8-19-2022

Comparative Anatomical Study of the Brachial Plexus of Primates

Alison Leann Camero
Grand Valley State University

Comparative Anatomical Study of the Brachial Plexus of Primates

Alison Leann Camero

A Thesis Submitted to the Graduate Faculty of

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

For the Degree of

Master of Health Sciences

Biomedical Sciences

August 2022

Thesis Approval Form

GRAND VALLEY STATE UNIVERSITY

The signatories of the committee members below indicate that they have read and approved the thesis of Alison Leann Camero in partial fulfillment of the requirements for the degree of Master of Health Science in Biomedical Sciences.

8/8/22

Dr. Melissa Tallman, Thesis committee chair — Date

8/8/2022

Dr. Dawn Richiert, Committee member — Date

8/8/2022

Dr. John Capodilupo, Committee member — Date

Accepted and approved on behalf of the College of Liberal Arts and Sciences

Dean of the College

8/11/2022

Date

Accepted and approved on behalf of the Graduate Faculty

Associate Vice-Provost for the Graduate School

8/18/2022

Date

ACKNOWLEDGMENTS

This thesis would not have been possible without the collaborative efforts and support of many people. I could not have undertaken this journey without my mentor, Dr. Melissa Tallman, who provided guidance and support throughout this degree. Because of her, I was able to believe in myself and my future career as an academic. I am also grateful for Dr. Dawn Richiert and Dr. John Capodilupo for serving on my committee, providing valuable feedback and guidance throughout my first time in a research laboratory, writing a thesis, and navigating the process of applying to graduate school. I would like to thank Angela Shall and Emily Lonskey for assisting with dissections. Thank you, Charles River Laboratory in Mattawan, MI; MD Anderson Cancer Center; Wayne State University; Western Michigan University; and Michigan State University for donating the specimens to make this project possible. A special thank you to Central Michigan University for allowing me to collect additional samples.

I would like to extend my sincere gratitude to others in the Biomedical Sciences department. Katie Haynes, thank you for providing a smile and help whenever I needed it. Dr. Kristin Renkema and Dr. Christopher Reed, thank you for always having an open-door policy, lending advice, and providing support. Chris, thank you for allowing me to dissect the monkeys from your laboratory. Special thanks to my close friends, Marlee Curnutt and Nick Bunda, for your support, kindness, and encouragement.

Lastly, I would like to recognize my family for their belief in me. Special recognition to my husband, Caleb, I would not have been able to complete this degree without your daily emotional support, constant affirmations, and love.

ABSTRACT

Old world monkeys, new world monkeys, and humans all originate from a common ancestor. Although humans and old world monkeys are phylogenetically more closely related, old world monkeys and new world monkeys have similar locomotion. A difference in muscle patterns exists between old world monkeys, new world monkeys, and humans. Different musculature may be due to differences in locomotive patterns and species-specific use of their forearms. Muscles in the forelimbs are innervated by the nerves of the brachial plexus. There are differences among the brachial plexuses of human and non-human primates as well as variability within the species.

In this study, we compared the level of variability of the branching patterns of the brachial plexus between primate species as well as within each primate species. Research has been published on the comparative anatomy of primates of bones and skeletal muscles; but little research has been reported on the neural pathway supplying these muscles. Muscular patterns changed with the evolution of locomotive pattern from quadrapedalism to bipedalism. The rates of evolution have been found to be higher in species that locomotive patterns diverged from sister taxon. Understanding the brachial plexus and its level of variability will help better understand the evolution of primate locomotion. Differing levels of variability have been attributed to the evolution of locomotive patterns.

This study analyzed 51 individual specimens and 81 individual brachial plexuses of old world monkeys, new world monkeys, and *Homo sapiens*. Each of the specimens were photographed and a written description given. The results showed that old world monkeys and new world monkeys exhibited similar levels of variability which were collectively higher than

that of *Homo sapiens*. Discussions of these variant branching patterns and levels of variability help build an understanding of the results discovered in this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

MCN: musculocutaneous nerve

MN: median nerve

UN: ulnar nerve

AN: axillary nerve

RN: radial nerve

BP: brachial plexus

n: number of individual specimens

np: number of individual brachial plexuses

ABBREVIATIONS

Figure labels used for Figures 8 to 31 and Appendix Figures 1 to 33

C4: C4 root

C5: C5 root

C6: C6 root

C7: C7 root

C8: C8 root

T1: T1 root

T2: T2 root

1: superior trunk

2: middle trunk

3: inferior trunk

4: lateral cord

5: medial cord

6: posterior cord

7: musculocutaneous nerve

8: median nerve

9: ulnar nerve

10: axillary nerve

11: radial nerve

12: dorsal scapular nerve

13: suprascapular nerve

14: nerve to subclavius

15: lateral pectoral nerve

16: medial pectoral nerve

17: ansa pectoralis

18: medial cutaneous nerve of forearm

19: lateral cutaneous nerve of forearm

20: superior subscapular nerve

21: middle subscapular (thoracodorsal) nerve

22: inferior subscapular nerve

CBM: *m. coracobrachialis*

AA: axillary artery

CHAPTER 1: INTRODUCTION

Understanding primate anatomy helps piece together phylogenetic relationships and evolutionary patterns. Phylogenetic relationships are constructed based on genetic and/or morphological characteristics of different species (Diogo & Wood, 2012; Harris, 2015; Dongoghue & Cracraft, 2004). In many previous studies, soft tissue analyses have been used to compare the phylogenetic relationships from muscular studies and from molecular studies; however, few studies have included neural tissues (Shearer, 2019). This study observed the brachial plexus in different old world monkey species, new world monkey species, and humans. Humans are more closely related to old world monkeys than to new world monkeys; however, locomotive patterns are more similar between old world monkeys and new world monkeys than to humans (Diogo & Wood, 2012; Gebo, 2014; Harris, 2015; Dongoghue & Cracraft, 2004). Locomotive patterns are reflected in the arrangement of muscles in these different species. The non-human primates are often quadrupedal, meaning that all four limbs are used during locomotion. This could include walking, climbing, leaping, or suspending (Harris, 2015; Gebo, 2014). There is a difference in muscle patterns in non-human primates due to the difference in the way they use their forelimbs. Many of these differences in muscle are within the digit I, the pollicis or "thumb" (Diogo, Richmond, & Wood, 2012). This musculature difference is due to the fact that humans have more manual dexterity in their hands and use their hands for more intricate and controlled movements compared to old and new world monkeys which mainly use their hands for grasping onto objects (Diogo, Richmond, & Wood, 2012; Boyle, Mahon, & Diogo, 2020; Harris, 2015; Gebo, 2014).

Due to a difference in muscle patterns, the brachial plexus in these different species should look different (Diogo, Richmond, & Wood, 2012). The brachial plexus is made up nerves from spinal roots C5 to T1 which innervate the muscles in the arm, forearm, and hand (Agur, Dalley, & Grant, 2017). The brachial plexus is known to be one of the most variant structures in the human body, making up about 50% of all variations found in the human body (Singhal, Rao, & Ravindranath, 2007). Although there has been research on bone structure and musculature in non-human primates, there has been little research on the neural pathways supplying the muscles. Understanding and knowing the common variations in the brachial plexus in non-human and human primate species is important. In an evolutionary sense, understanding the changes in the brachial plexus is integral to understanding the rate of evolution during locomotive pattern changes. Many of these non-human primates are used as a biological model used to research surgical procedures like nerve blocks, restoring function of nerves, and effects of trauma (Santos-Sousa, et al., 2016). In this study, we are looking for the level of variance of the brachial plexus within a species and comparing that between species to investigate whether the level of variability in the brachial plexus is similar between the primate species being studied.

Purpose, Assumptions, and Hypothesis

The purpose of this study is to determine the level of variability of the brachial plexus between primate species. We assume that: (1) brachial plexuses are variant within all primate species, (2) variations are related to differences in genetic and developmental factors, and (3) levels of variability can be attributed to different patterns of selection.

Therefore, we hypothesize that there will be more variability in human primate brachial plexuses compared to new world monkeys and old world monkeys due to the unique adaptations in manual dexterity humans made when evolving from their common ancestor. Current research reports humans have additional forearm and extrinsic hand muscles that are absent in other primates. These additional muscles could cause more variability in the branching pattern of the brachial plexus because they are involved in intricate fine motor movements (Diogo, Richmond, & Wood, 2012).

CHAPTER 2: REVIEW OF LITERATURE

Review of Primate Species Included in Research

The phylogenetic relationships between old world monkeys, new world monkeys, and humans have been reconstructed based on genetic and morphological characteristics (Diogo & Wood, 2012; Dongoghue & Cracraft, 2004; Harris, 2015). Old world monkeys and humans are under the parvorder Catarrhini and new world monkeys are under the parvorder Platyrrhini (Perelman, Johnson, Roos, Seuánez, & Horvath, 2011). The divergence of Catarrhini and Platyrrhini occurred about 43 million years ago (Perelman, Johnson, Roos, Seuánez, & Horvath, 2011) (Figure 1). There are differences in the locomotor pattern between old world monkeys and new world monkeys which stem from the environment in which the species live (Dunn & Cristóbal-Azkarate, 2016; Lawrence & Cords, 2012). Old world monkeys come from Africa, Asia, and Europe; and have a mixture of terrestrial and arboreal locomotor patterns. New world monkeys come from the Americas; and have arboreal locomotive patterns as they spend most of their time in the trees (Dunn & Cristóbal-Azkarate, 2016). Some new world monkeys have the ability to grasp objects with their tails to help them in arboreal locomotion (Dunn & Cristóbal-Azkarate, 2016). Based on phylogenetics, humans are more closely related to old world monkeys than to new world monkeys (Diogo & Wood, 2012; Dongoghue & Cracraft, 2004; Harris, 2015). Although humans and old world monkeys are closely related, when humans diverged, a variety of very specific species-wide adaptations occurred (Harris, 2015). Some of these include bipedal walking, increased brain to body ratio and increased manual dexterity (Gebo, 2014; Harris, 2015). Due to these unique adaptations in humans, locomotive patterns between the old world monkeys and new world monkeys are more similar than either are to humans.

Non-human primates have differences in muscles in the forelimb due to the difference in how human and non-human primates use their forelimbs (Diogo, Richmond, & Wood, 2012). Many of the studies on primate musculature are based on a small sample size, making it difficult to determine a usual muscle pattern. Broadly speaking, non-human primates have the following muscles that are typically absent in humans: *mm. contrahentes digitorum*, *m. levator claviculae*, *m. rhomboideus occipitalis*, *m. dorsoepithrochlearis*, *m. panniculus carnosus*, and three *m. deltoid*: anterior, middle, and posterior (Diogo, Richmond, & Wood, 2012; Boyle, Mahon, & Diogo, 2020). Humans do not usually have these muscles, but all these muscles can appear as a variation (2-5%) or as an anomaly (4-20%) in humans (Boyle, Mahon, & Diogo, 2020). The *m. contrahentes digitorum* in monkeys function similarly to the adductor pollicis and flexor indicis muscles in humans (Boyle, Mahon, & Diogo, 2020; Yamamoto, Murakami, & Ohtsuka, 1988). In some non-human primates, the *m. contrahentes digitorum* exist for all digits and are named in accordance to the digit in which they are associated. In humans, the *m. contrahentes digitorum* are present during embryonic development, but *m. contrahentes III, IV,* and *V* disappear leaving I and II to develop into the *m. adductor pollicis* in humans. The presence of *m. contrahentes III, IV,* and *V* can lead to problems such as hand cramping or compressing the median nerve (Boyle, Mahon, & Diogo, 2020; Yamamoto, Murakami, & Ohtsuka, 1988). The *m. levator claviculae* assists in thoracic breathing and neck rotation (Natsis, et al., 2009). The *m. levator claviculae* is found in about 1-3% of humans; its presence has been associated with vascular thoracic outlet syndrome due to the muscle crossing over the brachial plexus (Natsis, et al., 2009). The *m. dorsoepithrochlearis* is a flexor of the elbow (Boyle, Mahon, & Diogo, 2020; Aversi-Ferreira, Pereira-de-Paula, Prado, Lima-e-Silva, & Mata, 2007). The *m. dorsoepithrochlearis* is lost during human embryonic development due to differentiation of the *m. latissimus dorsi* and possibly the *m. teres major* (Boyle, Mahon, & Diogo, 2020). There is little research about the *m. rhomboid occipitalis*, but it is thought to have a similar action to the *mm. rhomboid major* and *minor* in humans, to retract the scapula (Rogawski, 1990). The *m. rhomboid occipitalis* is commonly found in other mammals. The *m. rhomboid occipitalis* is not usually found in humans, but when it is, it is commonly tied to clinical symptoms or misinterpreted as a tumor (Rogawski, 1990; Gradev, Malinova, Kasaboglu, & Jelev, 2020). The *m. panniculus carnosus* is a muscle that allows twitching and movement of the skin and is considered a nonessential muscle in humans (Naldaiz-Gastesi, Bahri, Munain, McCullagh, & Izeta, 2018). The *m. panniculus carnosus* is however found covering the *m. platysma* in non-human primates and is hypothesized to persist in that area due to the neck being a high risk area for animal attack (Naldaiz-Gastesi, Bahri, Munain, McCullagh, & Izeta, 2018). The three *mm. deltoid* in non-human primates behave similarly to the unit *m. deltoid* in a human. Due to quadrupedal locomotion in non-human primates, the more distal attachment of the *m. deltoid*, at the deltoid tuberosity, helps with supporting shoulders when pulling their body forward when moving terrestrially. The abduction, flexion, and extension actions of *m. deltoid* help provide support during brachiation (Aversi-Ferreira, Pereira-de-Paula, Prado, Lima-e-Silva, & Mata, 2007).

Old world and new world monkeys use their upper limbs walking quadrupedally, climbing, suspending, or leaping (Harris, 2015; Gebo, 2014). Although arboreal monkeys need to grasp branches and other arboreal substrates while moving, they do not have the same manual dexterity found in humans. Digit I in monkeys is often used more as a hook to hold onto curved surfaces as they swing from trees and grasp onto branches (Gebo, 2014; Harris, 2015). Humans are bipedal and use their forelimbs for more fine motor movements. The additional muscles associated with digit I in humans contribute to humans' increased need for manual dexterity

(Diogo, Richmond, & Wood, 2012; Gebo, 2014; Harris, 2015). The main additional muscles present in humans that are not found in old world and new world monkeys specifically involve digit I, the pollicis (Diogo, Richmond, & Wood, 2012). These additional muscles are a distinct *m. flexor pollicis longus* and *m. extensor pollicis brevis* (Diogo, Richmond, & Wood, 2012). Because humans have a longer digit I and these additional muscles, humans can perform more fine motor movements with their hands (Diogo, Richmond, & Wood, 2012; Gebo, 2014; Harris, 2015). The *m. flexor pollicis longus* allows for flexion of digit I at the metacarpophalangeal and interphalangeal joints along with wrist flexion at the carpometacarpal joint (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). The *m. extensor pollicis brevis* allows for extension of the proximal phalanx of digit I at the metacarpophalangeal joint and extension of the wrist at the carpometacarpal joint (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). Because there are different muscles within old world and new world monkeys' forearm, their innervation patterns will be different than that of humans (Diogo, Richmond, & Wood, 2012).

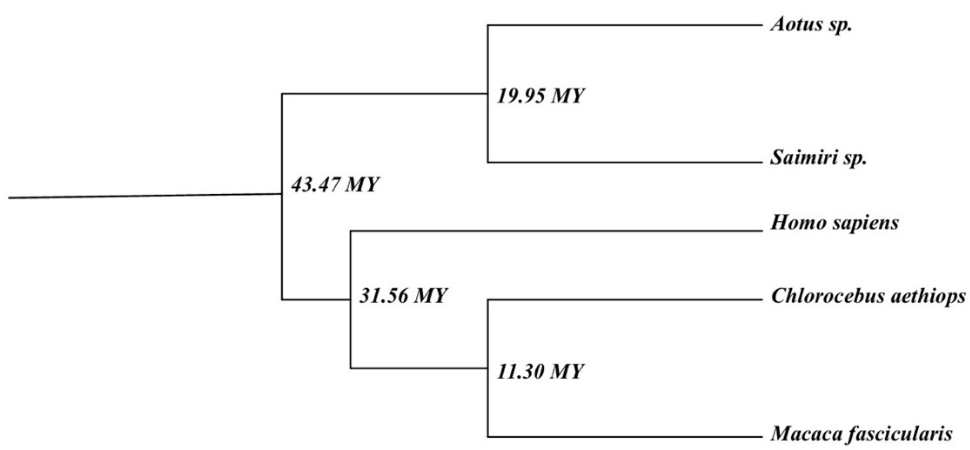


Figure 1. Phylogenetic tree of species used in this study.
Phylogenetic tree of the new world monkeys, old world monkeys, and *Homo sapiens* used in this study. MY: million years. Figure adapted from Perelman et al. 2011.

Anatomy of the Brachial Plexus

<u>Homo sapiens</u>

A typical human brachial plexus (Figure 2) is composed of roots from ventral rami of spinal nerves C5-T1. C5 and C6 combine to create the superior trunk, C7 creates the middle trunk, and C8 and T1 combine to create the inferior trunk (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). Each trunk has an anterior and posterior division. The anterior division of the superior trunk combines with the anterior division of the middle trunk to create the lateral cord. The anterior division of the inferior trunk creates the medial cord. The posterior division from the superior, middle, and inferior trunk all combine to create the posterior cord (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). Terminal nerves originate from different sections of the brachial plexus. The dorsal scapular nerve and the long thoracic nerve both originate from the roots. The suprascapular nerve and nerve to subclavius originate from the superior trunk (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). The lateral cord forms the lateral pectoral nerve, musculocutaneous nerve, and the lateral head of the median nerve. The medial cord forms the medial pectoral nerve, ulnar nerve, and medial head of the median nerve. The upper subscapular nerve, thoracodorsal (middle subscapular) nerve, lower subscapular nerve, axillary nerve, and radial nerve all originate from the posterior cord (Agur, Dalley, & Grant, 2017; Moore, Agur, Dalley, & Moore, 2015). The terminal branches of the brachial plexus extend from the cords carry both sensory and motor innervation (Table 1).

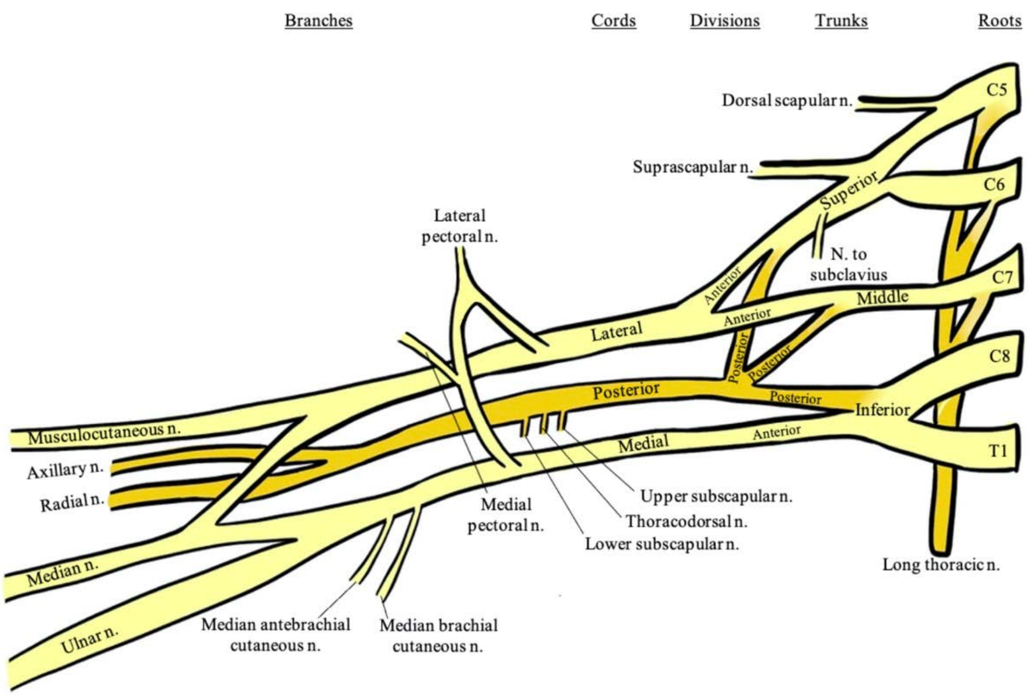


Figure 2. Schematic of Typical Branching Pattern of *Homo sapiens* Brachial Plexus. Drawing of the anterior view of the right brachial plexus. The lighter yellow indicates the anterior aspect of the brachial plexus. The darker yellow indicates the posterior aspect of the brachial plexus. Drawings are my own.

New world monkeys

Aotus sp.

