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ANATOMICAL VARIATIONS IN MORPHOLOGY OF RIGHT AND LEFT BRACHIAL PLEXUS AMONG BLACK AFRICAN POPULATION; A CADAVERIC STUDY IN WESTERN KENYA

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ABSTRACT

Background: Brachial plexus (Bp) is a network of bundles of nerves of spinal cord around neck and axilla in the body formed by union of anterior primary rami of C5 to C8, and T1. Technical expertise required for clinical and surgical procedures remains challenging for the beginners. Variations may be due to trauma, irradiation, neoplasm, infection, and autoimmune inflammatory disease. The purpose of this study was to determine the difference in variation of right and left Bp of the study population. **Methods:** Cross sectional descriptive study was used in Maseno, Uzima and Masinde Muliro Universities anatomy laboratory to get sample size of 35male and 35 female cadavers. Chi- square test was set at a $p = 0.05$. Ethical consideration was observed. **Results:** Statistically significant difference (p=0.009) between the right and the left upper limb in the branching of musculocutaneous nerve was recorded. A total of 17.8% variations in origin and segments of Bp, majority 9.9% were from left while 7.9% from right. Highest frequency of variation occurred at the prefixed root of Bp with 8.7% occurring on left upper limb and 12.13% on right upper limb. Right upper limbs had highest incidence of variations in branching patterns of Bp at 43% whilst left had incidence of 23.5%. Highest frequency of main terminal variation was of musculocutaneous nerve at 18.6% with 13.6% occurring on right side and 5% on left side. **Conclusion:** Knowledge of variations is essential in evaluation of unexplained sensory and motor loss after trauma and surgical interventions to the upper limb.

Keywords: Anatomical variations; Brachial plexus; cadaver; difference in laterality of right and left side
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INTRODUCTION

Brachial plexus is a network of nerves of spinal cord at the brachium (humerus) (Rasulic *et al*., 2020). It carries motor, sensory, innervation to extrinsic thoracic muscles and sympathetic impulses from spinal cord to the arms and travels through inter-scalene muscle between the anterior scalene and middle scalene muscle then via posterior triangle of the neck (Vaid & Vaid, 2015). The union of C5, C6, C7, C8 and T1 forms it. There are different sections thus the roots, trunks, divisions and cords (M. Emamhadi *et al*., 2016).

Studies done indicated that it is found in the upper limbs in human body with embryological origin history being the initial differentiation of mesenchyme that occurs in the fourth week of embryology(Standring, 2016). Primordial of dorsal nerves reach at the length of distal stretch of the humerus inside the sheath of the growing primordial arm muscle nerves as from C5 to T1 that begin to extend on day 32 of human life, where the nerves merge and form brachial plexus (Bala *et al*., 2014; Rasulic *et al*., 2020).The networks of nerves conducts signals from the spine to the shoulder, arm and hands. Brachial plexus injuries are caused by damage of those nerves (Sachar *et al*., 2020). Usually, injuries are caused by trauma to the neck and shoulder. Symptoms may include a limp or paralyzed arm, lack of muscle control in the arm, hand, or wrist and lack of sensation in the arms or hand(M. Emamhadi *et al.*, 2016).

Pizzo and others (2019) found that it's very significant in neurosurgeons, anatomists and anesthesiologists to grasp the technical awareness of anatomy of human neuron complex interconnecting network leading to a good outcome in critical and emergency patient care and better prognosis. The greatest significant challenges in human anatomy are nerve variations particularly in extreme is found in the upper limb (Pizzo *et al.*, 2019). Due to sports, car accidents or motorcycle, falls, medical conditions and physical activities the upper limbs are vulnerable to traumas (Hardcastle *et al.*, 2020; Verma *et al.*, 2020).It's all important to note that brachial plexus anatomical variations are very common. Most cadaveric anatomical studies of human nerves network is reported to manifest from the brachial plexus (Pizzo *et al.*, 2019).

