 79–123.