A typical *Aotus sp.* brachial plexus (Figure 3) is made of roots from ventral rami of spinal nerves C5-T1 (Bolk, 1902; Mizuno, 1966; Shearer, 2019). C5 and C6 combine to create the superior trunk, C7 creates the middle trunk, and C8 and T1 combine to create the inferior trunk (Bolk, 1902; Mizuno, 1966; Shearer, 2019). C5 has an anterior and posterior segment. The C5 posterior segment gives off the suprascapular nerve (Bolk, 1902; Mizuno, 1966; Shearer, 2019). The C5 anterior segment continues to merge with C6 to form the superior trunk (Bolk, 1902; Mizuno, 1966; Shearer, 2019). Each trunk has an anterior and posterior division. The anterior division of the superior trunk gives off the nerve to subclavius before it combines with the anterior division of the middle trunk to create the lateral cord (Bolk, 1902; Mizuno, 1966;

Shearer, 2019). The anterior division of the inferior trunk creates the medial cord. There is no true posterior cord in *Aotus sp*. (Bolk, 1902; Mizuno, 1966; Shearer, 2019). Instead, there are two portions to a pseudo-posterior cord. The upper portion is derived from the posterior division of the superior trunk and the posterior division of the middle trunk which gives off axillary nerve. The lower portion of the pseudo-posterior cord is derived from the upper portion combining with the posterior division of the inferior trunk (Bolk, 1902; Mizuno, 1966; Shearer, 2019). Terminal nerves branch off from many different sections of the brachial plexus. In *Aotus sp.*, the dorsal scapular nerve, long thoracic nerve, and the nerve to subclavius all originate from the roots. The suprascapular nerve originates from the superior trunk. The lateral cord gives off the lateral pectoral nerve, medial pectoral nerve, musculocutaneous nerve, and the lateral head of the median nerve (Mizuno, 1966; Bolk, 1902; Shearer, 2019). The medial cord forms the ulnar nerve, medial head of the median nerve, and the thoracodorsal (middle subscapular) neve. The upper subscapular nerve, lower subscapular nerve, axillary nerve, and radial nerve all originate from the pseudo-posterior cord (Mizuno, 1966; Bolk, 1902; Shearer, 2019). The terminal branches then come off from the cords carrying both sensory and motor innervation (Table 1).

There are many inconsistencies found in the literature regarding the brachial plexus of *Aotus sp.* Shearer (2019) describes the brachial plexus receiving contribution from C5-T1 with a sample size five. Mizuno (1966) also describes the brachial plexus as receiving contribution from C5-T1 and specifically highlights that there was no contribution from C4 or T2 found in the two brachial plexuses dissected. However, Mizuno (1966) suggests a post-fixed nature of the brachial plexus due to C6-C8 having the most mass which was not found in Shearer (2019) research. Bolk (1902) also describes the brachial plexus receiving contribution from C5-T1; but he describes the origin of nerves differently than both Shearer (2019) and Mizuno (1966). Bolk

(1902) describes the median nerve as receiving contributions from C7-T1, the thoracodorsal nerve receiving contributions from C7-8, and the radial nerve receiving contributions from C6-T1. This varies from Shearer and Mizuno in that each describes the median nerve as receiving contributions from C5-T1, the thoracodorsal nerve from C7-T1, and the radial nerve from C7-T1. Bolk also found that the *m. rhomboid major* and *minor* received innervation from C4-6, *m. levator scapulae* from C4-5, and *m. serratus anterior* from C5-8.; whereas Shearer and Mizuno report that the *m. rhomboid major and minor* received innervation from C5, the *m. levator scapulae* from C5, and the *m. serratus anterior* from C6-8.

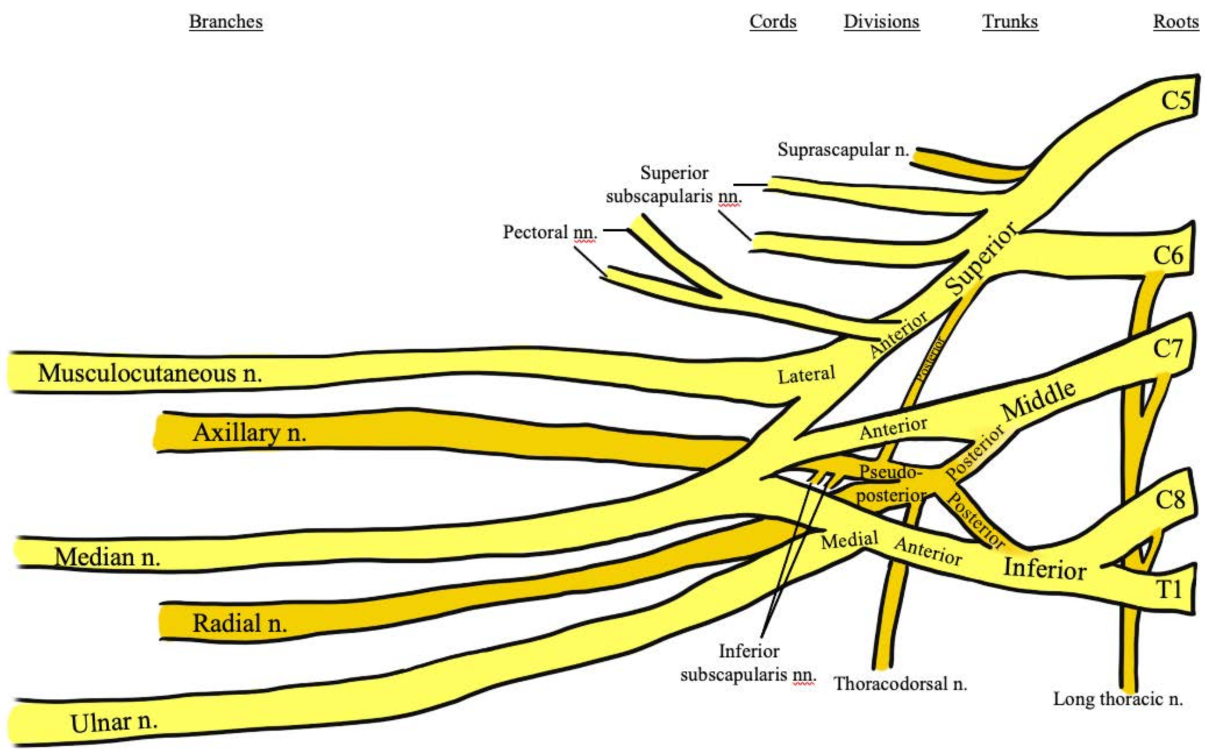


Figure 3. Schematic of Typical Branching Pattern of Aotus sp. Brachial Plexus. Drawing of the anterior view of the right brachial plexus. The lighter yellow indicates the anterior aspect of the brachial plexus. The darker yellow indicates the posterior aspect of the brachial plexus. Drawings are my own.

Saimiri sp.

A typical *Saimiri sp.* brachial plexus (Figure 4) is made of roots from ventral rami of spinal nerves C5-T1, with an occasional supplemental input from T2 (Mizuno, 1969; Shearer, 2019; Araujo, et al., 2012; Bolk, 1902). C5 and C6 combine to create the superior trunk. The contribution from C5 is minimal, therefore the superior trunk is not a true superior trunk (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). C7 creates the middle trunk; and C8, T1 and occasionally T2 combine to create the inferior trunk. C5 has an anterior and posterior segment. The C5 posterior segment gives off the suprascapular nerve. The C6 root gives off the nerve to subclavius before continuing to combine with C5 to create the "superior trunk" (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). *Saimiri sp.* does not have a true lateral cord, instead this small segment is considered a merging point between the superior and middle trunk anterior divisions. There is no true posterior cord in *Saimiri sp*. Instead, there are two portions to a pseudo-posterior cord (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). The upper portion is derived from the posterior division of the superior trunk and the posterior division of the middle trunk which gives off axillary nerve. The lower portion of the pseudo-posterior cord is derived from the upper portion combining with the posterior division of the inferior trunk (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). The terminal nerves originate from various sections of the brachial plexus. The dorsal scapular nerve, long thoracic nerve, suprascapular nerve, and nerve to subclavius all originate from the roots (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). The lateral and medial pectoral nerve which are combined in *Saimiri sp.* originate from the superior trunk along with the upper subscapular nerve. Due to the lack of a true lateral cord in *Saimiri sp.*, the musculocutaneous nerve originates from a junction point of the superior and middle trunk; while the median nerve originates from a junction point of the superior, middle, and inferior trunk (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). The medial cord forms the ulnar nerve. The lower subscapular nerve and axillary nerve originate from the upper portion of the pseudo-posterior cord. The thoracodorsal (middle subscapular) nerve and radial nerve originate from the lower portion of the pseudo-posterior cord (Araujo, et al., 2011; Bolk, 1902; Mizuno, 1969; Shearer, 2019). The terminal branches then come off from the cords carrying both sensory and motor innervation (Table 1).

Inconsistencies also exist in current research of *Saimiri sp*. Shearer (2019) and Bolk (1902) both describe the brachial plexus receiving contribution from C5-T1 with a supplemental contribution from T2. Mizuno (1969) suggests the contribution from T2 is a rare occurrence and that a typical brachial plexus only receives contribution from C5-T1. Both Mizuno (1969) and Araujo et al. (2012) found C5 to occasionally be absent. Araujo et al. (2012) describes the brachial plexus as receiving contribution from C4 as well and does not mention contribution from T2.

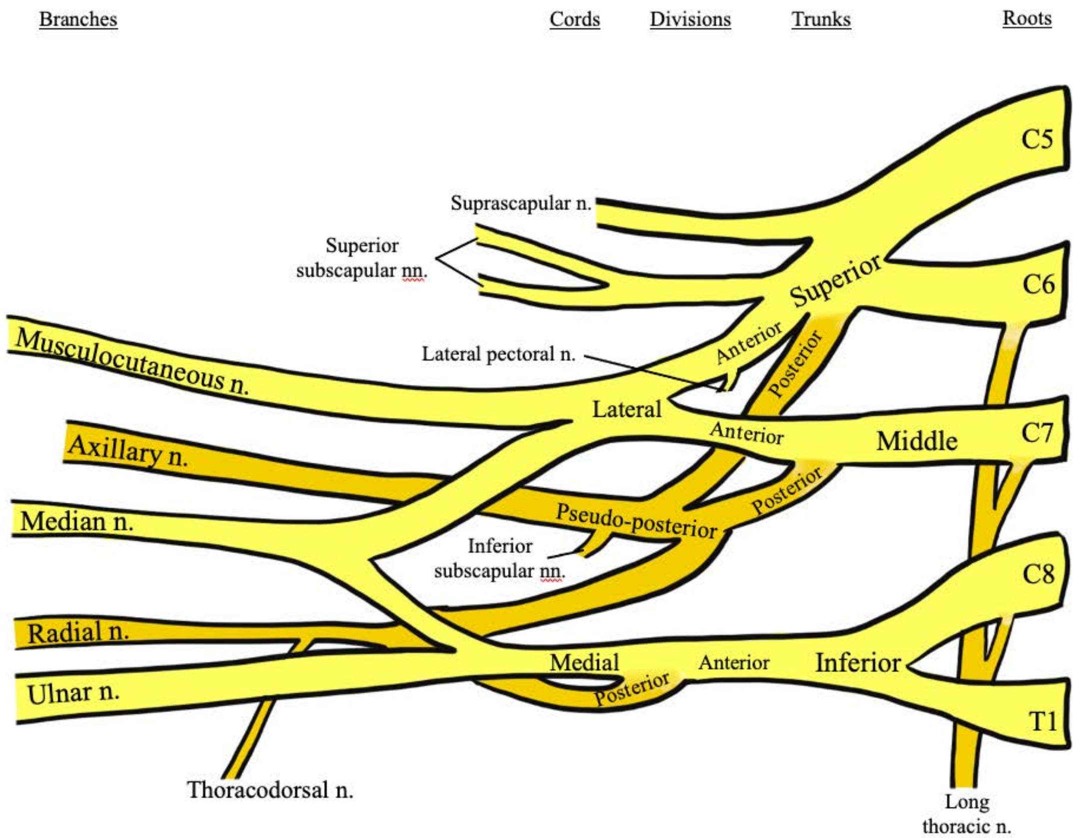


Figure 4. Schematic of Typical Branching Pattern of *Saimiri sp.* Brachial Plexus. Drawing of the anterior view of the right brachial plexus. The lighter yellow indicates the anterior aspect of the brachial plexus. The darker yellow indicates the posterior aspect of the brachial plexus. Drawings are my own.

Old world monkeys

Macaca sp.

A typical *Macaca sp.* brachial plexus (Figure 5) is made of roots from ventral rami of spinal nerves C5-T1 (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). C5 and C6 combine to create the superior trunk, C7 creates the middle trunk, and C8 and T1 combine to create the inferior trunk. Each trunk has an anterior and posterior division. The anterior division of the superior trunk combines with the anterior division of the middle trunk to create the lateral cord (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). The anterior division of the inferior trunk creates the medial cord. There is no true posterior cord, rather a pseudo-posterior cord is formed by the posterior divisions of the superior and middle trunks which gives off a terminating branch before joining with the inferior cord (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). Terminal nerves originate from different sections of the brachial plexus. The dorsal scapular nerve, long thoracic nerve, and nerve to subclavius originate from the roots. The superior trunk gives off the suprascapular nerve and upper subscapular nerve (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). The lateral pectoral nerve, musculocutaneous nerve, and lateral head of the median nerve originate from the lateral cord. The medial pectoral nerve, medial head of the median nerve, and the ulnar nerve originate from the medial cord. The upper portion of the pseudo-posterior cord gives off the lower subscapular nerve and axillary nerve. The lower portion of the pseudo-posterior cord gives off the thoracodorsal (middle subscapular) nerve and radial nerve (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). The terminal branches come off from the cords and carry both sensory and motor innervation (Table 1).

There are inconsistencies found in the research of *Macaca sp.* brachial plexuses. Most of the research agrees that the typical brachial plexus receives contribution from C5-T1 (Bolk, 1902; Brooks, 1883; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Ono, 1937; Santos-

Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004). However, it is also widely accepted that C4 and T2 are commonly included in the brachial plexus contributions. Bolk (1902), Ono (1936), Tokiyoshi et al. (2004), Sugiyama (1965), Santos-Sousa et al. (2016), and Chase and DeGaris (1940) report a common contribution from T2. Brooks (1883), Sugiyama (1965), Santos-Sousa et al. (2016), and Chase and DeGaris (1940) report a common contribution from C4. Brooks (1883) found that the brachial plexus receives contribution from C4-T1 with an uncertainty of C4 contribution. Brooks does describe the superior trunk to be made up of C4-C6. They also lack a true middle trunk as it divides into anterior and posterior divisions immediately after exiting the intervertebral foramen. Santos-Sousa et al (2016) found 55% of brachial plexuses dissected had contributions from C5-T1, 10% from C4-T2, 25% from C4-T1, and 10% from C5-T2. Chase and DeGaris (1940) found the normal brachial plexus to receive contributions from C5-T1 with 24% receiving contribution from C4 and 48% receiving contribution form T2. However, only 13% received contribution from both C4 and T2. In the 24% that received contribution from C4, C4 was included in contributing to the superior trunk. In the 48% that received contribution from T2, T2 was included in contributing to the inferior trunk.

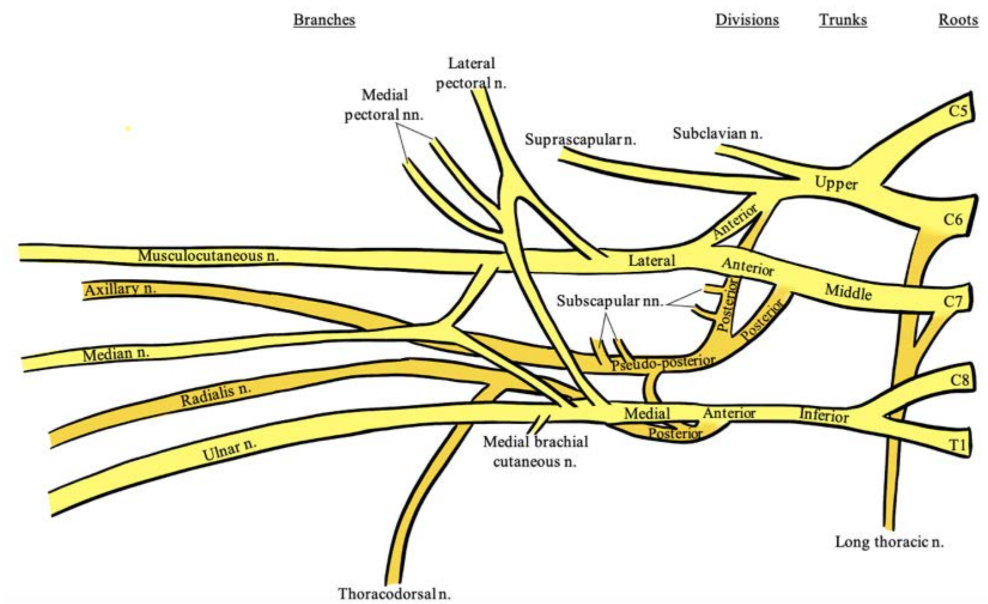


Figure 5. Schematic of Typical Branching Pattern of *Macaca sp.* Brachial Plexus. Drawing of the anterior view of the right brachial plexus. The lighter yellow indicates the anterior aspect of the brachial plexus. The darker yellow indicates the posterior aspect of the brachial plexus. Drawings are my own.

Chlorocebus aethiops

A typical *Chlorocebus sp.* brachial plexus (Figure 6) is made of roots from ventral rami of spinal nerves C5-T1, and a small but consistent contribution from T2 (Booth, 1991). C5 and C6 combine to create the superior trunk, C7 creates the middle trunk, and C8 and T1 combine to create the inferior trunk (Booth, 1991). Each trunk has an anterior and posterior division. The anterior division of the superior trunk combines with the anterior division of the middle trunk to create the lateral cord (Booth, 1991). The anterior division of the inferior trunk creates the medial cord. There is no true posterior cord, rather a pseudo-posterior cord formed by the posterior divisions of the superior and middle trunks which gives off a terminating branch before joining with the inferior cord (Booth, 1991). The terminal nerves originate from different sections of the brachial plexus. The roots give off the dorsal scapular nerve and long thoracic nerve. The suprascapular nerve originates from the superior trunk (Booth, 1991). The lateral pectoral nerve originates from the middle trunk. The lateral cord gives off the musculocutaneous nerve and the lateral head of median nerve. The medial cord gives off medial pectoral nerve, medial cutaneous nerve of forearm, medial head of the median nerve, and the ulnar nerve (Booth, 1991). The subscapular nerves and axillary nerve originate from the upper portion of the pseudo-posterior cord. The thoracodorsal (middle subscapular) nerve and radial nerve originate from the lower portion of the pseudo-posterior cord (Booth, 1991). The terminal branches come off from the cords and carry both sensory and motor innervation (Table 1).

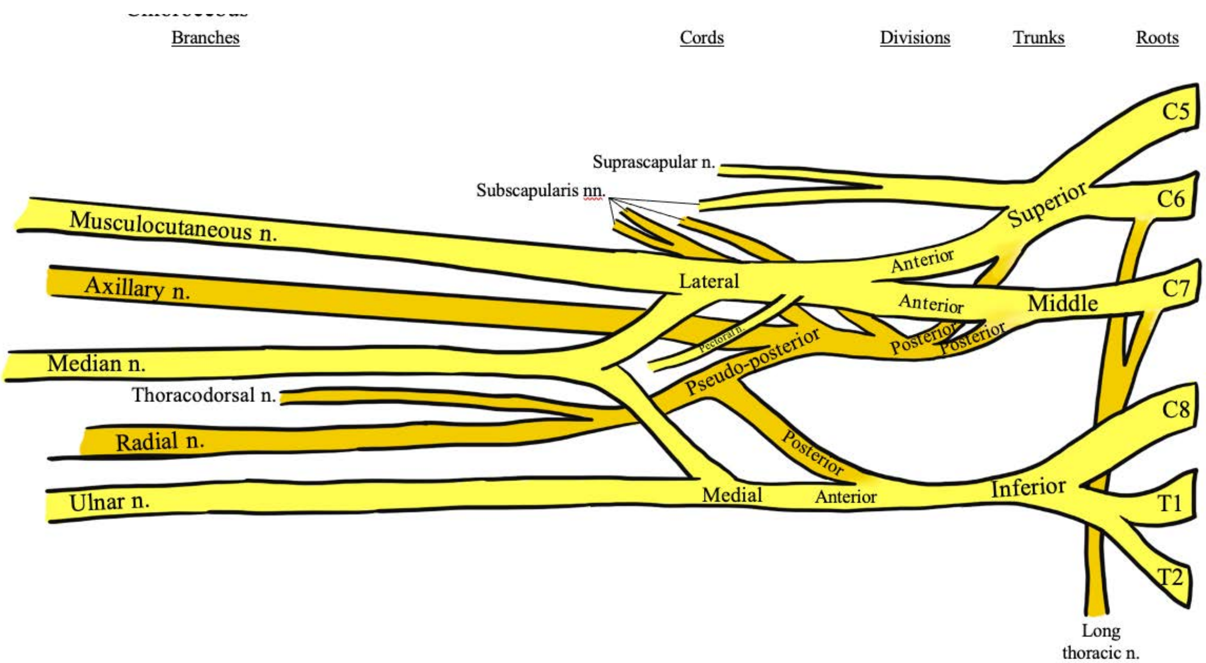


Figure 6. Schematic of Typical Branching Pattern of *Chlorocebus aethiops* Brachial Plexus.
Drawing of the anterior view of the right brachial plexus. The lighter yellow indicates the anterior aspect of the brachial plexus. The darker yellow indicates the posterior aspect of the brachial plexus. Drawings are my own. Drawings are my own.

Embryonic Development of the Brachial Plexus in Homo sapiens

Development of the brachial plexus begins around 28 to 32 days of development in the arm bud stage. The arm bud stage is initiated and supplied by one central artery. Axon bundles grow from the C5 to T1 spinal root areas through the sclerotomes. During this stage, a precursor to the arm skeleton begins to develop through a cartilaginous mass. In days 35 to 38, the arm bud will triple in size, and the cartilaginous mass will elongate as well, bifurcating at the end to create the radius and ulna bones. During this same period, the anterior axon bundles will begin to grow at the arm bud base, with C5 and T1 being outside of the width of the arm bud (Rodriguez-Niedenfuhr, Burton, Deu, & Sañudo, 2001; Leijnse, de Bakker, & D'Herde, 2020). All the axon bundles begin to converge centrally within the arm bud, which gives pressure to C5 and T1 to merge into the width of the arm bud. This is the beginning of trunk formation. When the C5 axon bundles converge centrally, the bundle merges with the C6 axon bundle to create the superior trunk. Likewise, as the T1 axon bundles are converging centrally, the bundles merge with the C8 axon bundles to create the inferior trunk. Because the C7 axon bundles are already located in the center of the width of the arm bud, there is little pressure for the course of the axon bundle to change and therefore it stays central without merging with other axon bundles. This is considered the middle trunk (Leijnse, de Bakker, & D'Herde, 2020; Landmesser, 1978).

