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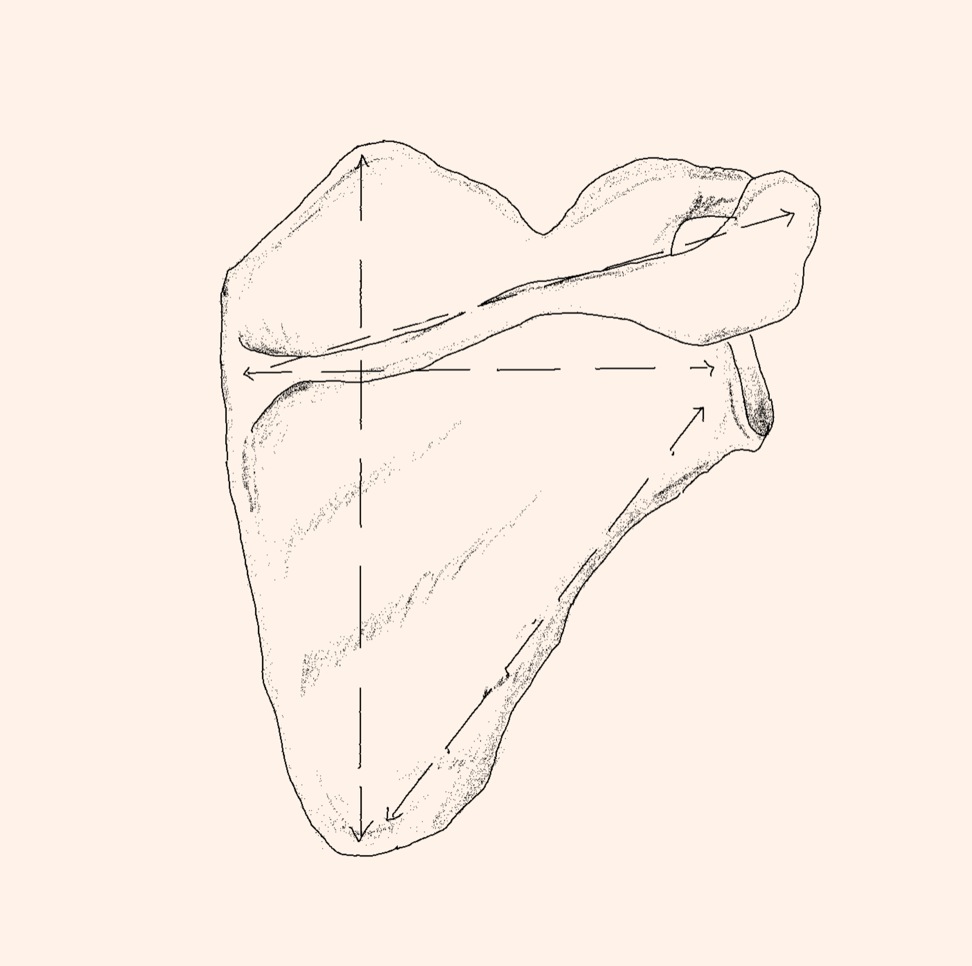
GENES OR PHYSICAL ACTIVITY



Scapular Axillary Border Variation in Three Modern Human Populations from The Netherlands and Sudan

Laura Tuomisalo

Cover image: Dorsal view of a scapula. Drawing by author.

Genes or Physical Activity: Scapular Axillary Border Variation in Three Modern Human Populations from The Netherlands and Sudan.

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Master Thesis Archaeological Science

St. Eustatius, 8th of May 2021

Final version

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Preface

The topic for this thesis stemmed from my deep interest in osteology, human evolution, and physiology. Since I wanted to work with large osteological collections, a topic from a purely human evolutional viewpoint was not possible. Therefore, this topic offered me a chance to study something paleoanthropologists have been studying for decades, but I was able to use extensive modern human skeletal collections.

Writing this thesis would not have been possible without my supervisor Dr S.A. Schrader's help and support. She would go over her way to answer emails during the weekends and correct chapters in the evenings. Her care for students is admirable, and I could not have asked for a better supervisor.

I would like to thank my "osteobuddies", Carlijne Wijngaarden, Iris Sluis, and Jenna Savolainen, for the peer support. Our WhatsApp group is always the first place I go whenever I have osteo-related questions. I am so grateful to have met you, and I hope we will always stay good friends and fellow "sciencers".

I am also grateful to my family and friends. Your encouragement and help have brought me to where I am today. And lastly, my most profound gratitude goes to my fiancé Matias. While writing this thesis with my earmuffs on, he was always there to cook me lunch and appreciate my concertation by soundlessly walking around our studio apartment.

Laura Tuomisalo
St. Eustatius, 8th of May 2021

1. Introduction

As there exists variation in our appearance, like hair and eye colour, there is also variation in our bones. No two humans are the same, not even twins. Muscles move bones and thus leave their marks on bones. Therefore, as much as our genes determine how we look like, the environment also plays a significant role.

Bone variation is usually growth- or sex-related or explained as geographical or individual variation (White et al. 2011, 26). However, as White and colleagues (2011, 429) explained, bones are also altered during life by cells, and this change may be a result of biological, environmental or cultural reasons. These reasons may be intrinsic or extrinsic and include pathological conditions, body modifications, surgeries, and biomechanical stresses (White et al. 2011, 429; Pearson and Lieberman 2004, 67). In this research, the variation in human shoulder blades, called scapulae, was studied to understand better whether the variation originates from genetic reasons, mechanical strain, or both.

The scapulae of modern humans exhibit variation in the lateral border of the bone called axillary border, which extends distally from the glenoid fossa where humerus articulates. The axillary border (figure 1), mainly consists of two parts. The first two-thirds of the border consists of sulci and crests, and the third part continues distally from the protuberantia marginis, or the teres protuberance (von Eickstedt 1925, 218; Dittner-Plasil 1981, 9). Variation mostly exists in the proximal two thirds, where the placing of sulci and crests may vary.

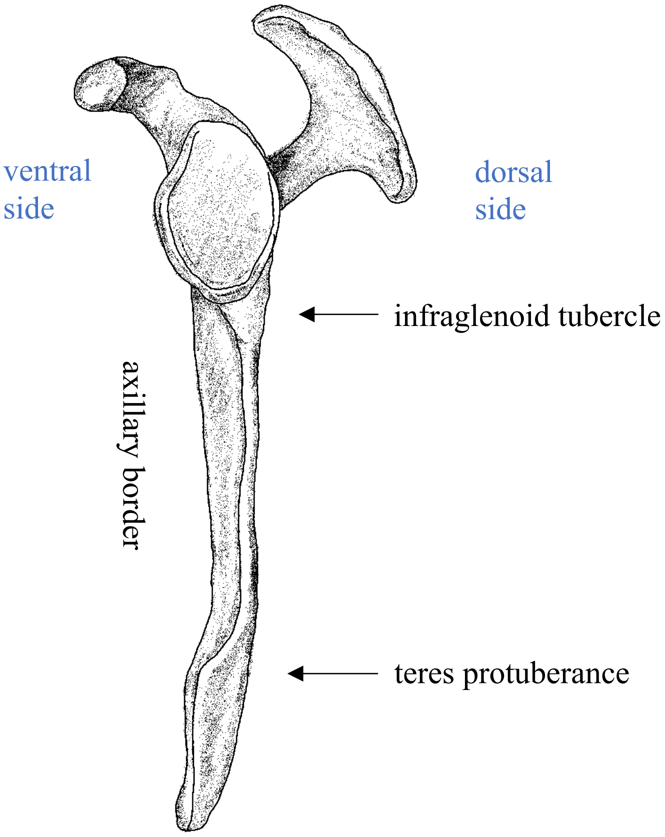


Figure 1. The morphology of the axillary border. This picture depicts the ventral border pattern. Drawing by author, based on Gray 1918, 207.

Even though the variation is observable within modern humans, it is even more distinct when modern humans are compared to the Late Pleistocene *Homo sapiens* or The Neanderthals. The most prevailing pattern in modern humans is called a ventral pattern, where the groove (axillary sulcus) of the axillary border runs along the ventral side of the border (see figure 2) (Trinkaus 1977, 231). Trinkaus (1977, 231) explained that Neanderthals, however, predominantly exhibit an opposite pattern, called the dorsal pattern. In addition to these two opposite patterns, he continued, that the Upper Paleolithic *Homo sapiens* display a transitional phase, the bisulcate pattern, where the axillary border is vertically divided into two sulci by a crest. The terms ventral, dorsal, and bisulcate are most easily understood by the placement of the sulcus. On the ventral pattern, where the sulcus is on the border's ventral side, the sulcus can be seen when viewing the bone from the ventral side. The opposite goes for the dorsal pattern.

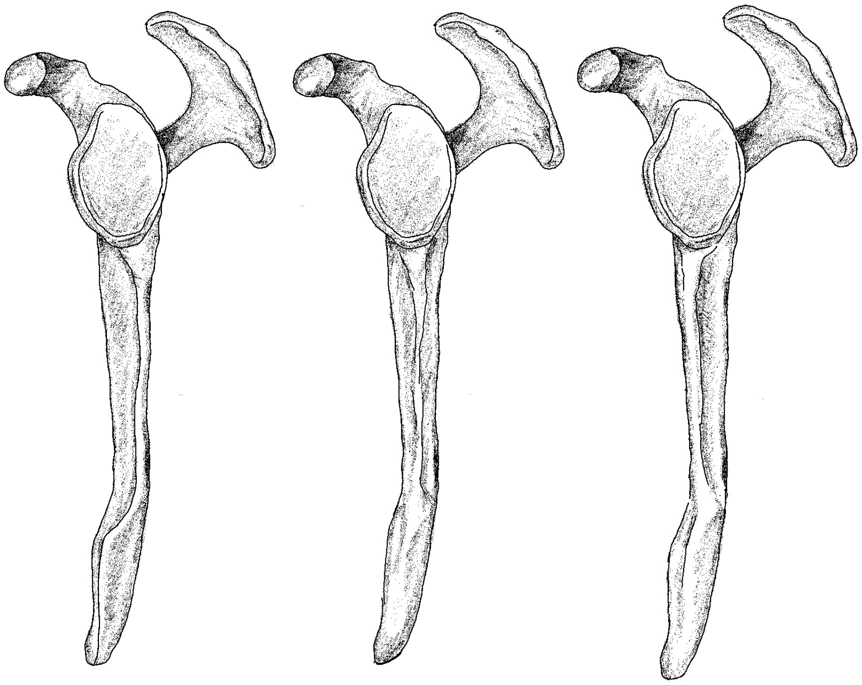


Figure 2. The axillary border pattern. Ventral on the left, bisulcate in the middle, and dorsal pattern on the right. Drawing by author, based on Gray 1918, 207.

The Neanderthals were a group of archaic humans, who lived in Western Eurasia from around 400,000 years to 30,000 years ago (Hublin 2009, 16022; Krause et al. 2007, 902; Stringer and Hublin 1999, 37:873). They lived below 55° N latitude and until Israel in the south (Hublin 2009, 16022). Neanderthal remains were found from Southern Siberia in the east, and France in the west. No Neanderthals have been found from Africa (Hublin 2009, 16022; Krause et al. 2007, 903). They were large-bodied compared to *Homo sapiens,* and especially the European Neanderthals were well adapted for colder climates with larger trunks and shorter limbs (Holliday 1997, 254–55).

Researchers have highlighted the differences and similarities between the Neanderthals and modern humans since they were recognised as a separate species of fossil humans, *Homo neanderthalensis* (Harvati 2010, 367). Our sister species' status has changed during the past decades, from being our ancestors to being just a distinct primitive species (Harvati 2010, 367–68). Currently, we know, that the ancestors of the present-day non-Africans interbred with them, and most of us still carry Neanderthal DNA in our genomes (Dannemann and Racimo 2018, 1). Trinkaus (1977, 233) has stated that the robusticity of Neanderthals also shows in their humeral adductor muscle attachments in latissimus dorsi, pectoralis major and teres minor. Since these strong humeral adductors also act as medial rotators of the humerus, they need strong counter muscles for powerful and precise adduction of the arm. Therefore, the dorsal pattern might indicate strong teres minor and infraspinatus muscles (Trinkaus 1977, 233).

The axillary border differences of the scapula were already noted in the late 1800s (Testut 1889), and discussion on the topic has been vibrant ever since. The variation is a well-studied subject with lots of literature, especially on the morphology of Neanderthals (Busby 2006, Dittner-Plasil 1981, Odwak 2006, Trinkaus 1977, 1983, 2006, 2008). However, debate and research still remain on whether the differences are mostly caused by muscular hypertrophy, meaning the increase and growth of muscle cells through exercise, or genetic reasons. Some of the latest studies (e.g. Di Vincenzo et al. 2019; Odwak 2006; Trinkaus 2008) have suggested that epigenetic basis for the variation is more plausible, since the lack of evidence between the muscular hypertrophy and dorsal pattern, and the finding of a young Neanderthal child exhibiting a dorsal pattern. However, most of the studies have concentrated on small samples of Neanderthal individuals, and large-scale studies on the topic are rare (including: Dittner-Plasil 1981; Moran and Chamberlain 1997; Odwak 2006).

This comparative study's fundamental purpose is to find evidence for the basis of the variation using large samples from three *Homo sapiens sapiens* collections. The evidence should indicate either a genetic basis of the adaptation or that it results from physical activity. There is also a possibility that both of these play a role. This will be achieved by obtaining statistical differences and similarities between or within the sample populations. The within-population aspects considered, are sex and age differences, and in addition to this, bilateral differences are noted at the individual level.

By having more knowledge on the origins of the variation, it is possible to draw more reliable hypotheses on the variation's primary function, and why Neanderthals mostly exhibit the dorsal pattern. As Trinkaus (1977, 321) has already stated, the variation's evolutionary importance can only be known after identifying its functional meaning. Therefore, a broader understanding of the variation would give a more comprehensive insight into the capabilities of the Neanderthals and explain their daily habits. We still do not know why they predominantly exhibited the dorsal pattern.

Besides knowing more about Neanderthals, we would learn more about modern scapulae and how they respond to mechanical stress and adapt. Pearson and Lieberman have studied bone functional adaptation in general, and they stated (2004, 63–64), that bone morphology is a result of a combination of genes and environmental influences, and purely genetically determined shape does not exist. Therefore, muscle use through physical activity would need to contribute to the bones' shape, but what does this mean for axillary border patterns? Odwak (2006, 362) has suggested, that bisulcate pattern would be the most robust and, therefore, resist most mechanical stress. Trinkaus however, has proposed (1989) that the dorsal pattern would be reinforced to resist dorso-ventral bending stress and would therefore be the strongest pattern.

If it is, in fact, right, that Neanderthal scapulae or early *Homo sapiens* were better equipped against bending strain, why has the quality diminished? Does it have to do with technical advantages and reduction in physical activity? Since scapula has a vital role in shoulder movements, could different patterns function differently? The muscles attaching to scapula need to be balanced for the glenohumeral joint (between scapula and humerus) to work as it is supposed to, while imbalance may cause altered motion and position of the bone, called scapular dyskinesis (Paine and Voight 2013, 619–20). With a broader understanding of the axillary border pattern function, the expertise to treat scapular dyskinesis could improve.

The amount of modern human scapulae is significantly greater than Neanderthal scapulae, making them valuable for a large-scale study. The scapula is also not known for its good preservation in archaeological contexts, and if preserved, it is often fractured. Thus, by studying from recent and more numerous collections, we will better understand the morphological differences of the scapula. Larger quantities are needed especially in comparative studies from adult specimens. This research focuses on only adult individuals from three osteological collections housed in the Faculty of Archaeology at Leiden University. Two of them are samples from Post-Medieval (1500-1700 CE) Dutch populations, Arnhem and Middenbeemster, who engaged in different lifestyles but are somewhat concurrent and genetically close. The third sample population is a much earlier group of people from Abu Fatima (*ca.* 2,500-1,500 BCE), in current Sudan, who are spatially and genetically distinct from the Dutch populations.

