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Dissectional Orientation: Morphological Variations of Teres Minor Muscle and its Nerve Supply

Orientación Diseccional: Variaciones Morfológicas del Redondo Menor y su Irrigación Nerviosa

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SUMMARY: The teres minor is one of the rotator cuff muscles that comprise the superior margin of the quadrangular space. Quadrangular space syndrome (QSS) refers to the entrapment or compression of the axillary nerve and the posterior humeral circumflex artery in the quadrangular space, often caused by injuries, dislocation of the shoulder joint, etc. Patients who fail the primary conservative treatments and have persistent symptoms and no pain relief for at least six months would be considered for surgical interventions for QSS. This cadaveric study of 17 cadavers (males: 9 and females: 8) was conducted in the Gross Anatomy Laboratory at the Department of Anatomy, Faculty of Medicine Siriraj Hospital, Mahidol University. The cadavers were preserved in a 10 % formaldehyde solution and obtained ethical approval by the ethical commission of the Siriraj Institutional Review Board. The morphology of the teres minor muscle-tendon junction, the bifurcation type of the axillary nerve, and the length and number of the terminal branches of the nerve to the teres minor were documented. Specimens with quadrangular space contents and surrounding muscles that had been destroyed were excluded from the study. The results showed that 47.06 % of the specimens had type A bifurcation, 47.06 % had type B bifurcation, and the remaining 5.88 % had type C bifurcation. It was observed that 58.82 % had nonclassic muscle-tendon morphology, while 41.18 % were classic. The average length of the terminal branches of the nerve to the teres minor in males was 1.13 cm, with the majority having two branches. For females, many showed one terminal branch with an average length of 0.97 cm. Understanding the differences in anatomical variations can allow for a personalized treatment plan prior to quadrangular space syndrome surgical procedures and improve the recovery of postsurgical interventions for patients.

KEY WORDS: Quadrilateral space syndrome; Quadrangular Space; Axillary Nerve; Teres Minor; Cadavers.

INTRODUCTION

Quadrangular space syndrome (QSS) is a rare condition that refers to the entrapment or compression of the axillary nerve (AXN) and the posterior humeral circumflex artery (PHCA) in the quadrangular space (QS). This syndrome is often caused by injuries, dislocation of the shoulder joint, tumors, or hematomas. The results of chronic compression of neural and vascular structures through the QS were first described in 1983 by Cahill and Palmer (Hangge *et al*., 2018). In addition, apart from combined neurovascular QSS, the syndrome can also be described as neurogenic quadrangular space syndrome or vascular quadrangular space syndrome (Dalagiannis *et al*., 2020). Generally, the prevalence of the syndrome is relatively low due to a lack of literature and misdiagnosis, making the pathophysiology of QSS unclear. Consequently, the prevalence is approximately 0.8 % (Kemp *et al*., 2021). The common etiology of patients with QSS is neck and shoulder pain, point tenderness above the quadrangular space, paresthesias in a nondermatomal distribution, and muscle atrophy (Dalagiannis *et al*., 2020), which in many cases are caused by repetitive external rotation and abduction movements among athletes (Kemp *et al*., 2021). Moreover, thoracic outlet syndrome, impingement syndrome, and rotator cuff syndrome are also considered differential diagnoses with these symptoms. Although the majority of QSS symptoms are vague and challenging to diagnose, observations confirmed by using radiographic imaging such as magnetic resonance imaging and ultrasound, can help with accurate diagnoses. Likewise, angiography imaging and electromyography are also methods of diagnosing QSS.

