1. STRESZCZENIE W JĘZYKU ANGIELSKIM

1.1. Introduction

Human anatomy, despite being the subject of intensive research for centuries, still harbors many undiscovered aspects. Traditionally perceived as fixed and unchanging, it actually exhibits significant variability, which can have profound implications for both clinical practice and scientific research. Anatomical variations - ranging from differences in vascular structures to morphological variants of the musculoskeletal system - affect the functioning of the human body and can influence the effectiveness of diagnostic and surgical procedures. A precise understanding of these variations is crucial for comprehending human biomechanics, personalizing medical therapies, and avoiding potential treatment errors. With advancements in imaging technologies and anatomical research, previously unnoticed or rare anatomical structures are now being increasingly identified.

It is, therefore, not surprising that the muscular system of the thoracic region also demonstrates considerable morphological variability [1,2]. The superficial layer of the chest muscles consists of the pectoralis major and pectoralis minor, both of which originate from a common embryonic muscle mass. Any disturbances in their differentiation during embryonic development may lead to the formation of additional muscular structures or atypical anatomical variants in this region [3,4].

These variations may have significant clinical relevance, particularly in diagnostic imaging, reconstructive surgery, and invasive procedures within the thoracic area. The pectoralis major muscle plays a key role in oncologic surgery, particularly in mastectomy, where damage to the pectoral nerves may result in functional impairment [5]. Differences in its structure, including variations in proximal and distal attachments, influence muscle function and reconstructive approaches, while its agenesis, as seen in Poland syndrome, often leads to thoracic asymmetry requiring surgical intervention [6.7].

The pectoralis minor, due to its location near the axillary vessels and the brachial plexus, can contribute to neurovascular compression, leading to the so-called pectoralis minor syndrome [8,9]. Its anatomical properties make it a valuable component in reconstructive procedures, including acromioclavicular joint reconstruction, repairing of chest wall and shoulder defects, and soft tissue reconstruction following trauma [1].

Knowledge of additional muscles within the chest and axillary region is crucial for surgeons performing axillary lymphadenectomy, as it helps avoid iatrogenic damage to neural and vascular structures [10]. Moreover, the presence of additional anatomical structures may lead to potential compression of nerves and blood vessels, increasing the risk of pain syndromes and circulation disorders.

1.2. Purposes

The aim of this doctoral dissertation was to investigate the morphological variations of the pectoralis major and pectoralis minor muscles in human fetuses, as well as to analyze the presence and course of accessory muscles within the thoracic region.

The objective of the study *Morphological variability of the pectoralis major muscle in human fetuses* was to examine the morphological structure of the pectoralis major muscle and its potential variations in terms of the number of parts and the proximal attachment. Since these changes may be related to embryological development, this study was conducted in human fetuses. The main goal of the study was to develop a new classification system for this muscle and to identify potential causes of the described morphological variations.

The objective of the study *Morphological variability of the pectoralis minor muscle. Study in human fetuses* was to examine the morphological structure of the pectoralis minor muscle and its potential variations in the number of bellies, their course, and proximal attachment. Since these changes may be linked to embryological development, this research was conducted in human fetuses. The main goal of the study was to develop a new classification system for this muscle and to determine the potential causes of the described morphological variations.

The objective of the study *Accessory thoracic muscles in human foetuses* was to conduct a detailed analysis of potential accessory muscles within the thoracic region of human fetuses. Given the lack of comprehensive studies on this topic in the available literature, the aim of this research was to examine the morphological variations in this area, with particular emphasis on potential associations with embryological development.

1.3. Materials and methods

The study for the publication *Morphological variability of the pectoralis major muscle in human fetuses* was conducted on thirty-five human fetuses (17 female and 18 male) aged from eighteen to thirty-eight weeks of gestation at death and fixed in a 10% formalin solution, totaling seventy examined pectoralis major muscles (35 right and 35 left). The fetuses were obtained from spontaneous abortion after the informed consent of both parents and were part of a donation program for the Department of Anatomical Dissection and Donation, Chair of Anatomy and Histology Medical University of Lodz. The study was approved by the Bioethics Committee at the Medical University of Łódź (approval number RNN/137/20/KE). Their age was estimated based on crown-rump length (CRL) measurements [11], head length, head circumference, and provided medical documentation.