Professor Ogeng'o (2013) and others indicated that brachial plexus injuries can occur during the delivery of newborns when after the delivery of the head, the anterior shoulder of the infant cannot pass below the pubic symphysis without manipulation (Bahm *et al.*, 2020; El Falougy *et al.*, 2013). This manipulation can cause the baby's shoulder to stretch, which can damage the brachial plexus to varying degrees (Feigl *et al.*, 2020; Singh *et al.*, 2020). This type of injury is referred to as shoulder dystocia. Shoulder dystocia can cause obstetric brachial plexus palsy (OBPP), which is the actual injury to the brachial plexus (Tay *et al.*, 2021). The incidence of OBPP in the United States is 1.5 per 1000 births, while it is lower in the United Kingdom and the Republic of Ireland (0.42 per 1000 births). While there are no known risk factors for OBPP, if a newborn does have shoulder dystocia it increases their risk for OBPP 100-fold (Menticoglou, 2018) Nerve damage has been connected to birth weight with larger newborns being more susceptible to the injury but it also has to do with the delivery methods. Although very hard to prevent during live birth, doctors must be able to deliver a newborn with precise and gentle movements to decrease chances of injuring the child (Fakoya *et al.*, 2019; Tay *et al.*, 2021).

Vajapey and associates (2021) explored human cadavers aged above 18 years where a total of 32 adult cadavers were included in the research and 64 bilateral upper extremities were finally assessed. Male cadavers showed that the brachial plexus was normal on both sides (Martin *et al.*, 2018). The median nerve was formed on the right side in distance of 45mm and on the left side in distance of 45mm away from the coracoid process. The musculocutaneous nerve entered to the coracobrachialis muscle on the right side in distance of 83mm and on the left side in distance of 105mm away from the coracoid process. While another male cadaver the brachial plexus was normal on both sides, the median nerve was formed on the right side in distance of 93mm and on the left side in distance of 99mm away from the coracoid process. The musculocutaneous nerve entered coracobrachialis on the right side in distance of 83mm and on the left side in distance of 105mm away from coracoid process (Pinto *et al.*, 2019)

According to study done by Costa and others (2019) throughout the profile regular dissection for undergraduate student, noticed was variation into emergence of the upper trunk of brachial plexus.one sided established at the right part of male adult cadaver where upper trunk established by alliance of the ventral rami in the C5 to C7 of the spinal nerve (M. P. da Costa *et al.*, 2019). Lower trunk was established by the association of the ventral branches of C8 together with T1 of spinal nerves of note was the middle trunk that was missing (Didesch & Tang, 2019). The atypical upper trunk then was cleared entirely to establish the facial correlation amid the middle and upper trunks

(El Falougy *et al.*, 2013). The noted anomaly in the upper trunk penetrated laterally interscalenus medius and scalenus anterior muscles (V. Vanaclocha *et al.*, 2015). After leaving those two trunks both nerves to subclavius together with suprascapular nerves, the trunk separated into posterior and anterior divisions in which advanced the course like as the division of the normal lower and upper trunk. Other parts of the brachial plexus were found to be within the normal range (Lague *et al.*, 2019).

According to Leape (2015), two plexuses had variation onto superior trunk both found at the right part. In the two cases, C5 with C6 roots were broken up into posterior together with the anterior division. The two anterior unite to give rise to a beginning to a" posterior superior trunk". Then these trunks unite to give a beginning of a superior trunk. Middle trunk got an association branch from C8 of the left part in a white male cadaver together with a transmitting branch as from inferior trunk on the right part of one black male cadaver, There was no variation noted on the inferior trunk amongst those cases(Leape, 2015). In the previous studies done by Vanaclocha (2015), variations at the supraclavicular side of the brachial plexus regularly were found more on the left part though in our case variation was in the right part(V. Vanaclocha *et al.*, 2015). Comprehensive understanding of the variations into the emergence of the brachial plexus is so resourceful to neurosurgeons for it would assist during surgical management of neuro fibromas, tumors and nerves sheaths as schwannomas (Pizzo *et al.*, 2019).