The cartilaginous mass growing in length alongside the arm bud and axon bundles is impenetrable to the axon bundles. Due to this circumstance, the axon bundles must change course again, traveling either anterior or posterior to the cartilaginous mass. Thereby creating the anterior and posterior of each trunk (Beller & Snow, 2014; Del Rio & Soriano, 2007; Leijnse, de Bakker, & D'Herde, 2020). The central artery supplying the axon bundles is now referred to as the subclavian artery. The subclavian artery runs through the arm bud anteriorly and centrally which causes another obstruction for the growth of the axon bundles. Typically, the subclavian artery splits the axon bundles into cranial and caudal sections. The superior and middle trunk are cranial to the subclavian artery, whereas the inferior trunk is caudal to the subclavian artery. While the axon bundles work to converge around the subclavian artery, the superior and middle trunk merge to create the lateral cord. The inferior trunk does not merge with another axon bundle at this time and continues as the medial cord. As the lateral cord continues to grow, the musculocutaneous nerve continues cranially. As the medial cord continues to grow, the medial antebrachial cutaneous nerve, medial brachial cutaneous nerve, and the ulnar nerve form caudally. Developmental pressures to have the axon bundles converge centrally, merge the lateral cord with the medial cord to create the median nerve. The posterior cord forms from the posterior division of the three trunks without interference by the subclavian artery due to the location. The posterior cord forms symmetrically, unlike the anterior division which split into the medial and lateral cords. The posterior cord forms the radial and axillary nerves (Leijnse, de Bakker, & D'Herde, 2020; Rodriguez-Niedenfuhr, Burton, Deu, & Sañudo, 2001).

Many of the variant branching patterns found in the brachial plexus can be associated with its formation around vessels. Abnormal cord formations may occur depending on from what intersegmental arteries the subclavian artery develops. The subclavian artery usually develops between the C7 and C8 roots. This produces the typical branching pattern of the brachial plexus (Figure 7A). If the subclavian artery develops more superiorly between C6 and C7, the C7 axon bundle would most likely merge with the C8 and T1 axon bundle (inferior trunk) which would then create a medial cord with C7 contribution and a lateral cord without C7 contribution (Figure 7B). If the subclavian artery developed more inferiorly between C8 and T1, this would cause the anterior division of the inferior trunk to merge centrally with the anterior divisions of the superior and middle trunks producing one anterior cord rather than a lateral and medial cord (Figure 7C) (Leijnse, de Bakker, & D'Herde, 2020; Rodriguez-Niedenfuhr, Burton, Deu, & Sañudo, 2001). There is also the potential for axon strands to cross the artery and merge with another axon bundle; thereby forming communicating branches. Another hypothesis for the development of communicating branches is the axon bundles splitting around a vessel then converging back again. Many of these variations occur in the anterior division of the brachial plexus due to more obstacles for the axon bundles to avoid while developmental forces are pushing the axon bundles centrally. The posterior cord may also experience obstructions in its pathway which could prevent the posterior division from merging symmetrically; thus, creating a two-part posterior cord (Leijnse, de Bakker, & D'Herde, 2020).

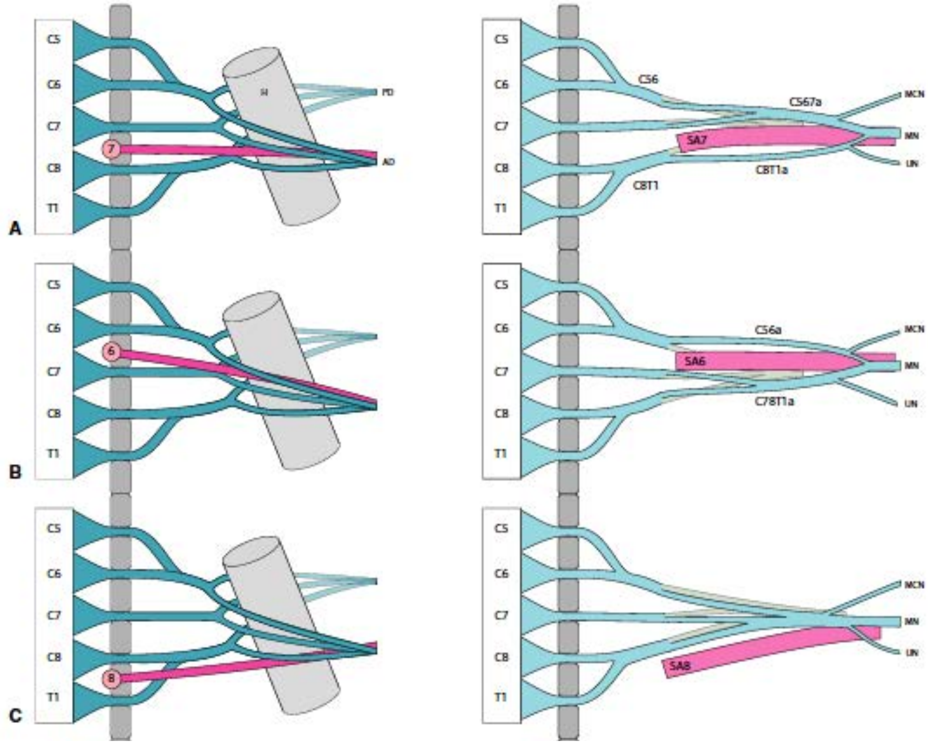


Figure 7. Brachial plexus morphologies associated with the subclavian artery. Left: embryonic schematics. Right: adult form. (A) Typical brachial plexus anatomy – The subclavian artery developing between C7 and C8. Axon bundles from C7 grow cranially and from C8 caudally. (B) The subclavian artery growing between C6 and C7. The axon bundles C5 and C6 (superior trunk) grow cranially and C7 grows caudally. This produces a variation in which the lateral cord is without C7 contribution, and a medial cord with C7 contribution. (C) The subclavian artery develops between C8 and T1. The inferior trunk forms anteriorly to the subclavian artery which allows for the anterior division of the inferior trunk to merge into the axon bundles with the anterior divisions of the superior and middle trunks. This creates one anterior cord rather than a lateral and medial cord (Leijnse, de Bakker, & D'Herde, 2020).

Clinical Relevance

Because the brachial plexus innervates muscles of the forearm, knowledge of common variations is clinically important. The upper limb is involved in many traumatic accidents and therefore may need immediate surgery without having a full overview of the patient (Aktan, Oztunk, Bilge, Ozer, & Pinar, 2001). In these situations, the surgical team needs to work together to perform nerve blocks and perform surgical skills quickly and effectively. With the brachial plexus being one of the most variant structures in the human body, it is important to realize there is a chance the nerves are not situated in a normal configuration. There are different types of brachial plexus blocks: interscalene (roots and trunks), supraclavicular (trunks or divisions), infraclavicular (cords), and axillary (branches) (Emamhadi, et al., 2016). Each of these brachial plexus block mechanisms are used for ensuring the correct area of the shoulder, arm, or hand is blocked from sensation (Emamhadi, et al., 2016). An understanding of the anatomy of the brachial plexus is crucial. Variations in this anatomy can make these blocks difficult and ineffective (Emamhadi, et al., 2016). Typical surgical procedures may cause additional damage to a variant brachial plexus (Emamhadi, et al., 2016).

There are two categories of brachial plexus injuries: upper and lower (Diogo & Molnar, 2016). The upper brachial plexus injuries include injuries in the C5 and C6 nerve roots which form the superior trunk. Upper brachial plexus injuries are typically caused by extreme lateral flexion of the neck. This can lead to Erb Duchenne Paralysis or Erb's Palsy (Diogo & Molnar, 2016). In an adult, this extreme lateral flexion of the neck can occur if someone falls onto their head. In an infant, this can occur during birth while the infant's head is being extracted from the mother. The lower brachial plexus injuries include injuries in the C8 and T1 nerve roots which form the inferior trunk. Lower brachial plexus injuries are usually caused by extreme abduction of the arm (Diogo & Molnar, 2016). This can lead to Klumpke's paralysis or Klumpke's Palsy which results in the fingers being flexed like a claw. This injury can occur in adults if they attempt to grab onto something while falling. In an infant, this can occur while pulling on their arm as the infant is being born (Diogo & Molnar, 2016).

There are also different brachial plexus nerve injuries experienced by athletes. The most common of these injuries is suprascapular nerve entrapment which occurs when the suprascapular nerve is compressed by the transverse scapular ligament as the nerve is going through the suprascapular notch (Diogo & Molnar, 2016; Safran, 2004). This can cause problems in the shoulder as the suprascapular nerve innervates *m. supraspinatus* and *infraspinatus*; and a lack of innervation may cause atrophy (Diogo & Molnar, 2016; Safran, 2004). Dorsal scapular nerve entrapment can also occur when the dorsal nerve is compressed while passing through the *m. scalene* (Diogo & Molnar, 2016; Sultan & El-Tantawi, 2013). This can lead to scapular winging, pain, and loss of sensation of the *mm. rhomboids* (Diogo & Molnar, 2016; Sultan & El-Tantawi, 2013). Another rare injury is quadrilateral space syndrome which is caused by the axillary nerve being compressed in the quadrangular space (Diogo & Molnar, 2016; Safran, 2004). This can happen during a dislocated humerus and can cause weakness and atrophy of *m. deltoid* (Diogo & Molnar, 2016; Safran, 2004).

Table 1. Summary of the Brachial Plexus.

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Dorsal Scapular	*Homo sapiens* (1, 11)	C5 root	C5	Rhomboid major, Rhomboid minor	--
	Aotus sp. (3, 10, 14)	C5 root	C5	Rhomboid major, Rhomboid minor	--
	Saimiri sp. (2, 3, 9, 14)	C5 root	C5	Levator Scapulae Rhomboid major, Rhomboid minor	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	C5, C6 root	C5, C6	Rhomboid major, Rhomboid minor	--
	Chlorocebus aethiops (4)	C4 root	C4	Levator Scapulae Rhomboid major, Rhomboid minor	--
Long thoracic	*Homo sapiens* (1, 11)	C5, C6, C7 root	C5, C6, C7	Serratus anterior	--
	Aotus sp. (3, 10, 14)	C6, C7, C8 root	C6, C7, C8	Serratus anterior	--
	Saimiri sp. (2, 3, 9, 14)	C6, C7, C8 root	C6, C7, C8	Serratus anterior	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	C6, C7 root	C6, C7	Serratus anterior	--
	Chlorocebus aethiops (4)	C6, C7 root	C6, C7	Serratus anterior	--

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Suprascapular	*Homo sapiens* (1, 11)	Superior trunk	C5, C6	Supraspinatus Infraspinatus	Glenohumeral joint
	Aotus sp. (3, 10, 14)	C5 root	C5	Supraspinatus Infraspinatus	--
	Saimiri sp. (2, 3, 9, 14)	C5 root	C5	Supraspinatus Infraspinatus	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Superior trunk	C5, C6	Supraspinatus Infraspinatus	--
	Chlorocebus aethiops (4)	Superior trunk	C5, C6	Supraspinatus Infraspinatus	--
Nerve to Subclavius	*Homo sapiens* (1, 11)	Superior trunk	C5, C6	Subclavius	Sternoclavicular joint
	Aotus sp. (3, 10, 14)	C7 root	C7	Subclavius	--
	Saimiri sp. (2, 3, 9, 14)	C6 root	C6	Subclavius	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	C6 root	C6	Subclavius	--
	Chlorocebus aethiops (4)	--	--	--	--
Lateral Pectoral	*Homo sapiens* (1, 11)	Lateral cord	C5, C6, C7	Pectoralis major, Pectoralis minor	--
	Aotus sp. (3, 10, 14)	Lateral cord	C5, C6, C7	Pectoralis major, Pectoralis minor	--
	Saimiri sp. (2, 3, 9, 14)	Superior trunk	C5, C6	Pectoralis major, Pectoralis minor	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Lateral cord	C5, C6, C7	Pectoralis major, Pectoralis minor	--
	Chlorocebus aethiops (4)	Middle trunk	C7	Pectoralis major, Pectoralis minor	--

Table 1 (continued).

Medial Pectoral	*Homo sapiens* (1, 11)	Medial cord	C8, T1	Pectoralis major, Pectoralis minor	--
	Aotus sp. (3, 10, 14)	Lateral cord	C5, C6, C7	Pectoralis major, Pectoralis minor	--
	Saimiri sp. (2, 3, 9, 14)	See "Lateral Pectoral"	See "Lateral Pectoral"	See "Lateral Pectoral"	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Medial cord	C8, T1	Pectoralis major, Pectoralis minor	--
	Chlorocebus aethiops (4)	Medial cord	C8, T1, T2	Cutaneous trunci muscle, pectoral muscles	Skin near caudal part of scapula
Musculocutaneous	*Homo sapiens* (1, 11)	Lateral cord	C5, C6, C7	Biceps brachii, Brachialis, Coracobrachialis	Continues as lateral cutaneous nerve of forearm
	Aotus sp. (3, 10, 14)	Lateral cord	C5, C6, C7	Biceps brachii, Brachialis, Coracobrachialis	Continues as lateral cutaneous nerve of forearm
	Saimiri sp. (2, 3, 9, 14)	Junction of Superior and Middle trunks	C5, C6, C7	Biceps brachii, Brachialis, Coracobrachialis	Continues as lateral cutaneous nerve of forearm
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Lateral cord	C5, C6, C7	Biceps brachii, Brachialis, Coracobrachialis	Continues as lateral cutaneous nerve of forearm
	Chlorocebus aethiops (4)	Lateral cord	C5, C6, C7	Biceps brachii, Brachialis, Coracobrachialis	Continues as lateral cutaneous nerve of forearm

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Medial Cutaneous Nerve of Forearm	*Homo sapiens* (1, 11)	Medial cord	C8, T1	--	Skin on medial side of forearm
	Aotus sp. (3, 10, 14)	Medial cord	C8, T1	--	Skin on medial side of forearm
	Saimiri sp. (2, 3, 9, 14)	--	--	--	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	--	--	--	--
	Chlorocebus aethiops (4)	Medial cord	C8, T1, T2	--	Skin on medial side of forearm
Ulnar	*Homo sapiens* (1, 11)	Medial cord	C8, T1	Flexor carpi ulnaris, Medial half of flexor digitorum profundus, Deep head of flexor pollicis brevis, Adductor pollicis, Lumbrical III, IV Palmaris brevis, Dorsal and palmar interossei muscles	Skin over medial 1/3 of palm, digit V and medial half of IV on palmar and dorsal surfaces
	Aotus sp. (3, 10, 14)	Medial cord	C8, T1	Flexor carpi ulnaris, Lumbrical III, IV	Skin over digit V and medial half of IV
	Saimiri sp. (2, 3, 9, 14)	Medial cord	C8, T1	Flexor carpi ulnaris, Lumbrical III, IV	Skin over digit V and medial half of IV
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Medial cord	C8, T1	Flexor carpi ulnaris, Lumbrical III, IV	Skin over digit V and medial half of IV
	Chlorocebus aethiops (4)	Medial cord	C8, T1, T2	Flexor carpi ulnaris, Lumbrical III, IV	Skin over digit V and medial half of IV

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Median	*Homo sapiens* (1, 11)	Medial cord, Lateral cord	C5, C6, C7, C8, T1	All forearm flexors **except** flexor carpi ulnaris Lumbrical I, II	Skin over lateral 2/3 of palm, palmar surface of digits I, II, III, lateral half of IV, dorsal portion of digits I, II, II, and lateral half of IV
	Aotus sp. (3, 10, 14)	Medial cord, Lateral cord	C5, C6, C7, C8, T1	All forearm flexors **except** flexor carpi ulnaris Lumbrical I, II	Skin over digits I, II, III, lateral half of IV
	Saimiri sp. (2, 3, 9, 14)	Medial cord, Lateral cord	C5, C6, C7, C8, T1	All forearm flexors **except** flexor carpi ulnaris Lumbrical I, II	Skin over digits I, II, III, lateral half of IV
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Medial cord, Lateral cord	C5, C6, C7, C8, T1	All forearm flexors **except** flexor carpi ulnaris Lumbrical I, II	Skin over digits I, II, III, lateral half of IV
	Chlorocebus aethiops (4)	Medial cord, Lateral cord	C5, C6, C7, C8, T1, T2	All forearm flexors **except** flexor carpi ulnaris Lumbrical I, II	Skin over digits I, II, III, lateral half of IV

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Upper Subscapular	*Homo sapiens* (1, 11)	Posterior cord	C5, C6	Superior portion of subscapularis	--
	Aotus sp. (3, 10, 14)	Upper Pseudo-posterior cord	C5, C6	Superior portion of subscapularis	--
	Saimiri sp. (2, 3, 9, 14)	Superior trunk	C5, C6	Superior and middle portions of subscapularis	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Superior trunk	C5, C6	Subscapularis	--
	Chlorocebus aethiops (4)	Upper Pseudo-posterior cord	C5, C6	Subscapularis	--
Thoracodorsal (Middle Subscapular)	*Homo sapiens* (1, 11)	Posterior cord	C6, C7, C8	Latissimus dorsi	--
	Aotus sp. (3, 10, 14)	Medial cord	C7, C8, T1	Latissimus dorsi	--
	Saimiri sp. (2, 3, 9, 14)	Radial nerve	C7, C8, T1	Latissimus dorsi	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Radial nerve	C7, C8, T1	Latissimus dorsi	--
	Chlorocebus aethiops (4)	Lower Pseudo-posterior cord	C5, C6, C7, C8, T1, T2	Latissimus dorsi	--

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Lower Subscapular	*Homo sapiens* (1, 11)	Posterior cord	C5, C6	Inferior portion of subscapularis Teres major	--
	Aotus sp. (3, 10, 14)	Upper Pseudo-posterior cord	C5, C6	Inferior portion of subscapularis Teres major	--
	Saimiri sp. (2, 3, 9, 14)	Upper Pseudo-posterior cord	C5, C6	Teres major	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Upper Pseudo-posterior cord	C5, C6, C7	Subscapularis Teres major	--
	Chlorocebus aethiops (4)	See "Upper Subscapular"	See "Upper Subscapular"	See "Upper Subscapular"	--
Axillary	*Homo sapiens* (1, 11)	Posterior cord	C5, C6	Deltoid, Teres minor	Glenohumeral joint, skin over lateral upper arm
	Aotus sp. (3, 10, 14)	Upper Pseudo-posterior cord	C5, C6, C7	Anterior branch – anterior 2/3 deltoid, Teres minor Posterior branch – Posterior 1/3 deltoid	--
	Saimiri sp. (2, 3, 9, 14)	Upper Pseudo-posterior cord	C5, C6, C7	Anterior branch – anterior 2/3 deltoid, Teres minor Posterior branch – Posterior 1/3 deltoid	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Upper Pseudo-posterior cord	C5, C6, C7	Anterior branch – anterior 2/3 deltoid, Teres minor Posterior branch – Posterior 1/3 deltoid	--
	Chlorocebus aethiops (4)	Upper Pseudo-posterior cord	C5, C6, C7	Teres major, Teres minor, Deltoid	--

Table 1 (continued).

Nerve	Species	Origin	Spinal Nerve Contribution	Motor Innervation	Sensory Innervation
Radial	*Homo sapiens* (1, 11)	Posterior cord	C5, C6, C7, C8	Triceps brachii, Brachioradialis, Extensor carpi radialis longus and brevis, Extensor digitorum, Extensor digiti minimi, Extensor carpi ulnaris, Anconeus, Supinator, Abductor pollicis longus, Extensor pollicis brevis and longus, Extensor indicis	Skin over posterior arm and forearm, lateral lower arm, and lateral dorsal hand
	Aotus sp. (3, 10, 14)	Lateral – Upper Pseudo-posterior cord; Medial – medial cord	C7, C8, T1	Dorsiepitrochlearis, Extensor compartment of arm and forearm	--
	Saimiri sp. (2, 3, 9, 14)	Lower Pseudo-posterior cord	C7, C8, T1	Dorsiepitrochlearis, Extensor compartment of arm and forearm	--
	Macaca sp. (3, 6, 7, 8, 12, 13, 14, 15, 16)	Lower Pseudo-posterior cord	C7, C8, T1	Dorsiepitrochlearis, Triceps brachii, Tensor fascia antebrachii, Anconeus, Extensor compartment of arm and forearm	--
	Chlorocebus aethiops (4)	Lower Pseudo-posterior cord	C5, C6, C7, C8, T1, T2	Dorsiepitrochlearis, Extensor compartment of arm and forearm	--

This table represents the normal contributions and innervations for each species involved in the study. Orange: *Homo sapiens*, Blue: New world monkeys, Green: Old world monkeys
References: 1: (Agur, Dalley, & Grant, 2017), 2: (Araujo, et al., 2012), 3: (Bolk, 1902), 4: (Booth, 1991), 5: (Booth, Baloyi, & Lukhele, 1997), 6: (Brooks, 1883), 7: (Chase & DeGaris, 1940), 8: (Howell & Straus Jr, 1947), 9: (Mizuno, 1969), 10: (Mizuno, 1966), 11: (Moore, Agur, Dalley, & Moore, 2015), 12: (Ono, 1937). 13: (Santos-Sousa, et al., 2016), 14: (Shearer, 2019), 15: (Sugiyama, 1965), 16: (Tokiyoshi, et al., 2004)

CHAPTER 3: METHODOLOGY

This study investigates six primate species, five non-human and *Homo sapiens*. The non-human species were the old world monkeys *Macaca fascicularis, M. mulatta* and *Chlorocebus aethiops*; and the new world monkeys *Saimiri sp.* and *Aotus sp*.

