박 사 학 위 논 문

Anatomical Correlation between the Muscles and Neurovascular Structures in the Arm

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이 논문을 박사학위 논문으로 제출함

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1. Introduction

In human, the muscles of the anterior part of the arm are the biceps brachii muscle (BBM), the coracobrachialis muscle (CBM), and the brachialis muscle (BM). The origin of the BBM consists of two part, namely, the coracoid process (CP) of the scapula and the supraglenoid tubercle of the scapula. This muscle is the most powerful flexor muscle (1). The CBM has been characteristically described as originating from the tip of the CP of the scapula, where it blends with the short head of the BBM and inserts into the medial surface of the shaft of the humerus. Its main functions are to assist with flexion and adduction of the humerus and to maintain the head of the humerus within the glenoid fossa. The musculocutaneous nerve (MCN) is a terminal branch of the lateral cord of the brachial plexus that pierces the CBM (2, 3). The BM is an elbow flexor that originates from the distal anterior humerus and inserts onto the ulnar tuberosity (4-6). The muscles in the anterior part of the arm were innervated by MCN (7) and supplied by the branches of the axillary and brachial arteries.

The brachial artery (BA) is an extension of the axillary artery originating at the inferior border of the teres major muscle (TM) and is the major artery of the upper extremity. The BA courses along the ventral surface of the arm and gives rise to multiple smaller branching arteries before reaching the cubital fossa. It give off small branches including the deep brachial artery (DBA) (8), the superior ulnar collateral artery, and the inferior ulnar collateral artery.

The brachial plexus originates from the anterior divisions of the spinal nerve roots of C5-T1. It is composed of the roots, trunks, divisions, cords, and branches. The brachial plexus terminates in the median nerve

(MN), MCN, ulnar nerve, radial nerve, and axillary nerve that supplies motor and sensory innervation to the upper extremity.

Variations in these muscles, such as supernumerary heads of the BBM, have been reported frequently (9-12). Some anomalies in the CBM manifested as an accessory slips of the muscle inserted into the medial epicondyle (ME) and medial supracondylar ridge of the humerus (2, 13). Furthermore, cases wherein the MCN does not pierce the muscle or variant innervations of the muscle have also been reported (2). A connection between the MN and MCN may form an additional loop (14). In 5% of cases, the MN loop is present (15). All these variations add to the complexity of the arm anatomy. Variations in the muscular or neurovascular structures have been well studied; however, their correlation has not yet been studied.

In this study, the anterior parts of 103 cadaveric arms were dissected to identify the topography of the muscular and neurovascular structures and to analyze the correlation between these structures. The findings of this study have clinical and embryological implications and can be helpful for accurate diagnostic interpretation.

2. Materials and Methods

2.1. Dissection and length of the structures of the anterior part of the arm:

In this study, the anterior part of 103 cadaveric arms (from 52 donated cadavers) were dissected. Each cadaver was placed in a supine position with arms extended and palms facing up (16). The skin and superficial fascia were removed to dissect the BBM, CBM and BM. Subsequently, the axillary sheath and adipose tissue were removed to expose the neurovascular structures. After the BA, the brachial plexus and muscles of the arm were dissected from the adipose tissue and fascia, and the structures was identified (Figure 1-4). The length of the structures was measured using digital calipers (NA500-300S, Blue bird, Korea). The reference line represents the distance from CP to ME. The distance between the CP and inferior border of the TM, distance from the root of MN to the CP, distance pierced point of the CBM by the MCN from the CP, the DBA from CP, distance of the proximal insertion of the CBM from CP, distal insertion of the CBM from the CP, origin of the BM from the CP, length of the BM, overlapped part of the CBM and BM, insertion of the short head of the BBM from the CP, insertion of the long head of the BBM from the head of the humerus, and merged point of the two heads of the BBM from the CP were measured (Figure 1).

The length of the each variable is described by the length of the reference line as a percentile. The correlation between the muscles and neurovascular structures was analyzed.

2.2. Type classification of the variation:

The BBM classification was determined by the presence of an accessory head as the most common variation of the arm. Three types of variation were included in the BA. First, the positional relationship between the BA and MN was classified as medial to medial, medial to lateral, lateral to lateral, lateral to medial. The presence of the superficial BA was also identified. Subsequently, the number of branches of the DBA was identified. For the identification of nerve variations, the connection between the MN and MCN was classified.

2.3. Statistical analysis:

All statistical analyses were conducted using SPSS (version 22.0, IBM SPSS®; Chicago, IL). The Mann-whitney U test and Kruskal - Wallis test were used to compare the variables. The Pearson correlation test was used to analyze the correlation between the muscles and neurovascular structures. Statistical significance was set at $P < 0.05$.

3. Results

3.1. The distance from the coracoid process, and length of the muscle and neurovascular structures:

The topography of the muscle and neurovascular structures in upper limb was successfully confirmed in 103 cadaveric arms. The average total length of the upper limb was found to be 486.83 mm (± 31.31 mm). The reference line is the distance from the CP to the ME, which is the distal tip of the humerus. Its average length was 262.50 mm (± 21.07 mm).

With respect to this reference line, the distance between the CP and proximal insertion of the CBM was 109.03 ± 16.78 mm (41.66%). The length between the CP and the distal insertion of the CBM was 147.36 ± 16.04 mm (56.36%). The origin of the BM was located at 48.39% (126.78 ± 13.91 mm). The BBM has the long head and short head. The short and long heads were inserted at 110.84% (290.19 ± 24.74 mm) and 107.51% (281.33 ± 23.87 mm) from the CP, respectively. These two heads were merged at 75.74% (198.04 ± 29.42 mm). The CBM and BM overlapped part was 10.2% (26.5 ± 13.84 mm) (Figure 5). The distance from the CP to the inferior border of the TM was 88.75 ± 12.39 mm (33.91%) (Figure 6). The origin of the DBA was 29.31% (76.5 ± 24.45 mm) from the CP. The root of the MN was at 11.03% (29.06 ± 24.81 mm) from the CP. The point of the MCN piercing the CBM was at 18.35% (48.43 ± 20.11 mm) (Figure 7) (Table 1,2).

3.2. Types of variations in the brachial artery and the median nerve:

First, the pattern of the BA and MN were classified according to their positional relationship. Based on the position of the MN, the BA ran from medial to medial 71/102 (69.6%), medial to lateral 20/102 (19.6%), lateral to lateral 8/102 (7.8%), and lateral to medial 3/102 (2.9%), respectively (Figure 8). The BA continued deep to the MN; however, a superficial course of the BA (superficial BA) was found 9/103 (8.7%) cadaveric arms (Figure 9). The typical pattern of DBA originating from the BA was 74/98 (75.75%) arms. As its variation, an additional branch of the DBA was found in 24/98 (24.5%) arms (Figure 10).

The variation that shows that in 13/103 (12.6%) arms, the MCN was connected to the MN, and no connection was found between the MN and MCN in 90/103 (87.3%) arms (Figure 11).

3.3. Correlation among the variation and location of the muscle and neurovascular structures:

The average of length of each structures is listed in Table 1. Table 2 displays the anatomical locations of each structures as a percentile. The presence of the accessory head of the BBM was found in 12/103 (11.65%) arms and was absent in 91/103 (88.35%). The anatomical locations of the each structure according to the presence of an accessory head are summarized in Table 3. When the accessory head was present, the length of the upper limb was longer (506.25 ± 32.55 mm) than when it was absent (484.27 ± 30.41 mm, P = 0.022).

The anatomical location according to the presence of an accessory head as a percentile is summarized in Table 4. The distal insertion point of the CBM was different according to the presence of an accessory head (56.8 ± 6.7 mm vs. 53.04 ± 6.56 mm); however, this difference did not reach statistical significance (P = 0.071). The anatomical location according to the presence of an accessory head is presented in Table 5 wherein each variable was divided by the total length of the upper limb. The distal insertion of the CBM was more proximal in limbs with an accessory head (28.18 ± 3.54 mm) than in those without it (30.59 ± 2.94 mm, P = 0.011). The long head of the BBM was shorter in limbs with an accessory head (55.11 ± 2.17%) than in those without it (58.18 ± 3.72%, P = 0.006). The other structures did not vary according to the presence of the accessory head.

Table 6 shows the anatomical location of each structure according to the presence of the connection between the MN and MCN. According to the connection between the MN and MCN, the DBA appeared earlier in those without the connection (12/103 vs. 90/103, 64.15 ± 29.86 mm vs. 78.28 ± 23.23 mm) (P = 0.051). Table 7 showed the anatomical location according to the presence of the connection of the MN and MCN as a percentile, but this value was not significant. The anatomical location according to the presence of the connection of the MN and MCN by upper limb is indicated in Table 8. The percentile according to the upper limb of the distance between the CP and the CBM was shorter than without the connection (32.01 ± 2.71% vs. 30.06 ± 3.08%) (P = 0.033). Other anatomical points did not vary according to the presence of the connection.