The Dutch population from rural Beemster (Middenbeemster cemetery) were mostly engaged in dairy farming as landowners to poor transitional labourers and everything in between (Veselka et al. 2015, 666). In urban Arnhem, the lower working class buried in the Oude Kirkhof cemetery were most likely working in industries as breweries or tanneries (Baetsen et al. 2018, 34,38-39). Both of these populations were engaged in physical activities in their day-to-day lives, but we can assume that their activities differed. Probably the rural farm chores were more wide-ranging, and the urban industry work included mostly monotonic activities. Suppose the sample populations from these cemeteries would reveal significant differences in this study, and another one of them exhibit a more robust axillary border. In that case, it could indicate that physical activities and mechanical strain would manifest in the axillary border pattern. Since the frequency of the strain is important in bone functional adaptation (Turner 1998, 399), a hypothesis is that the monotonic nature of urban industrial work would cause more robust axillary variations if the variation is indeed activity-related.

The third collection aside from the Dutch ones is from Sudan. This Nubian collection from the burial ground of Abu Fatima dates to around 2500-1500 BC (Schrader et al. 2019, 314), making it a lot older than the Dutch collections. Since their spatial and temporal distinctiveness, the Nubians are genetically diverse from the Dutch sample populations. Thus, they will be of value when evaluating the genetic basis behind the axillary border variation. Abu Fatima's population lived near the Nubian capital city, Kerma, but the area was more rural than in the city, and people engaged in manual labour (Schrader et al. 2019, 314). Suppose the sample population from Abu Fatima will show a statistically significant difference to the Dutch populations. In that case, the genetic component is probably a more significant cause behind the axillary border variation than physical activity.

The main research question, which this project aims to answer, is:

- Does muscular hypertrophy mostly cause the axillary border variation, or is it controlled by genes?

The main question above will be examined through these secondary research questions:

- Do the Dutch urban and rural population samples show significant differences in the predominant pattern or other measurements?
- Are there statistically significant differences between the genetically different Nubian and Dutch collections?
- Are there differences in the prevalent pattern between the right and left sides, between females and males, or different ages?

These questions will act as a base for this study. They will be answered through statistical methods in order to point out the differences and similarities. Lastly, the answers for these questions will be considered within the broader field of axillary border studies

The next chapter will focus on background by explaining the anatomy and physiology of the scapula and describing the history of axillary border studies. Chapter 3 will introduce the sites, describe the sampling strategy, and tell more about the measurements and analyses used. In chapter 4, the results of the analyses will be presented and they will be discussed further in chapter 5. Chapter 6 will wrap up everything and make suggestions of upcoming research.

2. Background

2.1. Anatomy and Physiology

2.1.1. Scapula

The scapula is a flat, triangular bone that is located posterior to the thoracic cage and forms the posterior aspect of the shoulder girdle (see figure 3) (Bakhsh and Nicandri 2018, 10). The bone is connected to clavicle by the acromioclavicular joint (AC), humerus by the glenohumeral joint (GH), and to the rib cage by scapulothoracic joint (ST), which is actually just a gliding mechanism and not a real joint (Bakhsh and Nicandri 2018, 10; Sarrafian 1983, 11). There are also multiple ligaments aiding in the stabilization of the joints. The GH is stabilized by the superior, middle, and inferior glenohumeral ligaments, and the coracoacromial ligament, as well as the AC by superior, inferior, anterior, and posterior ligaments (Bakhsh and Nicandri 2018, 11).

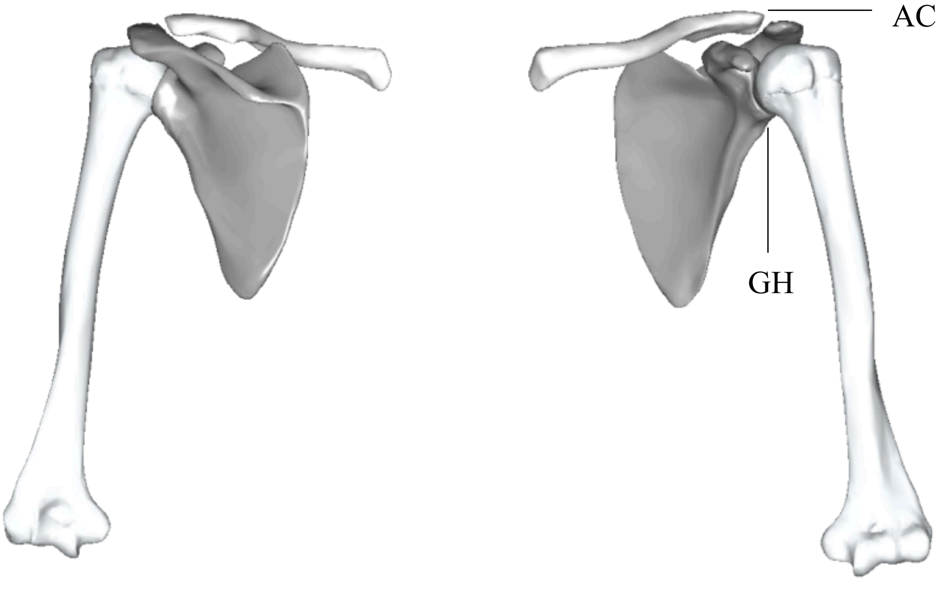


Figure 3. Scapula in relation to clavicle and humerus. Posterior view on the left and anterior on the right. http://lifesciencedb.jp/bp3d/ (CC BY-SA 2.1 JP).

As stated by Paine and Voight (2013, 618), there are no bony attachments between the scapula and the thoracic cage, and this enables immense range of mobility, including: “protraction, retraction, elevation, depression, anterior/posterior tilt, and internal/external and upward/downward rotation”.

However, the scapula is for the most part responsible of changing the plane of movement of the arm by elevation and depression, and it is also in control of one third of the range of abduction of the arm (Bakhsh and Nicandri 2018, 10). Paine and Voight also note (2013, 618), that the way scapula is connected to the thoracic cage, is a suction mechanism between the thorax and the subscapularis and serratus anterior -muscles and through the ligaments stabilizing the AC.

The scapula belongs to, and is a crucial part of the shoulder complex. As already said, the shoulder has an essential role in arm mobility and movements, and it connects the upper limbs to the axial skeleton (Bakhsh and Nicandri 2018, 10). When the surrounding musculature and ligaments around scapula are strong and well, the bone acts as a secure base for glenohumeral mobility (Paine and Voight 2013, 618). However, as Bakhsh and Nicandri noted (2018, 10), while the muscles around scapula need to be stable and strong, they also need to be flexible and durable, and be able to assist in hand dexterity. This is why the shoulder complex is so complicated and exceptional.

2.1.2 Bone Remodelling

The purpose of bone structure is to be able to withstand inside and outside forces and resist breaking (Pearson and Lieberman 2004, 65). As Pearson and Lieberman (2004, 66) wrote, bones also act as attachments to numerous muscles, tendons, and ligaments, and protect several organs. Furthermore, bones need to be able to carry out these tasks even when they are growing, which means staying strong against strains while intensely growing in size (Pearson and Lieberman 2004, 66).

In the 1800s, a German scientist Wilhelm Roux discovered that trabecular bone is composed of organized mesh, which responds to local stresses and therefore bones are able to adapt to new mechanical environments (Kivell 2016, 571). Julius Wolff (1870 in Heller et al. 2010, 1057) took this idea further in an attempt to explain adaptive bone growth through mathematical models, and therefore, bone remodelling is still generally recognized as Wolff's "Law" (Ruff et al. 2006, 484). However, his original methods concerning trabecular bone have later been falsely used to cortical bone as well, which still causes controversy around the theory (Pearson and Lieberman 2004, 65).

In Wolff's "Law", or bone functional adaptation, bone reacts to dynamic mechanical strain or the lack of it, by either modelling or remodelling new bone, or by resorption (Turner 1998, 403). Still, these actions are far from simple, and incorporate multiple different mechanisms (Pearson and Lieberman 2004, 88). Bone modelling and remodelling are based on mechanical stresses which cause strain on the bone (Ruff et al. 2006, 485). As Ruff and colleagues (2006, 485) have simply put it, increased strain initiates bone tissue deposition, which results in optimal level of strain. However, decreased strain results in bone resorption, which again returns the optimal strain level (Ruff et al. 2006, 485). According to Pearson and Lieberman (2004, 73–74), there is actually no clear answer to why bone is resorbed, but hypotheses range from bone returning to its original shape to bone getting rid of excess mass which is not needed anymore. They add, that mostly likely longer periods of resorption could be seen as a pathological response to the lack of epigenetic stimuli, which natural selection has not corrected because it is so uncommon for non-hibernating organisms.

It is currently acknowledged, that aside from physical activity, genetic factors also play a part in bone functional adaptation (Ruff et al. 2006, 484). Pearson and Lieberman (2004, 63) add, that it is challenging to know which traits are altered by genes, and to which degree. Ruff and colleagues (2006, 485) have additionally noted, that the age of the individual affects, and changes are not constant throughout life. They continued, that other elements which play a role, are diet, body size, and hormones. Studies of the effects of mechanical loading have been done on living people and they showed a significant importance with the activities done during adolescence and growth spurt in the adult morphology (Pearson and Lieberman 2004, 89). Even if all these factors are constant, bones still do not adapt to applied strain in a linear way; it depends on the repetitiveness of the loading environment (Turner 1998, 404). Turner (1998, 404) explains this by saying that bones respond less to daily strains as walking and more to new movements.

When examining the biomechanical stresses of the scapula, it is clear that they primarily come from the surrounding musculature (Trinkaus 1977, 233). As is tested in this study, biomechanical stresses might play part in the axillary border variation. This would mean that the scapula has remodeled at the axillary border to better resist the muscular stresses applied to it. Therefore, it is crucial to know which muscles attach to scapula, what are their purposes, and what direction do they contract.

2.1.3 Muscles

The scapula has 17 muscle attachment points with muscles serving various functions (Bakhsh and Nicandri 2018, 10). Some of them act as important stabilizers for the shallow glenohumeral joint (glenoid fossa and the head of humerus), since according to Bakhsh and Nicandri (2018, 10), the humeral head approximately only interferes with the glenoid fossa at 25% of the humeral head surface. However, most attaching muscles also have visible functions in abduction, adduction, and extension of the arm (figure 5) (Muscolino 2017, 59, 225). As seen in figure 4, the ones closest connected to the axillary border and most likely affecting its morphology, are teres minor, subscapularis, and teres major, and therefore, they are in more detail considered in this study.

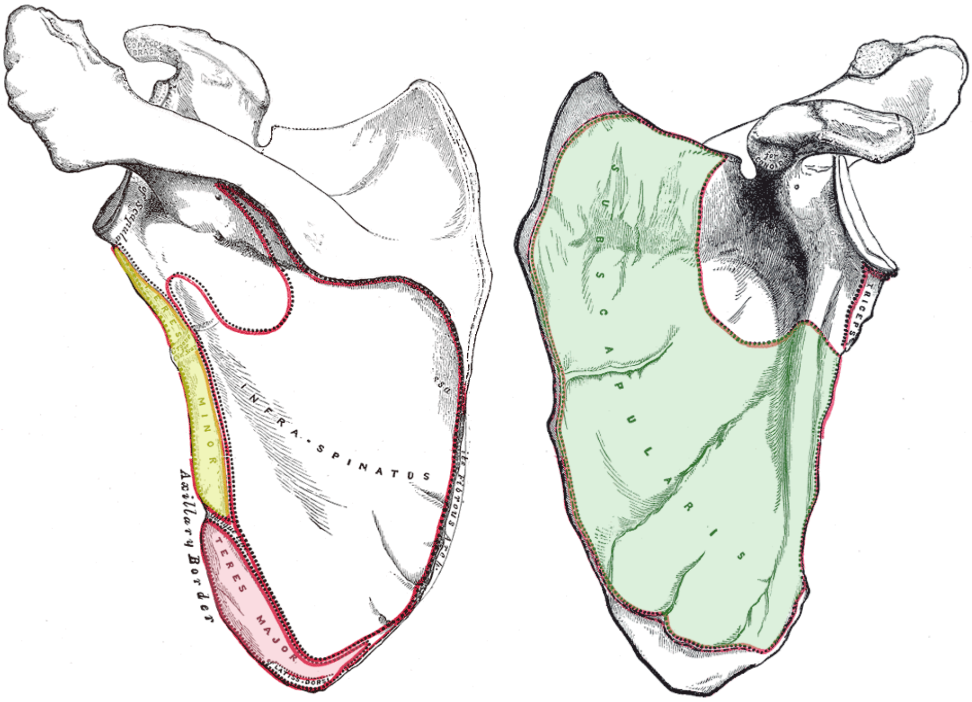


Figure 4. The anatomy of the scapula with muscle attachment sites considered in this study. Dorsal view of the scapula on the left and ventral on the right. The attachment site of teres minor in yellow, teres major in red, and subscapularis in green. Modified from Gray (1918, 204–5).

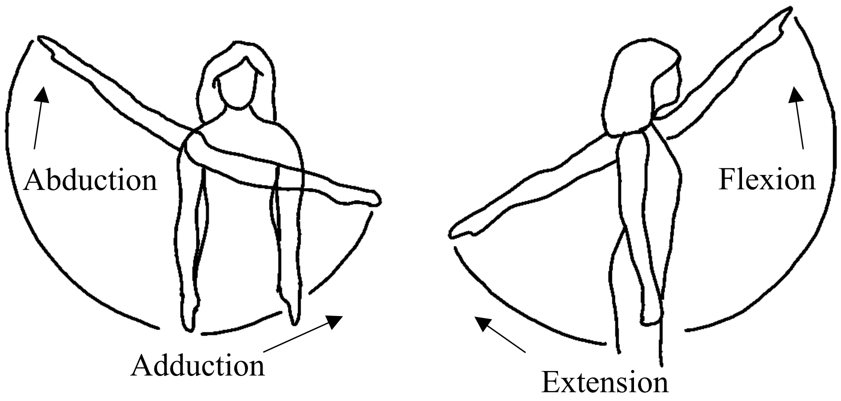


Figure 5. Movements of the arm. Drawing by author, based on Muscolino (2017, 65–66).

The rotator cuff is a group of muscles formed by supraspinatus, infraspinatus, teres minor, and subscapularis (Gilroy et al. 2020, 317). There are two main critical functions for this group: stabilisation of the glenohumeral joint and rotation on the humerus (Muscolino 2017, 225). Two of the rotator cuff muscles originate from the axillary border. Teres minor attaches on the dorsal aspect of the axillary border and subscapularis on the ventral. The terms *sulcus axillaris teretis* (dorsal pattern) and *sulcus axillaris subscapularis* (ventral pattern) (von Eickstedt 1925) also derive from the muscle attachment sites.

Teres minor originates from the superior 2/3 of the dorsal axillary border (figure 4) and attaches to the greater tubercle of the humerus (Muscolino 2017, 236). It crosses the glenohumeral joint posteriorly and by attaching to the greater tubercle, aids in lateral rotation of the humerus. Muscolino (2017, 236–37) notes, that it is called lateral rotation since the anterior humerus rotates laterally, but actually the contraction of teres minor pulls posterior humerus medially towards the scapula. He adds that, if the arm is fixed, the scapula moves towards the humerus causing a medial rotation of the scapula. The other actions for teres minor are adduction of the arm and horizontal abduction of the arm when the arm is at 90 degree abduction (figure 5) (Muscolino 2017, 236).