The non-human primates were frozen, thawed in wardsafe, then carefully dissected to expose the brachial plexus. During the dissection process skin, bone, muscle, and adipose tissue were removed. No animals were sacrificed for the purpose of this study. *Macaca sp.* were donated to Dr. Reed's laboratory from Charles River Laboratory (Appendix Table 1**Error! Reference source not found.**). *Chlorocebus aethiops* specimens were sourced from Wake Forest University in Winston-Salem, North Carolina. *Aotus sp.* and *Saimiri sp.* specimens were sourced from MD Anderson Cancer Center in Houston Texas (Appendix Table 1).

The human cadavers were dissected, and their brachial plexuses examined. Dissections were performed according to the twelfth edition of Grant's Dissection Guide (Tank & Grant, 2013). First, the clavicle was resected to expose the roots of the brachial plexus. Then each of the brachial plexuses were carefully dissected and evaluated from roots to terminal branches. The cadavers were sourced from Wayne State University, Western Michigan University, and Michigan State University body bequest programs with permission to photograph and use in this study (Appendix Table 2).

Each brachial plexus was analyzed, described, and photographed after dissection. Each species group was compared to the accepted normal brachial plexus for that species. The categories were split into variants in the following sections of the brachial plexus: roots, trunks, cords, and terminal branches (Appendix Tables 3 and 4). The root section determined whether the brachial plexuses were prefixed or postfixed. The trunks determined variant branching patterns within the superior, middle, and inferior trunks. The cords section includes variations in the lateral, medial, and posterior cords. The terminal branches include the musculocutaneous nerve, median nerve, ulnar nerve, axillary nerve, and radial nerve.

When available, the brachial plexus from each side of the specimen was dissected and observed. This allowed comparison of branching patterns within a specimen to observe if variants were bilateral or unilateral.

Justification of Sample Size

Due to difficulties in obtaining primates, the sample size available was not equal across species. The human cadavers were used for anatomical courses, therefore only one side was available for some of the samples (Table 2).

Table 2. Overview of number of samples available from each species.
"n" represents number of individuals. "np" represents number of brachial plexuses.

	Number of Individuals (n)	Number of Brachial Plexuses (np)	Number of Bilateral Subjects	Number of Unilateral Subjects
Homo sapiens	38	56	18	20
Macaca fascicularis	6	12	6	6
Macaca mulatta	2	4	2	2
Chlorocebus aethiops	2	4	2	2
Aotus sp.	1	1	0	1
Saimiri sp.	2	4	2	2

CHAPTER 4: RESULTS

Aotus sp. *Results.*

The left brachial plexus of *Aotus* 86508 (Figures 8 and 9) starts from cervical spinal roots C4, C5, C6, C7, C8, and T1. The superior trunk is made from the combination of C4, C5, and C6 spinal roots. The middle trunk is a continuation of C7 root. The inferior trunk is made from the combination of C8 and T1 roots. There is no distinction from the lateral and medial cord rather there is one anterior cord which formed from the superior, middle, and inferior trunk. This combined anterior cord forms the musculocutaneous nerve, the median nerve, and the ulnar nerve. The median nerve does not have two heads because the typical medial and lateral cord are absent. The musculocutaneous nerve continues laterally, piercing *m. coracobrachialis*, then branching to innervate *m. coracobrachialis, m. biceps brachii,* and *m. brachialis*. The ulnar nerve continues medially, traveling through the axillary region, behind the medial epicondyle, to innervate the medial forearm flexor muscles. The dorsal division of the superior, middle, and inferior trunks all combine posteriorly to the axillary artery to create the posterior cord (Figure 10B). The posterior cord gives off the axillary and radial nerve. The axillary nerve goes through the quadrangular space then divides into an anterior and posterior segment to innervate *m. deltoid* and *m. teres minor*. The radial nerve travels along the humerus then continues in the radial groove to before continuing into the lateral aspect of the posterior forearm. The radial nerve innervates *m. triceps brachii, m. brachioradialis, m. dorsoepitrochlearis,* and extensor forearm muscles.

The ventral division of the brachial plexus gives off the suprascapular, lateral pectoral, medial pectoral, musculocutaneous, median, and ulnar nerves. The suprascapular nerve arises from the superior trunk and dips behind the scapula to innervate *m. supraspinatus* and *m.*

infraspinatus. The nerve to subclavius originates from the superior trunk and innervates *m. subclavius*. The lateral and medial pectoral nerves were cut prior to dissection.

The dorsal division of the brachial plexus gives off the dorsal scapular, long thoracic, superior subscapular, middle subscapular (thoracodorsal), inferior subscapular, axillary, and radial nerves. The dorsal scapular nerve arises from the C5 root and continues dorsally to innervate *m. rhomboid major, m. rhomboid minor,* and *m. levator scapulae*. The long thoracic nerve receives contribution from the C6 and C7 roots and travels medially to innervate *m. serratus anterior*. The superior subscapular nerve originates from the posterior cord as one branch innervating the upper *m. subscapularis* (Figure 11C). The middle subscapular (thoracodorsal) nerve comes from the posterior cord, travels through the axillary region then innervates *m. latissimus dorsi*. The inferior subscapular nerve originates from the axillary nerve as one branch which innervates the lower *m. subscapularis* (Figure 12A). There was only one *Aotus* brachial plexus available for dissection.

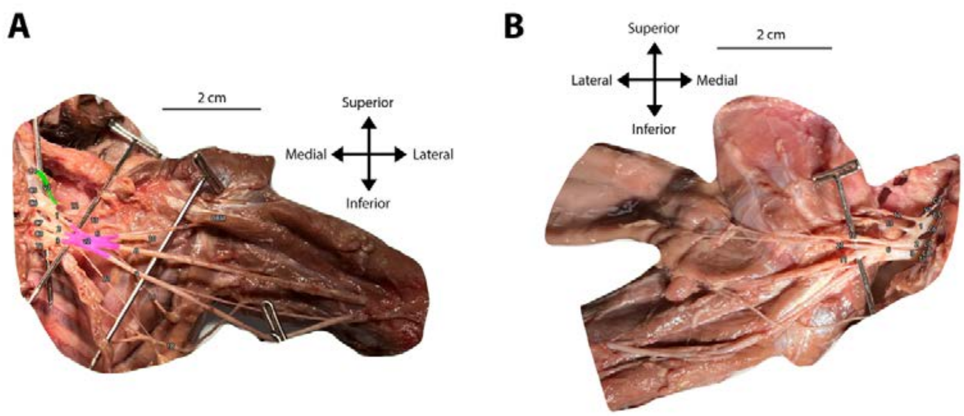


Figure 8. ***Aotus 86508*** **Left Brachial Plexus.**
(A) Left anterior view of the brachial plexus. C4 joins with C5 (green) making this a prefixed brachial plexus. There is no lateral cord or medial cord, just one anterior cord (pink). The musculocutaneous nerve, median nerve, and ulnar nerve all branch from one point off the anterior cord (pink). (B) Left posterior view of the brachial plexus. The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves.

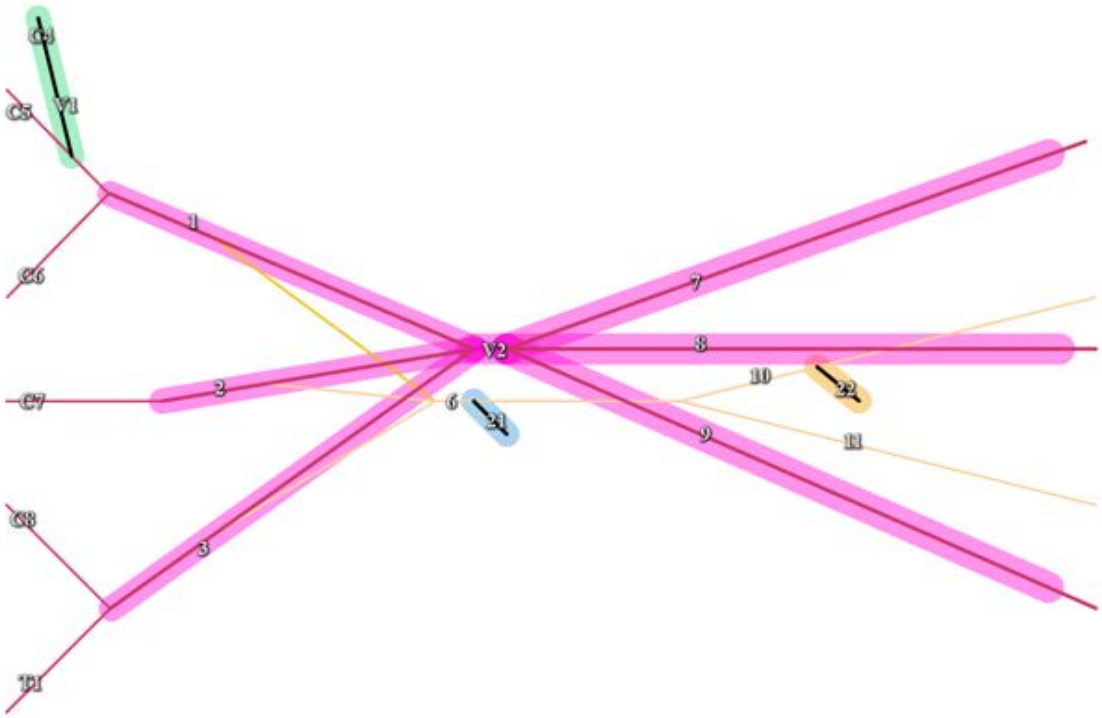


Figure 9. Schematic of *Aotus* 86508 Anterior Left Brachial Plexus.
Variant branching pattern of the left anterior brachial plexus. This brachial plexus is prefixed (green). The anterior divisions of the superior, middle, and inferior trunks combine to form an anterior cord which then split to form the musculocutaneous nerve, median nerve, and ulnar nerve (pink). The superior subscapular nerve originates from the posterior cord with one branch (blue). The inferior subscapular nerve originates from the axillary nerve with one branch (yellow). Drawings are my own.

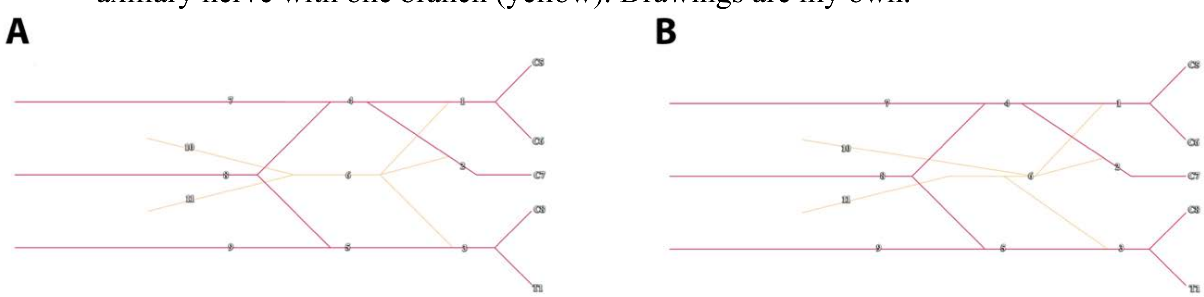


Figure 10. Schematic of Different Posterior Cord Branching Patterns.
(A) One-part posterior cord branching pattern. (B) Two-part posterior cord branching pattern. (A-B) Anterior brachial plexus displayed in red, posterior aspect shown in yellow. Drawings are my own.

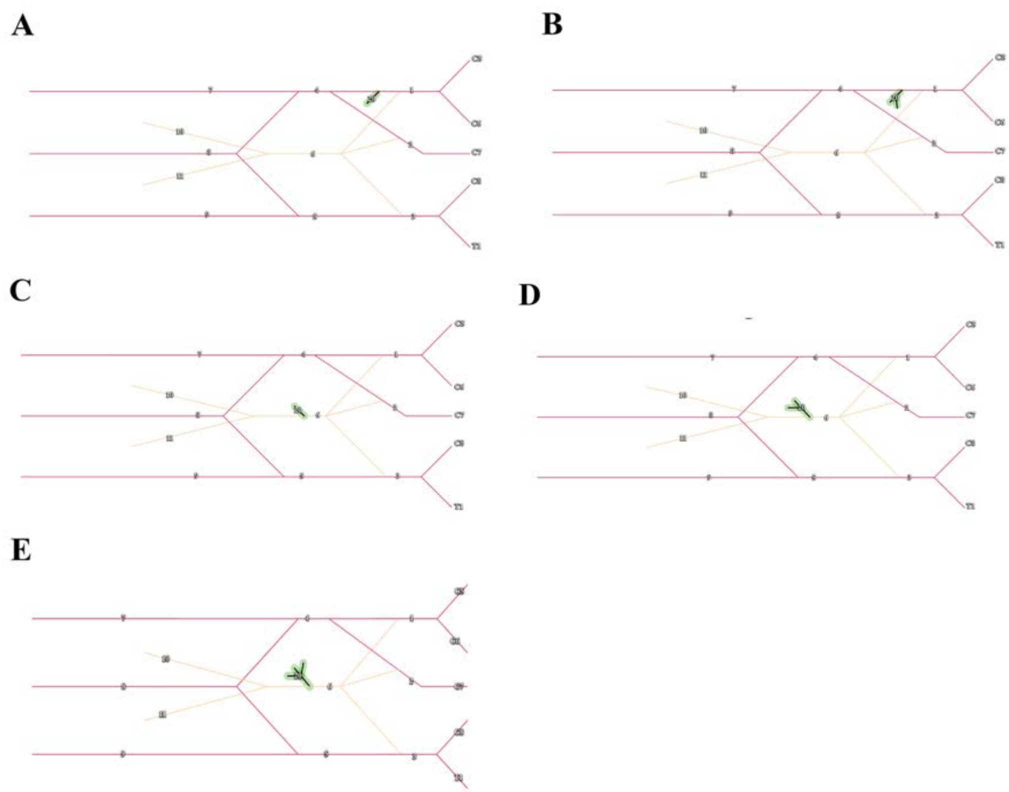


Figure 11. Schematic for Variations of the Superior Subscapular Nerve Branching Pattern.
(A-B) The superior subscapular nerve (green) originating from the superior trunk with one (A) or two (B) branches. (C-E) The superior subscapular nerve (green) originating from the posterior cord with one (C), two (D), or three (E) branches. Anterior brachial plexus displayed in red, posterior aspect shown in yellow. Drawings are my own.

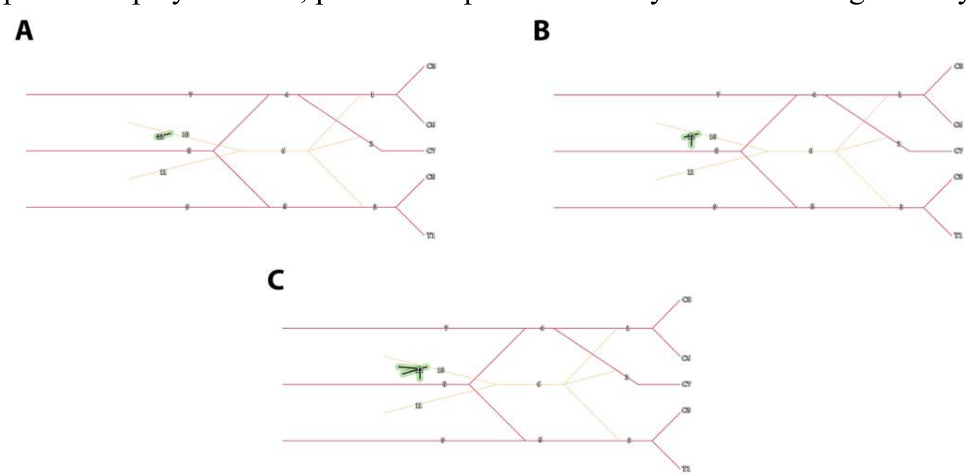


Figure 12. Schematic of Variations of the Inferior Subscapular Nerve Branching Pattern.
(A-C) The inferior subscapular nerve (green) originates from the axillary nerve forming one (A), two (B), or three (C) branches. Anterior brachial plexus displayed in red, posterior aspect shown in yellow. Drawings are my own.

Chlorocebus aethiops *Results.*

The left brachial plexus of 1448 (Figure 13B,D) forms from the cervical spinal roots C5 through thoracic spinal root T1. The spinal roots C5 and C6 combine to create the superior trunk, C7 continues as the middle trunk, and C8 and T1 combine to create the inferior trunk. The superior and middle trunk combine to create the lateral cord and the inferior trunk continues as the medial cord. The lateral pectoral, musculocutaneous nerve, and lateral head of the median nerve come from the lateral cord. The musculocutaneous nerve pierces the *m. coracobrachialis* then continues laterally to innervate the *m. coracobrachialis, m. biceps brachii,* and *m. brachialis*. The medial cord gives off the ulnar nerve and medial head of the median nerve. The ulnar nerve travels through the axillary region then continues to innervate the medial forearm flexor muscles. The median nerve innervates the lateral flexor muscles of the forearm. The ventral division of the brachial plexus contributes to the suprascapular, lateral pectoral, medial pectoral, musculocutaneous, median, and ulnar nerves. The suprascapular nerve comes from the superior trunk and innervates the *m. supraspinatus* and *m. infraspinatus*. The lateral pectoral nerve comes from the lateral cord then innervates the *m. pectoralis minor* and *m. pectoralis major* while the medial pectoral nerve comes from the medial cord and innervates the same two muscles. There is no ansa pectoralis connecting the medial and lateral pectoral nerves.

The posterior cord is made up of two segments (Figure 13D). The posterior divisions of the superior and middle trunk combine to create the upper part of the posterior cord. The upper part of the posterior cord gives off one superior subscapular nerve, one inferior subscapular nerve, and axillary nerve. The posterior division of the inferior trunk combines with the upper part of the posterior cord to create the lower part of the posterior cord. The lower part of the posterior cord gives off the radial nerve. The dorsal division of the brachial plexus gives off the dorsal scapular, long thoracic, superior subscapular, middle subscapular (thoracodorsal), inferior subscapular, axillary, and radial nerves. The dorsal scapular nerve originates from the C5 root and travels posteriorly to innervate the *m. levator scapulae, m. rhomboid major,* and *m. rhomboid minor*. The long thoracic comes off from the C6 and C7 spinal roots and continues medially to innervate the *m. serratus anterior*. The superior subscapular nerve comes off from the upper part of the posterior cord as one branch that innervates the upper *m. subscapularis*. The radial nerve gives off the middle subscapular (thoracodorsal) nerve which continues to innervate the *m. latissimus dorsi*. The inferior subscapular nerve branches from the axillary nerve as one branch to innervate the lower *m. subscapularis*.

The brachial plexus on the right side is identical to the left (Figure 13A,C).

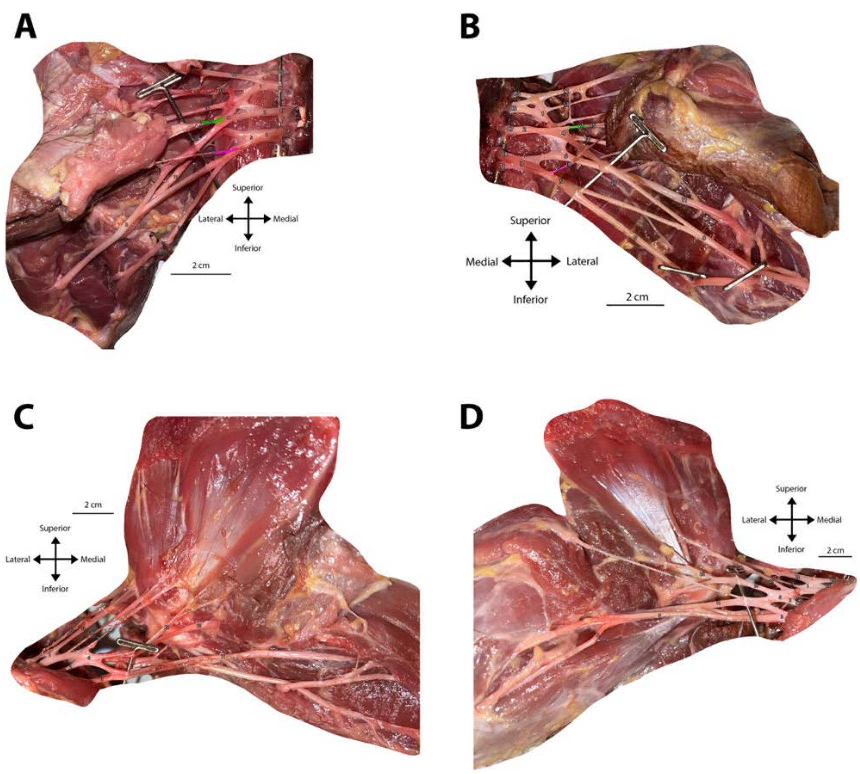


Figure 13. *Chlorocebus aethiops* 1448 Right and Left Brachial Plexuses.
(A-B) Right (A) and left (B) anterior view of brachial plexus. There is no ansa pectoralis connecting the lateral pectoral nerve (green) and the medial pectoral nerve (pink). (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior view of the brachial plexus exhibits the two-part posterior cord pattern.

Intraspecific Polymorphisms

_1248_

Bilateral

The inferior trunk and medial cord received contributions from T2 spinal root and the superior subscapular nerve has two branches that innervate the upper *m. subscapularis* (Figure 14).

Right

There is an ansa pectoralis between the medial and lateral pectoral nerves; the middle subscapular (thoracodorsal) nerve originates from the lower posterior cord; and there is a communicating branch between the axillary nerve and radial nerve (Figure 14A,C).