Upon dissection, the following morphological features of the pectoralis major muscle were assessed:

- the morphology of the pectoralis major muscle,

- the occurrence of accessory parts of the pectoralis major muscle,

- the possible absence of the pectoralis major muscle,

- morphometric measurements of the pectoralis major muscle.

Morphometric measurements were performed twice by two independent researchers with an accuracy of 0.01 mm. Measurements were obtained using an electronic caliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). The mean values from the measurements were used for statistical analysis.

The study for publication *Morphological variability of the pectoralis minor muscle. Study in human fetuses* was conducted on twenty-five (13 male and 12 female) spontaneously aborted human fetuses (25 left and 25 right) aged from eighteen to thirty-eight weeks of gestation at death and fixed in 10% formalin solution. The fetuses were donated after parental consent to the Medical University anatomy program. The study protocol was approved by the Bioethics Committee of the Medical University of Lodz, Poland (resolution RNN/137/20/KE). Their ages were determined based on the crown-rump length (CRL) [11], head length, head circumference, and provided medical documentation.

Upon dissection, the following morphological and morphometric features of the pectoralis minor muscle were assessed:

- the morphology of the pectoralis minor muscle,

- the occurrence of accessory bellies of the pectoralis minor muscle,

- the possible absence of the pectoralis minor muscle,

- morphometric measurements of the pectoralis minor muscle,

- morphometric measurements of the pectoralis minor tendon.

Morphometric measurements were performed twice by two independent researchers with an accuracy of 0.01 mm. An electronic caliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan) was used to obtain the measurements. The mean values from the measurements were used for statistical analysis.

The study for the publication *Accessory thoracic muscles in human foetuses* was conducted on fifty human fetuses (25 female and 25 male) aged from eighteen to thirty-eight weeks of gestation at death and fixed in a 10% formalin solution, resulting in the examination of one hundred thoracic regions. The fetuses were part of a donation program for the Department of Anatomical Dissection and Donation, Chair of Anatomy and Histology Medical University of Lodz. The study was approved by the Bioethics Committee at the Medical University of Łódź (approval number RNN/137/20/KE/RNN/114/24/KE). The gestational age of the examined fetuses was estimated based on crown-rump length (CRL) [11], head length, head circumference, and the provided medical documentation.

Upon dissection, the following morphological and morphometric features were assessed:

- the morphology of the pectoralis major and minor muscles,

- the presence of accessory muscles in the thoracic region,

- morphometric measurements of accessory muscles in the thoracic region.

Morphometric measurements were performed twice by two independent researchers with an accuracy of 0.01 mm. An electronic caliper (Mitutoyo Corporation,

Kawasaki-shi, Kanagawa, Japan) was used to obtain the measurements. The mean values from the measurements were used for statistical analysis.

1.4. Results

The results of the study *Morphological variability of the pectoralis major muscle in human fetuses* showed that the pectoralis major muscle was present bilaterally in all thirty-five examined fetuses. Following a detailed anatomical dissection, the world's first classification of the pectoralis major muscle based on the findings obtained from a study conducted in a human fetal population was developed. Considering the number of parts comprising the muscle, five types along with subtypes were distinguished.

- **Type I (10%)** - one claviculosternal part without division for distinct bellies. The part originated from the clavicle or only its medial part, from the ipsilateral half of the anterior surface of the sternum and costal cartilages (from the first to the sixth or from the first to the seventh).