Subscapularis muscle also belongs to the rotator cuff muscles, but it acts as the medial rotator of the humerus, since it crosses the glenohumeral joint anteriorly and attaches to the lesser tubercle (Muscolino 2017, 240). The originating attachment point is at the subscapular fossa and it extends all the way to the axillary border on the ventral side (figure 4). Muscolino (2017, 240) explains, that when subscapularis contracts, the anterior humerus moves medially resulting in medial rotation of the arm. He also notes, that if the muscle contracts and the arm is fixed, lateral rotation of the scapula occurs and the medial border of the scapula moves towards the rib cage. This medial rotation of the humerus and its reverse action are the only main actions of the muscle aside from its role as a stabilizer of the glenohumeral joint.

Teres Major similarly acts as a rotator of the humerus, even though it does not belong to the rotator cuff muscle group. It originates from the inferior 1/3 of the axillary border on the dorsal side and inserts onto the medial lip of the bicipital groove in the anterior humerus (Muscolino 2017, 221). Muscolino (2017, 65, 221) describes that the standard actions for teres major are medial rotation of the arm, adduction, and extension of the arm from the glenohumeral joint. If the arm if fixed, however, the inferior margin of the scapula moves towards the humerus and also towards the rib cage while the glenohumeral joint rotates upwards (Muscolino 2017, 222).

Connecting physiological information of muscles with actual everyday lives of the three populations sampled for this study, we will gain insight into the movements causing biomechanical stress to the shoulder girdle. Palmer and colleagues (2016, 83) studied the activity markers of Middenbeemster, and found out that most of them likely participated in strenuous labour as dairy farmers. This includes among other things, carrying food for the cattle, milking them, and producing and carrying dairy products. The people buried in the Oude Kirkhof cemetery in Arnhem were most likely belonging to the lower working classes and working in local industries as tanneries and breweries of the city (Baetsen et al. 2018, 34). Breweries required workers to move ingredients, maintain fires and stir mixtures (Unger 2001, 109–10). In the tanneries, hair and flesh was forcefully scraped off from the hides, and heavy hides were moved around and lifted in and out of tubs using large iron hooks (Ervynck et al. 2003, 67–68). The Nubians of Abu Fatima lived in a peri-urban borderland near the capital Kerma (Akmenkalns 2018, 32; Schrader et al. 2019, 347), and they engaged in farming, small livestock husbandry, and crafts (Akmenkalns 2018, 181, 184; Edwards 2004, 83). Some of them were possibly specialized in certain crafts with monotonic movements of the arms (Akmenkalns 2018, 181), but for most of them, farming and animal husbandry offered broad range of different tasks.

2.2. Research Background

The axillary border variation was already noted in 1889 by Leo Testut (1889), a French anatomist and anthropologist who studied a red ochre burial known as the Chancelade man (Reveron 2014, 39). When Testut (1889, 185-6) examined the skeleton, he noticed that the axillary border was different from what he had seen in the laboratory before. He stated that it looked robust and resistant. The variation was not named yet, but the bisulcate border pattern is still sometimes referred to as a Chancelade type (Odwak 2006, 355). In the bisulcate pattern, there are sulci on both sides of the crest dividing the axillary border (see figure 6) (Trinkaus 2006, 346).

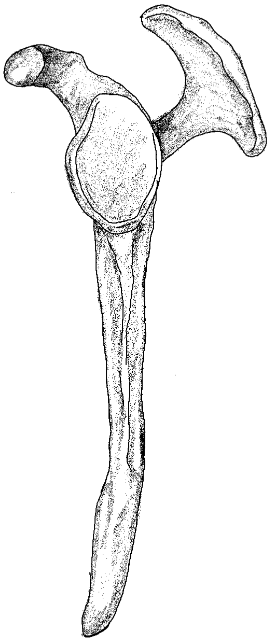


Figure 6. The bisulcate pattern. Modified from Gray 1918, 207.

In 1911, a French palaeontologist Marcelin Boule completed his study of La Chapelle-aux-Saints and included scapulae from La Ferrassie I to substitute scapulae which were not preserved in La Chapelle (Dittner-Plasil 1981, 21). Boule (1911, 123) noticed that both of the scapulae exhibited an opposite pattern on the axillary border than modern humans. According to him, another crest exists in the axillary border starting from the glenoid tubercle and extending towards the inferior angle on the ventral side, thus forming a very different appearance compared to the modern type (see figure 7). Here, the dorsal crest veers dorsally to the scapular fossa and divides it as almost a second spine. He also adds that, the dorsal crest is probably there to frame teres minor and infraspinatus muscles from each other, and that the variation must be mostly caused by musculature and physical

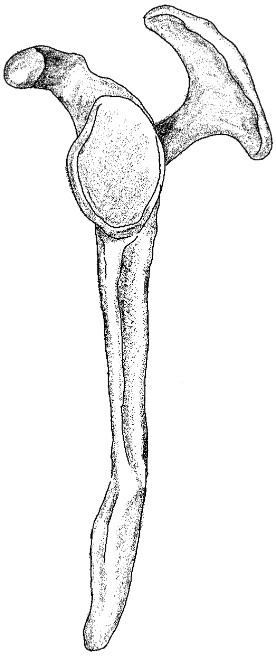


Figure 7. The dorsal pattern. Modified from Gray 1918, 207.

activity, since the closest mammal to exhibit such pattern is genetically very distant (Boule 1911, 124).

Schwalbe took part in this conversation in 1914 by responding to Boule's work and telling his own view of the matter. According to him (1914, 572), the pattern difference, or placement of the sulcus axillaris as he calls it, is due to the more dorsally oriented whole lateral part of the scapula in the Neanderthals. He details that the Neanderthal pattern includes two lips that form a sulcus between them, which is only visible dorsally. In his mind (1914, 572), the sulcus is the same in all patterns, but it just changes its location.

In 1925, Von Eickstedt wrote an article about the axillary border variation and named the ventral and dorsal patterns as sulcus axillaris subscapularis and sulcus axillaris teretis, respectively. The intention of von Eickstedt aside from naming these patterns was to give critique for Schwalbe's earlier work (Dittner-Plasil 1981, 22). According to him (1925, 219), the variation exhibits two totally different patterns, and it is not about the same crest moving to a different place through time. He added that, even though mechanical stress modifies the axillary border, it is not the only cause since innate "racial" differences exist (von Eickstedt 1925, 221). Von Eickstedt contributed significantly on the topic of axillary border variation, even though he did not have any new skeletal material, however, some years later he also wrote a book dividing humans into races and was, unfortunately, able to continue practising anthropology even after the Second World War (Lenz 2020, 5; Stewart 1962, 783).

These above-mentioned people were the first ones to note the existence of the variation and try to explain it. The examination of the axillary border variation has not slowed down since then, and some of the same concepts are still in consideration. During the following decades, the Neanderthal fossil record was examined and re-examined by multiple researchers, as Gorjavic-Kramberger (1914; 1927) who studied the Krapina fossils, and McCown and Keith (1939) the Mount Carmel remains. Stewart also took a closer look at the axillary border -discussion in 1962, when he wrote on the Shanidar Neanderthals from Iraq. According to him (Stewart 1962, 779), the axillary border has received this much attention because scapulae are usually poorly preserved from the other parts. He also reminded that the other features which seem to be distinct in the Neanderthals, in fact, fall within the normal variation of modern humans and that the shoulder and neck area of the Neanderthals is not so different to us.

The more recent research has shifted from merely identifying the variation towards trying to explain the processes behind it. Topics like genes, ontogeny, and biomechanical stresses are in the spotlight as researches dig deeper into the primary causes. Many researchers have taken part in this, but one name has continuously been in the frontline of the Neanderthal studies since the 1970s.

A paleoanthropologist Erik Trinkaus focused his studies on the Neanderthals from the 1970s until the 1990s, using the fossil record to interpret recent human diversity through for example biomechanical analyses, palaeopathology, bone biology, and taphonomy (https://artsci.wustl.edu/faculty-staff/erik-trinkaus). He wrote an essential article in axillary border research in 1977, where he deliberated the functional causes behind the variation and highlighted the importance of muscle attachments and the remodelling of the bone to resist biomechanical stresses better. In his opinion (1977, 233), the stronger deltoid muscle in the Neanderthals compared to modern humans would have required a strong counter muscle. Deltoid belongs to the medial rotators of the humerus, and therefore, teres minor as a lateral rotator must be powerful to offer balance to the movements (Trinkaus 1977, 233).

Throughout the decades until the present day, Trinkaus has re-evaluated the meaning and function behind the pattern variation. In 1990, Churchill and Trinkaus (1990, 158) stated that they no longer believe the robustness of teres minor being the leading cause behind the axillary border variation. In fact, Trinkaus and his colleagues (Trinkaus 2006, 348; Villotte et al. 2020, 9) now have argued that the morphology might be mainly epigenetic.

This section has explained the most critical steps in the history of axillary border studies, which have lasted for over a century. The basics of the topic have stayed unchanged, even though the names of the patterns have become established, and the interpretation of the main cause shifted during the years. The most popular view currently is that there are multiple causes that have an effect on the axillary border morphology, but to what extent, still remains uncertain.

This chapter has provided the anatomical and physiological background to understand the function of the scapula and the forces affecting the axillary border. The research history of axillary border variation provided the means to understand how the border has been perceived throughout the decades. In the following chapter, the osteological collections and the data collected from the sample populations will be introduced and explained in more detail.

3. Materials and Methods

3.1 Sites

The data used in this project were collected from three osteological collections at Leiden University Faculty of Archaeology. Two of these collections were from The Netherlands, Middenbeemster and Arnhem, and the third collection was from Abu Fatima, Sudan (figure 8). Good preservation and a sufficient amount of individuals made these collections stand out for this study. As already mentioned, it was necessary to get samples from two somewhat concurrent populations, who would be genetically close but engage in different lifestyles. But also, from a third temporally and spatially diverse collection, and therefore, also genetically distinct.

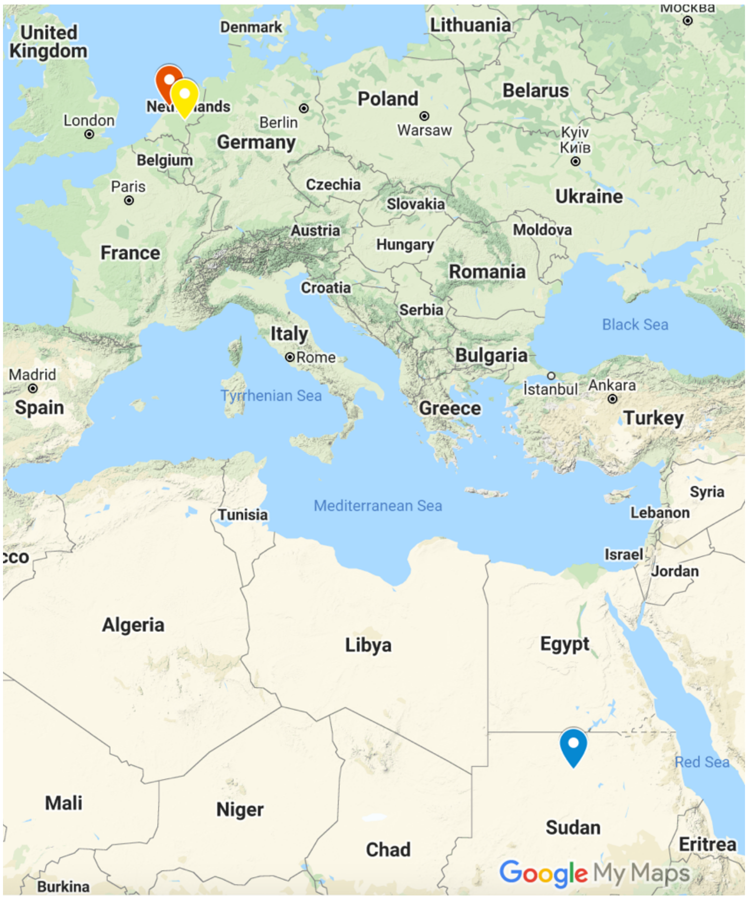


Figure 8. Map showing the sites. Map data: Google, © 2021 INEGI.

3.1.1 Middenbeemster

Middenbeemster is a town north of Amsterdam in the middle of the municipality of Beemster, as its name already indicates (figure 9). The Beemster area was reclaimed for plantation and recreation in 1607-1612 from a lake of the same name (de Jong 1998, 11–12). At first, the newly dried land was used for cultivation, but as time went by, it was discovered that the land was better used for growing cattle, and it stayed this way until the end of the 19th century (de Jong 1998, 26). Already in the 17th century, the area was already known for its cheese industry, but also butter, wool, and bulls (de Jong 1998, 26).

Industrialization hit The Netherlands quite late, not before the 1850s (Drukker and Tassenaar 1997, 333). Since the Keyserkerk cemetery in Middenbeemster was in use between 1623 and 1866, the individuals studied were most likely engaged in manual labour (Chilcote 2018, 39). Some known occupations from the area are dairy farmers, labourers, teachers, doctor, baker, shop keeper, and a priest (Falger et al. 2012 as cited in Chilcote 2018, 40).

Regardless of the scarce evidence of females in Dutch agriculture before the 20th century, Cruyningen (2005) studied women's engagement in farming in Zeeland, in the southern Netherlands. According to him (2005, 58–59), the status of farmer's wives was very different from the women workers, who were only a part of the full-time workforce before marriage. After getting married, they were only hired as seasonal workers. Farmers wives, however, were responsible for the household and dairy products (Chilcote 2018, 230). Therefore, it is safe to assume that both sexes were engaged in manual labour in the Middenbeemster area.

The cemetery was excavated in 2011, and approximately 450 individuals were recovered, mostly in well-preserved condition (Chilcote 2018, 39–40). Even though the cemetery was in use from the year 1613, the recovered skeletons are, for the most part, from 1829-1866 (Palmer et al. 2016, 79). The collection is currently housed at the Leiden University at the Laboratory for Human Osteoarcheology.

Figure 9. The Dutch sites Middenbeemster and Arnhem. Map data: Google, ©2021 GeoBasis-DE/BKG (©2009).

3.1.2 Arnhem

The area of today's city centre in Arnhem, previously called "Arneym", was already settled in the latter half of the 9th century by farmers who wished to stay on the stream Sint-Jansbeek's east bank (Baetsen et al. 2018, 34). The settlement was granted its city rights in 1233 by Emperor Otto II, and the city walls of the strategically well-placed city were reinforced (Baetsen et al. 2018, 34). The Sint-Jansbeek stayed as the main water provider for the people in Arnhem and made it possible for local industries as tanneries and breweries to succeed since good water was a necessity for drinkable beer (Baetsen et al. 2018, 34; Unger 2001, 17). However, in the early 1800s, the stream was built over, and it became the first sewer of Arnhem (Baetsen et al. 2018, 34).

The excavated cemetery Oude Kerkhof, where Arnhem's skeletal collection comes from, was in use from around 1444 until the year 1829, when cemeteries were ruled to be moved outside of the city in places where the population was over a thousand (Baetsen et al. 2018, 37). The excavated part of the cemetery was located on the north side of the Eusebius Church (Baetsen et al. 2018, 37). Haggrén (2015, 398) stated that the most valued area within a cemetery is on the south side of the church, and therefore, the north side is usually where the lower working class is buried. The northern location of Oude Kerkhof is therefore assumed to reflect lower social status (Baetsen et al. 2018, 38–39). Thus, the people in Arnhem osteological collection were most likely workers of local breweries, tanneries, and brickyards or worked with crafts, food production, or textile industry (Baetsen et al. 2018, 34; Buisman 2009, 135). As Baetsen and colleagues noted (2018, 41), the skeletons already showed signs of intense activity in the documentation phase.