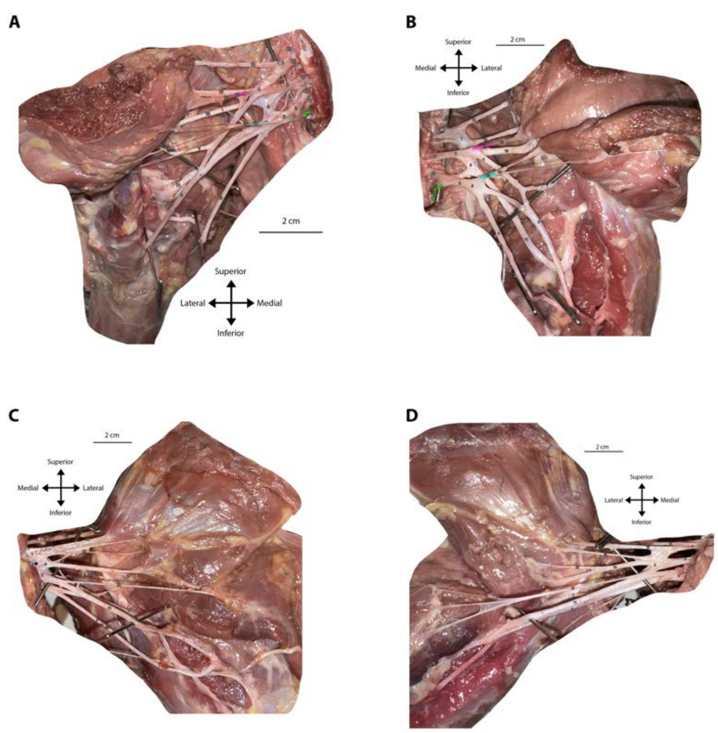


Figure 14. *Chlorocebus aethiops* 1248 Right and Left Brachial Plexuses.
(A-B) Right (A) and left (B) anterior view of brachial plexus. The brachial plexus is postfixed bilaterally (green). There is no ansa pectoralis connecting the lateral pectoral nerve (pink) and the medial pectoral nerve (blue). (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior view of the brachial plexus exhibits the two-part posterior cord pattern.

Summary of *Chlorocebus aethiops*

Of the four brachial plexuses dissected, three (n=2, np=3) did not have an ansa pectoralis. One specimen was postfixed bilaterally (n=1, np=2) (Figure 15B). Both specimens (n=2, np=4) bilaterally exhibited the two-part posterior cord branching pattern (**Error! Reference source not found.**B). The superior subscapular nerve formed from the posterior cord bilaterally in both specimens (n=2, np=4). In one specimen, the superior subscapular nerve formed one branch bilaterally (n=1, np=2); the other specimen, the nerve formed two branches bilaterally (n=1, np=2) (Figure 11). The inferior subscapular nerve had one branch in both specimens bilaterally (n=2, np=4) (Figure 12).

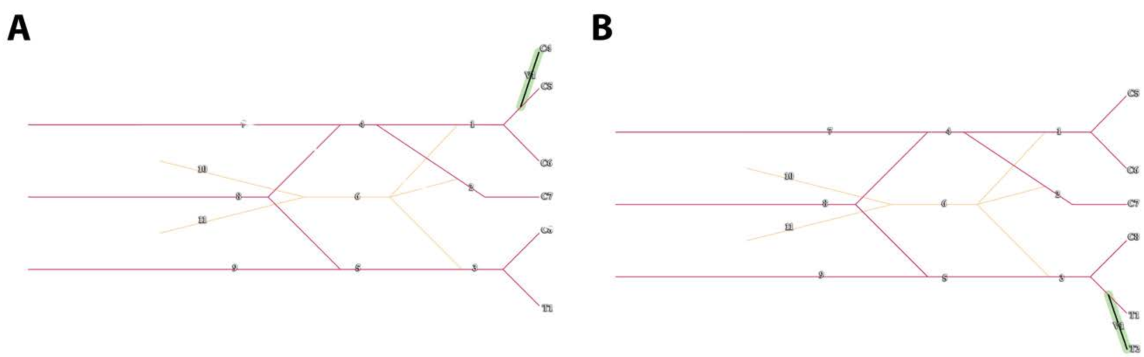


Figure 15. Schematic for Prefixed and Postfixed Brachial Plexus Branching Pattern. (A) Prefixed branching pattern with contribution from C4 (green). (B) Postfixed branching pattern with contribution from T2 (green). (A-B) Anterior brachial plexus displayed in red, posterior aspect shown in yellow. Drawings are my own.

Macaca sp. *Results.*

The typical brachial plexus of *Macaca* forms from spinal roots C5, C6, C7, C8, and T1, with occasional contribution from C4 (18.75%, n=2, np=3) and T2 (18.75%, n=2, np=3). The C5 and C6 roots combine to create the superior trunk, C7 root creates the middle trunk, and C8 and T1 roots combine to create the inferior trunk. The superior and middle trunk have an anterior division that combine to create the lateral cord which then continues as the musculocutaneous nerve. The musculocutaneous nerve pierces the *m. coracobrachialis* then continues under the *m.*

biceps brachii to innervate the *m. coracobrachialis*, *m. biceps brachii*, and *m. brachialis*. The anterior division of the inferior trunk continues as the medial cord which forms the ulnar nerve. The ulnar nerve travels through the axillary region then dives posterior to the medial epicondyle then arises distally to innervate the medial forearm flexor muscles. The median nerve has two heads, a medial head from the medial cord and a lateral head from the lateral cord. These combine and innervate the lateral flexor muscles of the forearm.

The posterior cord has two common branching patterns. The posterior cord originates from the combination of the posterior divisions of the superior, middle, and inferior trunks into one posterior cord (50%; n=5 np=8) (Figure 10A). Alternately, the posterior divisions of the superior and middle trunks combine and give off the axillary nerve prior to the addition of the posterior division of the inferior trunk which then gives off the radial (50%; n=5 np=8) (Figure 10B). The axillary nerve dives into the quadrangular space and divides into an anterior and posterior segment. The anterior segment of the axillary nerve innerves one third of *m. deltoid* and the posterior segment innervates two thirds of *m. deltoid* and *m. teres minor*. The radial nerve runs in the intermuscular septum of the *m. triceps brachii* then travels laterally around the arm to innervate the *m. dorsoepitrochlearis*, medial and lateral heads of *m. triceps brachii*, and extensor muscles of forearm. The suprascapular nerve comes off the C5 root (31.25%; n=4, np=5) or superior trunk (68.75%; n=7, np=11) then travels dorsally to innervate the *m. supraspinatus* and *m. infraspinatus*. The nerve to subclavius originates from the superior trunk and continues to innervate the *m. subclavius*. The long thoracic nerve originates from the dorsal division of C6 and C7 roots, traveling behind the *m. dorsal scalene* to innervate the *m. serratus anterior*. The lateral pectoral nerve originates from the lateral cord and the medial pectoral nerve originates from the medial cord; both innervate *m. pectoralis minor and major*. There is an ansa pectoralis that combines the lateral and medial pectoral nerves. The superior subscapular nerve originates from the dorsal division of the superior trunk (56.25%; n=6, np=9) or the posterior cord (43.75%; n=4, np=7) with either one (31.25%; n=3, np=5) or two (68.75%; n=7, np=11) branches which then innervate the upper *m. subscapularis* (Figure 11). The middle subscapular nerve (thoracodorsal nerve) originates from the posterior cord then travels through the axilla, running dorsally to innervate the *m. latissimus dorsi*. The inferior subscapular nerve originates from the axillary nerve containing one (6.25%; n=1, np=1), two (56.25%; n=6, np=9), or three (37.5%; n=4, np=6) branches which innervate the lower *m. subscapularis* (Figure 12).

Intraspecific Polymorphisms

Macaca fascicularis

<u>Y1305092</u>

<u>Bilateral</u>

The musculocutaneous nerve did not pierce the *m. coracobrachialis* (Figure 16A-B). The radial nerve came off the inferior trunk rather than the posterior cord. The superior subscapular nerve was made up of two branches from the dorsal division of the superior trunk (Figure 16C-D).

<u>Left</u>

The left side of the brachial plexus was missing a middle trunk. The superior trunk was normal, forming from the C5 and C6 roots. The second trunk was formed from C7, C8, and T1 roots. Due to the abnormal formation of the trunks, the medial and lateral cords have abnormal contributions. The medial cord receives contribution from C7 root. The lateral cord formed from the anterior division of the superior trunk and the C7 root (Figure 16B). The posterior cord was made of the dorsal divisions of the superior, middle, and inferior trunks which then gave off the axillary nerve. The inferior subscapular nerve had two branches which innervated the lower *m. subscapularis* (Figure 16D).

Right

The posterior cord was made up of the dorsal divisions of the superior, middle, and inferior trunk which then gave off the axillary nerve. The inferior subscapular nerve had three branches (Figure 16C).

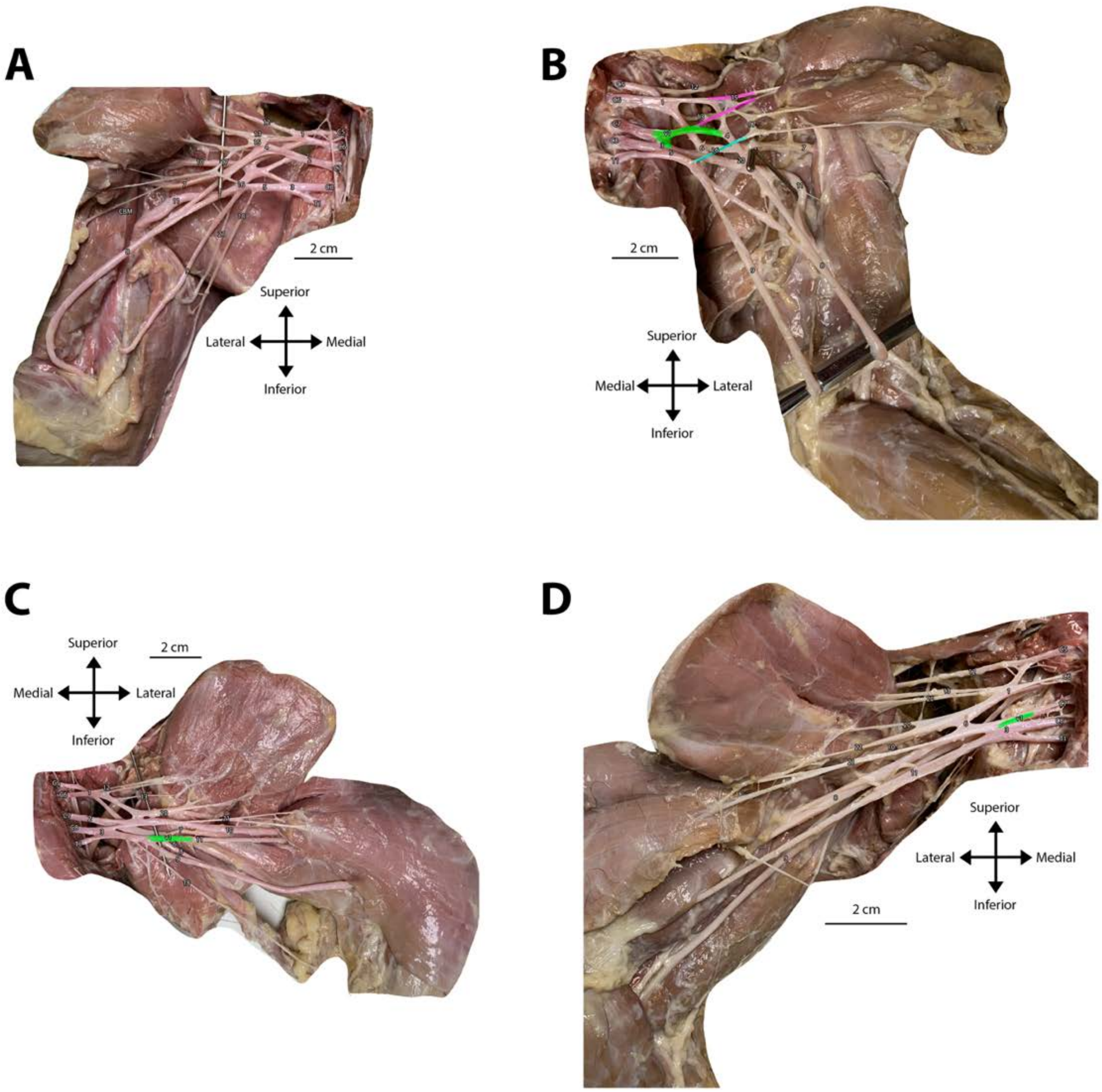


Figure 16. ***Macaca fascicularis*** **Y1305092 Right and Left Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. (B) There was no true middle trunk. The C7 root merged (green) with C8 and T1 to create the inferior cord. Part of the C7 root also merged (green) with the anterior division of the superior trunk to form the lateral cord. The lateral pectoral nerve (pink) branched from the C7 root and the superior trunk. The medial pectoral nerve (blue) branched from the medial cord with contribution from C7 root. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior view of the brachial plexus exhibits the onepart posterior cord with the inferior division of the superior, middle, and inferior trunks combining at one point to create the posterior cord. The radial nerve originates from the posterior division of the inferior trunk (green).

LC131604

Bilateral

The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves. The superior subscapular nerve formed two branches and originated from the posterior cord (Figure 17C-D).

Left

The lateral cord received contribution from C8. There was no ansa pectoralis between the lateral and medial pectoral nerves. The inferior subscapular nerve formed one branch. There was a communicating branch between the median and ulnar nerves (Figure 17B).

Right

The inferior subscapular nerve formed two branches (Figure 17C).

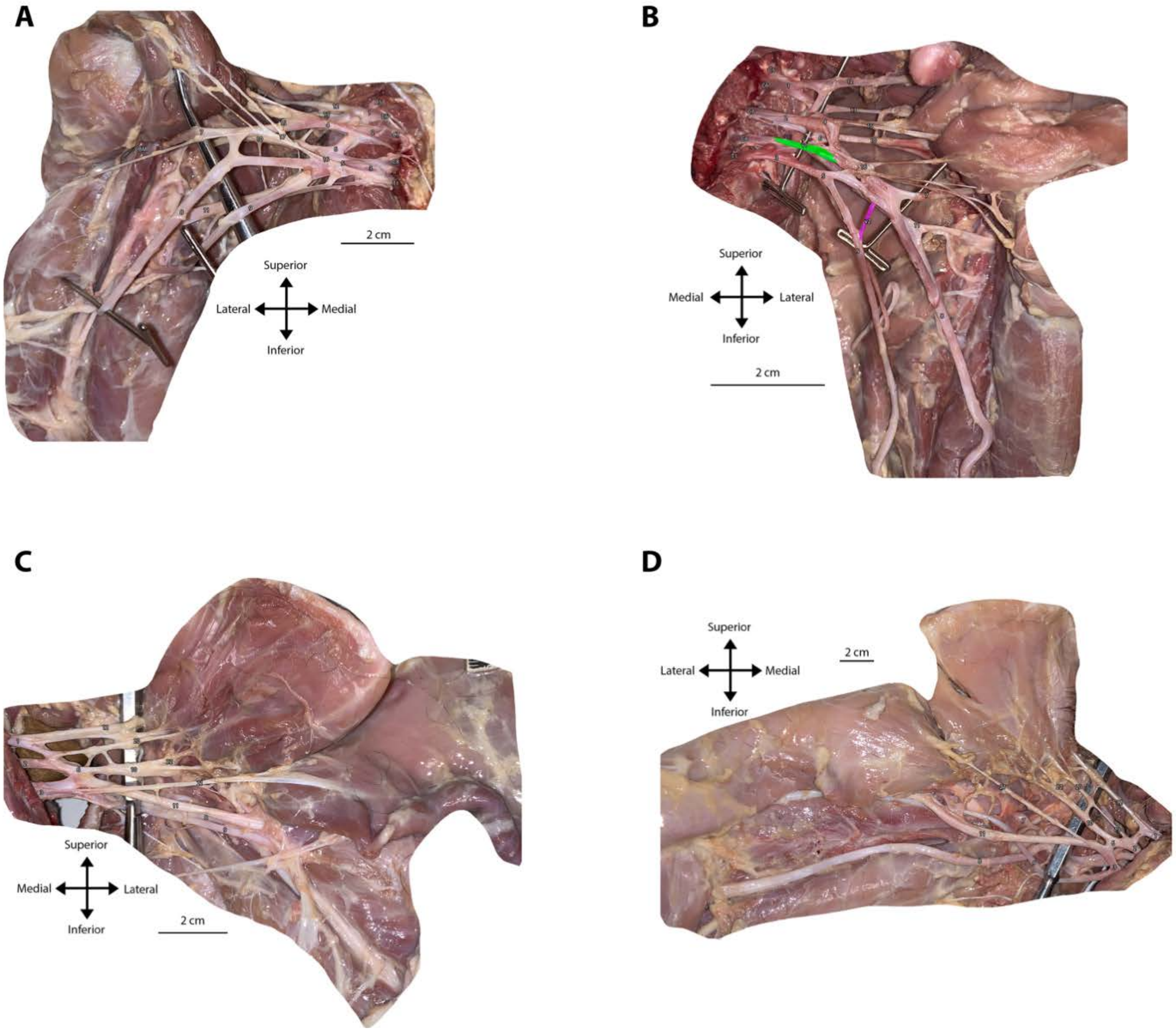


Figure 17. ***Macaca fascicularis*** **LC131604 Right and Left Brachial Plexuses.** (A-B) Right (A) and left (B) anterior view of brachial plexus. (B) C8 root sends a communicating branch (green) that merges with the lateral cord. There is a communicating branch (pink) between the ulnar nerve and median nerve. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves.

Y1409053

Bilateral

The superior trunk received a contribution from C4 spinal root (Figure 18A-B). The posterior cord had two segments (Figure 18C-D). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The thoracodorsal nerve came off the upper posterior cord (Figure 18C-D).

Left

The superior subscapular nerve formed one branch originating from the dorsal division of the superior trunk. The inferior subscapular nerve formed two branches (Figure 18D).

Right

The superior subscapular nerve formed two branches originating from the upper posterior cord. The inferior subscapular nerve contained three branches (Figure 18C). There was a communicating branch between the musculocutaneous and median nerves (Figure 18A).

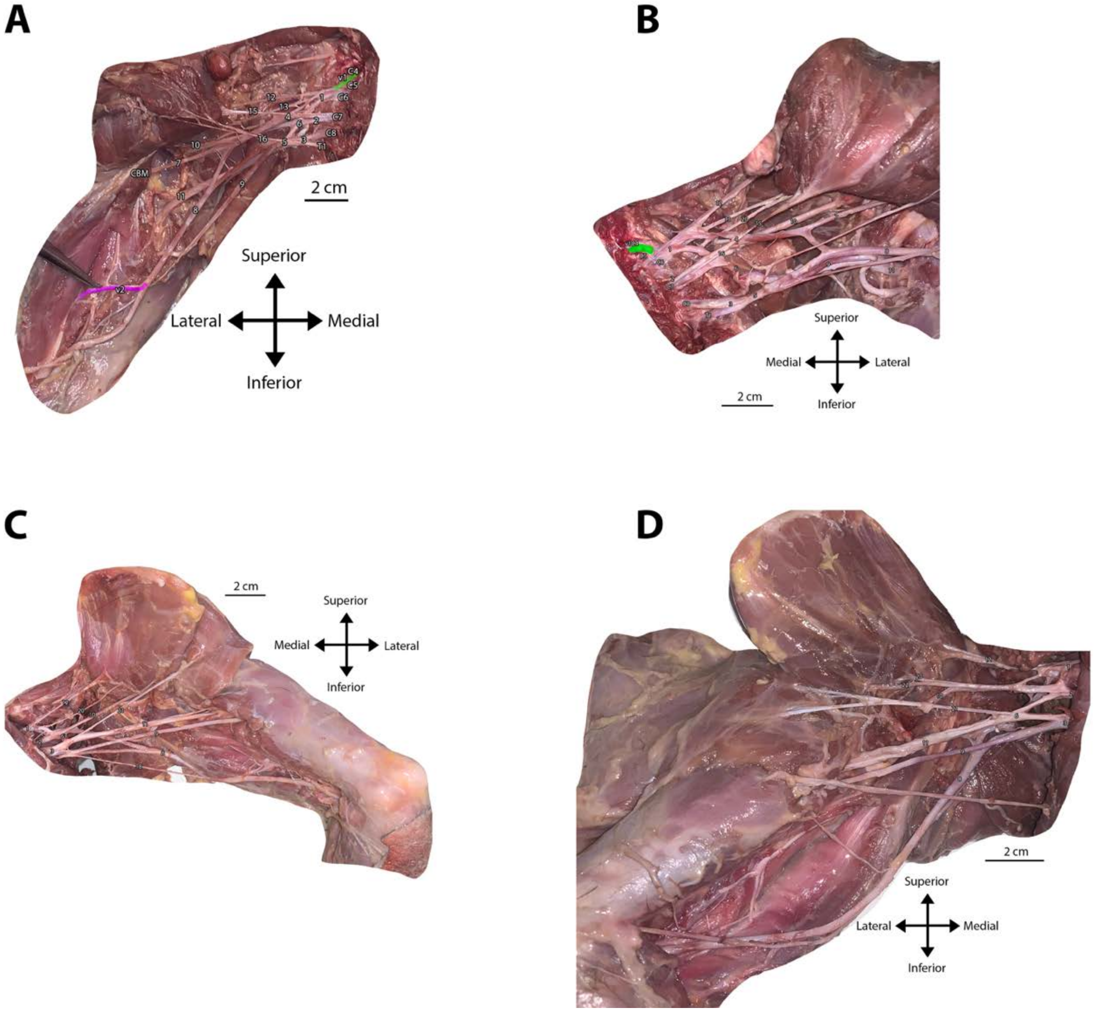


Figure 18. ***Macaca fascicularis*** **Y1409053 Right and Left Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. The brachial plexus has a prefixed branching pattern (green). (A) There is a communicating branch (pink) between the musculocutaneous nerve and median nerve. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves.