The anatomical location of each structure according to the superficial BA is shown in Table 9. The variation with the superficial BA was found in 9/103 arms. The presence of the superficial BA affected the

appearance of the DBA (39.33 ± 36.39% vs. 80.05 ± 19.88%) ($P < 0.001$). These results were the same as those in Tables 10 and 11. Table 12 represents the overall correlation between the structures by the reference line as a percentile. Table 12 shows that the muscles of the arm are related to each other; however, the neurovascular structures have no correlation with other structures.

Table 1. Anatomical Location of the Muscle and Neurovascular Structures

	Mean (mm)	Std. deviation	Minimum	Maximum
Upper Limb	486.83	31.31	420	550
Reference line	262.50	21.07	177	308
CBM proximal insertion	109.03	16.78	73	149
CBM distal insertion	147.36	16.04	114	203
The origin of BM	126.78	13.91	90	161
BM length	170.54	17.05	114	229
BBM short head	290.19	24.74	189	351
BBM long head	281.33	23.87	231	396
Merged point	198.04	29.42	82	261
Overlapped part	26.50	13.84	0	65
TMIB	88.75	12.39	54	124
DBA	76.50	24.45	0	124
MNR	29.06	24.82	0	104
Pierced point of CBM by MCN	48.43	20.12	0	93

Std. deviation : standard deviation

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 2. Anatomical Location of the Muscle and Neurovascular Structures as a Percentile

	Mean (%)	Std. Deviation	Minimum	Maximum
CBM proximal insertion	41.66	6.70	29.67	81.36
CBM distal insertion	56.36	6.73	43.85	95.48
The origin of BM	48.39	4.92	40.41	76.27
BM length	65.22	7.17	45.42	106.21
BBM short head	110.84	9.04	78.75	174.58
BBM long head	107.51	9.27	91.23	168.36
Merged point	75.74	11.37	27.70	101.13
Overlapped part	10.20	5.44	0.00	25.29
TMIB	33.91	4.76	20.00	57.06
DBA	29.31	9.36	0.00	46.61
MNR	11.03	9.43	0.00	43.33
Pierced point of CBM by MCN	18.35	7.32	0.00	32.86

Std. deviation : standard deviation

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 3. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of Accessory Head of the Biceps Brachii Muscle (continued)

	Accessory head (mm)		
	(-) (n = 91)	(+) (n = 12)	*P*-value
Upper Limb	484.27 ± 30.41	506.25 ± 32.55	0.022*
Reference line	261.6 ± 20.89	269.25 ± 22.12	0.239
CBM proximal insertion	109.21 ± 17.03	107.67 ± 15.35	0.766
CBM distal insertion	148.03 ± 15.94	142.25 ± 16.56	0.242
The origin of BM	126.27 ± 14.33	130.58 ± 9.811	0.316
BM length	169.98 ± 16.82	174.83 ± 18.89	0.356
BBM short head	289.48 ± 25.35	295.58 ± 19.55	0.425
BBM long head	281.67 ± 24.62	278.75 ± 17.77	0.692
Merged point	196.91 ± 27.53	206.58 ± 41.7	0.287
Overlapped part	27.01 ± 13.29	22.67 ± 17.69	0.309
TMIB	88.78 ± 12.48	88.5 ± 12.24	0.942
DBA	76.97 ± 23.71	72.92 ± 30.45	0.592
MNR	27.82 ± 24.01	38.42 ± 29.73	0.166
Pierced point of CBM by MCN	47.23 ± 20.1	57.5 ± 18.58	0.097

*$P < 0.05$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 4. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of Accessory Head of the Biceps Brachii Muscle as a Percentile

	Accessory head (%)		
	(-) (n = 91)	(+) (n = 12)	*P*-value
CBM proximal insertion	41.85 ± 6.78	40.21 ± 6.43	0.429
CBM distal insertion	56.8 ± 6.7	53.04 ± 6.56	0.071
The origin of BM	48.36 ± 5.15	48.62 ± 3.09	0.868
BM length	65.23 ± 7.3	65.14 ± 6.76	0.968
BBM short head	110.95 ± 9.46	110.04 ± 5.65	0.747
BBM long head	108 ± 9.59	103.83 ± 5.94	0.146
Merged point	75.51 ± 10.59	77.48 ± 16.99	0.579
Overlapped part	10.44 ± 5.29	8.44 ± 6.65	0.235
TMIB	34.01 ± 4.63	33.17 ± 6.02	0.569
DBA	29.54 ± 9.01	27.54 ± 12.3	0.493
MNR	10.6 ± 9.24	14.26 ± 11.02	0.210
Pierced point of CBM by MCN	17.97 ± 7.42	21.26 ± 6.43	0.145

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 5. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of Accessory Head of the Biceps Brachii Muscle by Upper Limb

	Accessory head (%)		
	(-) (n = 91)	(+) (n = 12)	*P*-value
CBM proximal insertion	22.52 ± 2.97	21.35 ± 3.42	0.213
CBM distal insertion	30.59 ± 2.94	28.18 ± 3.54	0.011*
The origin of BM	26.06 ± 2.39	25.8 ± 1.24	0.713
BM length	35.14 ± 3.19	34.63 ± 4	0.615
BBM long head	58.18 ± 3.72	55.11 ± 2.17	0.006**
Merged point	40.71 ± 5.53	41.08 ± 8.71	0.842
Overlapped part	5.6 ± 2.77	4.51 ± 3.55	0.220
TMIB	18.3 ± 2.05	17.61 ± 3.02	0.299
DBA	15.93 ± 4.91	14.54 ± 6.2	0.374
MNR	5.73 ± 5.05	7.57 ± 5.94	0.249
Pierced point of CBM by MCN	9.69 ± 3.97	11.3 ± 3.37	0.185

*$P < 0.05$, **$P < 0.01$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 6. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of the Connection of the Median Nerve and Musculocutaneous Nerve

	Connection (mm)		
	(−) (n = 90)	(+) (n = 13)	*P*-value
Upper Limb	487.54 ± 31.6	481.92 ± 29.96	0.548
Reference line	262.81 ± 21.49	260.31 ± 18.54	0.691
CBM proximal insertion	108.38 ± 16.6	113.54 ± 18.05	0.302
CBM distal insertion	146.38 ± 16.09	154.15 ± 14.47	0.103
The origin of BM	127.52 ± 13.56	121.62 ± 15.74	0.153
BM length	170.37 ± 17.87	171.77 ± 9.99	0.783
BBM short head	290.01 ± 25.58	291.46 ± 18.6	0.844
BBM long head	281.77 ± 24.92	278.31 ± 15.09	0.628
Merged point	196.8 ± 30.45	206.62 ± 19.73	0.263
Overlapped part	25.78 ± 14.01	31.54 ± 11.86	0.162
TMIB	88.89 ± 12.82	87.77 ± 9.28	0.762
DBA	78.28 ± 23.23	64.15 ± 29.86	0.051
MNR	29.19 ± 23.97	28.15 ± 31.18	0.889
Pierced point of CBM by MCN	49.33 ± 19.62	42.15 ± 23.14	0.231

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 7. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of the Connection of the Median Nerve and Musculocutaneous Nerve as a Percentile

	Connection (%)		
	(-) (n = 90)	(+) (n = 13)	*P*-value
CBM proximal insertion	41.39 ± 6.88	43.49 ± 5.46	0.296
CBM distal insertion	55.94 ± 6.92	59.29 ± 4.79	0.095
The origin of BM	48.65 ± 5.07	46.59 ± 3.61	0.161
BM length	65.07 ± 7.46	66.24 ± 5.3	0.590
BBM short head	110.65 ± 9.51	112.14 ± 5.28	0.583
BBM long head	107.56 ± 9.75	107.16 ± 5.67	0.886
Merged point	75.18 ± 11.74	79.62 ± 8.3	0.192
Overlapped part	9.91 ± 5.53	12.26 ± 4.68	0.148
TMIB	33.93 ± 5.01	33.74 ± 2.96	0.891
DBA	29.93 ± 8.91	24.95 ± 11.8	0.074
MNR	11.07 ± 9.17	10.76 ± 11.84	0.915
Pierced point of CBM by MCN	18.71 ± 7.17	15.89 ± 8.41	0.198

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 8. Anatomical Location of the Muscle and Neurovascular Structures according to the Presence of the Connection of the Median Nerve and Musculocutaneous Nerve by Upper Limb