The cemetery was excavated in 2017 as a part of a revitalization of the deteriorated southern part of the inner city (Baetsen et al. 2018, 35). The project aimed to enhance the deteriorated part of the city and bring back the stream Sint-Jansbeek as a beautiful element reconnecting to the history of the city and to reduce Arnhem's heat stress (Baetsen et al. 2018, 36). Baetsen and colleagues (2018, 36) explained that the project was aware of the creek's new construction cutting through the Oude Kerkhof cemetery. Therefore, an extensive archaeological excavation was needed, and almost 700 primary burials were recovered. However, only around half of these burials contained complete skeletons, probably due to intensive use of the cemetery and lack of a map and grave markings (Baetsen et al. 2018, 39). The collection is being housed at the Laboratory for Human Osteoarchaeology at Leiden University.

3.1.3 Abu Fatima

The site of Abu Fatima is located close to the third cataract on the east bank of the Nile River, approximately 10 kilometres north of the ancient capital city Kerma in current day Sudan (figure 10) (Akmenkalns 2018, 31; Schrader et al. 2019, 374). Kerma was a cultural and political centre, which dominated around 700 kilometres of the river valley of Nile (Edwards 2004, 75). Its influence lasted through Early Kerma (2500-2050 BCE), Middle Kerma (2050-1700 BCE), and Classic Kerma (1700-1500 BCE) until Nubia fell under Egyptian control (Akmenkalns 2018, 16). North and north-west from Abu Fatima, there was later occupation at administrative Tombos in 1550-656 BCE (east bank of Nile) and at a rural village of Hannek in 1550-656 BCE (west bank) (Schrader et al. 2019, 374).

Figure 10. Map of Abu Fatima and the surrounding areas. Abu Fatima depicted in red, and the other nearby villages and cities in blue. Kerma south from Abu Fatima, Hannek on the west bank of Nile and Tombos approximately 4 km north (Schrader et al. 2019, 374)*. Map data: Google, ©2021.*

The burial ground at Abu Fatima was in use during the Kingdom of Kerma, from the Early and Middle Kerma phases between 2500 and 1700 BCE, until the Classic Kerma (1700-1500 BCE) (Akmenkalns 2018, 73; S. Schrader, pers. comm., March 3, 2021). A most likely contemporaneous settlement site has also been located from the cemetery vicinity (Akmenkalns 2018, 32). People in the village lived a peri-urban lifestyle close to the capital city Kerma, but still cultivating and raising livestock, like sheep and goat (Akmenkalns 2018, 185; Edwards 2004, 83). They were probably also making crafts, baking, and brewing for a larger trading network (Schrader and Smith 2017, 30).

Local plans to build houses close to the burial ground generated a need to salvage what was left of the Kerma period cemetery, and excavations at the site started in 2015 (Akmenkalns 2018, 12). Unfortunately, a part of the cemetery had already prior destructed due to alluvium mining. (Akmenkalns 2018, 12). Nine skeletons were salvaged during the excavations in 2015 and 25 in 2016 (Schrader and Smith 2017, 28; S. Schrader, pers. comm., March 3, 2021). The collection is also currently housed at the Laboratory for Human Osteoarcheology at Leiden University.

3.2 Sampling

The number of individuals included in this study is 167. All individuals from the collections were checked for preservation, and the ones where axillary borders were well preserved, and at least one other measurement was possible, were chosen. Both scapulae were measured and observed if preserved well enough, and in most cases, the preservation was equal, and they could both be either measured or left out. Out of the 167 individuals chosen, 17 had only one well-preserved scapula, making the total amount of scapulae 317. Out of the whole sample, 102 individuals were from the Middenbeemster collection, 52 from Arnhem, and 13 from Abu Fatima (for sex and age distribution, see tables 1 and 2). The number of individuals reflects the size of the collections since Middenbeemster is the most numerous collection out of these three. The sample consists of individuals from both sexes and all age groups over 18 years of age. Subadults were left out from this study because ontogeny was not studied. Since this research studied activity-induced traces in the scapulae, which require strenuous and repetitive mechanical stress, subadults would not have been a valid group to include.

Table 1. The sex and age distribution within the Dutch samples. I stands for indeterminate, NA for ages that are in between two categories or unknown. EYA = early young adult, LYA = late young adult, MA = middle adult, OA = old adult.

	Middenbeemster			**Arnhem**		
Age	Female	Male	I	Female	Male	I
EYA (18-25)	4	4	-	5	3	-
LYA (26-35)	12	10	-	5	6	-
MA (36-49)	18	18	1	9	11	1
OA (50+)	7	18	-	2	5	-
NA	4	5	1	2	-	3
n=	*45*	*55*	*2*	*23*	*25*	*4*

Table 2. The sex and age distribution of the Nubian sample. Note the difference in the age categories compared to the Dutch samples. YA = young adult, MA = middle adult, OA = old adult.

	Abu Fatima	
Age	Female	Male
YA (18-29)	3	1
MA (30-45)	2	6
OA (45+)	1	-
n=	*6*	*7*

The sampling strategy was to examine all scapulae preserved well enough for the axillary border type observation and the border thickness measurement. A humerus and a femur were also needed for stature estimation. Even though, especially the Middenbeemster collection is numerous, there were multiple cases where scapulae were either completely missing or neither axillary border was not preserved. Therefore, the preservation of scapulae was the main limiting factor for the sample size. In some cases where the scapula was fractured, but the pieces fitted perfectly together, a measurement was taken by keeping the pieces accurately in place.

Master's students of Human Osteoarcheology conducted the age and sex estimations of the individuals in the Dutch collections. For sex estimation, crania, mandibles, pelves, and few additional postcranial measurements were used according to the Leiden University Laboratory for Human Osteoarcheology Laboratory Manual, mostly based on Buikstra and Ubelaker (1994, 16-21). The same manual was used for ageing these skeletons from cranial suture closure, dental wear, auricular surface degeneration, pubic symphyses, and sternal rib ends, also based on Buikstra and Ubelaker (1994, 21-38). The ages are divided into four groups, which are: early young adult (EYA) 18-25, late young adult (LYA) 26-35, middle adult (MA) 36-49, and old adult (OA) 50+ (table 1). The statures were calculated from the maximum lengths of humerus and femur, using Trotter 1970 and Trotter and Gleser 1958 equations for white females and males. An average of the results from humerus and femur was used.

In the Abu Fatima collection, sex was determined from pelvis and skull, and the age at death from the pubic symphysis and auricular surface, all using Buikstra and Ubelaker (1994) (Schrader et al. 2019, 375). The age categories of young adult (YA) 18-29, middle adult (MA) 30-45, and old adult (OA) 45+ (Schrader and Smith 2017, 31), which are used for this collection, differ somewhat from the categories used for the Dutch samples. Statures were calculated from the maximum lengths of humerus and femur using Raxter and colleagues' (2008, 150) equations.

The ethical aspect of handling human remains was carefully considered, and only necessary collections were used. The skeletal material was handled with dignity and respect, and the insights the material provided into scapular variation are highly valued. Measurements and observations used in this study were all non-invasive and left no marks on the bones.

3.3 Measurements and Observations

Data was collected from both sides of the individuals if both scapulae were preserved. This enabled a better understanding of the side differences since individual variation exists in the patterns and the measurements. In addition to the scapulae, the lengths of one humerus and one femur were measured for stature estimation. When the right and left sides of an individual exhibited different axillary border patterns, the lengths of claviculae were measured, and the proximal muscle attachment sites, and deltoid tuberosities of the humeri were observed.

The most important observation for this study was the pattern of the axillary border of the scapula. The three patterns, ventral, bisulcate, and dorsal, were observed based on the axillary border's sulcus and crest pattern (see figure 2, page 7). In some cases, the pattern was not clear but changed along the way from under the glenoid fossa towards the distal axillary border. In these instances, the border was assigned a pattern it resembled the most. Therefore, the observation is, to some extent, open to observer errors.

The pattern known as the ventral pattern exhibits a ventrally located sulcus and a dorsally located crest on the axillary border (see figure 2, page 7) (Trinkaus 2006, 346). The crest descends from the infraglenoid tubercle dorsolaterally and forms a sulcus on the ventral side, framed by a ventral lip (Dittner-Plasil 1981, 8).

Trinkaus (2006, 346) states that it varies how deep and pronounced the sulcus is, and the dorsal surface of the border is usually flat.

The bisulcate pattern, also known as the Chancelade pattern, consist of a crest on the midline of the axillary border and sulci on both sides of the crest (Trinkaus 2006, 346). The crest starting from the infraglenoid tubercle extends distally in the middle of the border, not connecting to either ventral or dorsal lip (Dittner-Plasil 1981, 12). According to Dittner-Plasil (1981, 12), two narrow longitudinal grooves are formed by the crest, of which the one on the ventral side is usually more pronounced.

The dorsal and currently the rarest pattern exhibits a dorsal sulcus and a ventral crest (Trinkaus 2006, 346). Dittner-Plasil (1981, 8) elaborates that the crest, again starting from the infraglenoid tubercle, now joins the ventral lip, and therefore, a dorsal sulcus is formed. She continues that this pattern is considered the typical Neanderthal type pattern, which can be seen as an opposite to the "modern" ventral type.

In addition to axillary border pattern observations, the scapular measurements mostly consist of straightforward ratio measurements with clear landmarks, and the chance of intra- and interobserver errors is minimal. Due to preservational properties of scapula, the bone was sometimes in two or three fragments. When necessary and only when noted as highly accurate, some length and breadth measurements were taken from combined fragments.

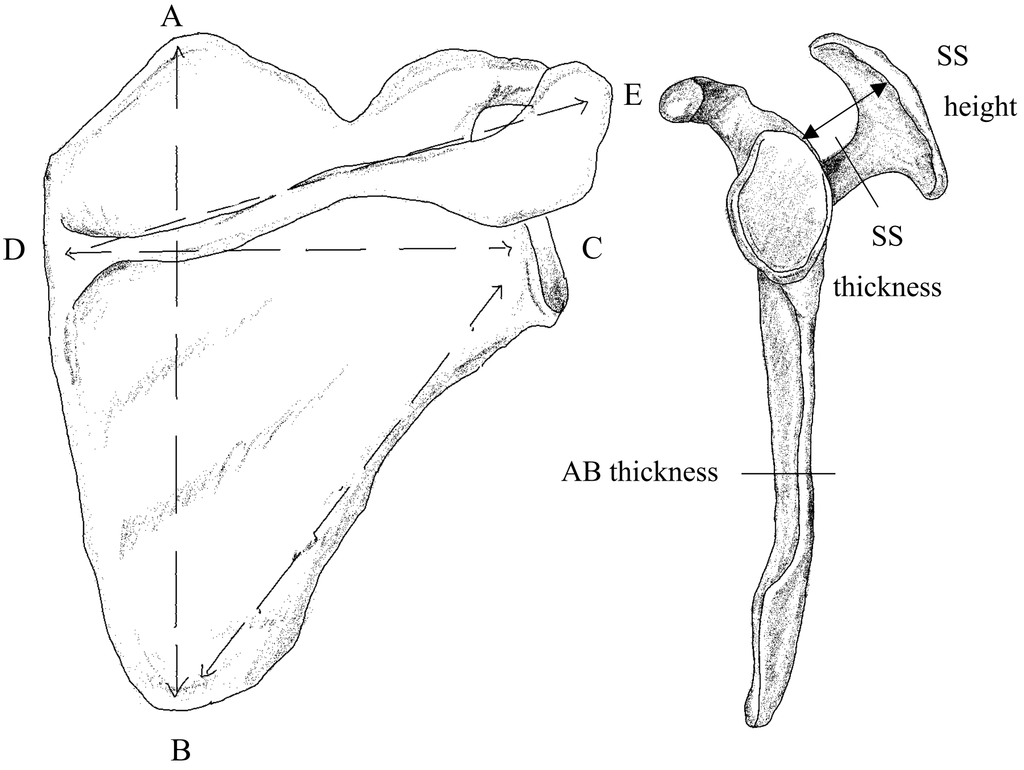


Figure 11. Measurements taken from the scapulae. Dorsal measurements based on Bass (2005, 117–18). Drawing by author. Lateral measurements modified from Odwak (2006, 359). AB = axillary border, SS = scapular spine. Drawing by author, based on Gray 1918, 207.

The length and breadth of the scapula, length of the axillary border, and the length of the scapular spine were measured from the dorsal side in accordance with Bass (2005, 117–18). The maximum length was measured from the superior to the inferior border (see A-B, figure 11) (Bass 2005, 117–18). The maximum breadth was taken from the margin of the glenoid fossa to the vertebral border where the spinal axis ends (see C-D, figure 11), and the length of the scapular spine from the most distal point of the acromion to the same vertebral point as before (see D-E, figure 11) (Bass 2005, 117–18). Axillary border length was measured from the same point of glenoid fossa margin as before to the inferior border (see D-B, figure 11) (Bass 2005, 117–18). All of these measurements were taken to an accuracy of one-tenth of a millimetre using a sliding calliper.

Scapular spine thickness was measured following Odwak (2006, 359), and the spine height and axillary border thickness measurements were modified from his work. Since the location of the thickest part of the axillary border was noted as variable, the measurement was adapted to be taken from the halfway of the axillary border. Scapular spine height was measured from the margin of the glenoid fossa to the closest margin of the coracoacromial ligament attachment on the acromion. Thus, a distance between the glenoid fossa and acromion was determined.

Standardization of size is needed when studying the relationship between axillary border pattern and robusticity. Larger body size generally means larger and more robust bones, and therefore, the sizes need to be standardized to be comparable. Since scapula is not weight-bearing, body mass estimation using bi-iliac breadth is not strictly needed for standardization (Ruff et al. 1993, 25). Thus, femora were used. However, it needs to be noted, that the climatic conditions between The Netherlands and Sudan differ, and Nubian individuals might have posed narrower bodies (Ruff 1991, 86). Nevertheless, following Ruff and colleagues (1993, 28), femoral length proportions to body width are considered equal between sample populations. Standardization was conducted by dividing the measurement by femoral length and multiplying the answer by 100 (Odwak 2006, 361).

3.4 Statistical Analyses

The data includes 13 variables (table 3). Four of these variables are nominal, one is ordinal, and the rest are ratio. The sex variable only includes three levels since probable females are combined with females, and the same goes for males. The individuals whose sex was assessed as indeterminate were left out from between sex comparisons. The same applied for between age category comparisons for those individuals whose age was interpreted as between categories.

Table 3. Data structure. For measurements, see figure 11.

Variable	Description	Level of Measurement
site	Middenbeemster, Arnhem, and Abu Fatima.	nominal
side	right = r, left = l	nominal
sex	Female and probable female = f, male and probable male = m, indeterminate = I.	nominal
age	The age at death of the individual using age groups. The ranges slightly differ between the collections, as explained before.	ordinal
stature	The estimated stature.	ratio
pattern	The pattern of the axillary border, dorsal = d, bisulcate = b, ventral = v.	nominal

Table 3. (continued).

ab_thickness	Axillary border thickness.	ratio
ab_length	Axillary border length.	ratio
scap_length	Total length.	ratio
scap_breadth	Total breadth.	ratio
ss_thickness	Scapular spine thickness.	ratio
ss_heigth	Scapular spine height.	ratio
ss_length	Scapular spine length.	ratio

R programming language was used for the analyses. The Chi-square test was conducted for nominal and ordinal variables to distinguish statistical pattern prevalence differences between the sites, sides, sexes, and ages. The ratio measurements were plotted for visualization of the data distribution, and descriptive statistics were calculated. Correlation analysis was conducted by using the correlation coefficient for ratio measurements to detect their statistical relationships. Additionally, analysis of variance was used between nominal and ratio measurements. These analyses offered an extensive assessment of the variables and their relationships on individual and population level, and between populations.