4982686557

Bilateral

The dorsal scapular nerve received contribution from C4. The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves. The superior subscapular nerve formed one branch originating from the posterior cord. The inferior subscapular nerve formed two branches. There were no differences between the right and left sides (Figure 19).

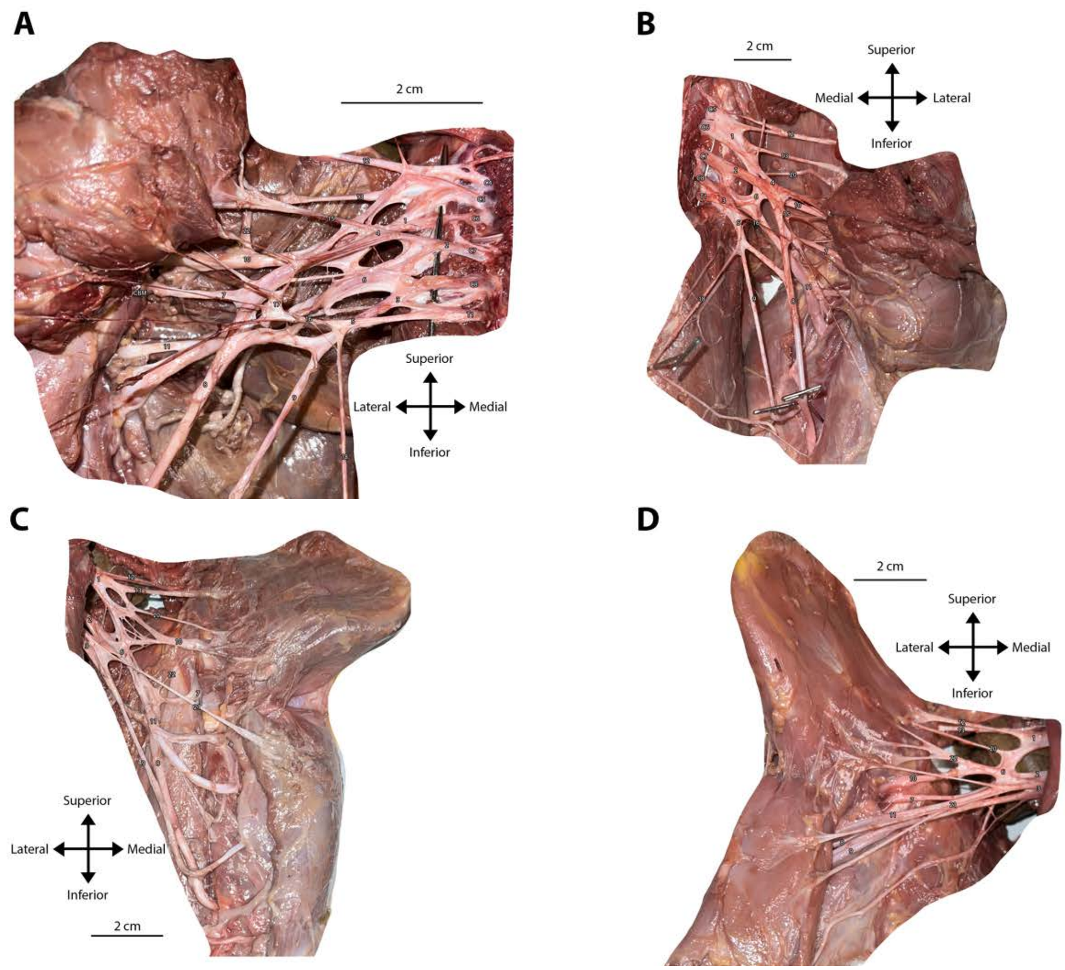


Figure 19. ***Macaca fascicularis*** **4982686557 Right and Left Brachial Plexuses.** (A-B) Right (A) and left (B) anterior view of brachial plexus. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves.

C1305246

Bilateral

The inferior subscapular nerve formed three branches. There was a communicating branch between the axillary and radial nerves (Figure 20A-B).

Left

The lateral cord received contribution from C8. The posterior cord had two segments. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The medial pectoral nerve came off the lateral cord (Figure 20B). The superior subscapular nerve formed one branch that originated from the upper posterior cord. The thoracodorsal nerve came from the upper posterior cord (Figure 20D).

Right

The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves. The superior subscapular nerve formed two branches originating from the superior trunk (Figure 20C).

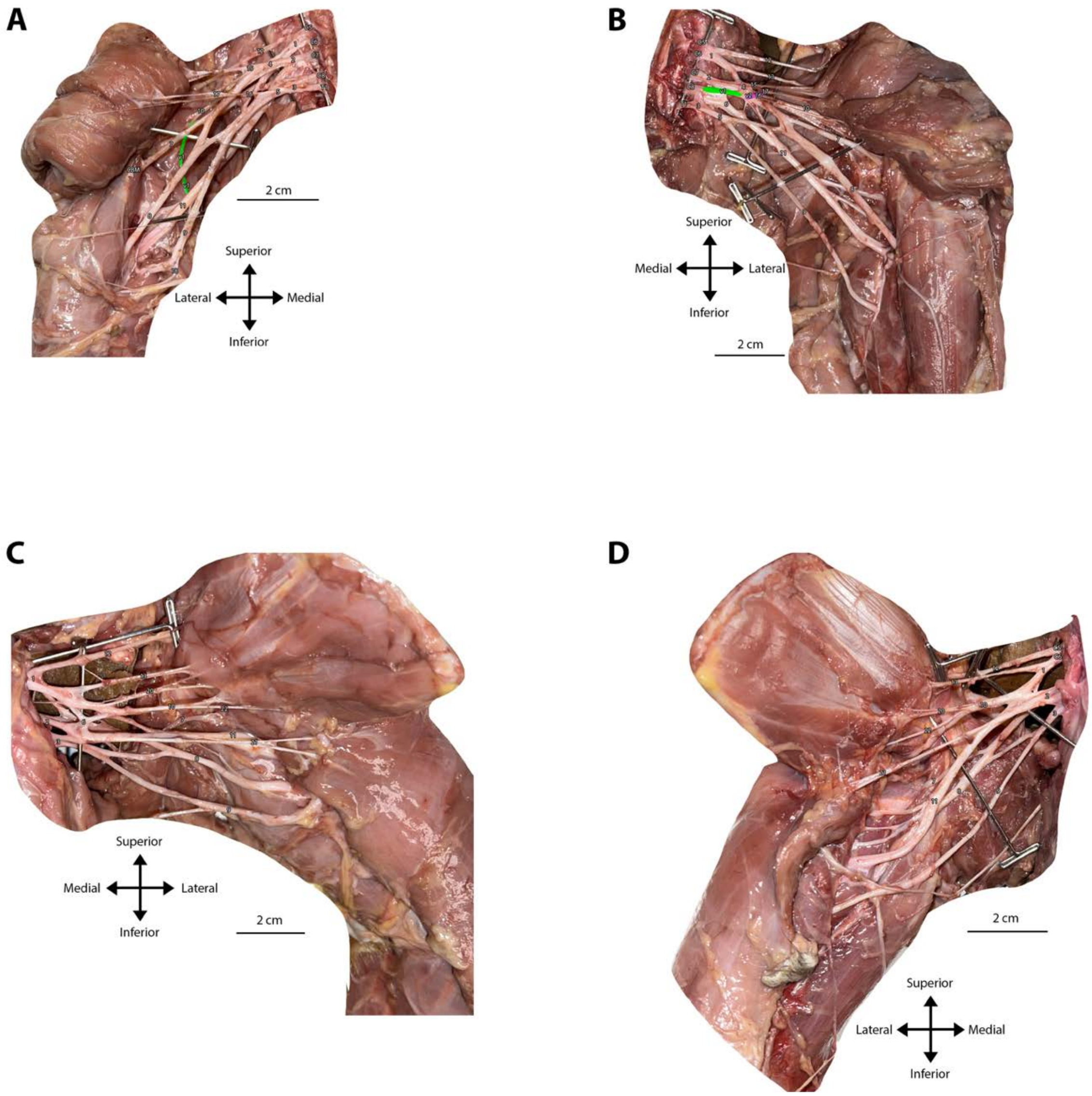


Figure 20. ***Macaca fascicularis*** **C1305246 Right and Left Brachial Plexuses.** (A-B) Right (A) and left (B) anterior view of brachial plexus. (A) There is a communicating branch (green) between the axillary nerve and radial nerve. (B) C8 root sends a communicating branch (green) to the lateral cord. The medial pectoral nerve (pink) originates from the lateral cord. (C-D) Right (C) and left (D) posterior view of the brachial plexus. (C) The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves. (D) The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

C1302037

Bilateral

The inferior subscapular nerve formed three branches. There was a communicating branch between the axillary and radial nerves (Figure 21C-D).

Left

The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves (Figure 21D). The medial pectoral nerve came off the lateral cord and lacked an ansa pectoralis connecting it to the lateral pectoral nerve (Figure 21B). The superior subscapular nerve had one branch originating from the posterior cord (Figure 21D).

Right

The posterior cord had two segments (Figure 21C). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The superior subscapular nerve formed two branches that originated from the superior trunk. The thoracodorsal nerve came off the upper posterior cord (Figure 21C).

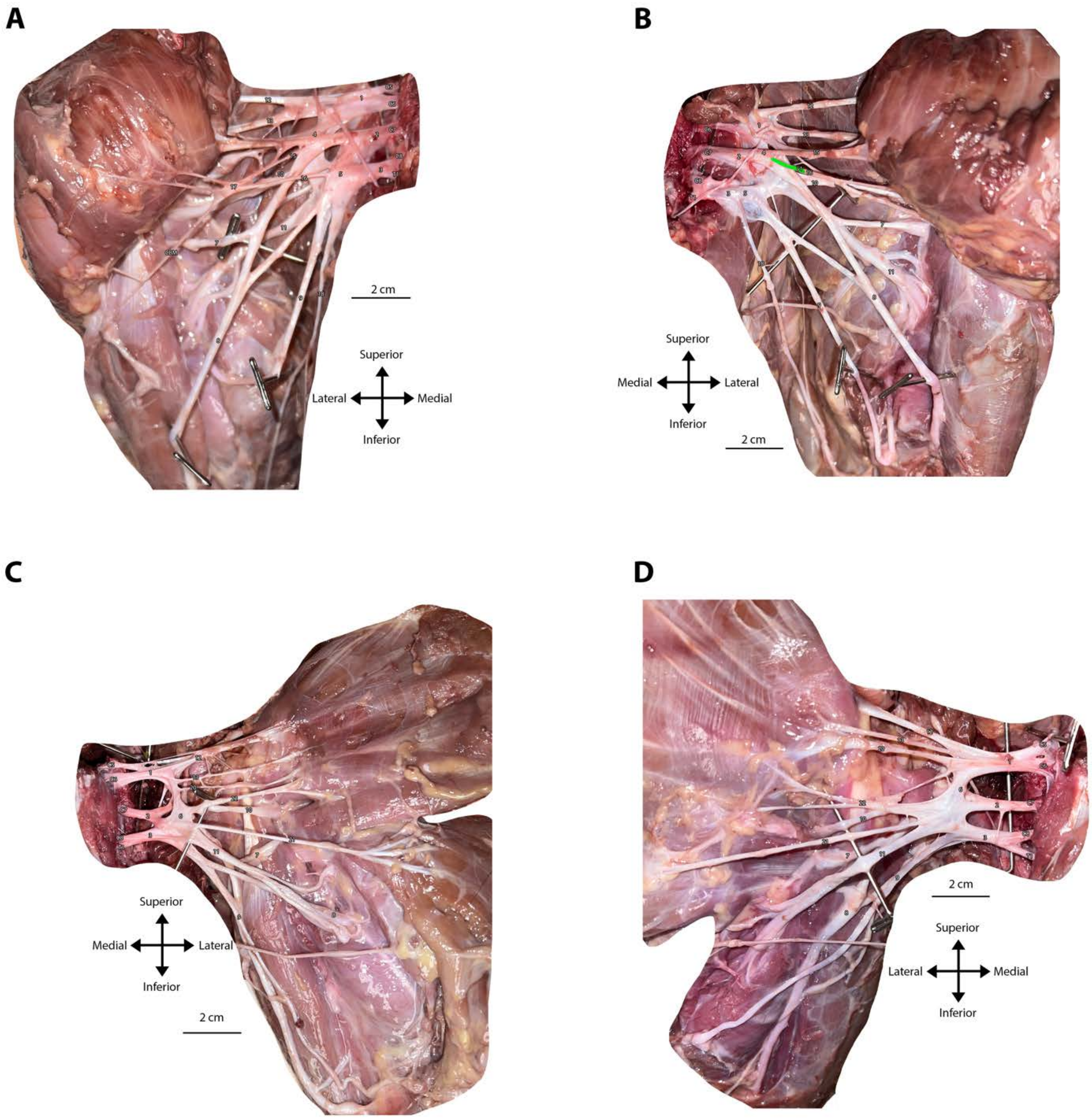


Figure 21. ***Macaca fascicularis*** **C1302037 Right and Left Brachial Plexuses.** (A-B) Right (A) and left (B) anterior view of brachial plexus. (B) The medial pectoral nerve (green) originated from the lateral cord and did not form an ansa pectoralis with the lateral pectoral nerve. (C-D) Right (C) and left (D) posterior view of the brachial plexus. (C) The posterior cord, made from the posterior divisions of the superior, middle, and inferior trunks, gave off a single branch which split to become the axillary and radial nerves. (D) The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

M. mulatta

<u>*12042391*</u>

<u>Bilateral</u>

The inferior trunk received contribution from spinal root T2 (Figure 22A-B). The posterior cord had two segments (Figure 22C-D). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The superior subscapular nerve formed two branches that originated from the superior trunk. The thoracodorsal nerve originated from the radial nerve (Figure 22C-D).

<u>Left</u>

The inferior subscapular nerve formed two branches (Figure 22D).

<u>Right</u>

There was no ansa pectoralis between the medial and lateral pectoral nerves (Figure 22A). The inferior subscapular nerve contained two branches (Figure 22C).

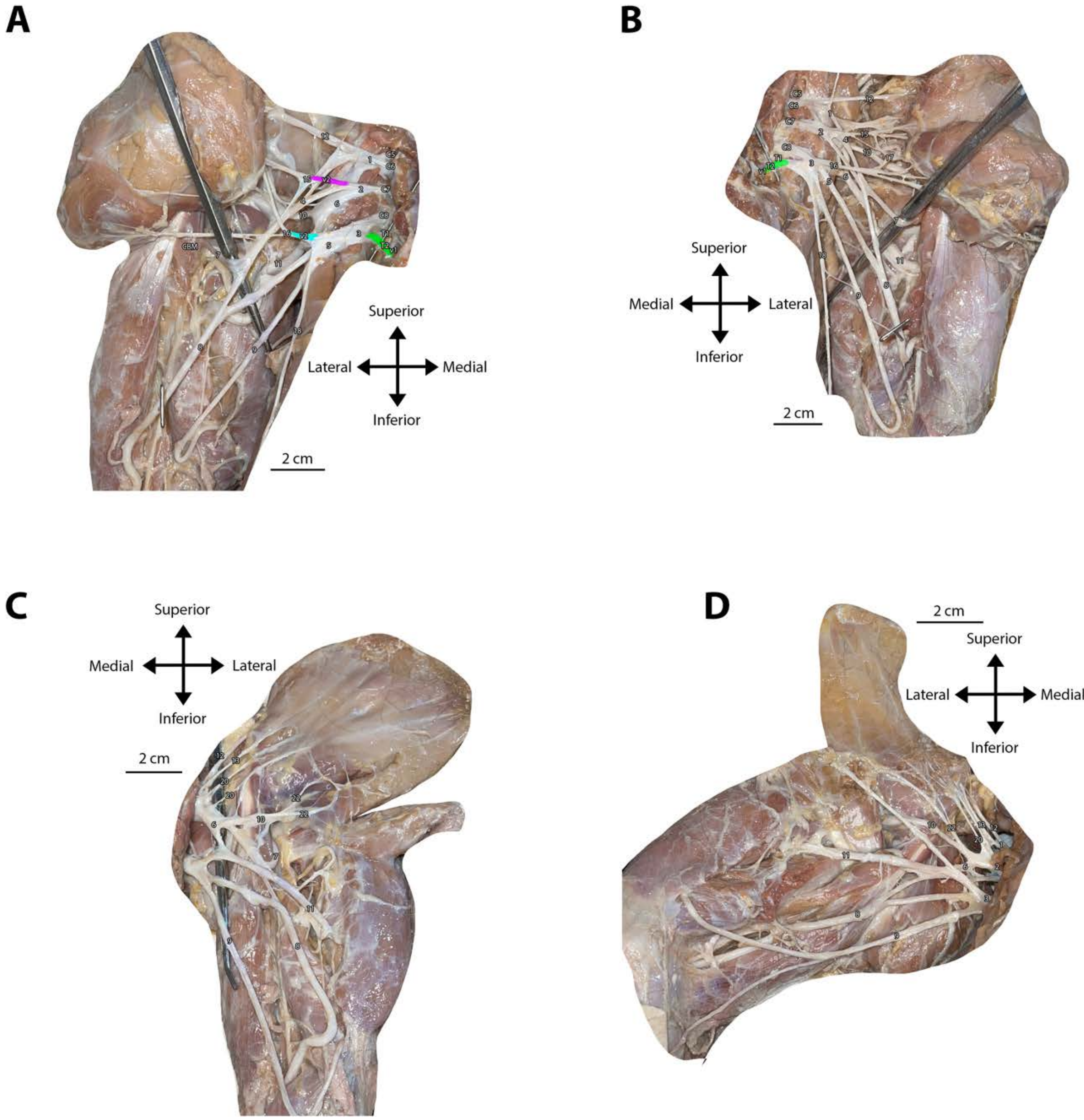


Figure 22. ***Macaca mulatta*** **12042391 Left and Right Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. The brachial plexus exhibited postfixed branching pattern (green). (A) There was no ansa pectoralis connecting the lateral pectoral nerve (pink) to the medial pectoral nerve (blue). (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

R1525R

Bilateral

The posterior cord had two segments (Figure 23C-D). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The superior subscapular nerve formed two branches originating from the superior trunk. The inferior subscapular nerve formed two branches. There was a communicating branch between the musculocutaneous and median nerves (Figure 24A).

Left

The superior trunk received contribution from spinal root C4 (Figure 23B). The inferior trunk received contribution from spinal root T2. The thoracodorsal nerve originated from the upper posterior cord (Figure 23D).

Right

The thoracodorsal nerve originated from the lower posterior cord (Figure 23C).

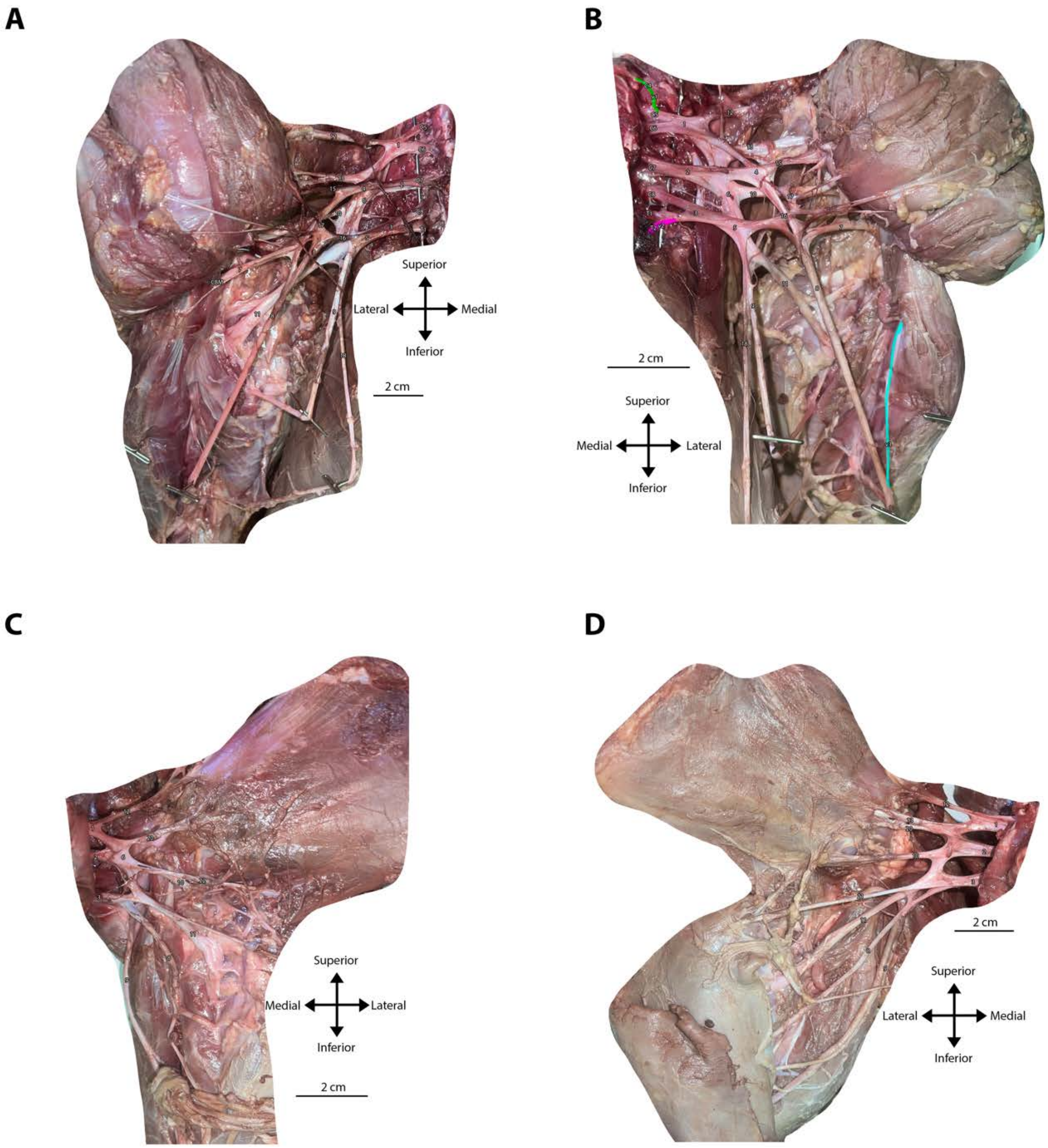


Figure 23. ***Macaca mulatta*** **R1525R Right and Left Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. (B) The brachial plexus exhibited both a prefixed (green) and postfixed (pink) branching pattern. There was a communicating branch (blue) between the musculocutaneous nerve and median nerve. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

Summary of *Macaca sp.*

The most common variant branching pattern found in *Macaca sp.* was either a prefixed (n=2, np=3) or postfixed (n=2, np=3) brachial plexus (Figure 15). A prefixed branching pattern occurred bilaterally in one specimen and unilaterally in another. A postfixed branching pattern also occurred bilaterally in one specimen and unilaterally in another. The prefixed and postfixed branching patterns did not occur in the same specimens. The posterior cord consisted of one-part in five specimens (n=5, np=8) and two-parts in five specimens (n=5, np=8) (**Error! Reference source not found.**). Two specimens displayed unilateral one-part and two-part posterior cord branching patterns. The superior subscapular nerve originated from the superior trunk (n=6, np=9) or posterior cord (n=5, np=7) (Figure 11). When originating from the superior trunk, the superior subscapular nerve either formed one (n=1, np=1) or two branches (n=5, np=8); similarly, the superior subscapular nerve originating from posterior cord also formed one (n=3, np=4) or two branches (n=2, np=3). The inferior subscapular nerve originated from the axillary nerve and formed one (n=1, np=1), two (n=6, np=9), or three (n=4, np=6) branches (Figure 12).