	Connection (%)		
	(−) (n = 90)	(+) (n = 13)	*P*-value
CBM proximal insertion	22.22 ± 2.99	23.5 ± 3.17	0.154
CBM distal insertion	30.06 ± 3.08	32.01 ± 2.71	0.033*
The origin of BM	26.16 ± 2.28	25.16 ± 2.15	0.141
BM length	34.98 ± 3.36	35.74 ± 2.57	0.442
BBM long head	57.82 ± 3.86	57.83 ± 2.48	0.999
Merged point	40.44 ± 6.08	42.97 ± 4.42	0.150
Overlapped part	5.3 ± 2.9	6.62 ± 2.53	0.125
TMIB	18.23 ± 2.26	18.21 ± 1.55	0.980
DBA	16.11 ± 4.8	13.44 ± 6.33	0.076
MNR	5.96 ± 5.01	5.83 ± 6.4	0.932
Pierced point of CBM by MCN	10.06 ± 3.82	8.64 ± 4.58	0.226

*$P < 0.05$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 9. Anatomical Location of the Muscle and Neurovascular Structures according to the Superficial Brachial Artery

	Superficial BA (mm)		
	(-) (n = 94)	(+) (n = 9)	*P*-value
Upper Limb	487.03 ± 32.14	484.78 ± 22.07	0.838
Reference line	262.52 ± 21.41	262.22 ± 18.17	0.968
CBM proximal insertion	109.44 ± 16.73	104.78 ± 17.78	0.429
CBM distal insertion	147.4 ± 16.33	146.89 ± 13.48	0.927
The origin of BM	127.18 ± 13.84	122.56 ± 14.77	0.343
BM length	169.89 ± 17.28	177.33 ± 13.25	0.213
BBM short head	289.82 ± 25.41	294.11 ± 16.65	0.621
BBM long head	281.6 ± 24.73	278.56 ± 12.18	0.717
Merged point	198.24 ± 29.68	195.89 ± 28.19	0.820
Overlapped part	25.87 ± 12.9	33.11 ± 21.33	0.135
TMIB	88.41 ± 12.20	92.22 ± 14.65	0.381
DBA	80.05 ± 19.88	39.33 ± 36.39	<0.001*
MNR	27.96 ± 23.99	40.56 ± 31.63	0.147
Pierced point of CBM by MCN	48.21 ± 20.11	50.67 ± 21.24	0.728

*$P < 0.001$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 10. Anatomical Location of the Muscle and Neurovascular Structures according to the Superficial Brachial Artery as a Percentile

	Superficial BA (%)		
	(-) (n = 94)	(+) (n = 9)	*P*-value
CBM proximal insertion	41.83 ± 6.82	39.91 ± 5.84	0.417
CBM distal insertion	56.38 ± 6.91	56.15 ± 5.24	0.924
The origin of BM	48.55 ± 4.98	46.73 ± 4.58	0.295
BM length	64.97 ± 7.3	67.84 ± 5.9	0.256
BBM short head	110.7 ± 9.4	112.33 ± 4.62	0.609
BBM long head	107.61 ± 9.62	106.49 ± 5.38	0.733
Merged point	75.86 ± 11.72	74.54 ± 8.07	0.743
Overlapped part	9.96 ± 5.11	12.74 ± 8.33	0.145
TMIB	33.78 ± 4.73	35.22 ± 5.47	0.392
DBA	30.62 ± 7.64	15.57 ± 14.72	<0.001*
MNR	10.59 ± 9.14	15.58 ± 12.22	0.133
Pierced point of CBM by MCN	18.27 ± 7.31	19.14 ± 8.24	0.737

*$P < 0.001$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 11. Anatomical Location of the Muscle and Neurovascular Structures according to the Superficial Brachial Artery by Upper Limb

	Superficial BA (%)		
	(−) (n = 94)	(+) (n = 9)	*P*-value
CBM proximal insertion	22.46 ± 3.01	21.58 ± 3.32	0.409
CBM distal insertion	30.31 ± 3.15	30.32 ± 2.65	0.992
The origin of BM	26.11 ± 2.25	25.25 ± 2.52	0.283
BM length	34.93 ± 3.29	36.62 ± 2.86	0.140
BBM long head	57.86 ± 3.83	57.5 ± 2.05	0.782
Merged point	40.8 ± 6.05	40.32 ± 4.83	0.819
Overlapped part	5.34 ± 2.67	6.87 ± 4.46	0.127
TMIB	18.15 ± 2.1	19.02 ± 2.92	0.252
DBA	16.49 ± 4.13	8.28 ± 7.73	<0.001*
MNR	5.71 ± 5	8.38 ± 6.55	0.139
Pierced point of CBM by MCN	9.83 ± 3.91	10.37 ± 4.35	0.696

*$P < 0.001$

All location was measured from coracoid process (CP) except the length of the brachialis muscle (BM), short and long heads of the biceps brachii muscles (BBM)

Reference line : from the coracoid process to medial epicondyle

Merged point : from merged point of the two head of BBM

Overlapped part : overlapped part between the corocobrachialis (CBM) and BM

TMIB : teres major inferior border

DBA : deep brachial artery

MNR : median nerve root

Table 12. Overall Correlation of between the Muscle and Neurovascular Structures by the Reference Line as a Percentile

		Reference line	CBM proximal insertion	CBM distal insertion	the origin of BM	BM length	BBM short head	BBM long head	Merged point	Overlapped part	TMIB	DBA	MNR	Pierced point of CBM by MCN
Reference line	Cor	1	-.463**	-.479**	-.471**	-.483**	-.660**	-.622**	-.298**	-.218*	-.490**	-0.139	-0.006	-0.085
	P		0	0	0	0	0	0	0.002	0.026	0	0.16	0.951	0.392
CBM proximal insertion	Cor	-.463**	1	.744**	.538**	.357**	.541**	.465**	0.184	.210*	.433**	0.052	0.093	0.156
	P	0		0	0	0	0	0	0.062	0.033	0	0.602	0.35	0.114
CBM distal insertion	Cor	-.479**	.744**	1	.423**	.458**	.551**	.492**	.237*	.523**	.332**	0.062	0.039	-0.025
	P	0	0		0	0	0	0	0.015	0	0.001	0.534	0.697	0.801
the origin of BM	Cor	-.471**	.538**	.423**	1	-0.016	.417**	.311**	.274**	-.279**	.443**	0.182	-0.113	.287**
	P	0	0	0		0.87	0	0.001	0.005	0.004	0	0.064	0.253	0.003
BM length	Cor	-.483**	.357**	.458**	-0.016	1	.610**	.743**	.205*	.526**	.297**	-0.118	0.125	-0.091
	P	0	0	0	0.87		0	0	0.037	0	0.002	0.232	0.204	0.358
BBM short head	Cor	-.660**	.541**	.551**	.417**	.610**	1	.706**	.246*	.318**	.462**	0.17	0.042	0.054
	P	0	0	0	0	0		0	0.012	0.001	0	0.084	0.675	0.589
BBM long head	Cor	-.622**	.465**	.492**	.311**	.743**	.706**	1	0.183	.300**	.389**	-0.039	-0.002	0.06
	P	0	0	0	0.001	0	0		0.063	0.002	0	0.696	0.983	0.543
Merged point	Cor	-.298**	0.184	.237*	.274**	.205*	.246*	0.183	1	0.105	0.163	0.101	-0.101	0.099
	P	0.002	0.062	0.015	0.005	0.037	0.012	0.063		0.288	0.099	0.306	0.309	0.317
Overlapped part	Cor	-.218*	.210*	.523**	-.279**	.526**	.318**	.300**	0.105	1	0.114	-0.075	0.15	-0.166
	P	0.026	0.033	0	0.004	0	0.001	0.002	0.288		0.249	0.448	0.129	0.093
TMIB	Cor	-.490**	.433**	.332**	.443**	.297**	.462**	.389**	0.163	0.114	1	0.065	0.024	0.148
	P	0	0	0.001	0	0.002	0	0	0.099	0.249		0.513	0.808	0.134
DBA	Cor	-0.139	0.052	0.062	0.182	-0.118	0.17	-0.039	0.101	-0.075	0.065	1	0.072	-0.037
	P	0.16	0.602	0.534	0.064	0.232	0.084	0.696	0.306	0.448	0.513		0.467	0.707
MNR	Cor	-0.006	0.093	0.039	-0.113	0.125	0.042	-0.002	-0.101	0.15	0.024	0.072	1	0.15
	P	0.951	0.35	0.697	0.253	0.204	0.675	0.983	0.309	0.129	0.808	0.467		0.128
Pierced point of CBM by MCN	Cor	-0.085	0.156	-0.025	.287**	-0.091	0.054	0.06	0.099	-0.166	0.148	-0.037	0.15	1
	P	0.392	0.114	0.801	0.003	0.358	0.589	0.543	0.317	0.093	0.134	0.707	0.128	