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The teres minor is one of the rotator cuff muscles that is described as being posterior to the shoulders. It is a narrow intrinsic muscle that extends between the scapula and the humerus head along with the infraspinatus, supraspinatus, and subscapularis (Dalagiannis *et al*., 2020). The muscle is inserted at the greater tubercle of the humerus and has the PHCA, which is a branch of the third part of the axillary artery, as its arterial supply. Furthermore, it is innervated by the AXN from the C5 and C6 ventral rami, which bifurcate from the posterior cord of the brachial plexus. As the AXN enters the posterior scapula, it bifurcates into the posterior and anterior terminal branches. As a member of the rotator cuff muscles, the teres minor muscle functions to externally rotate, adduct, and abduct the arms and provide stability to the humeral head in the glenoid cavity. Thus, it acts as an antagonist muscle to the medial rotation and allows the shoulder to be stabilized, preventing dislocation of the humerus (Juneja & Hubbard, 2022). Moreover, the teres minor comprises the margins of the QS. The QS has the teres minor as the superior margin; inferiorly is the teres major muscle; medially is the long head of the triceps; and its lateral margin is the humeral shaft (Dalagiannis *et al*., 2020). The main function of the QS is to provide a pathway for AXN and PHCA.

According to Holley *et al*., the teres minor muscle-tendon junction at the insertion point can be classified into "classic (C)" and "nonclassic (NC)" variations (Holley *et al*., 2020). The C type is described as two-headed, while the NC type is one-headed. Characterizing the differences between the morphologies of the muscle-tendon junction can help with personalizing treatment plans prior to QSS surgical procedures and maximize the effects of the recovery of postsurgical interventions for patients.

Conservative treatments for QSS can be approached through lifestyle modifications, injections (e.g., corticosteroids), and manual therapy, which are the starting points for treating the syndrome. In contrast, surgical decompression intervention of the QSS would be considered for patients who fail conservative treatments with persistent symptoms and have no pain resolution for at least six months (Hong *et al*., 2019). Prior to surgical interventions, presurgical tests with positive lidocaine blocks and Hornblower's sign can be performed to assess the conditions of the patients. Diagnosis upon physical examination can be challenging for QSS, and diagnostic imaging is usually recommended to eliminate other possible pathologies. Although there have been numerous intervention techniques to treat the syndrome, locating the precise injection site is essential for effective QSS resolution. The dissection of cadaveric specimens would shed light on the significance of the anatomical variations of the teres minor and its innervation as presurgical tools for improving the outcomes of QSS treatments. Such knowledge can contribute to the understanding of biomechanical characteristics that predispose patients to the formation of shoulder impingement, thus improving the quality of life of patients. The purpose of using cadavers in this study is to utilize their ability to be oriented in three dimensions and to differentiate the morphologies clearly.

MATERIAL AND METHOD

The teres minor muscles and the AXN were evaluated during human anatomy laboratory dissection at the Department of Anatomy, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand. The conventional anatomical dissection method of the upper limb was conducted using Grant's method (Basmajian, 1971). The cadavers were all Thai and fixed in a 10 % solution of formaldehyde. A total of 34 limbs from 17 cadavers were investigated, and photographs were taken on a Canon EOS 77D. Dissection of each specimen aimed to reveal the contents of the QS and the teres minor muscle-tendon morphology for observations. The dissection procedure for this study includes a skin incision and fascia removal to expose the deltoid muscle. Then, the deltoid muscle was reflected and removed from the inferior attachments of the spine of the scapula. The adipose and connective tissues were cleaned for a clearer visualization at the QS. Identification of the AXN, the number of axillary terminal branches, the morphology of the axillary nerve bifurcation, and the variations of the teres minor muscle-tendons were evaluated.

All dissections conducted on the specimens received approval from the ethics committee of the Siriraj Laboratory Animal Research and Care Center, Mahidol University (059/Exemption).

RESULTS

Demographic data. According to the demographic data of Thai cadavers, the mean age group for men (n = 9) was 77.50 years (maximum: 95 years, minimum: 60 years, age range: 60-95 years), and for females (n = 8) was 70.70 years (maximum: 90 years, minimum: 50 years, age range: 50-90 years). The age group's cumulative mean was 74.10 years (maximum: 95 years, minimum: 50 years). From 17 cadavers, 34 limbs in all were collected.