This chapter provided the background information behind the archaeological sites where the osteological collections came from. The means of sampling and measuring were also specified, and analyses explained. In the following chapter, the results of the analyses will be presented.

4. Results

This chapter presents the results of pattern prevalence between the sites, sexes, sides, and ages. The associations between the scapular measurements (see table 3) are also presented and their connection with the pattern. Lastly, the bilateral asymmetries are considered.

Descriptive statistics of all variables were first calculated, both from the whole dataset and separately from the site subsamples (table 4 and appendix 1, respectively). As seen from table 4, the variables are all normally distributed (skew = <0,5, >-0,5). From subsamples divided by sites, the only ones moderately skewed are scap_length in Arnhem subsample (0,52) and ss_length in Abu Fatima subsample (0,74) (see appendix 1), and the rest are normally distributed. No outliers were removed from the data.

Table 4. Descriptive statistics of the variables.

Variable	Mean	Median	SD	Min	Max	Var	Skew
stature	167	168	7,53	151	184	56,71	0,01
ab_thick	10,02	10,0	1,70	5,2	16,3	2,88	0,27
ab_length	146,51	145,3	10,62	124,3	171,6	112,70	0,08
scap_length	154,16	153,5	12,58	119,7	183,4	158,19	-0,04
scap_breadth	99,99	99,6	7,07	83,3	116,8	49,99	0,08
ss_thickness	8,44	8,3	1,44	5,5	13,0	2,07	0,33
ss_heigth	21,96	21,9	2,79	16,1	29,9	7,76	0,32
ss_length	132,49	132,2	9,97	107,7	153,5	99,49	0,14

No clear dorsal patterns were observed from the sample. Thus dorsal patterns are not considered in the results chapter. In addition to ventral and bisulcate patterns, 17 axillary border patterns were classified as indeterminate. In the indeterminate pattern, the pattern changed from one to another or was generally vague. Mostly, the indeterminate started from the glenoid tubercle as ventral and shifted into a bisulcate, or the other way round. Three of the ones classified as indeterminate partly obtained a dorsal pattern (figure 12). Nevertheless, the dorsal parts were too short for labelling the pattern as dorsal.

Figure 12. The axillary dorsal pattern changing from bisulcate to dorsal.

The scapular index (Bass 2005, 117) was calculated from all of the scapulae where it was possible using the index: maximum breadth * 100 / maximum length. The relationships between the index and site and the index and axillary border pattern were tested using the Analysis of Variance (ANOVA). Data was first calculated for skewness and observed as normally distributed (<0,5, >-0,5). Then, Levene's test showed no significant difference between the group variances in the site or pattern groups (p = 0,87 and p = 0,86, respectively). As a result, ANOVA showed no statistically significant relationship between the site and scapular index, $F(2, 84)$ = 2,68, p = 0,07, or the pattern and scapular index, $F(1, 84)$ = 1,94, p = 0,17.

4.1 The Axillary Border Pattern Prevalence

As shown in table 5, the prevalence of the ventral pattern is 71% throughout the whole sample, and therefore, it is the most common pattern. It is notably more frequent in Middenbeemster (76%) and Arnhem (67%) than Abu Fatima (41%), where the bisulcate pattern covers almost half of the patterns (45%). The bisulcate pattern covers 28% of the scapulae in Arnhem, and 19% in Middenbeemster. However, it needs to be noted from the results that the sample size of Abu Fatima ($n = 22$) was significantly smaller than the Dutch samples ($n = 98$, $n = 197$).

Table 5. The observed frequencies of patterns between the sites and sexes. I is for indeterminate.

	Middenbeemster			**Arnhem**			**Abu Fatima**		
Pattern	Female	Male	I	Female	Male	I	Female	Male	% of all
Ventral	73	74	3	30	29	7	2	7	71 %
Bisulcate	9	28	1	13	14	-	6	4	24 %
Dorsal	-	-	-	-	-	-	-	-	0 %
I	4	5	-	1	4	-	2	1	5 %
$n=$	197			98			22		

The Chi-square test was used to analyze the statistical significance of the pattern prevalence between the sites. An association was found since the p-value was 0,004. However, there is no statistical significance in the association between the Dutch sites ($p = 0,10$). Comparing Abu Fatima to the Dutch sites, a significant p-value of 0,004 was received. Therefore, the Abu Fatima collection shows a difference in the pattern prevalence compared to the Dutch sites.

The association between pattern prevalence and sex was also calculated using the Chi-square test (table 6). The p-value of association between the sex and pattern is 0,1, which indicates no significant association. However, when only the Dutch samples are considered, there appears to be a clear difference between Middenbeemster and Arnhem. The association of pattern and sex is statistically significant in the Middenbeemster sample, $\chi2(1, N = 184) = 7,86$, $p = 0,006$, but not in Arnhem, $\chi2(1, N = 86) = 0,05$, $p = 0,82$. In Middenbeemster, only 24% of the bisulcate patterns were observed from females, while in Arnhem, the percentage is 48% (see table 5). The sample size of Abu Fatima alone is too small for a Chi-square test. As figure 13 indicates, contrary to the Dutch collections where males exhibit more bisulcate pattern, more than half (60%) of the bisulcate patterns from Abu Fatima were observed from females. Out of women's scapulae, 60% exhibited the bisulcate pattern, while the percentage for men was only 33.

Table 6. *A contingency table of the observed frequencies of patterns between sexes.*

	Bisulcate	Ventral
Females	28	105
Males	46	110

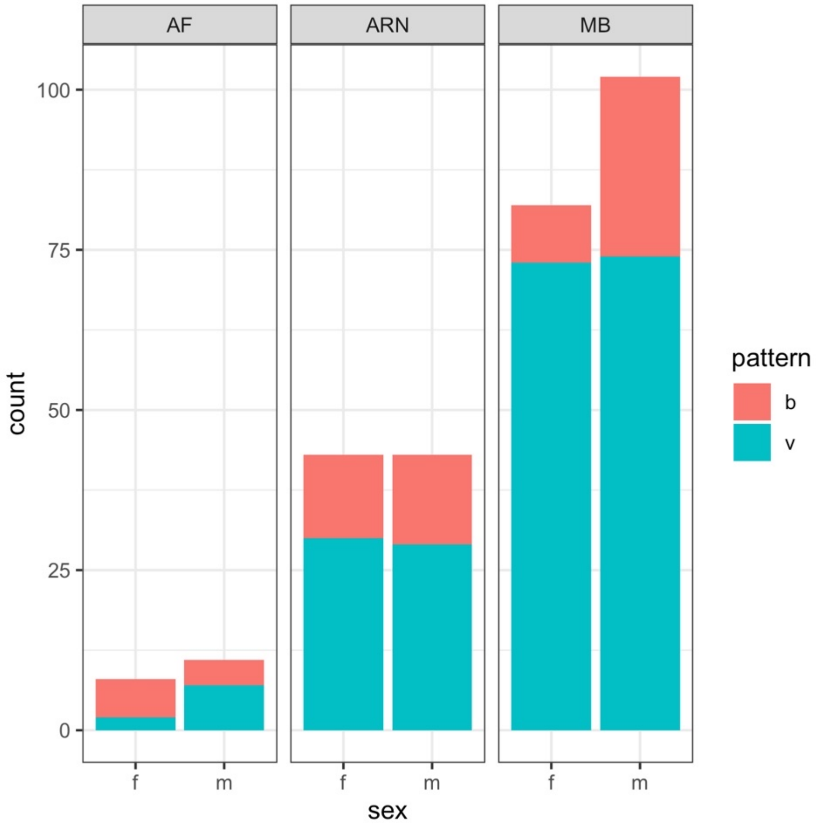


Figure 13. The amount of ventral and bisulcate patterns divided by sexes across the sites.

Since individual variation between sides was observed, the association between pattern and side was tested using the Chi-square test. That said, no association was observed between them, χ2(1, *N* = 300) = 0,44, *p* = 0,50. No association was either observed between the ages and patterns χ2(3, *N* = 256) = 3,21, *p* = 0,36. The bisulcate pattern prevalence does not seem to significantly increase with age, since 30% prevalence of bisulcate pattern was observed from early young adults, 22% from late young adults, 27% from middle adults, and 42% from old adults. The individuals from Abu Fatima were left out from age comparisons, since the age groups differed from the Dutch collections. However, the Dutch collections offered a large enough sample size for reliable comparisons.

The statistical significance between stature and pattern was tested using ANOVA. First, the statures of ventral and bisulcate groups were tested for skewness and observed as approximately symmetric (<0,5, >-0,5), and Levene's test indicated that variances are unequal (*p* = 0,47). Therefore, Welch ANOVA was used. As a result, the patterns and stature did not show significant correlation, *F*(1, 128,6) = 0,203, *p* = 0,65. To conclude, the stature variation is greater within the pattern groups than the stature means are between the patterns.

Additionally, a binomial logistic regression model was conducted from the Middenbeemster sample to predict the pattern prevalence based on the axillary border thickness (see table 7). The variable "pattern" was used as a dependent variable, and the scaled axillary border thickness as an independent variable. Axillary border thickness was selected due to its significant correlation with the pattern variable, as explained in the next section.

Table 7. Presenting a ventral or a bisulcate axillary border pattern in Middenbeemster: Logistic regression results.

Independent variable	**Logistic regression coefficient**	**SE**	***p*-value**	**Mean**
Scaled axillary border thickness	-1.1809 [0,31]	0,48	0,01	2,30 (0,36)

Note: n =206. Ventral pattern = 1, bisulcate = 0. Odds-ratio in brackets and standard deviation in parenthesis.

The model predicted 0,31 times the odds for having a bisulcate pattern for every unit increase in the axillary border thickness. However, the AUC of the model is only 61,9% (figure 14), indicating a low prediction. The model was then tested using the Arnhem sample to see whether the model could predict the pattern prevalence in the Arnhem sample, and an AUC of 58,8% (fail) was received.

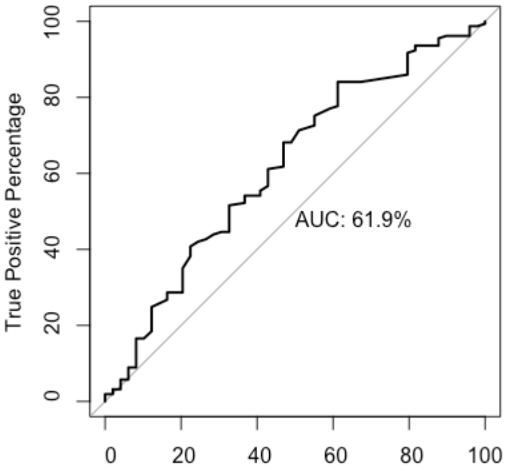


Figure 14. The ROC curve of the predictive model.

4.2 The Axillary Border Thickness Associations

To receive more accurate results, the scapular measurements were scaled against the length of the femur (measurement/femoral length * 100). These scaled measurements were better comparable against the nominal observations because the individuals' size did not matter. The scaled measurements were used in addition to the actual measurements in every test. However, if the result was not statistically significant, only the actual measurements' result is noted.

The association between the axillary border thickness and pattern was tested using ANOVA. The ventral and bisulcate thickness measurements were first tested for skewness and noted as approximately symmetric (<0.5, >-0,5). Levene's test showed no significant difference between the group variances in the pattern groups (p = 0,08). The ANOVA results showed a significant correlation between the pattern and axillary border thickness, $F(1, 296) = 11{,}65$, $p = <0{,}001$. Thus, the border thickness is affected by the pattern or vice versa. The same test was conducted for the scaled values of axillary border thickness, and a significant correlation was found, $F(1, 254) = 7{,}81$, $p = 0{,}006$. Figure 15 shows that the mean axillary border thickness is higher in the bisulcate pattern than in the ventral pattern.

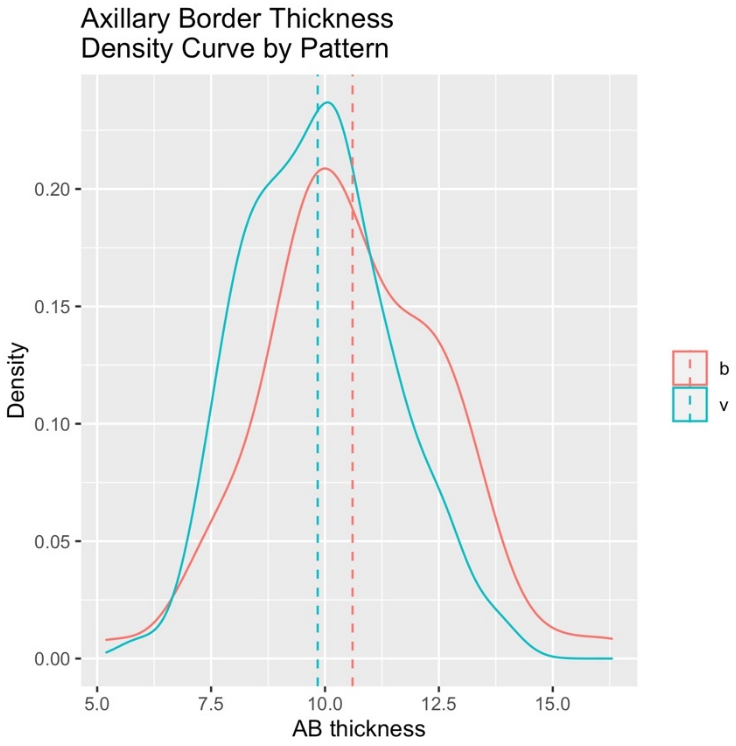


Figure 15. Density curves of the axillary border thickness divided by pattern. B = bisulcate, v = ventral. Means indicated with dashed lines.

ANOVA was also used to test the association between the axillary border thickness and site. The datasets were observed as normally distributed (skewness = <0,5, >-0,5), and Levene’s test showed equal variances in the groups (*p* = 0,63). The result confirmed no statistical significance in the relationship between the site and border thickness, *F*(2, 312) = 2,443, *p* = 0,09. No association was either found when the Dutch sites were compared against Abu Fatima, *F*(1, 313) = 1,446, *p* = 0,23, or when Middenbeemster was compared against Arnhem, *F*(1, 291) = 3,483, *p* = 0,063. Neither was association found between the normally distributed axillary border thickness measurements and the sides right or left, (Levene’s *p* = 0,62) *F*(1, 313) = 0,201, *p* = 0,65.

The correlation between sexes and the axillary border thickness was tested using ANOVA. Both actual and scaled measurements were observed as normally distributed (skewness = <0,5, >-0,5). Levene’s test indicated unequal variances in the sex groups for actual measurements (*p* = 0,005) and equal for scaled measurements (*p* = 0,21); thus, the Welch ANOVA was used for the actual measurements. The Welch ANOVA test using the actual measurements indicated a statistically significant correlation, *F*(1, 295,4) = 147,3, *p* = <0,001. The same statistically significant result was received from the ANOVA for the scaled measurements, *F*(1, 260) = 48,1, *p* = <0,001. As seen in figure 16, the mean scaled axillary border thickness is higher in male scapulae. Table 8 reveals that the thickness is slightly higher in female than male scapulae from Abu Fatima, while the situation is reversed in the Dutch samples.