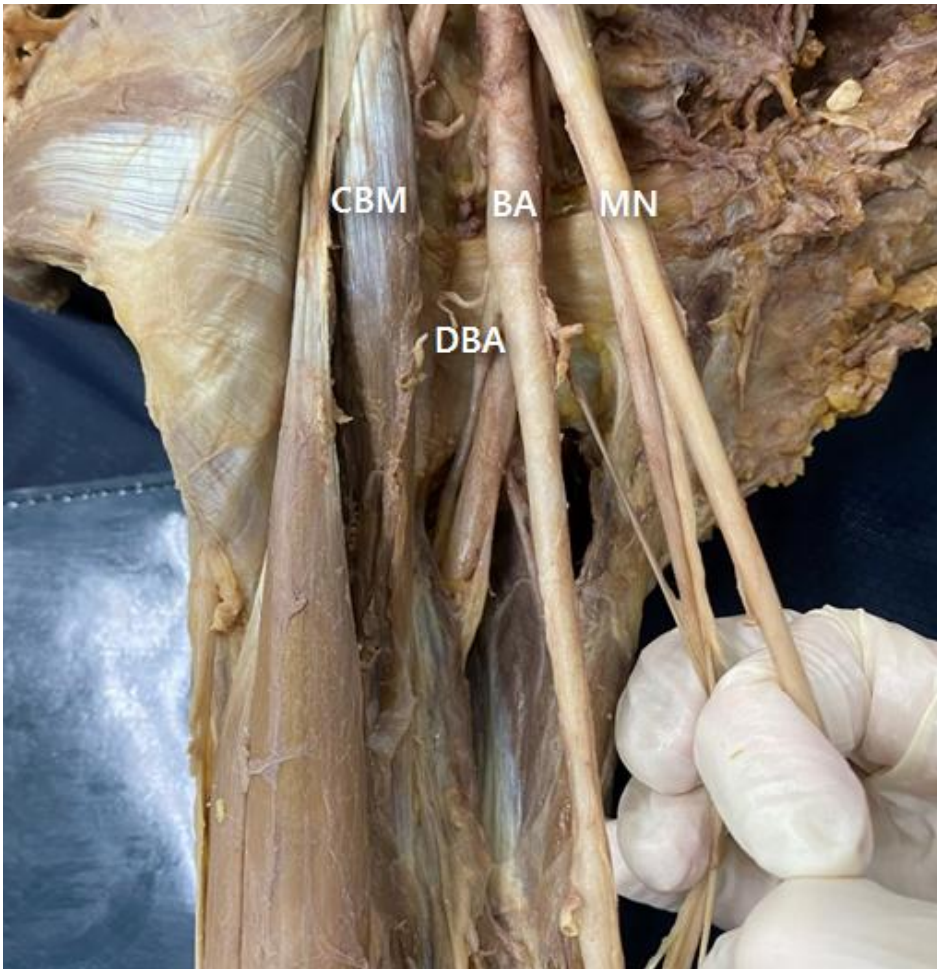

Figure 1. Identification of the muscles and neurovascular structures in axilla. CBM, coracobrachialis muscle; BA, brachial artery; MN, median nerve; DBA, deep brachial artery.

Figure 2. Identification of the muscles and neurovascular structures in upper limb. MCN, musculocutaneous nerve; MN, median nerve; TM, teres major muscle; LH, biceps brachii long head; SH, biceps brachii short head.

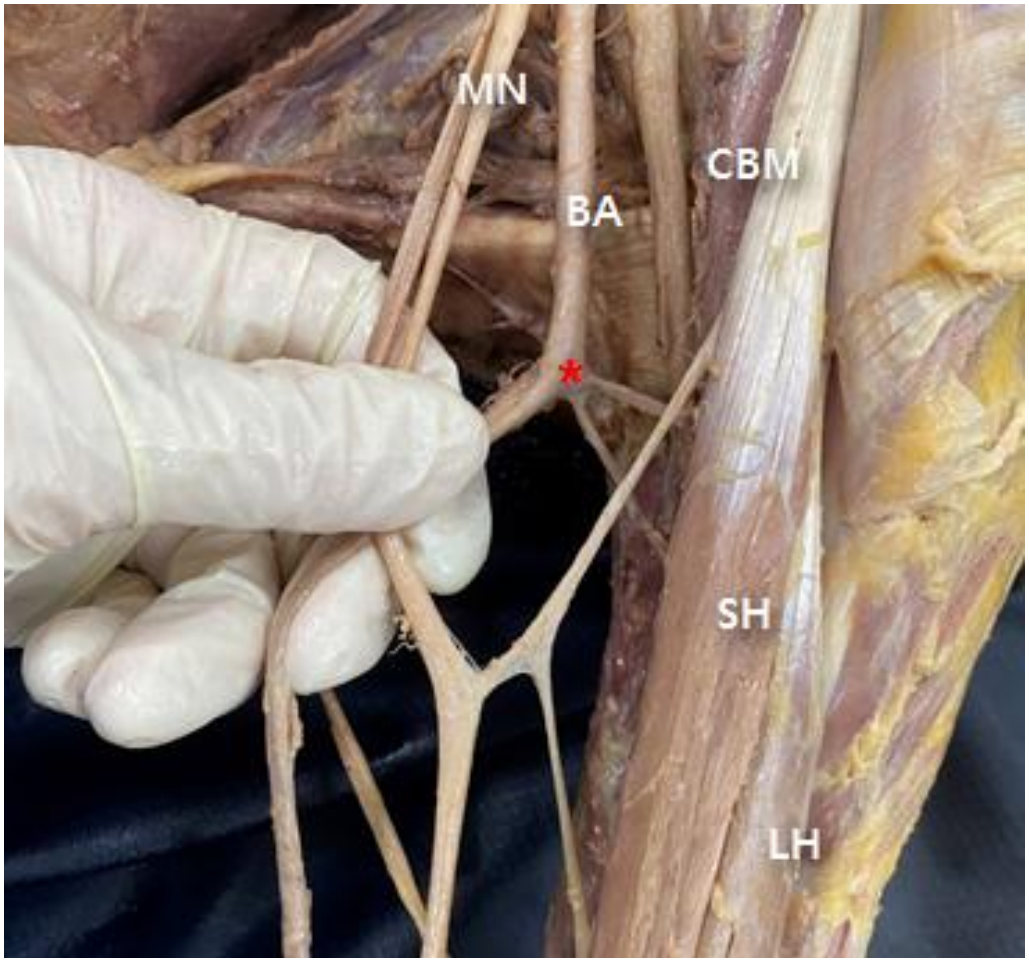

Figure 3. Identification of the double branching of the deep brachial artery. MN, median nerve; BA, brachial artery; CBM, coracobrachialis muscle; LH, biceps brachii long head; SH, biceps brachii short head; *, deep brachial artery double branch.

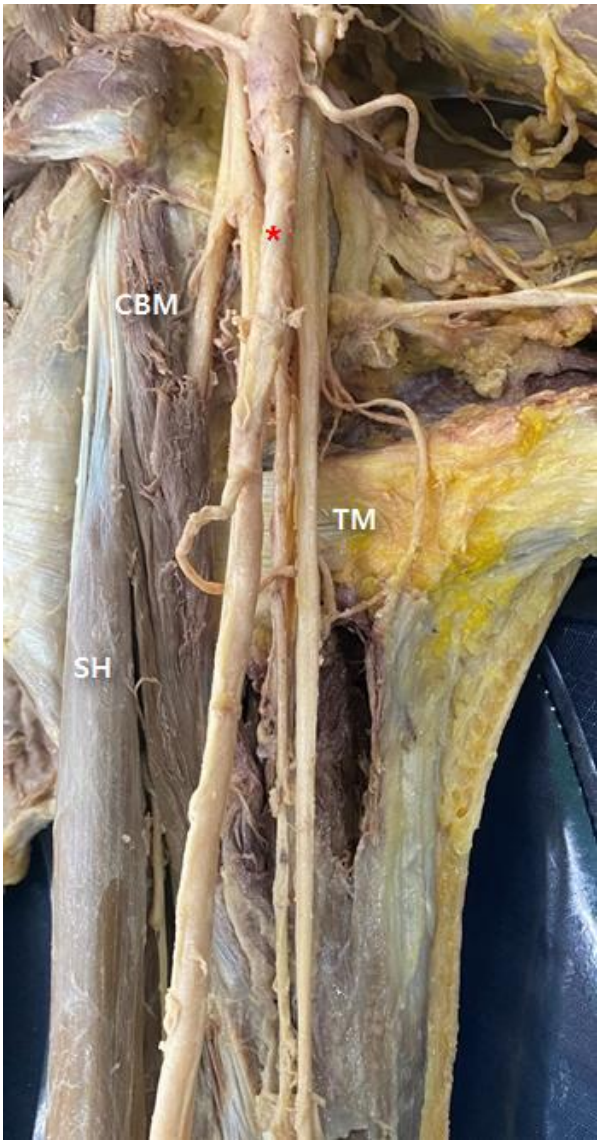

Figure 4. Identification of superficial course of the brachial artery named as superficial brachial artery. CBM, coracobrachialis muscle; TM, teres major muscle; SH, biceps brachii short head; *, superficial brachial artery.