- **Type II (37.1%)** - represented by two muscle bellies. The first part was the clavicular part, originated from the anterior surface of the clavicle. The second part was the sternocostal part, which origin was located on the ipsilateral half of the anterior surface of the sternum and costal cartilages (ribs from the first to the sixth in four cases, from the first to the seventh in one case, from the second to the fifth in three cases, from the second to the sixth in eighteen cases). In all cases, the abdominal part was absent.

- **Type III (31.4%)** - represented by three muscle bellies. The first part was the clavicular part, originating from the anterior surface of the clavicle. The second part was the sternocostal part originating from the ipsilateral half of the anterior surface of the sternum and costal cartilages (ribs from the second to the fifth in seven cases, from the second to the sixth in twelve cases, from the second to the seventh in three cases). The third part was the abdominal part, originating from the rectus sheath.

- **Type IV (17.2%)** - represented by four muscle bellies. This type was divided into four subtypes based on the variability of additional heads. The sternocostal and abdominal parts were found in all cases. The sternocostal part originated from the ipsilateral half of the anterior surface of the sternum and costal cartilages (ribs from the second to the fifth in one case, from the second to the sixth in seven cases, from the third to the sixth in four cases), in turn, the abdominal part originated from the rectus sheath.
  - Subtype IVa (4.3%) - was characterized by one additional clavicular part. The first clavicular part originated from the lateral part of the anterior surface of the clavicle, and the second clavicular part from its medial part.
  - Subtype IVb (8.6%) - was characterized by one additional belly, referred to as the claviculosternal part. This part originated from the medial part of the clavicle, the ipsilateral half of the anterior surface of the sternum and costal cartilages (from the first to the second rib). The course of the clavicular part was standard and its origin was located on the anterior surface of the clavicle).
  - Subtype IVc (1.4%) - was characterized by one additional sternocostal part, called the 'sternocostal superior', which originated from the ipsilateral half of the anterior surface of the sternum and costal cartilages (from the first to the second rib). The clavicular part originated from the anterior surface of the clavicle, but there was also a connection with the sternocleidomastoid muscle.
  - Subtype IVd (2.9%) - was characterized by two additional parts: one claviculosternal (originated from the medial part of the clavicle, the ipsilateral half of the anterior surface of the sternum and the first costal cartilage), and one sternocostal superior (originated from the ipsilateral half of the anterior surface the sternum and costal cartilages from the second to the third rib). The clavicular part was absent.

- **Type V (4.3%)** - represented by five muscle bellies (two additional). All cases included the clavicular part (originating from the lateral part of the anterior surface of the clavicle), the additional clavicular part (originating from the medial part of the anterior surface of the clavicle), the sternocostal part (originating from the ipsilateral half of the anterior surface of the sternum and costal cartilages from the third to the sixth rib), and the abdominal part (originating from the rectus sheath).

This type was divided into two subtypes based on the variability of the second additional muscle belly:

- Subtype Va (2.9%) - the second additional belly was formed by the sternocostal superior part, which originated from the ipsilateral half of the anterior surface of the sternum and costal cartilages (from the first to the second rib).
- Subtype Vb (1.4%) - the second additional belly was formed by the claviculosternal part, which originated from the medial part of the clavicle, the ipsilateral half of the anterior surface of the sternum and costal cartilages (from the first to the second rib)

The results of the study *Morphological variability of the pectoralis minor muscle. Study in human fetuses* showed that the pectoralis minor muscle was present bilaterally in all twenty-five examined fetuses. Following a detailed anatomical dissection, the world's first classification of the pectoralis minor muscle based on the findings obtained from a study conducted on a human fetal population was developed. Considering the number of parts comprising the muscle, three types along with subtypes were distinguished. In all cases, the distal attachment was located on the coracoid process of the scapula.

- **Type I (66%)** – with one muscle belly and this type was divided into two subtypes (Ia and Ib).
  - The subtype Ia (58%) - was characterized by a belly originating from the third to the fifth, or from the second to the fifth, or from the second to the fourth ribs, or from the third to the fourth ribs.
  - The subtype Ib (8%) - was characterized by a belly originating from the second to the third ribs, or from the third rib only, with two muscular structures connecting each other and one muscle belly distally attached as a tendon to the coracoid process.