MATERIALS AND METHODS

The study was carried out in the anatomy laboratories of 3 medical universities where cross-sectional study design was used and selection done according to the number of cadavers in each lab. Universities were identified purposively and conveniently because of their functional human anatomy Department that have met the commission of university education standards for storage of human tissue.

To ensure equal distribution of samples, sampling was done proportionately with the strata population by location, where the sample size per laboratory was calculated by dividing laboratory cadaver (*d*) by total location population (86), then multiplying by the desired sample size (70) n= (*d**70)/86. As a result, 70 cadavers were acquired as the total actual sample size using the Yamane Taro formula (1967) from a total available specimen of 86 cadavers. Ethical clearance from the university ethical committee was obtained.

The cadavers were dissected according to the Cunningham manual of practical anatomy where they were examined as per the general principles of anatomy. They were serially numbered from 1-70 then preserved in 10% formalin. A vertical incision was made to expose the site between the triceps and biceps muscles and the following were exposed; roots which were in scalene gap, trunks that were found superior to the clavicle, divisions that sit around the posterior portion of clavicle, cords and branches which were inferior to the clavicle median, axillary, ulnar, radial, and musculocutaneous nerves were located with their origin as well. The observations were recorded in a data sheet and on digital photography.: Statistical package for social sciences (SPSS) version (26) was used for analysis. Chi square test was used to compare the means of independent variables and determine for any statistical significance. Pearson's Correlation test was used to test for linear relationship among the same pairs of variables in the population. Contingency tables were used to determine for statistical relevance between sections of brachial plexus.

RESULTS

In table 1 of the total 25 (17.8%) variations in the origin and segments of brachial plexuses, the majority 14 (9.9%) were from the left side while only 11 (7.9%) were from the right. The highest frequency of variation occurred at the prefixed root of the brachial plexus with 12 (8.7%) variations occurring on the left upper limb and 17 (12.13%) occurring at the right upper limb. The lowest occurrence of variation was at the trunk with the anterior division of the medial trunk connecting with medial nerve. This only occurred in one (0.7%) right limb of the total 140 specimens.

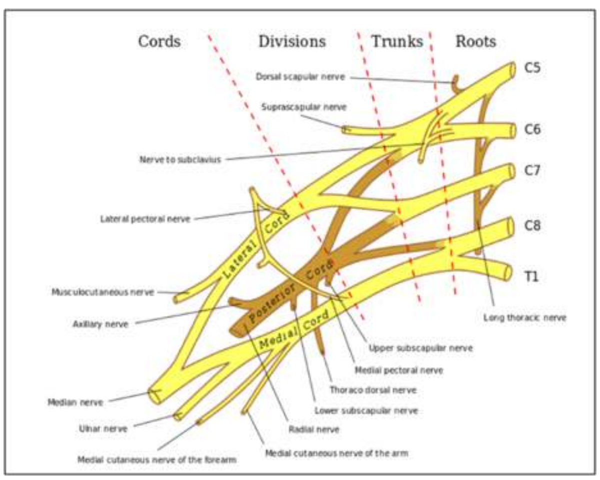

Figure 1: The anatomical diagram of normal brachial plexus (M. Emamhadi *et al.*, 2016)