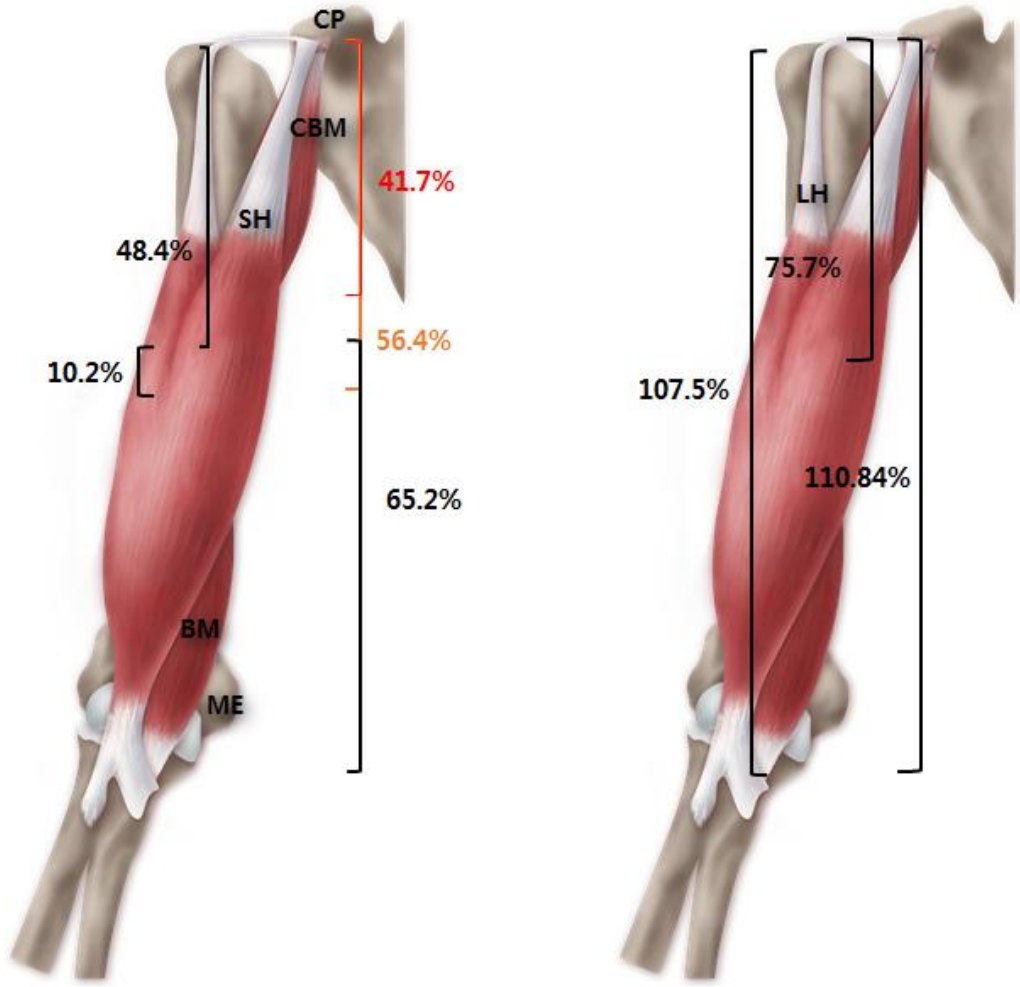

Figure 5. The length of the muscles by the length of the reference line as a percentile. CP, coracoid process; CBM, coracobrachialis muscle; SH, biceps brachii short head; BM, brachialis muscle; ME, medial epicondyle; LH, biceps brachii long head.

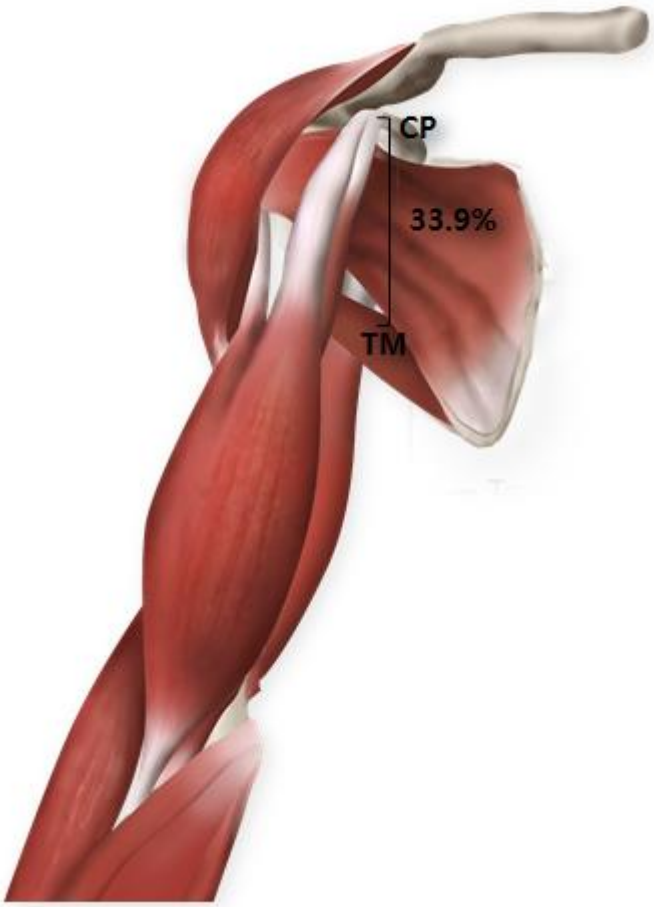

Figure 6. The length of inferior border of the teres major by the length of the reference line as a percentile. CP, coracoid process; TM, teres major.

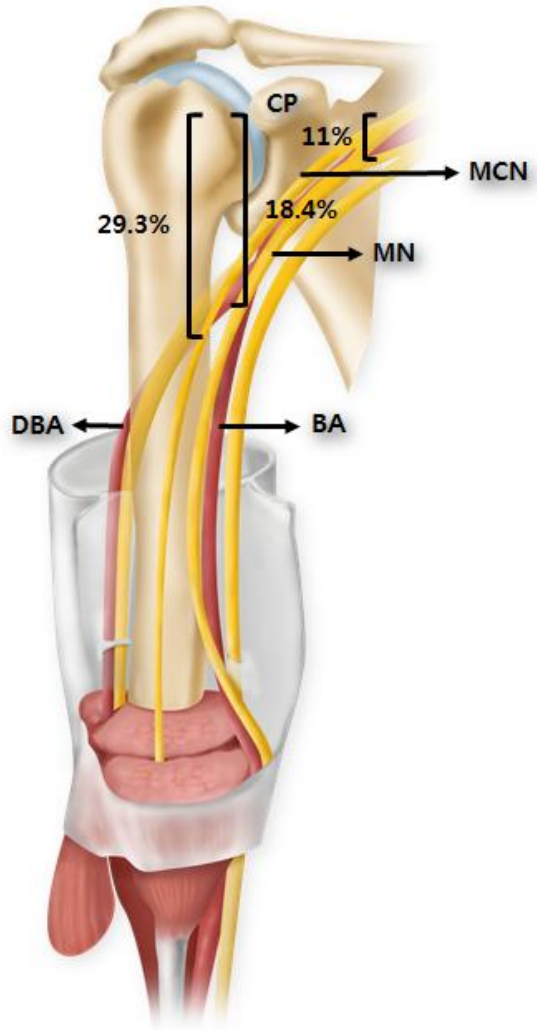

Figure 7. The distance of the neurovascular structures by the length of the reference line as a percentile. CP, coracoid process; MCN, musculocutaneous nerve; MN, median nerve; BA, brachial artery; DBA, deep brachial artery.