- **Type II** (24%) - with two bellies. The first belly originating from the second rib, or from the second and the third ribs, and the second belly from the third rib, or the fourth rib, or the third and the fourth ribs, or the fourth and the fifth ribs.

- **Type III** (10%) - with three bellies. The first belly originating from the second or third ribs, the second belly from the inferior part of the second rib, the external intercostal muscle, and the superior part of the third rib, or from the external intercostal muscle and superior part of the fourth rib, or from the inferior part of the third rib, external intercostal muscle, and superior part of the fourth rib, and the third belly was attached to the third or the fourth rib only, or the external intercostal muscle and the superior part of the fourth rib.

In the study *Accessory thoracic muscles in human foetuses*, the presence of sixteen additional muscles in the thoracic region (16%) was observed. Based on their course, we distinguished four types of additional thoracic muscles.

- **Pectoralis quartus muscle** (8% of studied cases and 50% of observed accessory thoracic muscles) – in all cases, the point of origin was the fifth or sixth rib. Five cases were distally attached to the bicipital groove located on the humerus, and three cases were fused with the fascia of the upper limb.
- **Axillary arch muscle** (3% of studied cases and 18.75% of observed accessory thoracic muscles) – in all cases, originating from the latissimus dorsi muscle, this muscle was distally fused with the pectoralis major muscle.
- **Chondrocoracoideus muscle** (3% of studied cases and 18.75% of observed accessory thoracic muscles) - all cases originated from the sixth or seventh rib and rectus sheath as a muscle belly. Two cases were distally fused as a tendinous structure with the short head of the biceps brachii and attached to the coracoid process. One case was distally attached as a tendinous structure directly to the coracoid process.
- **Sternalis muscle** (2% of studied cases and 12.5% of observed accessory thoracic muscles) - the first case originated from the body of sternum at the level of the second intercostal space as a single muscular band and inserted into the fifth rib. The second case originated from the distal part of the sternocleoidomastoid muscle and sternum, as a bifurcated muscle belly distally merged into one belly attaching to the sixth and the seventh ribs.

1.5. Conclusions

The conducted studies provided new data on the morphological variability of chest muscles in the human fetal population. For the first time, classifications of the pectoralis major and pectoralis minor muscles in human fetuses have been developed, and additional anatomical structures in this region were characterized.

The pectoralis major muscle was bilaterally present in all examined fetuses and exhibited significant variability in both the number of parts and the location of their proximal attachments, which may be attributed to disturbances in embryogenesis. The most frequently observed division consisted of two parts (clavicular and sternocostal), followed by a three-part configuration. Significant differences in the prevalence of specific types were observed between sexes, as well as a higher occurrence of certain variants in younger fetal developmental stages. Further studies, both anatomical and imaging-based, are necessary to verify this new classification in the adult population.

The pectoralis minor muscle exhibited considerable morphological variability in terms of the number of muscle bellies and the location of its attachments. The most common type (Type I) was characterized by a single muscle belly. The anatomical diversity of this muscle may have important clinical implications, particularly in relation to brachial plexus compression syndromes and individual anatomical differences relevant to surgical and rehabilitative procedures.

Additional muscles in the thoracic region were identified in 16% of the examined fetuses. Based on their course, four types of accessory thoracic muscles were distinguished, with the most frequently observed being the pectoralis quartus muscle. These structures may play a significant clinical role, contributing to the development of thoracic outlet syndrome, postural asymmetries, and potential complications during surgical interventions in this region.

The obtained results highlight significant anatomical variability in the development of thoracic muscles and its potential clinical relevance. Further studies, including anatomical dissections of the adult population and imaging techniques (MRI, ultrasound), may provide additional insights into the morphology and function of these structures, as well as their role in the pathogenesis of musculoskeletal and neurological disorders.