Axillary nerve branching (Figs. 1 to 3). After fine dissection, the results of axillary nerve branching are shown as type A (n = 8), type B (n = 8), and type C (n = 1). First, type A can be counted in eight cadavers and was present in both males (n = 4) and females (n = 4). Moreover, it was found that axillary branching type A had the same number and could be identified on both the left (n = 8) and right (n = 8) sides in both males and females.

The type B can be counted in eight cadavers. Both males (n = 5) and females (n = 3) had type B. Additionally, it was discovered that axillary branching type B was expressed in both males and females on both the left (n = 8) and right (n = 8) sides.

Males lacked axillary branches of type C. Only one female had type C on both of their upper limbs.

Finally, type A and type B both had an identical number of limbs with various bifurcation types (47.06 % of type A and type B and 5.88 % of type C).

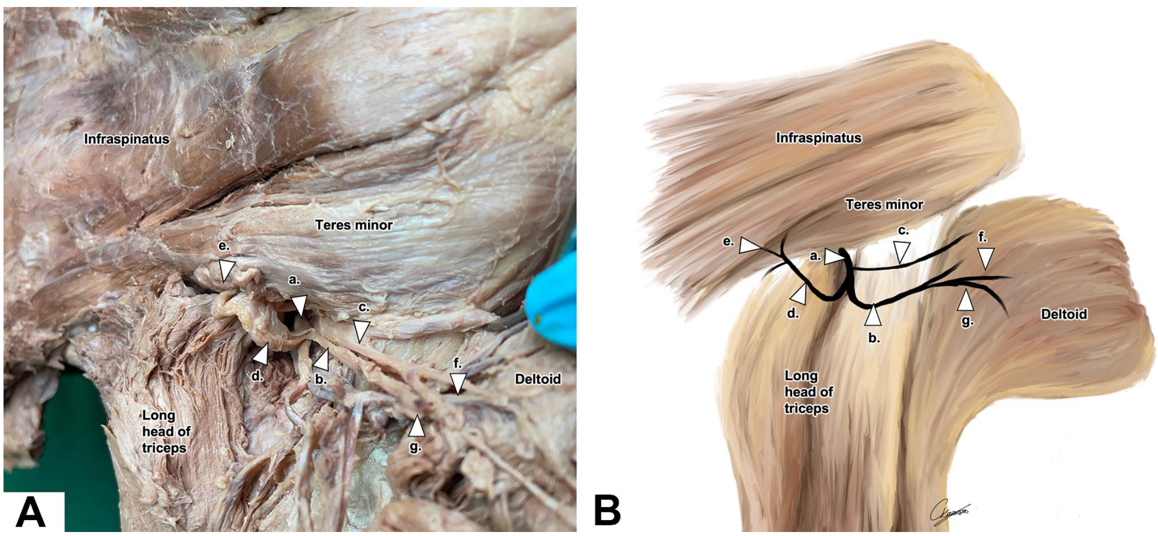


Fig. 1. Schematic of Axillary nerve bifurcation types at the right shoulder. A. The posterior view of the right shoulder displaying type A variation of the axillary nerve course. B. A diagram of the axillary nerve branching type A. a: Main axillary nerve trunk; b: posterior branch of axillary nerve; c: anterior branch of axillary nerve; d: teres minor nerve; e: terminal branches of axillary nerve; f: posterior branch to deltoid; g: superior lateral brachial cutaneous nerve branch.