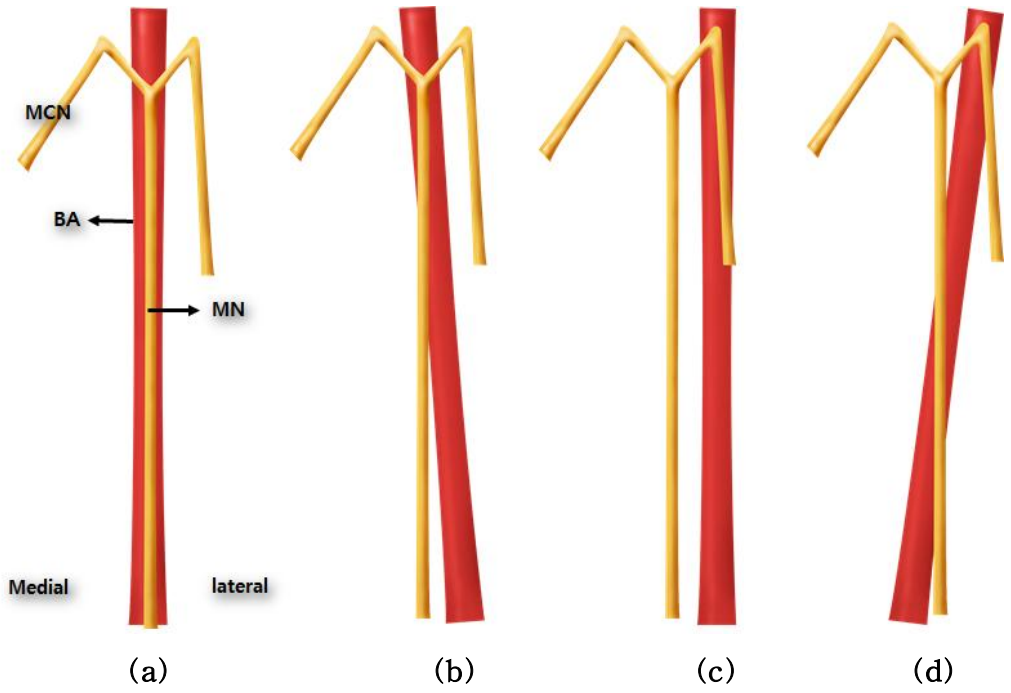

Figure 8. The positional relationship between the brachial artery and the median nerve. (a) medial to medial (b) : medial to lateral (c) : lateral to lateral (d) : lateral to medial. MCN, musculocutaneous nerve; BA, brachial artery; MN, median nerve.

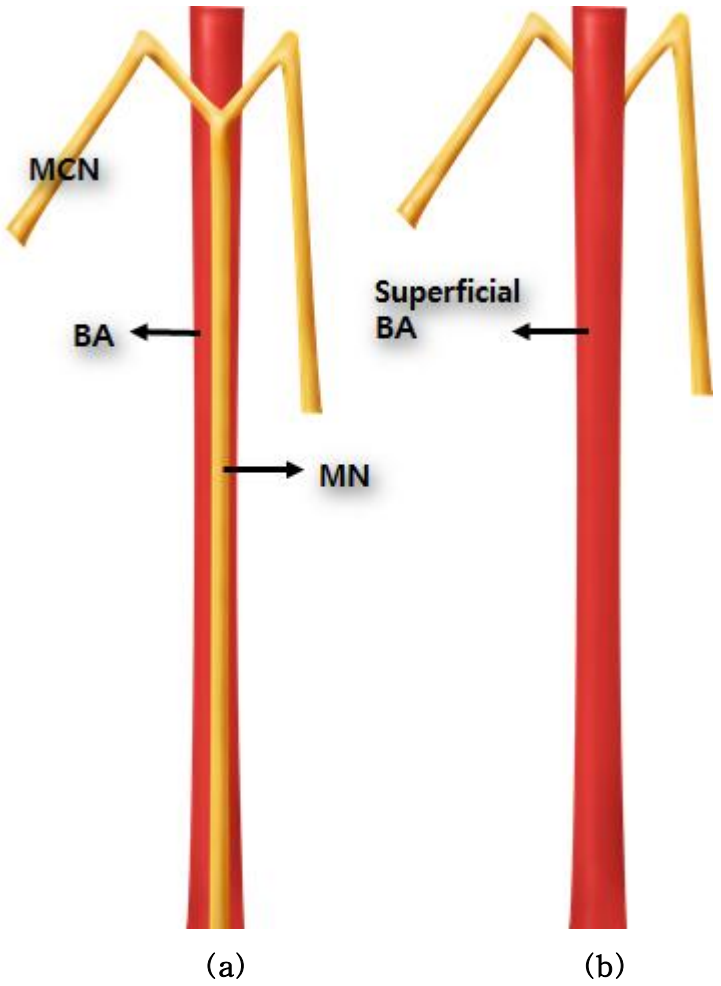

Figure 9. The pattern of the brachial artery based on the relation with the median nerve. (a) normal type of the brachial artery (b) superficial course of the brachial artery. MCN, musculocutaneous nerve; BA, brachial artery; MN, median nerve.

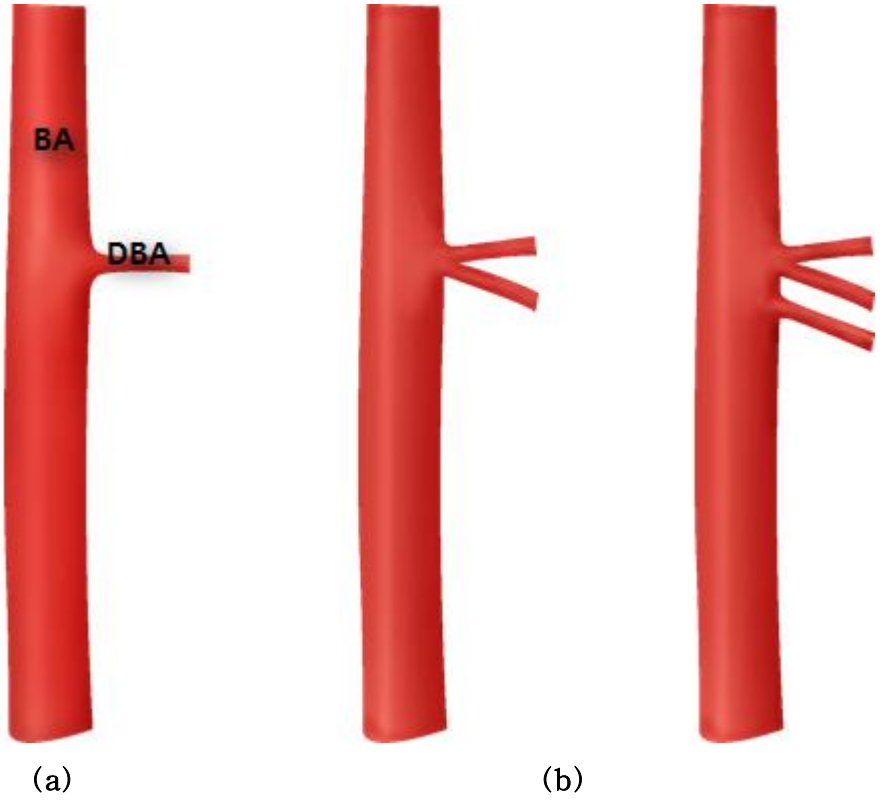

Figure 10. Branching pattern of the deep brachial artery. (a) normal type of the deep brachial artery (b) abnormal type of the deep brachial artery. BA, brachial artery; DBA, deep brachial artery.