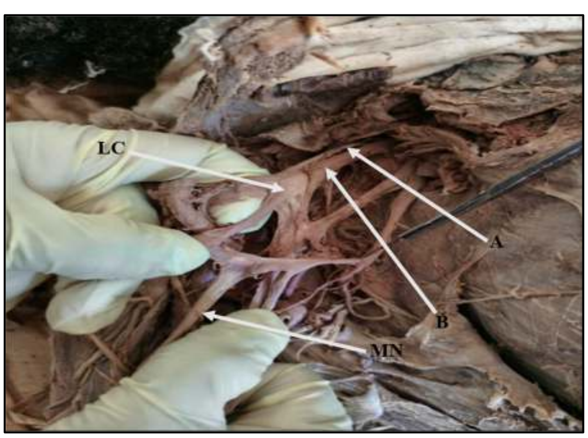

Figure 2: Lateral cord formation by two cords**.** ***A=*** *Cord one,* ***B=*** *Cord two****,*** ***LC=*** *Lateral cord* ***and MN=****musculocutaneous nerve****.***

In table 2, there was no statistically significant difference in variations between the left and the right upper limbs in all the segments of the brachial plexus.

Illustrated in table 3 in the study, the right upper limbs had the highest incidence of variations in the branching patterns of brachial plexus at 43% (61) whilst the left had a variation incidence of only 23.5% (33). The highest frequency of variation was of musculocutaneous nerve (18.6%) with 19 (13.6%) variations occurring on the right side whilst only 7 (5%) variations occurred on the left side. Variation in origin of radial nerve had the lowest frequency with only 2 (1.42%) on the left side and 5 (3.5%) incidences on the right side.

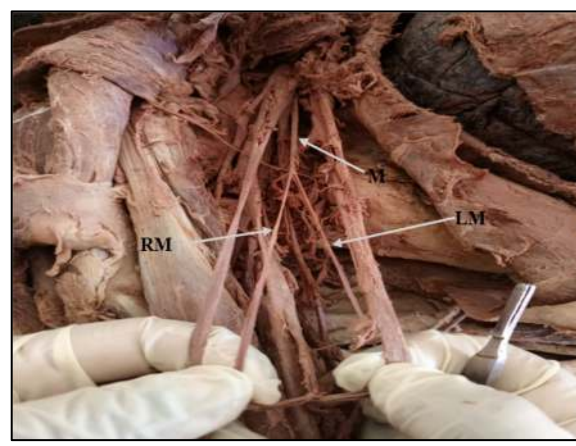

Figure 3: Musculocutaneous nerve have two branches and not piercing coracobrachialis muscle. ***M=****musculocutaneous nerve****,*** ***RM=*** *right branch of musculocutaneous nerve* ***LM=*** *left branch of musculocutaneous nerve.*

There was a statistically significant difference (p=0.009) between the right and the left upper limb in the branching of musculocutaneous nerve. There was no statistically significant difference in variations between the left and the right upper limbs in the remaining terminal branches of the brachial plexus (Table 4).

Figure 4: Median nerve formation by a single root while musculocutaneous nerve gives a communicating branch to median nerve. ***M=****Musculocutaneous nerve,* ***MN=*** *Median nerve* ***CM=*** *Communicating branch of musculocutaneous joining the median nerve.*

Table 1: Correlation between Laterality and variations in segments of brachial plexus

		Side			
		Left	Right	Total	
		Count	Count	Count	Column N %
Roots Variation	Normal	54	48	102	72.9%
	Variant Post fixed	4	5	9	**6.4%**
	Variant Prefixed	12	17	29	**20.7 %**
Trunks Variation	Anterior division of medial trunk connecting with medial nerve	0	1	1	0.7%
	Normal	64	67	131	93.6%
	Superior trunks pass midway via anterior scalene muscle	6	2	8	5.7%
Divisions Variation	Anterior division of medial trunk connecting with medial nerve	2	1	3	2.1%
	Normal	68	69	137	97.9%
Cords Variation	Normal	68	68	136	97.1%
	Variant	2	2	4	2.9%
	TOTAL VARIATION INCIDENCE	**14**	**11**	**25**	**17.8 %**

Table 2: Test for significance between Laterality and variations in sections of brachial plexus

Pearson Chi-Square Tests		
		Side
Roots Variation	Chi-square	1.326
	df	2
	Sig.	.515a
Trunks Variation	Chi-square	3.069
	df	2
	Sig.	.216a,b
Divisions Variation	Chi-square	.341
	df	1
	Sig.	.559a
Cords Variation	Chi-square	.000
	df	1
	Sig.	1.000a
Results are based on nonempty rows and columns in each innermost sub table.		