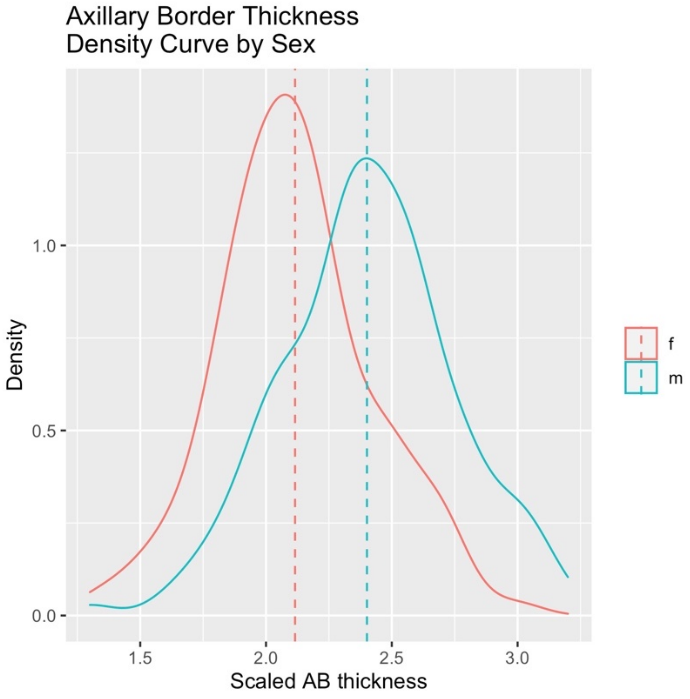


Figure 16. Density curves of the axillary border thickness divided by sex. F = female, m = male. Means indicated with dashed lines.

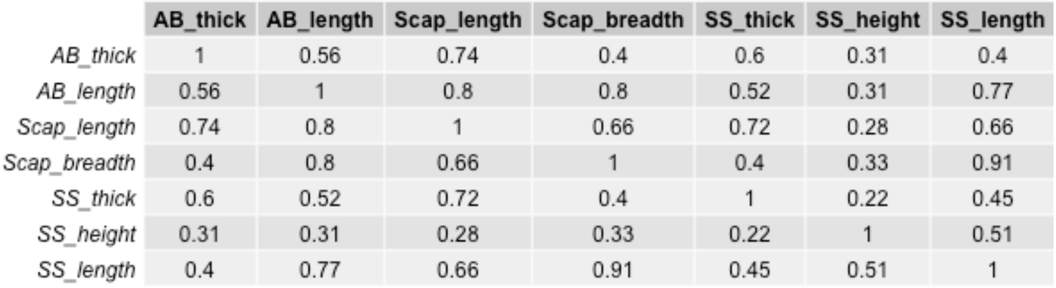
Table 8. Mean scaled axillary border thickness divided by sex across the sites.

	Middenbeemster		**Arnhem**		**Abu Fatima**	
	Female	Male	Female	Male	Female	Male
Mean scaled ab_thick	2,10	2,40	2,12	2,38	2,28	2,24

4.3 Other Scapular Measurements

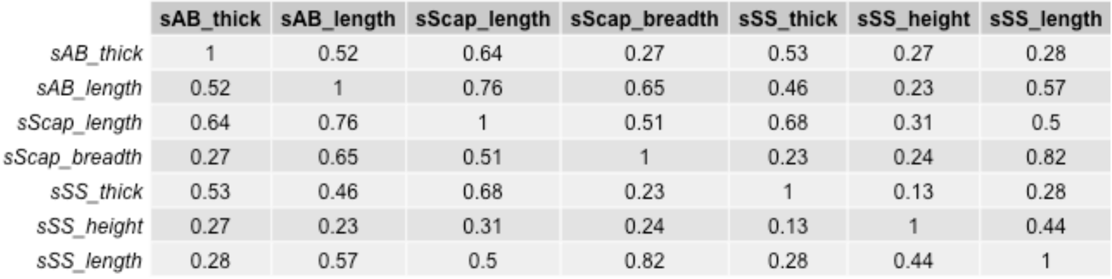
Considering the relationships between the scapular measurements, minimizing the effect of body size was important. Therefore, the scaled measurements were mostly used and the results are a more reliable indicator of correlation between the variables. The relationships were tested using the correlation coefficient (*r*) (see tables 9 and 10). The primary measurement examining the axillary border pattern is the axillary border thickness. Therefore, it was the main one tested against other measurements.

Table 9. The correlation coefficient table of scapular measurements.



	AB_thick	AB_length	Scap_length	Scap_breadth	SS_thick	SS_height	SS_length
AB_thick	1	0.56	0.74	0.4	0.6	0.31	0.4
AB_length	0.56	1	0.8	0.8	0.52	0.31	0.77
Scap_length	0.74	0.8	1	0.66	0.72	0.28	0.66
Scap_breadth	0.4	0.8	0.66	1	0.4	0.33	0.91
SS_thick	0.6	0.52	0.72	0.4	1	0.22	0.45
SS_height	0.31	0.31	0.28	0.33	0.22	1	0.51
SS_length	0.4	0.77	0.66	0.91	0.45	0.51	1

Table 10. The correlation coefficient table of scaled scapular measurements.



	sAB_thick	sAB_length	sScap_length	sScap_breadth	sSS_thick	sSS_height	sSS_length
sAB_thick	1	0.52	0.64	0.27	0.53	0.27	0.28
sAB_length	0.52	1	0.76	0.65	0.46	0.23	0.57
sScap_length	0.64	0.76	1	0.51	0.68	0.31	0.5
sScap_breadth	0.27	0.65	0.51	1	0.23	0.24	0.82
sSS_thick	0.53	0.46	0.68	0.23	1	0.13	0.28
sSS_height	0.27	0.23	0.31	0.24	0.13	1	0.44
sSS_length	0.28	0.57	0.5	0.82	0.28	0.44	1

Some of the measurements, like scapular breadth and scapular spine breadth, should logically have a clear association. Thus, they are not considered here in more detail. The same goes with the axillary border length and scapular length since clearly, the length of the bone has a significant effect on the border length.

As seen in table 10, the scaled measurements of the axillary border thickness are correlating with the scaled measurements of axillary border length ($r = 0,52$), scapular length ($r = 0,64$), and scapular spine thickness ($r = 0,53$). The same can be observed from scatterplots in figures 17-19. The measurement which correlates the strongest with axillary border thickness is the scapular length (figure 18), where 40% of the variation in axillary border thickness can be explained by the variation in scapular length ($r^2 = 0,40$).

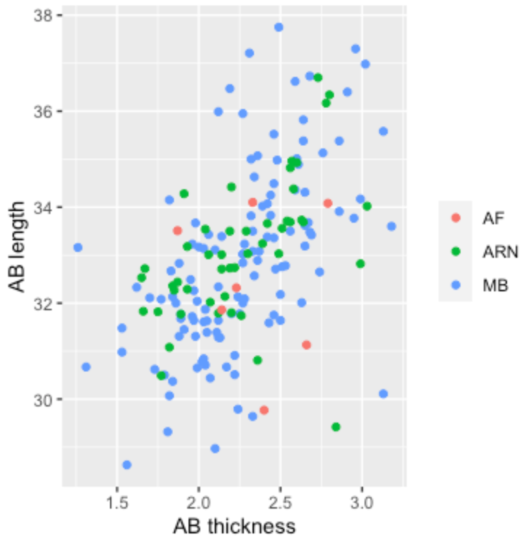


Figure 17. The correlation of scaled axillary border thickness and scaled axillary border length.

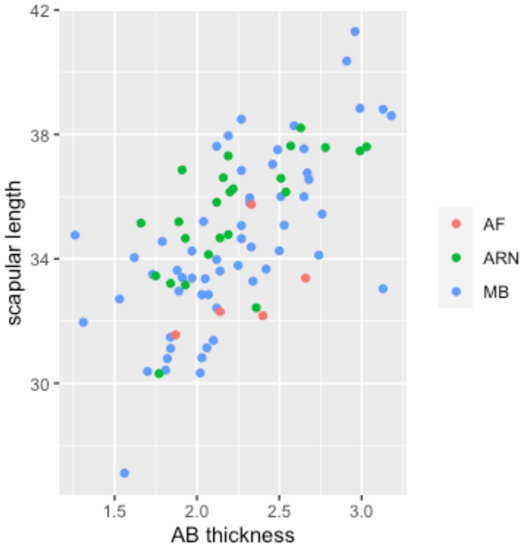


Figure 18. The correlation of scaled axillary border thickness and scaled scapular length.

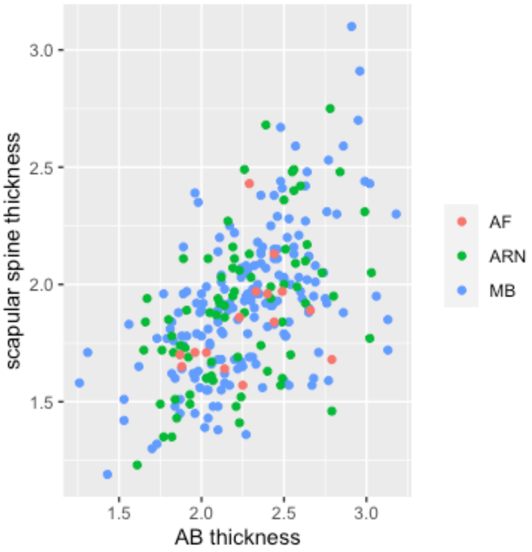


Figure 19. The correlation of scaled axillary border thickness and scaled scapular spine thickness.

Interestingly, the not correlating measurements are the thickness measurements (scaled AB-thick and scaled SS_thick) with the breadth of the scapula (table 10). However, as previously mentioned, the thickness measurements are somewhat correlating with each other (r = 0,53), but both are correlating even more with the length of scapula (sAB_thick r = 0,64 and sSS_thick r = 0,68).

4.4 Bilateral Variation

Out of the whole sample of 167 individuals, 34 exhibited a bilateral difference in the axillary border pattern. Their humeri and claviculae were studied further to get an insight into the bilateral nature of the variation. The observations are compared, thinking that there exists a “stronger” pattern (Busby 2006, 370; Odwak 2006, 361). Thus, bisulcate is thought to be stronger than ventral. Fourteen individuals out of the 34 were left out, because they exhibited a pattern that could not be labelled as either bisulcate and ventral.

The “stronger” bisulcate pattern was observed to exists 70% on the right side and 30% on the left side (*n* = 20). Eleven individuals had clavicles that could both be measured, and two out of these gave an identical result. Therefore, 9 of the individuals with bilateral differences had either clavicle longer. On the “stronger” pattern, the clavicle was longer on 22% (2/9) and shorter on 78% (7/9). From 15 individuals, it was possible to observe which side had more pronounced deltoid tuberosity. The deltoid tuberosity was more pronounced on the same side as the bisulcate pattern on 60% of the individuals.

The proximal humerus attachment sites of arm rotator muscles teres minor, teres major, and pectoralis major were also observed by noting their more pronounced side. The teres minor muscle was pronounced on the same side as the bisulcate pattern on 55% (6/11) of the individuals. Teres major was more pronounced on the same side as bisulcate pattern on 67% of the individuals, and pectoralis major on 62%. However, the sample size of these results is small to make any certain conclusions.

This chapter has provided the results of observed pattern prevalence throughout the data and subsamples. The results of analyses and bilateral asymmetry were also presented. In the following chapter, the results will be explained, and they will be given a broader context.

5. Discussion

The main purpose of this study was to investigate the primary driving force behind the axillary border variation. The goal was to determine if the pattern difference is caused by muscular hypertrophy through physical activity or mainly controlled by genes. The main research question for investigating the causes behind the variation was:

- Does muscular hypertrophy mostly cause the axillary border variation, or is it controlled by genes?

The following research questions were used to examine the topic in more detail:

- Do the Dutch urban and rural population samples show significant differences in the predominant pattern or other measurements?
- Are there statistically significant differences between the genetically different Nubian and Dutch collections?
- Are there differences in the prevalent pattern between the right and left sides, between females and males, or different ages?

Data from three different collections were used, two from The Netherlands and one from Sudan. As indicated in the previous chapter, the results showed some statistically significant associations, which will be further interpreted and given a broader context in this chapter. The discussion approaches the main research question by first addressing the more detailed questions. The pattern prevalence between sides, sexes, and ages is discussed. The differences between the Dutch sites and between Abu Fatima and the Dutch sites are then examined in more detail. Lastly, at the end of this chapter, this study attempts to answer the main research question of whether genes or behavioural reasons are behind the variation.

5.1 Are there differences in the prevalent pattern between the right and left sides, between females and males, or different ages?

5.1.1 Side

The results showed no statistical significance in the pattern prevalence between the right and left sides. Despite this, the individuals who exhibited bilateral asymmetry had 70% of the “stronger” bisulcate pattern on their right side. This finding is well in line with Trinkaus (1977, 233), noting the association with right-handedness. However, his results also indicated stronger teres minor on the right side. This connection is one aspect of how he supports the association of axillary border variation and teres minor. As will be explained more later in this section, contrary to the hypothesis presented by Trinkaus (1977), this study found no significant connection with the teres minor muscle and bilateral variation.

The clavicle length results from this study also support the hypothesis of a more robust pattern on the dominant side. Mays and colleagues (1999, 27) studied clavicle lengths and noted an association between the length of the bone and the dominant side. Their results indicated that the clavicle is shorter but more robust on the dominant side. The connection between handedness and clavicle length was also supported by Danforth and Thompson (2008, 778–79), who found that 90% of the left-handers had longer claviculae on their right side. The clavicle measurements from this study support the view that the bisulcate pattern and dominant hand would have an association. Out of the individuals with bilateral asymmetry, 78% had a shorter clavicle on the same side as the bisulcate pattern.

Some of the individuals who exhibited bilateral asymmetry in their right and left sides had humeri preserved well enough for muscular asymmetry observations. The results showed that out of the individuals who only had one scapula with a bisulcate pattern, 55% had more pronounced teres minor on the same side as the bisulcate pattern, whereas the same amount for teres major is 67%, pectoralis major 62% and deltoid 60%. Out of these muscles, teres minor has been initially the muscle which hypertrophy was thought to cause the dorsal pattern (Trinkaus 1977, 233). However, based on the results of muscle asymmetry presented here, it seems more probable that the overall robusticity of the upper extremities and arm rotator muscles would cause the axillary border variation and not only muscular hypertrophy of teres minor. These results, however, can only draw conclusions of the bisulcate and ventral patterns and not about the origins of the dorsal pattern since no dorsal patterns were observed from the sample.

As expressed in this section, even though the side and pattern did not show a statistically significant correlation, we may still draw conclusions from bilateral asymmetry. When only the individuals with bilateral asymmetry in their axillary border variation are examined, it is shown that (1) bisulcate pattern is more prevalent on the right side, (2) bisulcate pattern has an association with a shorter clavicle, which is linked to hand-dominance, and (3) multiple muscles show more pronounced muscle attachments on the same side as the bisulcate pattern. Still, the teres minor muscle thought to be connected to the variation did not show a significant association to the bisulcate pattern in this study. Therefore, it seems likely that the bisulcate pattern is connected to an overall increase in muscle use and not just teres minor muscle hypertrophy.

5.1.2 Age

A significant increase in bisulcate pattern prevalence with age was noted by Dittner-Plasil (1981, 71–72). She states that it supports the view that pattern types reflect physical activity and muscle use since it takes some time for physical stress to manifest in bones. However, no statistically significant correlation was observed in this study. The highest bisulcate prevalence was observed from old adults (48%), which fits the picture, but the next highest was from early young adults (30%). Then again, early young adults were underrepresented in the data, which might distort the results (*n* = 30, while other groups had 60 or over).

Age affects bone properties. Pearson and Lieberman (2004, 88–89) have studied bone modelling and remodelling and found out that the bones of old adults express very little response to changes in mechanical loading. They add that the morphological features seen in cortical bone might mainly come from physical strain experienced during the growth spurt in adolescence. Could the base of axillary border variation already stem from adolescence?