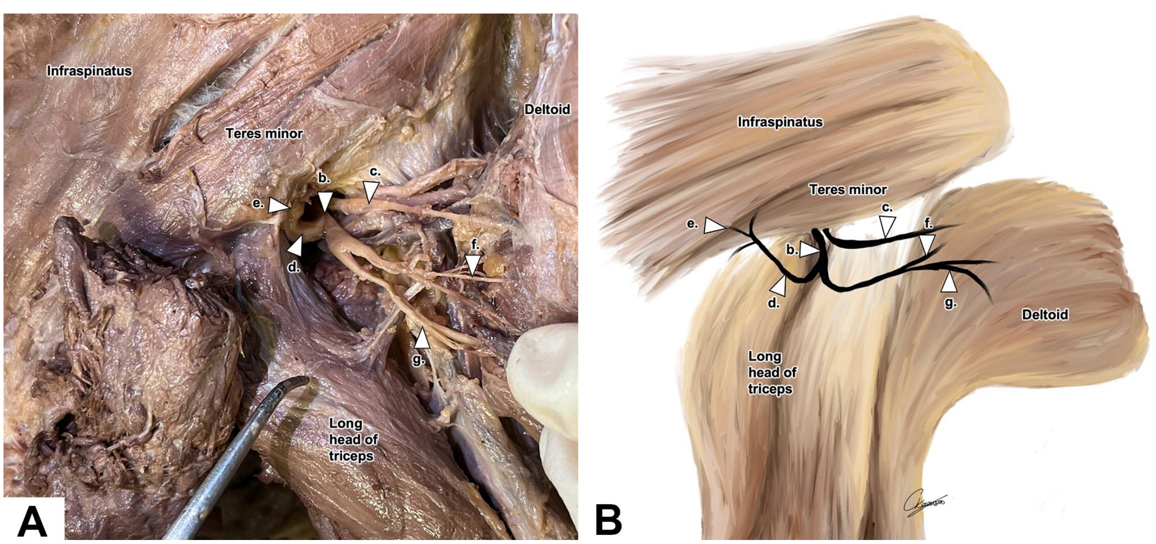


Fig. 2. Schematic of Axillary nerve bifurcation types at the right shoulder. A. The posterior view of the right shoulder displaying type B variation of the axillary nerve course. B. A diagram of the axillary nerve branching type B. b: posterior branch of axillary nerve; c: anterior branch of axillary nerve; d: teres minor nerve; e: terminal branches of axillary nerve; f: posterior branch to deltoid; g: superior lateral brachial cutaneous nerve branch.

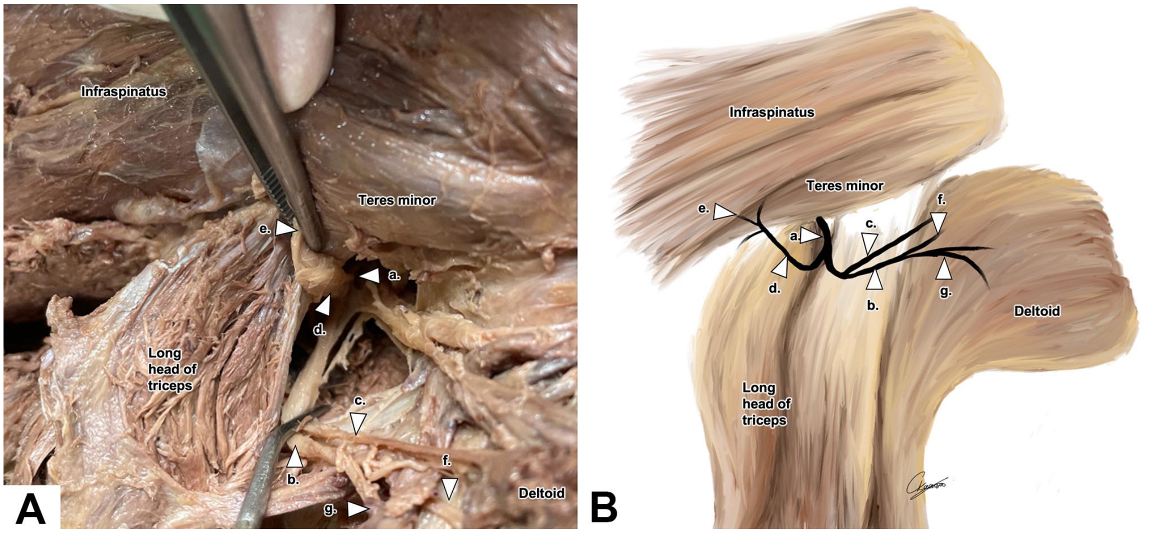


Fig. 3. Schematic of Axillary nerve bifurcation types at the right shoulder. A: The posterior view of the right shoulder displaying type C variation of the axillary nerve course. B: A diagram of the axillary nerve branching type C. a: Main axillary nerve trunk; b: posterior branch of axillary nerve; c: anterior branch of axillary nerve; d: teres minor nerve; e: terminal branches of axillary nerve; f: posterior branch to deltoid; g: superior lateral brachial cutaneous nerve branch.