Table 3: correlation between Laterality and terminal branches of the brachial plexus

		Side			
		Left	Right	Total	
		Count	Count	Count	Column N %
Axillary Variation	Normal	62	56	118	84.3%
	Variant	8	14	22	15.7%
Radial Variation	Normal	68	65	133	95.0%
	Variant	2	5	7	5.0%
Ulnar Variation	Normal	64	58	122	87.1%
	Variant	6	12	18	12.9%

Musculocutaneous Variation	Normal	63	51	114	81.4%
	Variant	7	19	26	18.6%
Median Nerve Variation	Normal	60	59	119	85.0%
	Variant	10	11	21	15.0%
TOTAL VARIATION INCIDENCE		33	61	94	67%

Table 4: Test for significance between Laterality and variations in branching of brachial plexus

Pearson Chi-Square Tests		
		Side
Axillary Variation	Chi-square	1.941
	Df	1
	Sig.	.164
Radial Variation	Chi-square	1.353
	Df	1
	Sig.	.245
Ulnar Variation	Chi-square	2.295
	Df	1
	Sig.	.130
Musculocutaneous Variation	Chi-square	6.802
	Df	1
	Sig.	.009*
Median Nerve Variation	Chi-square	.056
	df	1
	Sig.	.813
Results are based on nonempty rows and columns in each innermost suitable.		
*. The Chi-square statistic is significant at the .05 level.		

Table 5: Frequency distribution of variations of terminal branches of brachial plexus

		Male	Female	Total	Percentage
		Frequency	Frequency	L+R UL	%
Auxiliary Nerve	Normal	61	57	118	84.2
	Variant	9	13	22	15.8
Radial Variation	Normal	68	65	113	95
	Variant	2	5	7	5
Ulnar Variation	Normal	61	61	121	86.4
	Variant	9	9	18	13.6
Musculocutaneous Variation	Normal	59	55	114	81.4
	Variant	11	15	26	18.6
Median Nerve Variation	Normal	56	63	119	85
	Variant	14	7	21	15

DISCUSSION

Difference in variation of right and left brachial plexus of the study population.

It was observed that of the total 25 (17.8%) variations in the origin and segments of brachial plexuses, the majority (14) were from the left side while only 11 (7.9%) were from the right. This observation is similar to the reports (Vicente Vanaclocha *et al.*, 2015) who established that variations of the supraclavicular side of the brachial plexus were more on the left side as compared to the right side. This also concurs with reports of (Mohammadreza Emamhadi *et al.*, 2016) in Table 1 in Iranian cadavers which noted that most of suprascapular nerve which emerges from the supraclavicular zone was more on the left side than right side. This type of variation, therefore, establishes a comprehensive understanding by surgeons and neurosurgeons when conducting surgical procedures following injury or carcinomas of the brachial plexus.

It was observed that the highest frequency of variation occurred at the prefixed root of the brachial plexus with 12(8.7%) variations occurring on the left upper limb and 17 (12.13%) occurring at the right upper limb. These findings are dissimilar to (Chaudhary *et al.*, 2012) who found out that most of the variations were postfixed in females than males while assessing the conjunction or co-incidence of a four trunked brachial plexus and a post fixed brachial plexus. However, the findings in the study are similar to the reports of (Kirik *et al.*, 2017) in Turkey who found out that half of the brachial plexus were found to be prefixed, while 15% were post fixed while studying the anatomical variations of the brachial plexus in fetal cadavers. These anatomical variations noted may lead to deviations from the expected dermatological distribution and contribute to the differences in the motor innervation of muscles of the upper limb. This can further contribute to pathological changes on the upper limbs, might produce conditions that are clinically attributable to abnormal relations between the brachial plexus and ribs and altered surgical approaches of brachial plexus.