The Krapina and Kiik-Koba subadults have been subjected to the only Neanderthal ontogeny studies of the axillary border (Busby 2006, 366; Trinkaus 2008). In addition to this, Busby (2006) also studied recent human samples to compare their ontogeny of the Neanderthals. She found out (2006, 369) that between 6 and 8 years of age, the axillary border crest and sulcus start to form, and they are consistent with adult morphology at the age of 14-17 years old. Her research also indicates that the bisulcate pattern would be the strongest of the patterns and typically develops through time (Busby 2006, 370). Trinkaus (2008), on the other hand, studied probably less than a year old Neanderthal infant from Kiik-Koba and concluded that, since the individual exhibited a developing phase of a dorsal pattern, the variation must mostly have a genetic base. These findings considered further research of the variation in subadults is needed.

In old adults, bones might not show as much response to changes in loading as the adolescents' bones, but remodelling still happens throughout life (White et al. 2011, 406). Entheses, meaning muscle attachments, have also been found to be accumulative in nature, and there is a clear connection between age and entheseal changes (Palmer et al. 2016, 85; Schrader 2018, 78). With increasing age, the changes seen in entheses might not necessarily come from physical activity, though, but it is more likely that damage to enthesis does not heal and will accumulate (Schrader 2018, 78). Therefore, the results from younger adults should be considered more reliable (Schrader 2018, 78).

While this study's results did not show an association between age and axillary border pattern, the possibility of correlation cannot be ruled out either. With more research of the pattern in adolescents and young adults, we will learn how their scapulae respond to stress. Future research on bone remodelling and entheseal changes in old adults will make the effect of physical strain on the pattern variation clearer.

5.1.3 Sex

Even though the results showed no statistical significance between site and pattern, or sex and pattern, a closer look at the pattern prevalence between sexes within the sample populations presented some notable differences. Looking at the bisulcate patterns, in Abu Fatima, 60% were observed from females while the same number in Arnhem is 48% and in Middenbeemster only 24%. The association between pattern and sex was noted as statistically significant (p = 0,006) in Middenbeemster, but not in Arnhem (p = 0,82). While the Abu Fatima collection is much smaller than the Dutch collections, and a Chi-square test from the data was not possible, 60% of women's scapulae exhibit a bisulcate pattern and only 33% of men's. This would also indicate a difference in the pattern prevalence between sexes, but contrary to the Dutch collection, women are the more prevalent sex exhibiting the bisulcate pattern.

The pattern prevalence differences are also seen in table 11, which shows that the percentage of bisulcate patterns is equal between the sexes in the Arnhem sample, whereas notable differences exist in Middenbeemster and Abu Fatima samples. Note also how the prevalence is higher in male scapulae from Middenbeemster but in female scapulae from Abu Fatima. Since the Dutch populations are expected to be genetically very close, the results indicate that the variation could be, at least to some extent, caused by behavioural differences. Female bisulcate pattern prevalence in Abu Fatima may also suggest behavioural difference but the relatively small sample size needs to be taking into account before making any conclusions.

Table 11. The prevalence of bisulcate pattern observed from female and male scapulae in the sample populations.

	Middenbeemster		**Arnhem**		**Abu Fatima**	
Pattern	Female	Male	Female	Male	Female	Male
Bisulcate	10%	26%	30%	30%	60%	33%

As the bisulcate patterns in males are almost equal throughout the data, females' differences suggest taking a closer look into women's daily activities. Could their activities shed light on the differences in the variation? What are the possible behavioural differences between the women from these sites? Looking into women's lives in Middenbeemster and Arnhem, their status already indicates that their daily activities differed. Since the women in the urban Arnhem collection were most likely lower in social status than the rural Middenbeemster, their labour was probably different to Middenbeemster, but to what extent?

Traditional sex division of labour is relatively well known from the Post-Medieval Netherlands, both from urban and rural settlements. Dairy products and household chores have traditionally been labelled as female responsibilities in rural settlements, and working in the textile industry, especially as spinners, as their profession in urban cities (Chilcote 2018, 230; Schmidt and van Nederveen Meerkerk 2012, 74). The settlement at Abu Fatima is yet to be excavated. Still, it is believed that as a non-urban community, the occupants would have engaged in agropastoralism, crafts, brewing, and baking (Edwards 2004, 83–84; Schrader et al. 2019, 374). These day-to-day activities will be examined in more detail in the following sections.

5.2 The Dutch sites

As the research questions indicated, to study the variation's behavioural basis, it is logical to examine the similarities and differences between the two concurrent Dutch populations. There is a spatial and temporal distinction between the Dutch and Nubian data, and the Dutch populations, in contrast, are somewhat contemporary. Thus, the differences in the pattern prevalence across the sites tell a lot about the origins of the variation. This section answers the following research question:

- Do the Dutch urban and rural population samples show significant differences in the predominant pattern or other measurements?

Based on the results, the bisulcate pattern was more prevalent in the Arnhem sample population (28%) than Middenbeemster (19%). While the difference in pattern prevalence between the Dutch sites was not statistically significant, the axillary border variation between women indicates a behavioural component behind the variation. In both Dutch sites, men were probably engaged in physically strenuous labour using similar tools like shovels and other handheld equipment. Therefore, their scapulae showed a similar distribution of ventral and bisulcate patterns. Women, however, were the ones exhibiting differences in their scapulae, possibly through physical activities.

The women from rural Middenbeemster were primarily engaged in dairy production activities and household chores, while the women of Arnhem were strongly participating in urban industrial work in breweries and textile industry, for example (Baetsen et al. 2018, 34; Buisman 2009, 135; Falger et al. 2012 as cited in Chilcote 2018, 40; Chilcote 2018, 230). Their occupational differences might well affect the variation observed from their scapulae. Therefore, their daily activities need a closer investigation.

5.2.1 Women in Arnhem

In the urban setting as Arnhem was, the clothing industry was one of the primary employers for women (Schmidt and van Nederveen Meerkerk 2012, 74). There was a guild for the textile industry in Arnhem (Van Hasselt 1804, 100), and therefore, many women in Arnhem probably worked in textile manufacturing. While weaving was done mainly by men, spinning is principally thought to be a female profession (van Nederveen Meerkerk 2014, 5). As noted by van Nederveen Meerkerk (2014, 9), spinning has been connected to lower social status and poverty, and they were working long days in the same physical positions (see figures 20 and 21). Before spinning, the fibres needed to be either carded, comber, or both, and this was also done by female workers (Hutton 2018, 391). Until the fourteenth century, spinning was done using a distaff and a spindle, and later, both spindle and a spinning wheel were used (Hutton 2018, 391). Spinning might not have been physically the most strenuous profession. However, combining the long hours of work and habitually working with hands, upper extremities were undeniably affected by the repetitive work.

Figure 20. A woman spinning with a spinning wheel in the 17th century. The Spinner, Nicholas Maes 1652-1662, Rijksmuseum, Amsterdam.

Figure 21. A woman using a hand spindle. Finnish Heritage Agency (Finna.fi/CC By 4.0).

It is known that brewing was an essential industry in Arnhem (Baetsen et al. 2018, 34). Unger (2001, 159–60) explains that women worked side-by-side with their husbands until the sixteenth century, while brewing was still a household operation. Whereas in the sixteenth century, breweries became bigger and work became more specialized. Brewing was still a significant employer of women and a possible way to earn and develop status (Unger 2001, 160). In the better status and physically lighter tasks, women kept records of the outgoing beer and overseeing the boiling process of wort (Unger 2001, 160). The physically more strenuous work was done by *wringsters,* who mixed the malt with hot water and moved the thick dough-like malt around in big mash tuns using paddles and long and large rakes (Unger 2001, 160). Shovels were also repeatedly used in breweries for stoking and moving grain (Unger 2001, 109).

In addition to textile and brewing industries, women in Arnhem might have also worked in garment or food production or helped their spouses in various enterprises and workshops (Schmidt and van Nederveen Meerkerk 2012, 75). Since the textile industry was the leading employer of urban women and brewing was known to be an essential industry in Arnhem, most of the lower working-class women from the Arnhem collection were probably engaged in these professions. In brewing, the heavy mixing of malt involved rotator cuff muscles for lateral and medial rotation of the humerus. In spinning, the movements were not as powerful. However, the static and repetitive nature of both keeping hands elevated and using tension and twisting with the fibres (figure 21) might have increased the strength of rotator cuff muscles.

5.2.2 Women in Middenbeemster

In Middenbeemster, dairy farming was the primary form of agriculture until the 1880s (de Jong 1998, 26). The work of married housewives mainly was confined to household chores like cleaning surfaces and dishes and making dairy products (Chilcote 2018, 230). In addition to married housewives, the women workforce at farms consisted of live-in servants and daily wage workers (van Nederveen Meerkerk and Paping 2014, 448). Servants were usually unmarried women, who lived on the farm, and the work of female wage workers was usually seasonal (van Nederveen Meerkerk and Paping 2014, 449).

Chilcote (2018) studied the Middenbeemster dairy farming community's social identities based on the same osteological collection used in this study. Her results (2018, 229) stated that women in Middenbeemster had been lowering and lifting their arms and extending their forearms. No single activity causing these changes was found, but they are probably caused by multiple dairy product manufacturing and cleaning activities (Chilcote 2018, 233). While Chilcote (2018, 228) connects the male flexed lower limb position and anterior-posteriorly enforced upper limbs with milking cows, Palmer and colleagues (2016, 85) indicate that women were most likely the ones milking cows. Their results from entheseal changes indicate that men were doing the heavy lifting. Women were engaged in tasks where lower arms were extended in pulling down (Palmer et al. 2016, 85), as is expected in milking, doing laundry, and especially in churning butter (see figure 22).

Figure 22. Butter churning. Kauko Tanskanen/ The Museum of Lieksa (Finna.fi/CC By 4.0).

Males' work at dairy farms consisted of multiple activities, which could cause increased strain to the rotator cuff muscles attaching to both sides of the axillary border. Since they were mostly taking care of the farm and the cattle, they had to clean the stalls, probably using scrapers or shovels, dig trenches and move hay using pitchforks and rakes (Chilcote 2018, 228–29). Most of these activities include lateral and medial rotation of the humerus caused by either contracting teres minor or subscapularis, respectively. However, the chores traditionally perceived as women's mainly include pulling down and lifting up with arms in the front. These activities are not primarily caused by activating the rotator cuff muscles attaching to the axillary border. Therefore, the statistically significant difference in the axillary border pattern between sexes in Middenbeemster is most likely caused by the sex-based division of labour. Men engaged more in activities involving the rotator cuff muscles.

As seen throughout this section, the sex-based differences in the Dutch sample populations' axillary border variation follow the assumed activity patterns of their day-to-day lives closely. In Middenbeemster, female activities mainly included movements that would have not primarily needed rotator cuff muscles, whereas in Arnhem, brewing, for example, is seen as highly strenuous for arms involving rotation of the humerus. This difference in the pattern prevalence between the women and the differences in their daily activities indicates a behavioural component behind the variation.

5.3 Abu Fatima compared to the Dutch sites

Data from the spatially and temporally distinct Nubian population presents an essential opportunity to evaluate the axillary border variation's genetic aspect. Their subsistence was most likely relying on agriculture and small livestock (Akmenkalns 2018, 185; Edwards 2004, 83), but probably also hunting and fishing to some extent (Akmenkalns 2018, 13–14; Van Neer 2004, 266). The following research question will be examined in more detail in this section:

- Are there statistically significant differences between the genetically different Nubian and Dutch collections?

The bisulcate pattern prevalence is highest in the sample population from Abu Fatima than the Dutch sample populations. However, the difference can almost only be seen between women. For men, the work in Arnhem and Middenbeemster was also strenuous manual labour using similar equipment, and therefore no apparent physical reason for a difference exists. The role of women in the Dutch populations was already considered in the previous section, and the daily activities in Nubia are considered next.

5.3.1 Daily Activities and Women's Role

In Abu Fatima, 60% of female scapulae exhibited the bisulcate pattern and only 33% of male (see table 11). This high percentage in females is especially interesting since the prevalence of bisulcate patterns is contradictory to Middenbeemster, where the percentage is higher in males. The overall bisulcate pattern prevalence was also higher in Abu Fatima than the Dutch sample populations, but the scaled axillary border thickness did not differ notably.

The Abu Fatima settlement has not been excavated yet, so it must be relied on the burial finds to reconstruct their daily activities. Unfortunately, the finds do not fully reflect the villagers' daily activities, but there are some known aspects of their lives. Faunal data from the burials indicate that the population using the cemetery was growing small livestock, like sheep and goats (Akmenkalns 2018, 183). The lithics found from the burials also indicate tool production and leatherwork (Akmenkalns 2018, 181). They were also almost certainly growing crops, most likely barley and wheat (Edwards 2007, 218). The location of Abu Fatima in the Kerma overflow basin offered arable land surrounded by a harsh environment (Adams 1977, 29–30). Local crafts and pottery were also made (Akmenkalns 2018, 177, 193).

In addition to the grave finds, inferences have also been made based on the traces on their bones. Schrader and Smith (2017, 36–39) have proposed that multiple signs of severe skeletal trauma suggest both women and men engaging in intra- and intergroup violence throughout their adulthood. The possible use of weapons, like clubs, maces, arrows, swords, and axes while fighting, as Schrader and Smith indicate, would have required force. If the use of these weapons was repetitive enough, it could have resulted in muscular hypertrophy of rotator cuff muscles and possible variation in the axillary border.

Excavation of the settlement is needed to get more confident information on their subsistence strategies. Nonetheless, it has been suggested that people were using riverine resources in addition to domesticated fauna (Van Neer 2004, 266). Fishing would have probably included both primitive fishing techniques in the floodplain and more technical fishing in the main river (Van Neer 2004, 261–62). Rowing or paddling small vessels along the river is a physical activity that would have significantly affected the rotator cuff muscles.

Very little definite can be said about the range of their physical day-to-day activities or division of labour. Most likely, the activities consisted of various farming, hunting and fishing activities, food preparation, and the making of tools and crafts. For now, too little is known to explain the higher prevalence of bisulcate patterns in women than men.

Based on the results from this study, women in Abu Fatima had a lot higher prevalence in bisulcate pattern than women in Arnhem, even though the women in Arnhem were probably engaged in strenuous labour affecting the rotator cuff muscles. Thus, it would be inaccurate to assume that the variation is based solely on physical activity. Future studies might reveal that women in Abu Fatima were more than men engaged in activities highly inducing upper body strength. However, it is currently more likely that there is also a genetic factor affecting the axillary border pattern in addition to the activity component.

More research is needed on the daily activities based on the settlement finds and bone material to determine which activities would have caused the axillary border variation. Also, a larger sample of scapulae would prove if the difference in prevalence between sexes is as significant as it seems. Based on the pattern prevalence difference between men and women in Abu Fatima and between Abu Fatima and the Dutch sites, it seems that there exists a genetic factor in the variation.

5.4 The Role of Axillary Border Thickness in the Variation

The axillary border thickness was noted highly correlating to the pattern type by Odwak (2006, 360), and similar results were also presented in this study. Because of this correlation and the evident connection of the measurement with the pattern because of the location of the measurement, the axillary border thickness variable was the essential measurement tested against the other scapular measurements. Equally to Odwak (2006, 361), the data here also indicates the bisulcate as thicker from the axillary border than the ventral pattern. Therefore, this study supports the hypothesis of the bisulcate pattern being stronger than the ventral. However, no consensus can be made about the dorsal pattern since no dorsal patterns existed in the data. Neither does the bisulcate pattern being stronger than the ventral directly indicate anything about the cause of the variation. A stronger pattern might be either genetically selected or acquired.