Number of terminal branches, including mean length, minimum, and maximum. The results of the terminal branch lengths of the nerve to the teres minor are displayed in Table I as the number, mean length, minimum, and maximum. While most females only displayed one branch, the majority of males exhibited two terminal branches of the nerve heading to the teres minor. Additionally, compared to the right side, the average length of terminal branches was usually shorter on the left side of both females and males.

Morphology of muscle-tendon of teres minor muscle. Table II displays that there were differences in the muscle-tendon morphology of the teres minor muscle. In Figures 4 and 5, these variances were depicted. Twenty of the 34 limbs (58.82 %) exhibited the NC muscle-tendon morphology, while 14 of the 34 (41.18 %) had the C variation. The opposite sides of the cadaveric couples had the same kinds of morphologies.

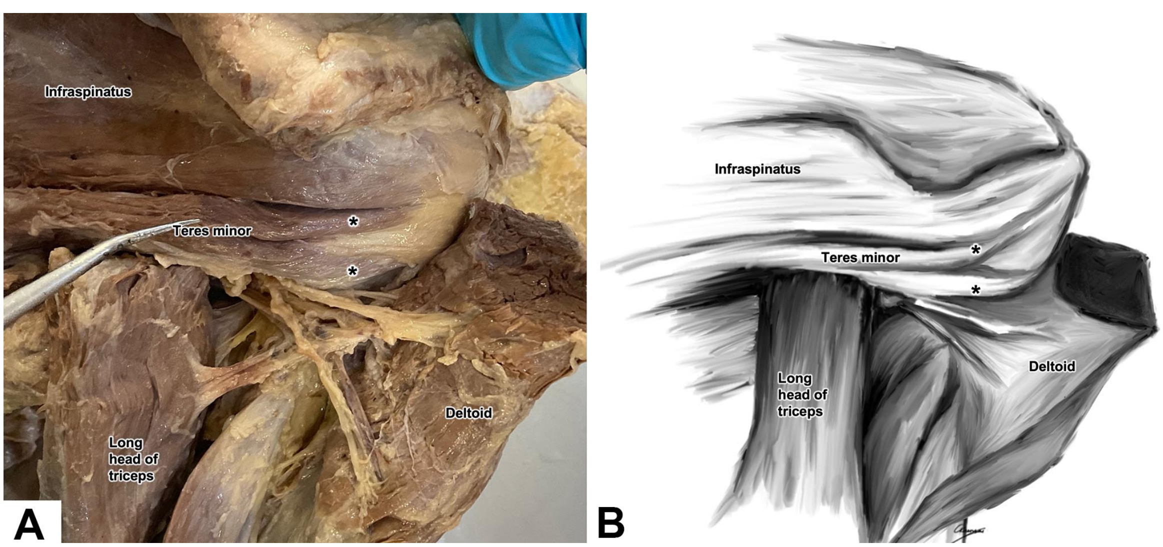
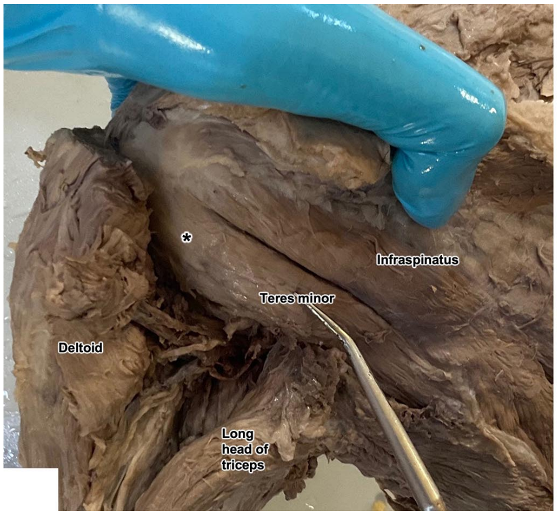