In this study, the right upper limbs had the highest incidence of variations in the branching patterns of brachial plexus at 43% (61) whilst the left had a variation incidence of only 23.5% (33). This is in agreement with observations of (Uysal *et al.*, 2003) who found out that most of the brachial plexus variations were from right (19.5%), (12%) and left (10.5%), (11.5%) among female and male respectively while assessing the brachial plexus variations in human fetuses. This study therefore postulates that although the variations are more on the right side than left side, this might interfere much with the surgical procedures at that moment and time.

Studies of Miguel Pereira da Costa *et al.* (2019) while assessing the emergence of upper and lower trunk noted that the upper trunk variation of brachial plexus were of the right part of male adult cadavers.

It was observed that the highest frequency of variation was of musculocutaneous nerve (18.6%) with 19 (13.6%) variations occurring on the right side whilst only 7 (5%) variations occurred on the left side. These results are similar to the reports of Bhattarai and Poudel (2009) in Nepal who established a 6.25% of variation of musculocutaneous nerve which was unilaterally of the right side while assessing the unusual variation in musculocutaneous nerve. Here musculocutaneous nerve variation of right side pierced the coracobrachialis muscles to run downwards between short head biceps brachii and medial intermuscular septa to join the median nerve on the medial side of the arm. In the current study Figure 3, musculocutaneous nerve branched into 2 where the right branch pierced coracobrachialis muscle while the left remained afloat.

In Figure 3, the musculocutaneous nerve gives a branch that communicates with median nerve which is an anomaly. In rare cases of variation, musculocutaneous nerve does not pierce coracobrachialis muscle however it can be observed joining the median nerve at the arm Nasrabadi *et al.* (2017).These types of variations might provide important knowledge in understanding the peripheral nerve distribution as this remains the leading cause of pain and dysfunctional injuries around the shoulder joint. On the other hand, median and musculocutaneous nerve variations can be noted during the embryonic life, and this may be due to several factors influencing mechanism of forearm muscle development. During the development of brachial plexus, as the axonal spinal fibers grow distally into the limb buds to give a dorsal and ventral division, the latter will give rise to median and ulnar nerve whereby musculocutaneous nerve later develops from the median nerve. Therefore, any developmental abnormalities might lead to significant variation(Nasrabadi *et al.*, 2017; Schoenwolf *et al.*, 2020).

In the current study, it was observed that there was a statistically significant difference (p=0.008) in the variation of distribution of median nerve in relation to the sexes. This is in agreement with the observations of Pandey and Shukla (2007) in India where it was established that median nerve variation prevalence was 12.8% and 13.2% among male and females respectively. These changes are variant in terms of origin, location and course in relation to axillary artery. This study therefore postulates that this kind of variation are more prone during radical neck dissection and axilla surgical procedures. Formation of median nerve occur laterally to axillary artery in axilla, which is normal anatomy, however, median nerve can be associated with variations in the abnormal communication with nerves like musculocutaneous and ulnar nerves or even splitting and penetrating vessels. The following anatomical variations were observed in the reports of (Budhiraja *et al.*, 2017; Samarawickrama, 2017) in Brazil where in 22.4% of upper limbs 3 roots took part in formation of median nerve, 6.12% medial to axillary artery and 1.53% anterior to axillary artery.

In the current study Figure 4, it was observed that median nerve was formed by a single root which is abnormal rather than the normal two roots. It was also observed that the brachial artery was superficial to the median nerve which is abnormal as compared to normal anatomy brachial artery courses below the median nerve.