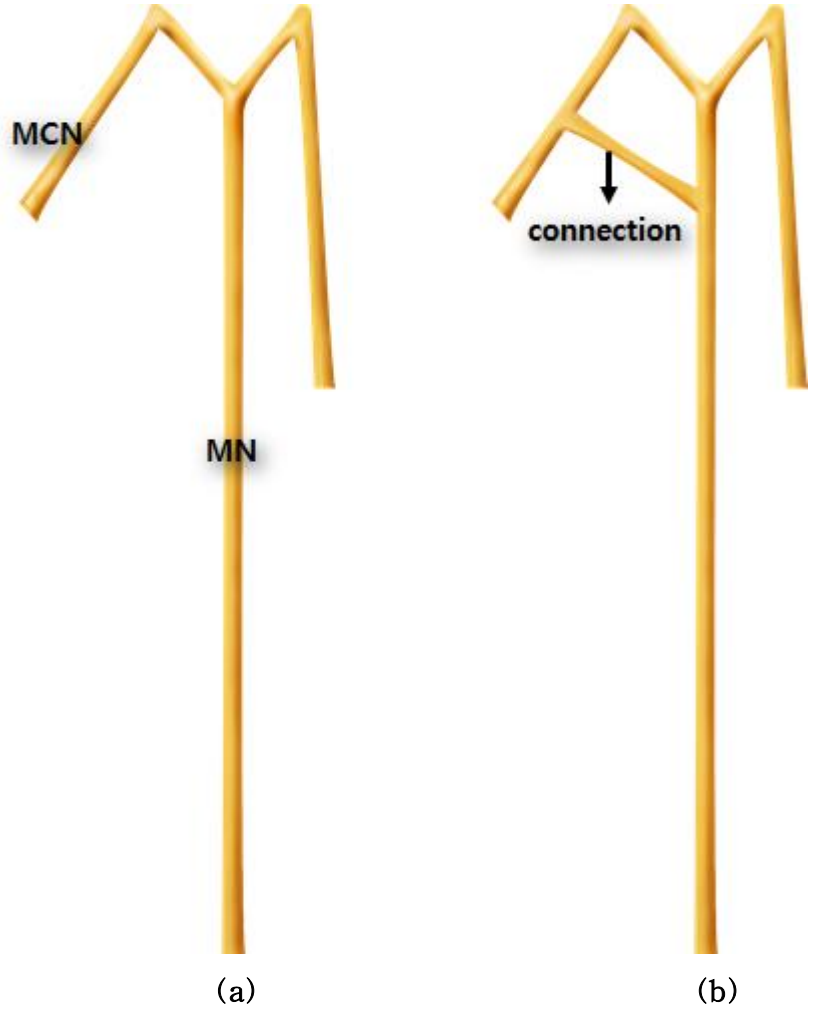

Figure 11. The variation of the connection between the median nerve and the musculocutaneous nerve. (a) normal type of the brachial plexus (b) the connection between the median and the musculocutaneous nerves. MCN, musculocutaneous nerve; MN, median nerve.

4. Discussion

The structures of the anterior part of the arm include the BBM, CBM, BM, MN, MCN, BA and DBA. The arm muscles function as the flexor of the elbow joint. The BA is responsible for blood supply of the arm (17) and the arm muscles are innervated by the MCN (3, 7).

Many authors have reported variations in the muscular and neurovascular structures of the arm (9, 12, 14, 18-21). In these structures, the number and pattern of the BBM are the most variable features. The frequency of the accessory head ranges from 8% to 37.5% (22). In this study, the accessory head of the BBM was found in 11.65% of Korean cadavers. Interestingly, the length of the upper limb was significantly longer in cadavers with the accessory head than in those without it. However, the percentile level by the reference line between the CP and the CBM was shorter in cadavers with the accessory head than in those without it. In addition, the accessory head was associated with a shorter percentile level of the length of the long head of the BBM. If the arm is longer, the muscles require more space; therefore, the frequency of additional muscle may increase. When additional muscles are present, other muscles near the variant muscles may be inserted differently. Therefore, I suggest that additional variant muscles can affect the length of other muscles. However, its embryological mechanism should be further investigated.

In the MCN and MN, failure of nerve fibers to segregate within the brachial plexus into the common anatomic form often leads to distal communicating fibers or abnormal branch patterns (23). The frequency of this communication was reported from 1.4% to 63.5% and it was associated with other variations (7, 9, 12, 14, 15). In this study, the

DBA appeared earlier when the connection between the MN and MCN was present than when it was absent. This connection was associated with the short percentile distance between the CP and the CBM. Because the nerves and blood vessels are formed together embryologically (24), it is possible that nervous variation may affect other structures, especially the arterial structures. As the MCN pierces the CBM, the presence of this connection could be associated with the position of the CBM.

In the early embryonic stage, arterial development in the upper limb is characterized by the formation of the superficial and deep pathways anastomosed at different levels of the arm (25). The BA possesses two main arterial stems, namely, a BA and superficial BA, and then superficial BA disappers, a BA gives off one branch, which is the DBA. The DBA was classified into seven types by previous study (8). The finding of this study show that the presence of superficial BA affected the earlier branching of the DBA and that arterial variation can influence the branching point of other arteries.

In the Pearson correlation test, the anatomical location of arm muscles was correlated to each other but not with the neurovascular structures. According to previous studies (11, 16), the development of muscular structures may affect the topography of the neurovascular structures. However, the development of neurovascular structures did not have any effect on muscular anatomy.

All these variations add to the complexity of the arm anatomy. In clinical surgery, the choice of plate position depends on the fracture morphology and location, nerve pathology and surgeon's preference. Proximally, the plate may interfere with the deltoid insertion if it is placed laterally or with the long head of the biceps tendon if it is placed anteriorly. In addition, the DBA could be at risk if the plate is applied

to the lateral surface of the distal accessory. The plate should be twisted to ensure that the distal end avoids damaging DBA (26). For this reason, it is crucial to confirm the anatomy of the arm in the upper extremity fracture (27-30).

In conclusion, this study elucidated the topography of the arm structures and analyzed their correlations. These data demonstrate that the variation in the arm structures could affect other structures of the arm. However, in the absence of the variation, the location of the muscles is correlated each other, but the location of the neurovascular system did not affect other structures. This result contributes to the embryological knowledge of the arm structures and has important values in clinical fields.

5. Summary

In this article, I dissected 103 upper arms to identify the topography of the muscular and neurovascular structures and then, their correlation was analyzed. The reference line is the distance from the coracoid process (CP) to the medial epicondyle (ME). The length of the each variable describe by the length of the reference line as percentile. When the accessory head was present, the length of the upper limb was longer than that absent. Distal insertion point of CBM was more proximal in limb with accessory head than that without it. And the length of long head of BBM was shorter in limb with accessory head than that without it. According to the connection between MN and MCN, DBA are appeared earlier than without the connection. The presence of the superficial BA affected to earlier division of DBA.

This information is particularly useful for surgeons and clinicians. I tried to provide important information to anatomical research and clinicians.

References

1. Landin D, Thompson M, Jackson MR. Actions of the biceps brachii at the shoulder: A review. J Clin Med Res 2017;9(8):667-670.

2. Ilayperuma I, Nanayakkara B, Hasan R, Uluwitiya S, Palahepitiya K. Coracobrachialis muscle: Morphology, morphometry and gender differences. Surg Radiol Anat 2016;38(3):335-340.

3. Osborne AW, Birch RM, Munshi P, Bonney G. The musculocutaneous nerve. J Bone Joint Surg Br 2000;82(8):1140-1142.

4. Herrera JE, Cooper G. Essential sports medicine. Springer; 2008.

5. Leonello DT, Galley IJ, Bain GI, Carter CD. Brachialis muscle anatomy. A study in cadavers. J Bone Joint Surg Am 2007 Jun;89(6):1293-1297.

6. Plantz MA, Bordoni B. Anatomy, Shoulder and Upper Limb, Brachialis Muscle. [Updated 2020 Sep 18]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551630/

7. Nakatani T, Tanaka S, Mizukami S. Absence of the musculocutaneous nerve with innervation of coracobrachialis, biceps

brachii, brachialis and the lateral border of the forearm by branches from the lateral cord of the brachial plexus. J Anat 1997;191(3):459-460.

8. Epperson TN, Varacallo M. Anatomy, Shoulder and Upper Limb, Brachial Artery. [Updated 2021 Jul 26]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537145/

9. Abu-Hijleh MF. Three-headed biceps brachii muscle associated with duplicated musculocutaneous nerve. Clin Anat 2005;18(5):376-379.

10. Saluja S, Das SS, Kumar D, Goswami P. Bilateral three-headed biceps brachii muscle and its clinical implications. Int J Appl Basic Med Res 2017;7(4):266-268.

11. Kervancioglu P, Orhan M. An anatomical study on the three-headed biceps brachii in human foetuses, and clinical relevance. Folia Morphol (Warsz) 2011;70(2):116-120.

12. Asvat R, Candler P, Sarmiento EE. High incidence of the third head of biceps brachii in south african populations. J Anat 1993;182 (Pt1)(Pt 1):101-104.

13. Zielinska N, Duparc F, Polguj M, Borowski A, Olewnik Ł. A proposal for a new classification of the coracobrachialis longus: A

rare case or a new, distinct muscle? Ann Anat 2022;239:151825.

14. Darvishi M, Moayeri A. Anatomical variations of the musculocutaneous and median nerves: A case report. Folia Med (Plovdiv) 2019;61(2):327-331.

15. Claassen H, Schmitt O, Wree A, Schulze M. Variations in brachial plexus with respect to concomitant accompanying aberrant arm arteries. Ann Anat 2016;208:40-48.

16. Yang K, Jung S, Lee H, Choi I, Lee J. Topographical relations between the gantzer's muscle and neurovascular structures. Surg Radiol Anat 2017;39(8):843-848.

17. Tucker WD, Arora Y, Mahajan K. Anatomy, Blood Vessels. [Updated 2021 Aug 11]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470401/

18. Cai H, Annaswamy TM. Trifid median nerve: A rare variant in a patient with carpal tunnel syndrome. Am J Phys Med Rehabil 2019;98(6):e67-e68.