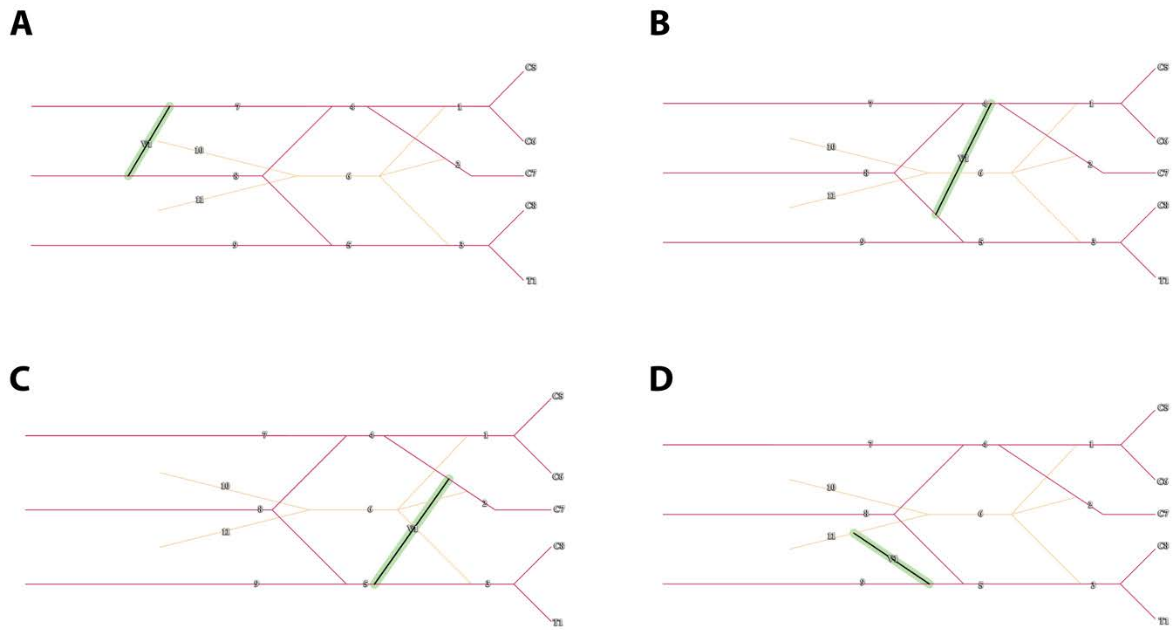


Figure 24. Common Communicating Branch Patterns.
(A-D) Variant communicating branch is shown in green. (A) Communicating branch between the musculocutaneous nerve and the median nerve. (B) Communicating branch between the lateral cord and the medial head of the median nerve. (C) Communicating branch between the middle trunk and the medial cord. (D) Communicating branch between the ulnar nerve and radial nerve. (A-D) Anterior brachial plexus displayed in red, posterior aspect shown in yellow. Drawings are my own.

Saimiri sp. *Results.*

The left brachial plexus of *2231* (Figure 25B) originates from the spinal roots of C5-T1. The C5 root gives off the dorsal scapular nerve which innervates the *m. rhomboid major, m. rhomboid minor,* and *m. levator scapulae*. The C6 and C7 roots give off branches that combine to create the long thoracic nerve which innervates the *m. serratus anterior*. The superior trunk is formed by the combination of C5 and C6, the middle trunk is formed by the continuation of the C7 root, and the inferior trunk is formed by the combination of C7 and T1. The superior trunk gives off the suprascapular nerve which dives posteriorly to innervate the *m. supraspinatus* and *m. infraspinatus*. The superior and middle trunks combine to create the lateral cord. The lateral cord gives off the lateral pectoral nerve, musculocutaneous nerve, and the lateral head of the median nerve. The musculocutaneous nerve travels laterally to pierce the *m. coracobrachialis* to innervate it and the *m. brachialis* and *m. biceps brachii*. The inferior trunk continues to form the medial cord which then gives off the medial pectoral, ulnar nerve, and the medial head of the median nerve. Both pectoral nerves innervate the *m. pectoralis minor* and *m. pectoralis major*. The ulnar nerve dives dorsally behind the medial epicondyle before it travels anteriorly to innervate the medial forearm flexor muscles. The median nerve innervates the lateral flexor muscles of the forearm.

The posterior cord (Figure 25D) is made of two segments, upper and lower. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve and superior subscapular nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The axillary nerve travels into the axillary region to innervate the *m. deltoid* and *m. teres minor*. The radial nerve runs laterally through the *m. triceps brachii* to innervate the *m. triceps brachii, m. dorsoepitrochlearis*, and the extensor muscles of the forearm. The superior subscapular nerve gives off two branches to innervate the superior portion of the *m. subscapularis*. The middle subscapular (thoracodorsal) nerve arises from a common stalk with the radial nerve and innervates the *m. latissimus dorsi*. The inferior subscapular nerve originates from the axillary nerve to innervate the inferior portion of *m. subscapularis*.

Intraspecific polymorphisms

<u>*2231*</u>

<u>Right</u>

The superior subscapular nerve forms three branches that innervate the superior portion of the *m. subscapularis* (Figure 25C).

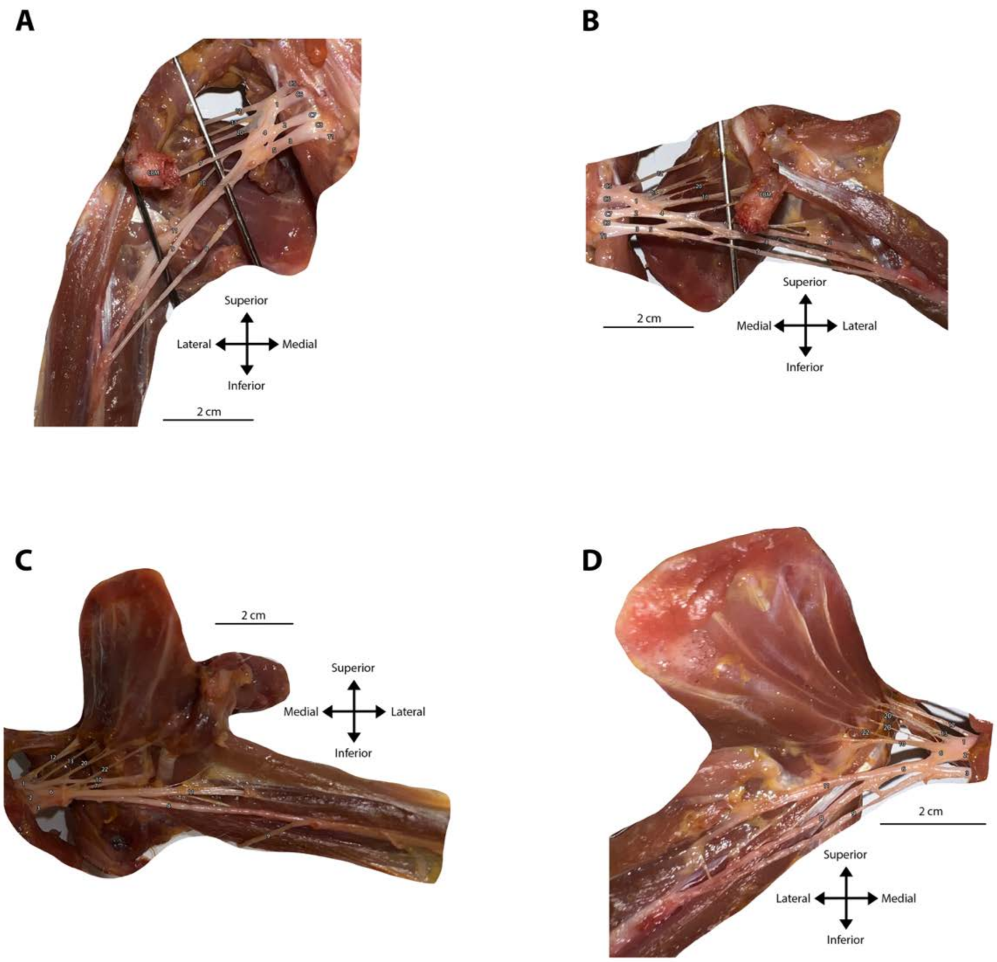


Figure 25. ***Saimiri*** **2231 Right and Left Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

2254

Bilateral

The middle subscapular (thoracodorsal) nerve comes off the radial nerve rather than originating from a common stalk with the radial nerve (Figure 26).

Left

There are three branches of the inferior subscapular nerve that innervate the inferior portion of the *m. subscapularis* (Figure 26D).

Right

There are two branches of the inferior subscapular nerve that innervate the inferior portion of the *m. subscapularis* (Figure 26C). There is a communicating branch from the lateral cord to the medial head of the median nerve (Figure 26A).

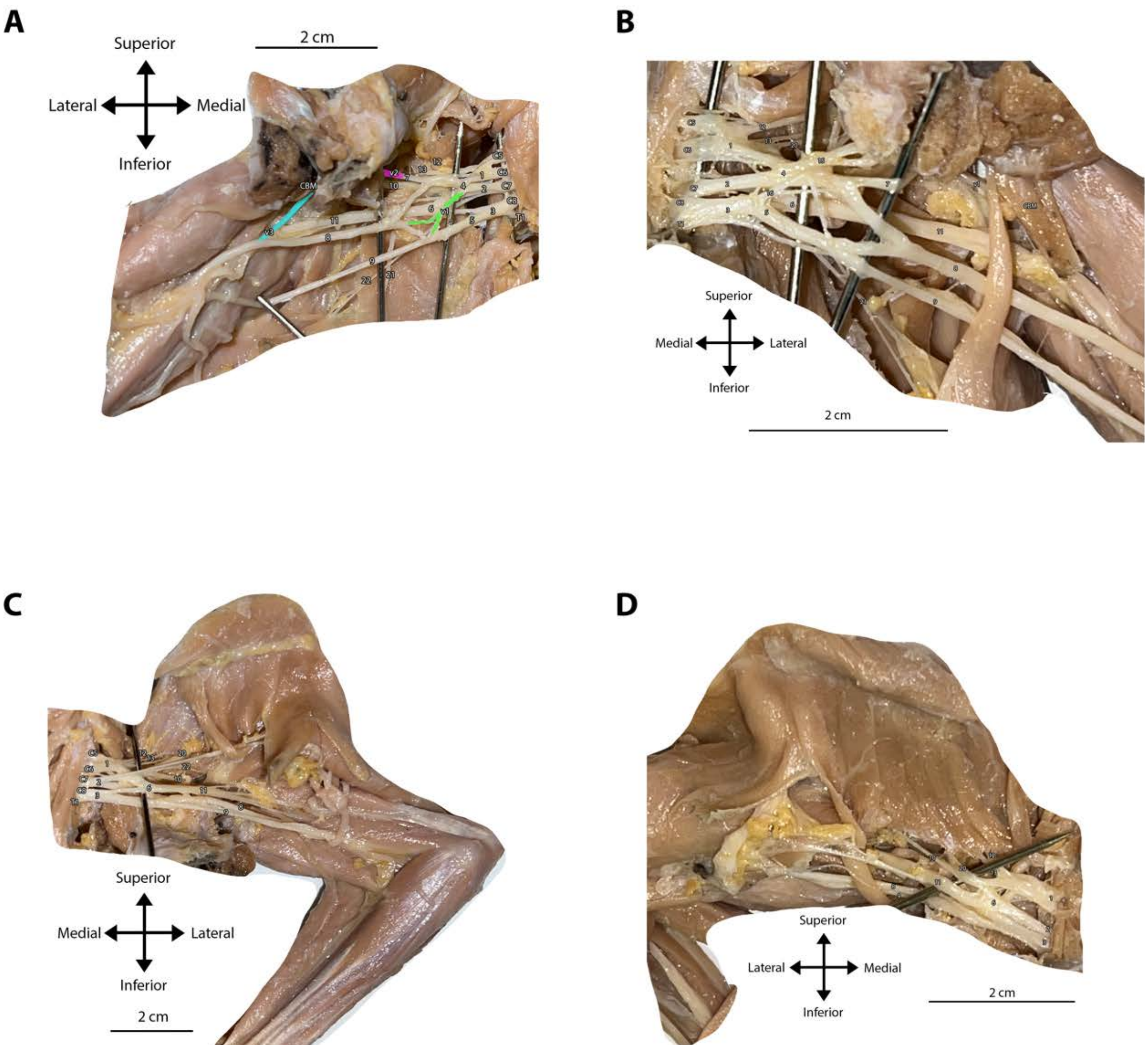


Figure 26. ***Saimiri*** **2254 Right and Left Brachial Plexuses.**
(A-B) Right (A) and left (B) anterior view of brachial plexus. (A) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve. The musculocutaneous nerve (pink) does not pierce *m. coracobrachialis*. There is a communicating branch (blue) between the musculocutaneous nerve and the median nerve. (C-D) Right (C) and left (D) posterior view of the brachial plexus. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

Summary of *Saimiri sp.*

In *Saimiri sp.* one of the specimens bilaterally did not have an ansa pectoralis (n=1, np=2). One specimen (n=1, np=2) displayed a bilateral variation in the branching pattern of the musculocutaneous nerve with the nerve not piercing *m. coracobrachialis*. The posterior cord formed in the two-part branching pattern bilaterally in both specimens (n=2, np=4) (Figure 10B). The superior subscapular nerve originated from the posterior cord bilaterally in both specimens (n=2, np=4) forming two (n=2, np=3) or three (n=1, np=1) branches (Figure 11). The inferior subscapular nerve originated from the axillary nerve forming one (n=1, np=2), two (n=1, np=1), or three (n=1, np=1) branches (Figure 12).

Error! Reference source not found. is a summary table of the non-human primate species results.

Homo sapiens *Results.*

The right brachial plexus of *4050* (Figure 27A) will be used to describe the typical human brachial plexus. The right brachial plexus of *4050* is formed by the spinal roots C5, C6, C7, C8, and T1. The superior trunk is formed by the combination of the C5 and C6 roots, the middle trunk is a continuation of the C7 root, and the inferior trunk is a combination of the C8 and T1 roots. Each trunk has an anterior and posterior division. The anterior division of the superior and middle trunks combine to create the lateral cord. The anterior division of the inferior trunk forms the medial cord. The posterior division of the superior, middle, and inferior trunks all combine at one point to form the posterior cord. The dorsal scapular nerve originates from C5 root and innervates the *m. rhomboid major, m. rhomboid minor,* and *m. levator scapulae*. The long thoracic comes from the C6, C7, and C8 roots and innervates the *m. serratus anterior*. The superior trunk gives off the suprascapular nerve and the nerve to subclavius. The suprascapular nerve goes posteriorly to innervate the *m. supraspinatus* and *m. infraspinatus*. The nerve to subclavius stays anterior and innervates the *m. subclavius*. The lateral cord forms the lateral pectoral nerve, musculocutaneous nerve, and the lateral head of the median nerve. The musculocutaneous nerve pierces through the *m. coracobrachialis* and innervates the *m. coracobrachialis*, *m. biceps brachii*, and *m. brachialis* before becoming the lateral cutaneous nerve of the forearm. The medial cord forms the medial pectoral nerve, ulnar nerve, and the medial head of the median nerve. The ulnar nerve dives behind the medial epicondyle before arising anteriorly to innervate the medial forearm flexor muscles. The median nerve, which receives contribution from the lateral and medial cords, continues down the forearm to innervate the lateral forearm flexor muscles. The lateral pectoral nerve and the medial pectoral nerve are connected via the ansa pectoralis, and both innervate the *m. pectoralis major* and *m. pectoralis minor*. The posterior cord gives off the axillary nerve, radial nerve, superior subscapular nerve, thoracodorsal (middle subscapular) nerve, and inferior subscapular nerve. The axillary nerve enters the quadrangular space within the axillary region to innervate the *m. deltoid* and *m. teres minor*. The radial nerve travels through the *m. triceps brachii* to innervate the *m. triceps brachii* and extensor muscles of the forearm. The *m. subscapularis* is innervated by the superior subscapular nerve and the inferior subscapular nerve. The thoracodorsal (middle subscapular) nerve innervates the *m. latissimus dorsi*.

The figures representing the *Homo sapiens* results can be found in the appendix with data tables explaining the variants in more detail due to repetitiveness and large sample size.

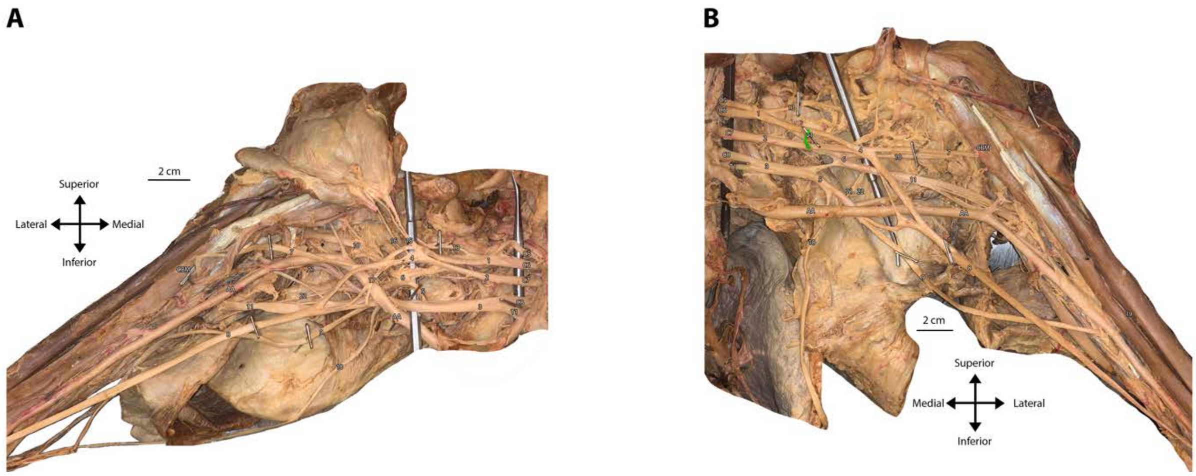


Figure 27. *Homo sapiens* 4050 Right and Left Brachial Plexuses.
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) Typical branching pattern of the brachial plexus. (B) There is a communicating branch (green) between the superior and middle trunks.

Intraspecific Polymorphisms

*Indicates only one side available for dissection.

<u>*437-W**</u>

<u>Right</u>

The middle trunk sends a communicating branch to the medial cord (Appendix Figure 1).

<u>*482-D**</u>

<u>Left</u>

The musculocutaneous nerve does not pierce the *m. coracobrachialis*. There is a communicating branch between the musculocutaneous and median nerves (Figure 28).