Fig. 4. A. The Classic (two-headed) morphology of the muscle-tendon junction of teres minor muscle at the right shoulder. B. An illustration of the muscle-tendon junction of teres minor muscle of classic variant. Asterisks: Two-headed muscle-tendon (C type).



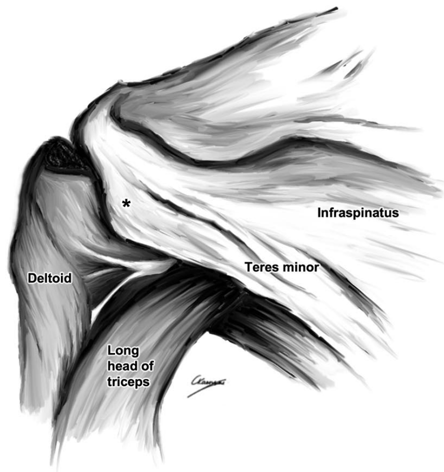


Fig. 5. A. The Non-Classic (one-headed) morphology of the muscle-tendon junction of teres minor muscle at the left shoulder. B. An illustration of the muscle-tendon junction of teres minor muscle of non-classic variant. Asterisks: One-headed muscle-tendon (NC type).

Table I. Number of terminal branches, including mean length, minimum, and maximum.

	Number of terminal branches						Mean length (cm) ± SD		Minimum length (cm)		Maximum length (cm)	
	Left			Right			Left	Right	Left	Right	Left	Right
	1	2	3	1	2	3						
Male (n = 9)	2	5	2	4	3	2	1.06 ± 0.37	1.19 ± 0.46	0.4	0.6	1.8	2
Female (n = 8)	4	4	0	5	2	1	0.89 ± 0.46	1.04 ± 0.49	0.5	0.6	1.1	2.1

Table II. Morphology of muscle-tendon of teres minor muscle.

	Muscle-tendon morphologies			
	NC		C	
	Left	Right	Left	Right
Male (n = 9)	4	4	5	5
Female (n = 8)	6	6	2	2

NC: non-classic; C: classic.

DISCUSSION

The majority of the nerve type bifurcations were type A and type B, specifically 47.06 % of the 34 dissected limbs. Meanwhile, type C bifurcation accounted only 5.88 %. It is therefore valid to conclude that type A and type B bifurcation types are the leading branching patterns of the axillary nerve in this study of Thai cadavers. In comparison to Friend *et al*. (2010), 4/9 (44.4 %) of their cadavers had anterior bifurcation to the QS, and 5/9 (55.6 %) had posterior bifurcation to the QS. Furthermore, the average age of the cadavers (72±9 years) was similar to that of this study (Friend *et al*., 2010). Likewise, a study from Oluoch *et al*. (2018) stated that 64.7 % of the cases had the nerve to the teres minor branching from the posterior branch of the AXN, while the other proportion branched directly from the main trunk of the AXN. Hence, this study suggests that the entrapment of the posterior branch of the AXN can result in the loss of sensation and motor impairment of the deltoid muscle in 64.7 % of the population, while the loss of the normal functions of the deltoid muscles may not be a reliable indication of the impairment of the nerve to the teres minor in the other 35.3 % of the study population (Oluoch *et al*., 2018). Additionally, the results of Oluoch *et al*. (2018) also support the outcomes of this study, as a higher percentage of specimens were found to have the nerve to the teres minor branched from the posterior branch of AXN (types A and B) compared to branching from the main AXN nerve trunk directly (type C), with and 94.1 %, respectively. Additionally, results from Loukas *et al*. (2009) showed all their specimens from the investigation (100 %) had the nerve to the teres minor branching from the posterior branch of AXN (Loukas *et al*., 2009), which is also further supported by Gurushantappa & Kuppasad (2015) and Ball *et al*. (2003).