In this study table 5, among the variations at the terminal branches, the musculocutaneous nerve had the highest variation at 18.6% (26) while the least was the radial nerve at 5% (7). (Mohammadreza Emamhadi *et al.*, 2016)recorded 3 variations in the ulnar nerve and noted that ideally the ulnar nerve originates from the medial cord, but in their study, it received a communicating branch from the lateral cord while the median nerve received communication from the posterior cord yet it was supposed to receive communication from the lateral and medial cord. In this study, variation of the ulnar and the median nerve was higher than the previous study because the communications received by this branch were from the posterior, lateral and medial cords combined thus increasing the number of variations.

Although this may be confusing to the surgeon during treatment of neck surgeries, the communications received from other variant branches may as well have a saving effect to the parts innervated. In case of diseases, injury or tumor of specific regions affecting the functioning of nerves innervating the regions, there can be an alternate pathway for nerve transmission which will help to prevent further injury and loss of function in the affected areas. Similarly, (Aktan *et al.*, 2001; Benes *et al.*, 2021)in their study which was to determine the relationship between the terminal branches of the brachial plexus and the functioning of the arm that was done on 48 Turkish cadavers noted a lot of variations in the branches which could cause confusion to the health care providers and surgeons during assessment of nerve injuries like carpal tunnel syndrome, cubital tunnel syndrome and other neuropathies. However, they also noted that these variations in connections may also be good because they may provide sensory or motor innervation when an alternate nerve has trauma or defect and cannot function. They advised that since the variants had both positive and negative implications, it was important to identify the type of variant that an individual had so that management could be established early enough.

Another study by (Patel & Smith, 2023) on 39 previously dissected cadavers among them 20 females and 19 males observed variations in the musculocutaneous branch where it was formed by the medial and the lateral cords and even changed its course of movement to innervate additional muscles of the anterior fore arm apart from the coracobrachialis, biceps and the brachialis. The same case applies to the present study where the musculocutaneous nerve had the highest variation which could be attributed to receiving branches from the posterior and medial cord. This could affect the conduction of plexus blockade as a component of anesthesia in the upper arm.

Further studies by (Yang *et al.*, 2009)in China on 306 cadavers observed how variations in the brachial plexus could facilitate the deterioration of the functioning of the axillary artery. The previous study found variations in 12 study subjects whose axillary nerves merged from the lateral and medial cord and ran anteromedial towards the axillary artery which brought intertwining of the artery and nerve therefore compromising the activity of the axillary artery and the other blood vessels adjacent to them. In the present study, 22 axillary nerves had variations which was higher than the previous study. These variations included originating from lateral and medial cord, or both combined which could highly interfere with the distribution of the axillary artery. This could seriously affect the functioning of the upper limb due to numbness and reduced circulatory flow.

Other variations on the branches of the brachial plexus were observed by (Guday *et al.*, 2017)) where radial nerve received communication from the inferior trunk in 7% of the cases, the ulnar nerve had communication with the lateral cord in 30% of the cases while the median nerve originated from the 2 lateral roots and the medial root in 52% of the cases. This variation from the previous studies were higher than the present study and this could be attributed to the gender and geographical location.

CONCLUSION

Musculocutaneous nerve variations are more common with most of the variation occurring on the right-side compared to left side. The multiple astonishing anatomical variations found had significant clinical correlation. This diversity suggests some level of impairment in the target muscle extreme challenge in administration of regional anesthetic injection nerve block. As in anatomical variation whereby median nerve had 3 interconnections around the axillary artery, this can lead to entrapment and vascular problems. These unfamiliar spreading of variant nerve is vulnerable to injury and can also expedite diversified scope of muscle debilitation. Clinicians and principally neuro and vascular surgeons must assert a high extent of intuition for their respective existence, if confronted with Bp variations they must be prepared in a suitable state to transform their curative and surgical intersession and to ensure excellent action design for the sufferer.

RECOMMENDATIONS

Early pre-operative radiological imaging to detect any anomaly of brachial plexus. A lot more studies should be done on the causes of anatomical variations in terms of origin and embryological characteristics and to explore more on genetics and or with environmental components.

Conflict of interest: No conflict of interest

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