19. Clarke E, Wysiadecki G, Haładaj R, Skrzat J. Fusion between the median and musculocutaneous nerve: A case study. Folia Med Cracov 2019;59(3):45-52.

20. Guerri Guttenberg RA, Ingolotti M. Classifying musculocutaneous nerve variations. Clin Anat 2009;22(6):671-683.

21. Honma S, Kawai K, Koizumi M, Kodama K. The superficial brachial artery passing superficially to the pectoral ansa, the highest superficial brachial artery (arteria brachialis superficialis suprema). Anat Sci Int 2011;86(2):108-115.

22. Tubbs RS, Shoja MM, Loukas M. Bergman's comprehensive encyclopedia of human anatomic variation. John Wiley & Sons; 2016.

23. Higashi N, Sone C. A study of the accessory head of the biceps brachii in man. Kaibogaku Zasshi 1988;63(2):78-88.

24. Martin P, Lewis J. Origins of the neurovascular bundle: Interactions between developing nerves and blood vessels in embryonic chick skin. Int J Dev Biol 1989;33(3):379-387.

25. Yoshinaga K, Tanii I, Kodama K. Superficial brachial artery crossing over the ulnar and median nerves from posterior to anterior: Embryological significance. Anat sci Int 2003;78(3):177-180.

26. Michael B, Stanley T, Emily K. B, et al. Dynamic Stabilization of Simple Fractures With Active Plates Delivers Stronger Healing Than Conventional Compression Plating. J Orthop Trauma

2017;31(2):71-77.

27. Asensio JA, Kessler II JJ, Miljkovic SS, et al. Brachial artery injuries operative management and predictors of outcome. Ann Vasc Surg 2020;69:146-157.

28. Dydyk AM, Negrete G, Cascella M. Median Nerve Injury. 2021 Aug 25. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021.

29. Pederson WC. Median nerve injury and repair. J Hand Surg 2014;39(6):1216-1222.

30. Ergunes K, Yilik L, Ozsoyler I, Kestelli M, Ozbek C, Gurbuz A. Traumatic brachial artery injuries. Tex Heart Inst J 2006;33(1):31-34.

Anatomical correlation between the muscles and neurovascular structures in the arm

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(Abstract)

Variations in the muscular and neurovascular structures in upper limbs occur frequently and are extremely diverse. The locations of biceps brachii muscle (BBM), coracobrachialis muscle (CBM), and brachialis muscle (BM) are associated with each other, and their innervation and blood supply vary according to the muscle variation.

This study describes the anatomical correlation between the arm muscles and the neurovascular structures. A total of 103 cadaveric arms were dissected, and the topography of the BBM, CBM, brachial artery (BA), and deep brachial artery (DBA) and the connection between the median nerve (MN) and musculocutaneous nerve (MCN) were evaluated. The reference line is the distance from the coracoid process (CP) to the medial epicondyle (ME). The average of each measurement value was

41.7% (CBM proximal insertion), 56.4% (CBM distal insertion), 48.4% (BM origin), 65.2% (BM length), 10.2% (overlapped length between CBM and BM), 110.84% (the length of the BBM short head), 107.5% (the length of the BBM long head), 75.7% (the merged part of the BBM), 33.9% (the inferior border of the teres major), 11% (MN root), 18.4% (pierced point of CBM by MCN), and 29.3% (DBA origin). In the BBM with an accessory head, the length of upper limb, CBM distal insertion, and long head of the BBM were longer in the arms with an accessory head than in those without it (P = 0.011). The DBA appeared proximally in arms with a connection between the MN and MCN compared to that in arms without a connection (P = 0.051), but the difference was not significant. When the BA continued superficially, the DBA appeared proximally (P < 0.001). Muscles locations are related to each other; however, they do not affect the location of the nerves and vessels. In conclusion, variations in the muscular structure of the arm may affect the topography of other muscular structures. This information provides the embryological association between the muscles

and neurovascular structures. Further studies are required to elucidate its clinical implications.

팔 근육과 신경혈관 구조의 해부학적 상관관계

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(초록)

위팔의 근육 및 신경 혈관 구조의 변화는 매우 다양하고 빈번하다. 위팔두갈래근, 부리위팔근, 위팔근의 위치는 서로 연관되어 있으며 근육의 변화에 따라 신경분포와 혈액공급도 다르다.

따라서 나는 팔 근육과 신경혈관 구조 사이의 해부학적 상관관계를 연구하였다. 총 103개의 팔을 해부하여 위팔두갈래근, 부리위팔근, 위팔동맥, 깊은위팔동맥, 정중신경과 근육피부신경의 연결부위를 측정하였다. 기준선은 부리돌기에서 안쪽위관절융기까지의 거리이다. 각 측정값의 평균은 41.7%(부리위팔근의 몸쪽 닿는곳), 56.4%(부리위팔근의 먼쪽 닿는곳), 48.4%(위팔근의 이는곳), 65.2%(위팔근의 길이), 10.2%(부리위팔근과 위팔근이 겹치는 부분), 110.84%(위팔두갈래근 짧은갈래의 길이), 107.5%(위팔두갈래근 긴갈래의 길이), 75.7%(위팔두갈래근의 두갈래가 만나는 지점), 33.9%(큰원근의 아래쪽 경계), 11%(정중신경의 뿌리), 18.4 %(근육피부신경이 부리위팔근을 지나는 지점) 및 29.3%(깊은위팔동맥의 갈림점)이다. 위팔두갈래근에 변이

가 있는 사체에서 팔 길이, 부리위팔근의 먼쪽 닿는곳 및 위팔두갈래근의 긴 갈래는 변이가 없는 것보다 더 길다(P = 0.011). 정중신경과 근육피부신경 간의 연결이 있을 때 깊은위팔동맥은 연결이 없는 것보다 몸쪽에 가깝다(P = 0.051). 위팔동맥의 변이인 얕은위팔동맥이 있는 경우 깊은위팔동맥은 몸쪽에서 나타난다(P < 0.001). 근육의 위치는 서로 관련이 있지만 신경과 혈관의 위치는 다른 구조에 영향을 미치지 않았다. 결론적으로, 팔의 근육 구조의 변화는 다른 근육 구조의 지형에 영향을 미칠 수 있다. 이 연구는 근육과 신경혈관 구조 사이의 발생학적 연관성을 제공하며, 이에 대한 임상적 의미는 더 논의되고 연구되어야 한다.

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□ 논문 및 저서

「Telomere shortening in non-tumorous and tumor mucosa is independently related to colorectal carcinogenesis in precancerous lesion s」 *Int J Mol Epidemiol Genet*. 2017;8(5):53-58.

「TERT-CLPTM1 locus polymorphism (rs401681) is associated with the prognosis of hepatocellular carcinoma」 *Onco Targets Ther*. 2017;10:4853-4858.

「A TERT-CLPTM1 locus polymorphism (rs401681) is associated with EGFR mutation in non-small cell lung cancer」 *Pathology-Research and Practice*. 2017;213(11):1340-1343.

「Telomere length is correlated with mitochondrial DNA copy number in intestinal, but not diffuse, gastric cancer」 *Oncology letters*. 2017;14(1):925-929.

「Prognostic value of TZAP expression in various cancers: TCGA data analysis」 *Keimyung Medical Journal*. 2018.

「Positive correlation between TZAP and TERT in most cancers: A new player in cancer diseases」 *Ann Transl Med.* 2018.

「Association between telomere length and PIK3CA amplification in gastric cancer」 *Clinical and experimental medicine*. 2018;18(1):133-134.

「TZAP mutation leads to poor prognosis of patients with breast cance r」 *Medicina*. 2019;55(11):748.

「Variations in branching patterns of the anterior circumflex humeral artery」 *Keimyung Medical Journal*. 2018:38-42.

「The prognostic significance of TERT locus polymorphism (rs36115365) in surgically resected non-small cell lung cancer」 *Ann Clin Lab Sci*. 2020;50(5):645-649.

「Clinicopathological characteristics of TZAP expression in colorectal cancers」 *Onco Targets Ther*. 2020;13:12933-12942.

「Participation of memorial ceremony affects student attitude on gross anatomy practice」 *Anatomy & Biological Anthropology*. 2020;33(1):21-25.

「Variation of the sternocleidomastoid muscle: A case report of three heads and an accessory head」 *Surgical and Radiologic Anatomy*. 2020;42(6):711-713.

「No association between telomere length and osteonecrosis of the femoral head」 *BMC Musculoskeletal Disorders*. 2021;22(1):1-5.

「Accuracy of new deep learning model-based segmentation and key-point multi-detection method for ultrasonographic developmental dysplasia of the hip (DDH) screening」 *Diagnostics*. 2021;11(7):1174.