However, McClelland & Paxinos (2008) obtained 15 of 16 (93.75 %) cadaveric specimens showing the branching of the nerve to the teres minor before the QS, and the remaining shoulder (1/16) showed branching after entering the QS (McClelland & Paxinos, 2008). This contradicts the findings of Friend *et al*. (2010), who found a higher proportion of posterior branching types. Furthermore, according to Friend *et al*. (2010), early bifurcation could increase the likelihood of nerve entrapment, which would explain the results of McClelland & Paxinos (2008), who also found that 14 of 16 cadavers had fibrous bands, the majority of which were between the teres major and the long head of the triceps. Ultimately, this would reduce the cross-sectional area of the QS, thus compressing its contents. Moreover, Loukas *et al*. (2009) have reported that 65 % of their results showed the axillary nerve branched within the QS, while 35 % divided within the deltoid muscle (their study included 50 cadavers). Another study of 25 cadavers by Gurushantappa & Kuppasad (2015) revealed that 88 % of the cases demonstrating AXN branching were within the QS and 12 % were divided in the deltoid muscle (Loukas *et al*., 2009; Gurushantappa & Kuppasad, 2015).

This study showed that 20/34 (58.82 %) had NC muscle-tendon morphology and 14/34 (41.18 %) had the C variant. Both sides of the cadaveric pairs exhibit the same type of morphology. Furthermore, males had more C muscle and tendon morphology than NCs. Meanwhile, female cadavers showed more NC morphology. When taking sex into account, approximately 35.3 % of females had the NC type, and 11.8 % had the C type. Likewise, 23.5 % of males demonstrated NC, and 29.4 % of males had the C variant. In contrast with Holley *et al*. (2020), these trends do not correspond to their results. They revealed that 85 % of the results were classified as having C morphology, 15 % were NC, and 5 % were unidentifiable. Holley *et al*. (2020) postulated that the formation of the NC morphology is due to embryonic origins, hypertrophied TM secondary to a rotator cuff tear, or atrophy of the C variant resulting in a NC presentation. However, because the investigation did not include the cadavers' ages and sexes, it is difficult to determine whether other variables such as age and sex played a role in the differences in outcomes. The mean length of the terminal branches of the nerve to the teres minor for males was 1.13 cm and for females was 0.97 cm. The majority of male specimens had 2 branches of the terminal branches of the nerve to the teres minor, and females had 1 branch (Table I).

The discrepancies in the results may be due to the sample size and the lack of general information about the cadavers. This could also be an indication that the Thai population may need a new or altered treatment design to fit the morphological variations. Previous studies conducted by Shaari & Sanders (1993) using rabbit models for histological studies have shown that injections approximately 5 mm away from the muscle end-plate lead to a 50 % reduction in paralysis. Therefore, with this as supporting evidence, Lee *et al*. (2016) hypothesized that the recommended injection regions are located close to the neuromuscular junctions. Moreover, in 2017, Nakajima *et al*. (2017) reported that the most appropriate site for intramuscular injections is the intersection between the anteroposterior axillary line and the perpendicular line from the mid-acromion. They supported their findings by demonstrating that the axillary nerve runs approximately 5 cm below the mid-acromion lateral margin, making this site unsuitable for intramuscular injection. However, at the intersection of the anteroposterior axillary line and the perpendicular line from the mid-acromion, the distance was safe enough to reduce the risk of nerve complications (Nakajima *et al*., 2017). As of now, the current approach to the injection site to treat QSS was mentioned by Waldman (2022). The book The Atlas of Pain Management Injection Techniques reports the injection technique for QSS using anatomical landmarks. Primarily, a line is drawn from the lateroposterior angle of the acromion to the tip of the ipsilateral olecranon process. Another line is drawn perpendicular to the first, starting from the anterior axillary fold and continuing until it reaches the first line. After the identification of where the two lines intersect, the point of interest is located approximately 2 cm above the intersection (Waldman, 2022). Moreover, Flynn *et al*. (2018) support the idea of the approximate distance of an effective injection point for QSS treatment. They advised doing a lidocaine block test, in which 5 mL of 1 % lidocaine would be injected in the QS within 2-3 cm inferior to the normal posterior shoulder portal, if the discomfort did not go away after 6 months (Flynn *et al*., 2018).