When tested against the other scapular measurements, the axillary border thickness correlates most with the axillary border length, scapular length, and scapular spine thickness. Generally, this means that the axillary border gets thicker when the length of the scapula and the scapular spine thickness measurements increase. Therefore, the scapula’s general robusticity and bigger size would be in association with the bisulcate pattern. With a thicker axillary border also comes more area for muscle attachment. The increased axillary border area might thus be a by-product of biomechanical forces acting on the bone, not just an outcome of muscular hypertrophy (Odwak 2006, 363).

The association between sex and pattern in the Dutch samples was found to result from behavioural differences in physical activity previously in this chapter. Still, there exists a significant correlation between the scaled axillary border thickness measurement and sex. This means that male scapulae have a higher mean axillary border thickness, even when the measurements are scaled for size. However, it should be noted that the scaled measurements are only scaled for the estimated stature of the individual and not for body mass, and stature says nothing about body composition. A detailed explanation of complex factors affecting muscle growth is out of the scope of this study, but in short, hormones affect muscle growth. In males, bones are generally larger, and testosterone and insulin-like growth factors increase muscle mass and strength (Lang 2011, 2). Therefore, the overall higher muscle strength and muscle size probably explain the thicker axillary borders in men compared to women.

The results also indicated that women in Abu Fatima have a higher prevalence in the bisulcate pattern, and their mean thickness of axillary borders was slightly higher than men. Still, a larger sample size is needed to show it certainly. At least for now, the difference is not significant enough to prove that there is a meaningful association. Thus, although the thickness showed a significant correlation with sex and border pattern and no correlation with the site variable, the connection between axillary border thickness and the bisulcate pattern remains unclear. The more robust pattern and thicker axillary border are most likely outcomes of overall increased muscle use and robusticity of the upper body. However, to determine if a thicker axillary border has allowed for a greater area for muscle attachment, resulting in a bisulcate pattern, or if a bisulcate pattern is thicker by nature, remains to be solved.

5.5 Lastly, Genes or Physical Activity?

After going through the additional research questions and interpreting most of the results, we are finally able to answer the main research question of this study:

- Does muscular hypertrophy mostly cause the axillary border variation, or is it controlled by genes?

Gkiatas and colleagues (2015) explained three types of bone growth factors in width: systemic, local, and mechanical regulation. Since systemic factors, as hormones, affect the whole body, local factors as genetic control must have a more significant influence on bone growth in width (Gkiatas et al. 2015, 64). Thus, genetic control and mechanical factors are the ones most affecting bone growth in width. Even though this mainly applies to long bones, the same approaches may be used for scapula in this study (Ruff 2019, 189).

The results of this study also indicate that multiple factors influence the scapular axillary border measurements and pattern. Trinkaus (2006, 348) has clearly stated that the interpretation of physical activity causing the variation is not valid anymore, but the base of the variation is principally epigenetic. However, the behavioural differences of the sample populations and their differences in the pattern prevalence strongly indicate that the bisulcate pattern can be considered the stronger pattern than the ventral and that physical activity must have some basis behind the variation. Still, the notable difference in Abu Fatima's pattern prevalence compared to the Dutch sites also indicates a genetic component affecting the pattern variation. The generally more robust scapulae of people in Abu Fatima possibly result from natural selection, but the differences between the Dutch populations are caused by remodelling.

Finally, distinguishing the effect of genetic control and activity-induced remodelling in axillary border pattern has proven difficult. The main aspects that favour remodelling are: (1) the differences in the bisulcate prevalence between women in the Dutch samples and (2) bilateral differences in the pattern prevalence and muscle robusticity. While the aspects favouring genetic causes are: (1) overall higher bisulcate prevalence in Abu Fatima, and especially (2) women's high bisulcate prevalence there. While it appears that axillary border variation is a complex feature with many affecting mechanisms, this study also provided more evidence supporting the claim that physical activity serves a more significant role than has been recently thought.

5.6 Limitations of the Study

There are always biases affecting the collections working with archaeological remains. The osteological collections are only samples of the once lived populations, and in some cases, only a part of the burial ground has been excavated. We do not know how representative the sample is of the population. Some individuals might have died away from home and buried elsewhere, burials might have been looted, or parts of the cemetery destroyed. Sometimes children have been buried elsewhere, but this is fortunately not a limitation for this study since only adult individuals were examined.

The collections are usually chosen based on their suitability for the topic but also for their accessibility. The three collections chosen for this study were all housed at the same university, and especially the Dutch collections offered an adequate amount of individuals to study. The Dutch collections should therefore also represent the populations quite well. There are archival sources of the people buried in Middenbeemster, but poor historical sources of the individuals from Arnhem (Baetsen et al. 2018, 37; Veselka et al. 2015, 668). The Abu Fatima collection was unfortunately somewhat limited for this study, and a larger volume of individuals and more knowledge of their daily activities are needed for more reliable conclusions.

Since the axillary border pattern of the scapula cannot be measured, but it is an observable quality, there are intra- and interobserver errors present. The clear ventral and bisulcate patterns were easily distinguished, but there were also borders with mixed patterns which had to be left out from the analyses. Some studies, as Dittner-Plasil (1981, 40–41), have divided the whole sample into clear pattern categories, while others, as Trinkaus (2006, 347), have noted the mixed nature of certain axillary borders. This aspect makes it difficult to compare other axillary border studies.

The preservational bias is another aspect affecting osteological collections. Since this study compares three types of patterns existing in scapulae, how can we be sure that the patterns have similar preservational qualities? Because the scapula is thin and fragile, it is not one of the best preserving bones. Unfortunately, we cannot know if having all scapulae preserved would have changed the outcome of this study.

5.7 Future Directions in Axillary Border Studies

In future studies of the topic, the role of bone modelling of the scapula during adolescence should be noted. As Pearson and Lieberman (2004, 89) stated, much of the cortical bone morphology results from the activities engaged during adolescence. This indicates that the subadults taking part in strenuous manual labour or other activities strongly affecting the rotator cuff muscles might be more prone to developing the "stronger" bisulcate pattern. Therefore, it would be essential to include growth spurt aged adolescents in axillary border pattern studies. More attention should also be given to the changes happening to scapulae with old age. Why do some studies give a higher prevalence of bisulcate pattern in old adults? Can the pattern change through accumulative physical strain?

A collection with known and specific occupation, like soldiers, would bring valuable additional knowledge to comparisons. The topic also needs more information on the dorsal pattern other than the scarce amount of Neanderthal scapulae. Further, radiographs and CT scans of different pattern types' trabecular compositions should reveal more of the bone strength and composition inside the axillary borders (Ruff 2019, 214).

In axillary border studies, the scapulae exhibiting a combination of two or three patterns have received very little attention. While they have been noted in other studies and either included or disregarded in the analyses, their meaning remains unclear. There are still multiple open questions and different views to be studied within this much-studied topic.

This chapter provided a discussion of the results within a broader context. Primarily the women's activities were explained in detail since the pattern prevalence differences were highest between females. The next chapter, which is also the last, will summarize the study and give final thoughts about the topic.

6. Conclusions

This study is one of the most extensive of axillary border sulcus variation using modern human skeletal material. The aim was to use large quantities of scapulae to receive reliable results of the cause behind the variation. Axillary borders have been studied by paleoanthropologists, osteologists, and archaeologists for over a century now. However, the function of the variation remains unclear, and whether it is mainly caused by genes or physical activity and increased muscle use. The three patterns recognized in axillary border variation are dorsal, bisulcate, and ventral. Ventral is the most common in modern humans and dorsal in the Neanderthals, whereas the bisulcate pattern has been determined as either the transitional phase (Trinkaus 1977) or the most robust pattern (Odwak 2006).

This study's data consisted of three modern human populations, two from The Netherlands and one from Sudan. The Dutch collections represented genetically close populations engaged in different lifestyles, whereas the collection from Sudan was spatially and temporally distinct from the Dutch collections. Altogether 317 scapulae were measured, and the results compared using statistical analyses.

The main question this study aimed to answer was about the cause behind the pattern, whether it is mostly from muscular hypertrophy or if it is controlled by genes. The pattern prevalence across the sites was one of the main aspects to consider. The highest prevalence was observed in scapulae from Abu Fatima with a 45% bisulcate prevalence, followed by Arnhem (28%), and the lowest prevalence was in Middenbeemster (19%). An even more notable difference was seen between women since 60% of the women's scapulae in Abu Fatima exhibited the bisulcate pattern, 30% in Arnhem and only 10% in Middenbeemster. No dorsal patterns were unfortunately observed from the sample for this study. Out of the two observed pattern types, bisulcate was observed as correlating to the increased muscle use, and it was noted as thicker than the ventral. Therefore, the bisulcate pattern was determined to be more robust and resistant than the ventral pattern.

The difference in the bisulcate pattern prevalence between women from the Dutch sites was one critical aspect favouring the physical activity and muscular hypertrophy being behind the variation. Even though the populations were genetically close, women exhibited a significant difference in the relative amount of bisulcate patterns between the sites. This difference was determined to be caused by their different daily activities since women in Arnhem were more engaged in activities affecting the rotator cuff muscles. In addition, the bilateral asymmetry in the muscle attachment sites of the individuals exhibiting different patterns in their scapulae also indicates a behavioural cause behind the variation. Contrary to what has been previously thought about the connection between the variation and teres minor, the results from this study showed more connection with other muscles than teres minor, indicating a connection between the bisulcate pattern and overall increased muscle use.

Even though especially the lower working-class individuals in Arnhem were engaged in strenuous labour, the bisulcate pattern prevalence was still notably higher in the genetically distinct Abu Fatima. Especially the women's high amount of bisulcate patterns compared to the Dutch collections is noteworthy. It is currently unknown if they could have engaged in more strenuous and repetitive activities than the Dutch collections. However, the difference is so notable that, most likely, the pattern is also affected by a genetic component. Unfortunately, however, the number of individuals in the Abu Fatima collection was lower than the Dutch collections'. Larger sample size and more information on their daily activities are needed for further conclusions of the difference.

This study offers comprehensive research of axillary border variation using a large sample from both genetically similar and distinct populations. The results provided even more reason behind the physical base of the variation than has been recently thought. Even though the discussion on Neanderthal scapulae currently mainly supports the genetic view (Trinkaus 2008, Villotte et al. 2020), this study shows that there is no reason to forget the physical component. A correlation was noted between the bisulcate pattern and activity in modern humans. Thus a behavioural component should also be considered one cause behind the variation in the Neanderthals.

The effects of age on the pattern still remains to be solved. While other studies have detected a correlation with the more robust bisulcate pattern and older age, no apparent correlation was found in this study. The other age group which remains a mystery for the axillary border studies are the adolescents. The effects of activities during adolescence in the axillary border have not been studied yet. Their bones are highly plastic to mechanical stress factors, especially during the growth spurt (Pearson and Lieberman 2004, 89) and, therefore, could provide insight into the forming of a more robust pattern. Thus, upcoming studies of axillary border variation should focus on, or at least include, adolescents.

More attention should also be given to the anomalies where the axillary border exhibits a combination of two or three patterns. Where do they fit in terms of robusticity and muscle use? Are they transitional phases towards a particular pattern, or do they, for example, reflect muscular imbalance? Radiographs and CT scans of the trabecular composition inside the scapulae of different patterns could provide additional information on the robusticity of the patterns.

The variation in our bones appears a complex topic with many affecting causes in the background. Today, with the advancing science, genetics studies are providing us with a more profound knowledge of where we came from and what makes us us. Still, the environmental factors are always there to leave marks on our bones and tell about the lives we have lived. Therefore, it is the combination of genetic makeup and mechanical stresses that displays as variation in the bones. Based on this study, it appears certain that also behavioural factors affect the axillary border variation and not just genes.

Abstract

There exists variation in the axillary border of the scapula. Even though the variation is most noticeable comparing the Neanderthals to modern humans, it is also observable from modern human skeletal material alone. This study aims to compare Homo sapiens sapiens scapulae from three populations to determine the cause behind the axillary border pattern variation. The variation consists of three scapular axillary border patterns, dorsal, bisulcate, and ventral.

To study the prevailing cause behind the pattern variation, two spatially and temporally close Post-Medieval (1500-1700 CE) Dutch collections were included and one temporally and spatially distinct Kerma culture (*ca.* 2,500-1,500 BCE) Nubian collection from current Sudan. The scapulae were measured using multiple measurements and observed for axillary border pattern, and the pattern prevalence throughout the data was studied. Statistical analyses were used to determine the correlations between the variables.

The results showed a significant difference in the bisulcate pattern prevalence between the women from different sites. The difference in the prevalence between the genetically similar Dutch collections point to a physical cause behind the variation. However, the notable difference in the Abu Fatima collection compared to the Dutch collections also suggests that genetic aspects play a role. Based on the scapular measurements and muscle attachment sites, the bisulcate pattern was more robust than the ventral pattern. The bilateral asymmetry in the axillary border pattern in relation to the surrounding musculature showed no significant correlation between teres minor and the bisulcate pattern. Rather, the more robust bisulcate pattern appears to be connected to overall stronger muscles or increased muscle use.

Axillary border variation proved a complex feature with multiple affecting factors, and the variation function still remains unclear. This study concludes that the variation is more affected by muscle use than has recently been suggested. These results do not challenge the interpretation that genes are a cause behind the axillary border variation. Rather, it indicates that the importance of physical activity behind the variation should not be overlooked.

Keywords: scapula, axillary border, Middenbeemster, Arnhem, Abu Fatima, Leiden University

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Appendices

Appendix 1. Descriptive Statistics of the Three Collections

Table A 1.1 Descriptive statistics of the Middenbeemster sample.

variable	mean	median	SD	min	max	var	skew
stature	168	168	7,65	151	184	58,45	-0,12
ab_thick	10,18	10,20	1,73	5,9	16,3	2,98	0,24
ab_length	146,85	147,20	10,82	124,3	171,6	117,08	0,02
scap_length	155,18	156,00	12,49	123,1	181,7	156,11	-0,13
scap_breadth	100,00	99,60	7,42	83,3	114,8	55,11	0,01
ss_thickness	8,54	8,50	1,43	5,8	13,0	2,05	0,37
ss_heigth	21,93	21,80	2,71	16,1	29,5	7,35	0,32
ss_length	132,68	133,25	10,69	107,7	153,5	114,38	0,05

Table A 1.2 Descriptive statistics of the Arnhem sample.

variable	mean	median	SD	min	max	var	skew
stature	167	166	6,68	155	181	44,66	0,27
ab_thick	9,79	9,80	1,57	7,1	13,9	2,46	0,46
ab_length	146,08	143,55	10,11	129,4	164,2	102,23	0,19
scap_length	154,04	151,50	11,85	135,2	183,4	140,41	0,52
scap_breadth	100,57	101,00	6,69	85,7	116,8	44,78	0,16
ss_thickness	8,36	8,20	1,43	5,5	12,5	2,04	0,34
ss_heigth	21,67	21,60	2,73	16,1	27,8	7,44	0,19
ss_length	132,56	131,20	9,12	114,0	151,4	83,13	0,23

Table A 1.3. Descriptive statistics of the Abu Fatima sample.

variable	mean	median	SD	min	max	var	skew
stature	164	160	9,19	153	182	84,45	0,49
ab_thick	9,60	9,5	1,86	5,2	13,0	3,45	-0,18
ab_length	144,18	142,2	11,50	129,8	159,5	132,33	0,24
scap_length	144,96	143,6	14,26	119,7	165,5	203,29	-0,33
scap_breadth	97,89	98,3	5,00	89,5	109,6	25,02	0,25
ss_thickness	7,91	8,1	1,44	5,7	10,6	2,08	0,07
ss_heigth	23,90	23,7	3,28	17,8	29,9	10,77	0,17
ss_length	130,51	129,7	7,05	121,7	146,4	49,71	0,74