To conclude, knowledge of the variations of the AXN and the teres minor muscles becomes essential in administering the anesthetic blocks, treating nerve compressions, and providing guidance for surgeons to improve clinical outcomes (Tiwari & Nayak, 2017). Furthermore, these iatrogenic injuries are caused by a lack of awareness of the anatomical variations of the AXN (Gurushantappa & Kuppasad, 2015); hence, understanding the anatomical morphologies would also help reduce the risks and complications.

CONCLUSION

The best method for finding the axillary nerve's variations in the quadrangular area is dissection. The axillary nerve primarily branches out in the kinds A and B of bifurcation, according to Thai cadavers. Understanding the distinctions in anatomical variances might help patients recover more quickly from postsurgical treatments and increase understanding in developing a specific treatment plan prior to QSS surgical operations.

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KAENSA, C.; SRICHAROENVEJ, S.; LANLUA, P. & BAIMAI, S. Orientación diseccional: variaciones morfológicas del músculo redondo menor y su irrigación nerviosa. *Int. J. Morphol., 41(5)*:1445-1451, 2023.

RESUMEN: El músculo redondo menor es uno de los músculos del manguito rotador que comprende el margen superior del espacio cuadrangular. El síndrome del espacio cuadrangular (QSS) se refiere al atrapamiento o compresión del nervio axilar y la arteria circunfleja humeral posterior en el espacio cuadrangular, a menudo causado por lesiones, dislocación de la articulación humeral, entre otros. En los pacientes en los que fracasan los tratamientos conservadores primarios y presentan síntomas persistentes y ningún alivio del dolor durante al menos seis meses se considerarían para intervenciones quirúrgicas para QSS. Este estudio cadavérico de 17 cadáveres (hombres: 9 y mujeres: 8) se llevó a cabo en el Laboratorio de Anatomía Macroscópica del Departamento de Anatomía de la Facultad de Medicina del Hospital Siriraj de la Universidad Mahidol. Los cadáveres se conservaron en una solución de formaldehído al 10 % y obtuvieron la aprobación ética de la comisión ética de la Junta de Revisión Institucional de Siriraj. Se documentó la morfología de la unión músculo-tendón del músculo redondo menor, el tipo de bifurcación del nervio axilar y la longitud y el número de las ramas terminales del nervio para el músculo redondo menor. Se excluyeron del estudio los especímenes con contenido de espacios cuadrangulares y músculos circundantes que habían sido destruidos. Los resultados mostraron que el 47,06 % de los especímenes presentó bifurcación tipo A, el 47,06 % una bifurcación tipo B y el 5,88 % restante una bifurcación tipo C. Se observó que el 58,82 % presentaba una morfología músculo-tendinosa no clásica, mientras que el 41,18 % era clásica. La longitud pmedia de los ramos terminales del nervio hasta el músculo redondo menor en los hombres era de 1,13 cm, y la mayoría tenía dos ramos. En el caso de las mujeres, mostraron un ramo terminal con una longitud promedio de 0,97 cm. Comprender las diferencias en las variaciones anatómicas puede permitir un plan de tratamiento personalizado antes de los procedimientos quirúrgicos del síndrome del espacio cuadrangular y mejorar la recuperación de las intervenciones posquirúrgicas de los pacientes.

PALABRAS CLAVE: Síndrome del espacio cuadrilátero; Espacio cuadrangular; Nervio axilar; Músculo redondo menor; Cadáveres.

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