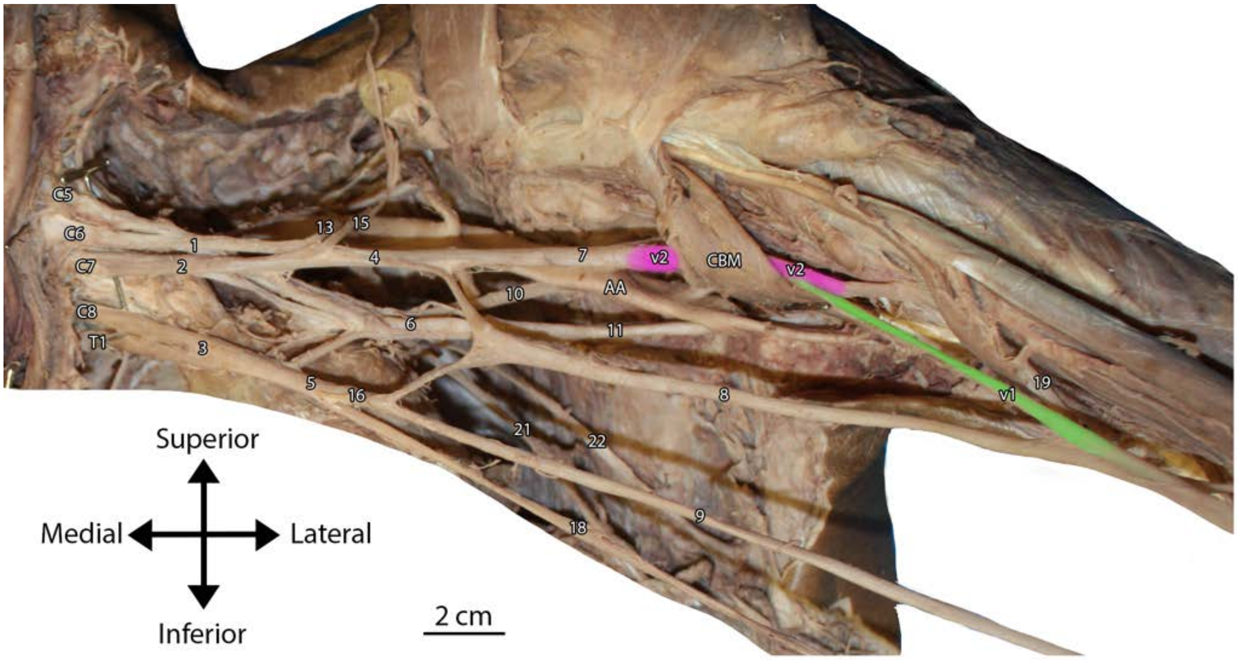


Figure 28. *Homo sapiens* 482-D Left Brachial Plexus.
Anterior view of the left brachial plexus. The musculocutaneous nerve does not pierce *m. coracobrachialis* (pink). There is a communicating branch between the musculocutaneous nerve and the median nerve (green).

<u>*4049*</u>

<u>Bilateral</u>

There is a communicating branch between the medial and lateral cords (Appendix Figure 2).

<u>Right</u>

The lateral antebrachial cutaneous nerve arises from the lateral head of the median nerve (Appendix Figure 2A).

<u>*4050*</u>

<u>Left</u>

There is a communicating branch between the superior and middle trunks that does not contribute to the formation of the lateral cord (Figure 27B).

4055

Bilateral

There is a communicating branch between the medial and lateral cords (Appendix Figure 3).

4060

Right

There is a communicating branch between the medial and lateral cords (Appendix Figure 4).

4063

Bilateral

The inferior trunk contributes directly into the radial nerve only (Appendix Figure 5).

Left

The posterior cord does not receive contribution from the inferior trunk. The posterior cord, created by the combination of the posterior division of the superior and middle trunks, gives off the axillary and radial nerve (Appendix Figure 5B).

Right

Brachial plexus is prefixed with contribution from the C4 root. There are four trunks rather than the typical three. The most superior trunk is created by C4 and C5. C6 forms a separate trunk. C7 continues as the typical middle trunk. C8 and T1 combine to create the typical inferior trunk (Appendix Figure 5A).

4064

Bilateral

The lateral and medial pectoral nerves arise from the anterior divisions of the superior, middle, and inferior trunks rather than from the lateral and medial cords respectively. The ansa pectoralis is still present (Appendix Figure 6).

4065

Right

Distal to piercing the *m. coracobrachialis,* the musculocutaneous nerve forms a communicating branch with the median (Appendix Figure 7A).

4067

Left

The lateral antebrachial cutaneous nerve arises from the median nerve (Appendix Figure 8B).

Right

The superior and inferior subscapular nerves come off from the axillary nerve (Appendix Figure 8A).

4070

Left

There is a communicating branch between the medial and lateral cords. There is a communicating branch between the musculocutaneous nerve and median nerve (Appendix Figure 9B).

Right

The musculocutaneous nerve does not pierce the *m. coracobrachialis*. The lateral antebrachial cutaneous nerve arises from the median nerve (Appendix Figure 9A).

4070

Left

There is a communicating branch between the medial and lateral cords. The superior subscapular nerve originates from the posterior division of the superior trunk. The thoracodorsal nerve comes off the inferior trunk before the trunk merges into the posterior cord. The inferior subscapular nerve originates from a common stalk with the axillary nerve. The axillary nerve originates from the posterior division of the superior trunk before the trunk merges into the posterior cord (Appendix Figure 10B).

Right

The anterior division of the middle trunk has a communicating branch to the ulnar nerve (Appendix Figure 10A).

*WMED-16-009**

Right

There is a communicating branch between the middle trunk and median nerve (Appendix Figure 11).

WMED-18-010

Bilateral

There is a communicating branch between the lateral cord and medial head of the median nerve (Figure 29).

Left

The musculocutaneous nerve does not pierce the *m. coracobrachialis* (Figure 29B).

Right

This brachial plexus is prefixed with contribution from the C4 root. The superior trunk receives contribution from the C4 root. There is a communicating branch between the distal end of musculocutaneous nerve and median nerve. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The superior subscapular and thoracodorsal nerves come off the upper portion of the posterior cord before the merger of the inferior trunk. The inferior subscapular nerve comes from the lower portion of the posterior cord after the inferior trunk joins (Figure 29A).

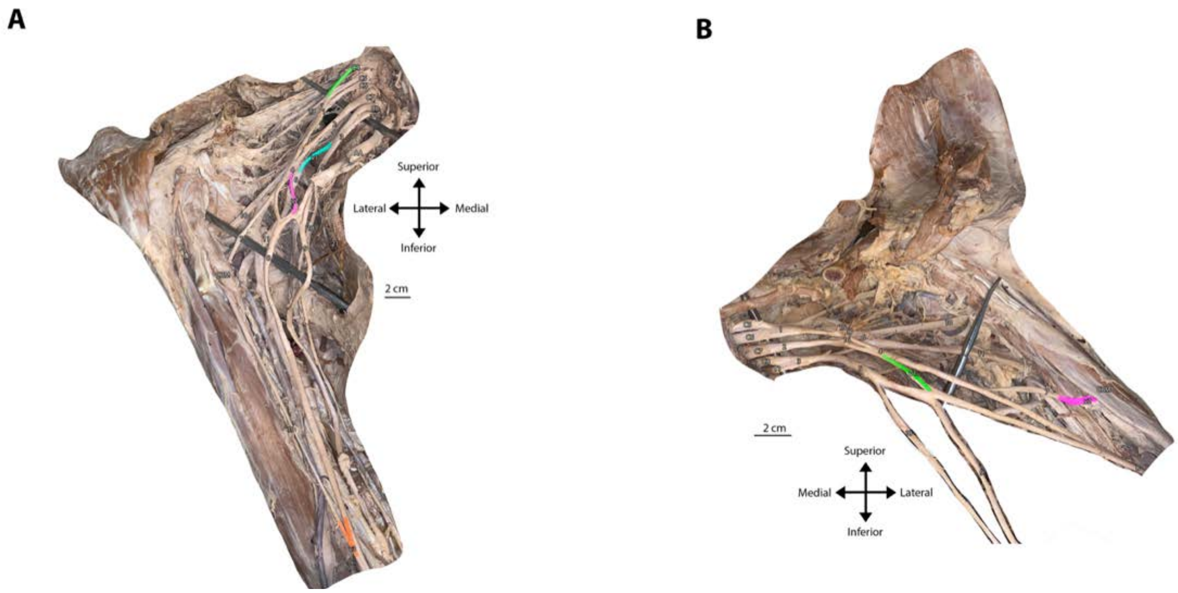


Figure 29. *Homo sapiens* 18-010 Right and Left Brachial Plexuses.
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) This brachial plexus is prefixed (green). There is a communicating branch (pink) between the lateral cord and the medial head of the median nerve. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern (blue). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. There is a communicating branch (orange) between the musculocutaneous nerve and the median nerve. (B) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve. The musculocutaneous nerve (pink) does not pierce *m. coracobrachialis*.

WMED-18-019

Left

There is a communicating branch between the distal end of the musculocutaneous nerve and median nerve (Appendix Figure 12B).

WMED-18-025

Left

There are only two trunks, the middle trunk is missing. The inferior trunk is made from the combination of C7, C8, and T1 roots. There is a communicating branch between the anterior divisions of the superior and inferior trunks (Appendix Figure 13B).

Right

There is a communicating branch between the C7 and C8 roots. The middle trunk and inferior trunk continue as normal (Appendix Figure 13A).

WMED-19-004

Right

There is a communicating branch between the C7 and C8 roots. The middle trunk and inferior trunk continue as normal. The musculocutaneous nerve does not pierce the *m. coracobrachialis* (Appendix Figure 14A).

*WMED-19-011**

Right

The posterior division of the superior trunk gives off the axillary nerve before the posterior divisions of the middle and inferior trunks combine to create the posterior cord and give off the radial nerve. The musculocutaneous nerve does not pierce the *m. coracobrachialis*. There is a communicating branch between the distal end of the musculocutaneous nerve and median nerve. The medial head of the median nerve comes from the middle trunk with a communicating branch from the inferior trunk (Appendix Figure 15A).

*WMED-19-012**

Left

This brachial plexus is prefixed with contribution from the C4 root. The superior trunk receives contribution from the C4 root. The lateral cord does not receive contribution from the middle trunk, it is a continuation of the superior trunk. The middle trunk gives a branch to the median nerve. The posterior cord is formed in two portions. The upper portion of the posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower portion of the posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The superior subscapular, thoracodorsal, and inferior subscapular nerves come from the posterior cord prior to the inferior trunk merging (Appendix Figure 16B).

WMED-19-013

Right

The posterior divisions of the superior and middle trunks combine and give off the axillary nerve. The posterior division of the inferior trunk then merges with the other two posterior divisions and gives off the radial nerve. There is a communicating branch between the musculocutaneous nerve and median nerve (Appendix Figure 17A).

WMED-19-015

Left

There is a communicating branch between the musculocutaneous nerve and median nerve (Appendix Figure 18B).

Right

There is a communicating branch between the ulnar nerve and radial nerve (Appendix Figure 18A).

WMED-19-016

Right

There is a communicating branch between the lateral cord and medial head of the median nerve (Appendix Figure 19A).

WMED-19-017

Left

The musculocutaneous nerve does not pierce the *m. coracobrachialis* (Appendix Figure 20B).

WMED-19-019

Bilateral

Brachial plexus (Appendix Figure 21) is prefixed with contribution from the C4 root. The superior trunk receives contribution from the C4 root.

*WMED-20-013**

Right

There is a communicating branch between the lateral cord and medial head of the median nerve (Appendix Figure 22).

*WMED-20-017**

Right

There is a communicating branch between the C6 and C7 roots. There is a communicating branch between the lateral cord and medial head of the median nerve (Appendix Figure 23).

*WMED-20-018**

Right

Brachial plexus (Appendix Figure 24) is prefixed with contribution from the C4 root. The C4 root combines with C5 root then gives off the suprascapular nerve. There is no superior trunk. The combined C4 and C5 roots, C6, and C7 roots all merge at one point to create the lateral cord. The lateral cord gives off a branch that turns into the axillary nerve before the inferior trunk combines to create the posterior cord. The middle trunk directly contributes to the median nerve. There is a communicating branch between the middle trunk and ulnar nerve.

*WMED-20-024**

Right

There is a communicating branch between the lateral cord and medial head of the median nerve (Figure 30).

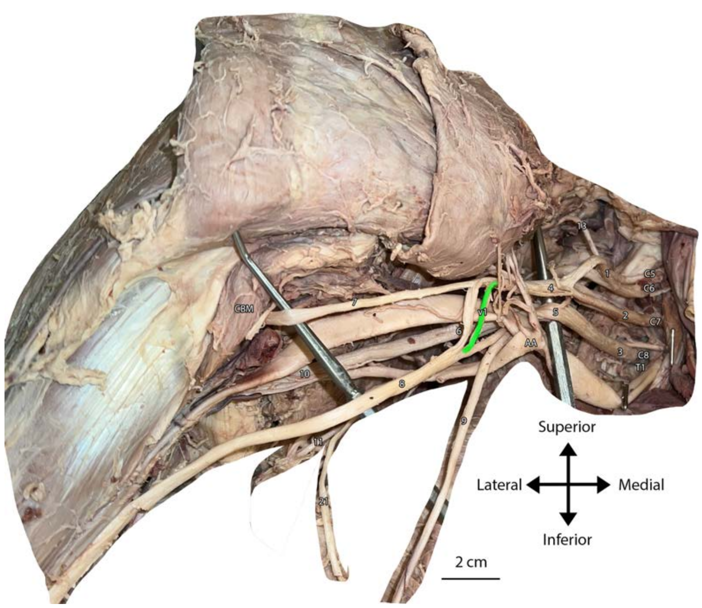


Figure 30. ***Homo sapiens*** **20-024 Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch between the lateral cord and the medial head of the median nerve.

*WMED-21-013**

Right

There is no musculocutaneous nerve. The median nerve provides muscular branches to the muscles normally innervated by the musculocutaneous nerve. The median nerve does not pierce the *m. coracobrachialis* like the musculocutaneous nerve does. There is a communicating branch between the median nerve and medial cutaneous antebrachial nerve (Figure 31).

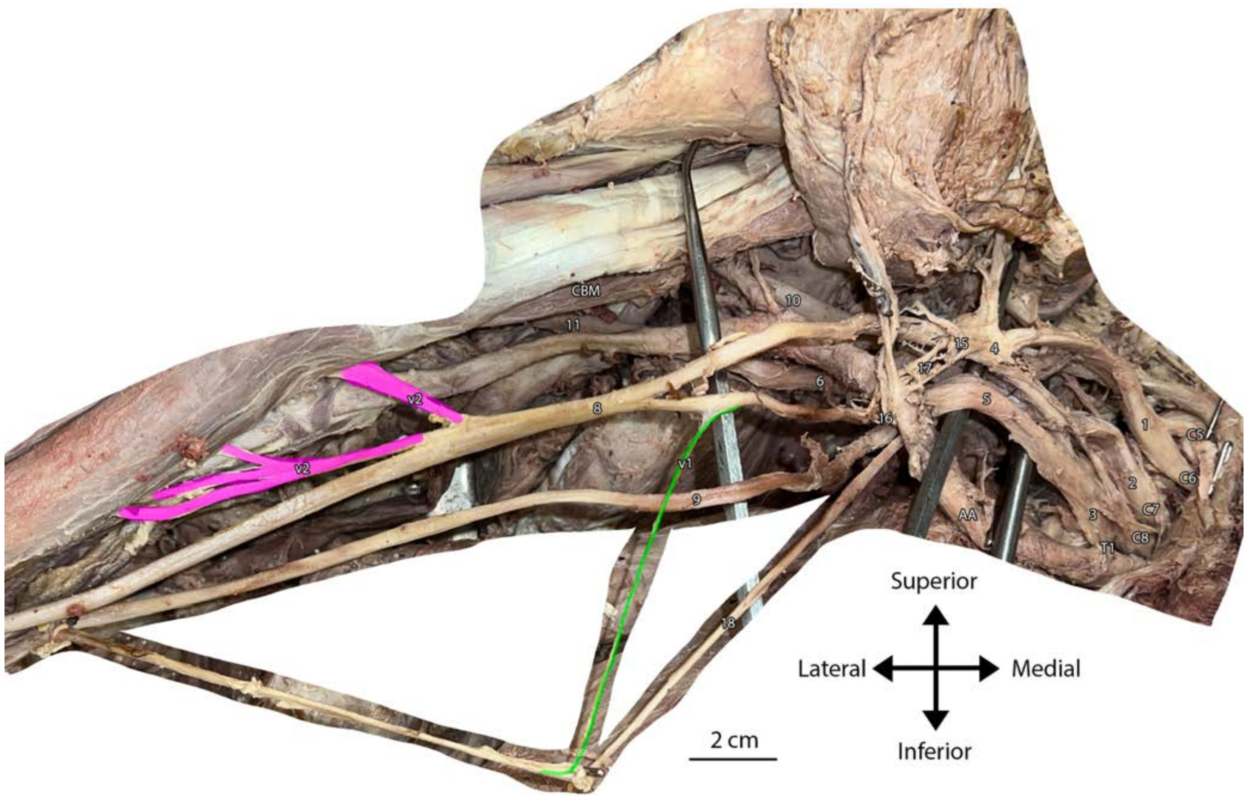


Figure 31. *Homo sapiens* 21-013 Right Brachial Plexus.
Anterior view of the right brachial plexus. There is no musculocutaneous nerve. The median nerve sends muscular branches (pink) to the muscles usually innervated by the musculocutaneous nerve. There is a communicating branch (green) between the medial cutaneous nerve of the forearm and the medial head of the media nerve.

*WMED-21-031**

Right

There is a communicating branch between the lateral cord and medial head of the median nerve (Appendix Figure 25).

All other specimens followed the typical branching pattern (Appendix Figures 26 to 33).

Summary of *Homo sapiens*

Eight specimens unilaterally (n=8, np=8) displayed a variant branching pattern the musculocutaneous nerve failing to pierce *m. coracobrachialis*. A communicating branch was discovered between the lateral cord and the medial head of the median nerve in eight specimens (n=8, np=10); two were bilateral variations and six were unilateral variations. There was also a communicating branch formed between the musculocutaneous nerve and the median nerve in eight specimens (n=8, np=9); seven were unilateral variations and one was found bilaterally. All variant branching patterns can be found in Appendix Table 6.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This investigation aimed to complete a comparative study of the variant branching patterns of the brachial plexus amongst *Homo sapiens* (n=38, np=56), *Macaca fascicularis* (n=6, np=12), *M. mulatta* (n=2, np=4), *Chlorocebus aethiops* (n=2, np=4), *Aotus sp.* (n=1, np=1), *Saimiri sp.* (n=2, np=4). Comparative studies have been published on *Homo sapiens* only or non-human primates only, but there are no studies comparing *Homo sapiens* with non-human primate brachial plexuses. We expected to find a higher level of variability in the *Homo sapiens* due to increased manual dexterity of the forelimb; however, this was not our result.

Level of Variability at Roots, Trunks, Cords, and Terminal Branches

In both *Homo sapiens* and non-human primates, much of the variation in the branching pattern occurred at the terminal branches. Each terminal nerve supplies important motor and sensory function to the arm, forearm, and hand through specific spinal roots.

Homo sapiens

As predicted, the most variation in branching pattern was found in the terminal branches with 26.8% (n=15, np=15) with no known bilateral occurrence. Amongst the terminal branches, the musculocutaneous nerve and median nerve had the highest occurring variation at 14.29% (n=8, np=8) and 7.27% (n=4, np=4), respectively. The most common variation was the musculocutaneous nerve failing to pierce *m. coracobrachialis*, although the muscle was still innervated by the musculocutaneous nerve through multiple muscular branches. The most conserved area of the brachial plexus was the roots; with 12.5% (n=5, np=7) of the plexuses being prefixed. The trunk and cords exhibited 23.3% (n=9, np=13) and 19.6% (n=10, np=11) variant branching patterns, respectively. A majority (n=4, np=6) of the trunk variation was due to C4 contributing to the superior trunk in prefixed plexuses. Only one plexus had two middle trunks, two had a communicating branch between the middle trunk and C8 root, and one plexus lacked a middle trunk, and two had inferior trunks that did not join into the posterior cord until after the axillary nerve diverged. 63.6% of the variation occurring at the level of the cords occurred within the posterior cord (n=6, np=7). There were two common variant branching patterns occurring at the posterior cord. The posterior cord split into two sections. The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. The second variant was total lack of contribution of the inferior trunk to the posterior cord. The inferior trunk sent contributions directly into the radial nerve which still came off the posterior cord.

Non-human Primate Species

The roots are the most conserved sections of the brachial plexus with 36% (n=6, np=9) exhibiting a variant branching pattern. Of the plexuses with variants within the roots, 16% (n=3, np=4) were prefixed and 20% (n=3, np=5) were post fixed. The terminal branches showed variation in 52% (n=8, np=11) of plexuses, with the most common variation being the musculocutaneous nerve not piercing *m. coracobrachialis* in 20% (n=3, np=5) of the plexuses. The musculocutaneous nerve still sent muscular branches to *m. coracobrachialis* to provide innervation. The origin of the radial nerve had a 16% (n=2, np=4) variation rate. The radial nerve branched from the inferior trunk rather than the posterior cord (n=2) or it shared a common branching point with the axillary nerve (n=2). If the radial nerve originated from the inferior trunk, there would be lack of contributions from spinal root C7 which could affect the functionality of many extensors of the arm, forearm, and hand.

Comparative Analysis Between OWM, NMW, and Homo sapiens

The level of variability in the species studied was expected to be higher towards the terminal branches when compared to the roots of the brachial. The results of this study confirmed the most variable area was the terminal nerves, followed by the trunks, cords, then roots in all species (Table 3). Less variation in the branching pattern of the roots and more variation towards the terminal branches should be expected due to the specificity of contribution to muscle innervation and sensory distribution. Additionally, there may be more variation as the brachial plexus develops distally as the axon bundles encounter more obstacles such as developing blood vessels and muscles. With more obstacles, there is an increased chance that the axon bundles need to diverge, thus creating a variant branching pattern (Leijnse, de Bakker, & D'Herde, 2020). Although the roots were the most conserved in both human and non-human primates, the non-human primates showed more variant branching patterns within the roots than the *Homo sapiens* (n=6, np=9 and n=5, np=7), respectively. Of the six non-human primate specimens showing variant root patterns, five were OWMs and one was a NWM. All the postfixed brachial plexuses (n=3, np=5) belonged to OWMs. Within the terminal branches, the musculocutaneous nerve was responsible for many of the variant branching patterns. The most common variant in both human and non-human primate species was the musculocutaneous nerve not piercing the *m. coracobrachialis*. This variant occurred in OWM, NWM, and *Homo sapiens* at a high frequency (n=1, np=2; n=2, np=3; n=7, np=7), respectively.

Table 3. Summary of the Comparative Level of Variability at the Roots, Trunks, Cords, and Terminal Branches Between *Homo sapiens* and Non-human Primates

		Homo sapiens	Non-human Primates
Roots	Overall	**12.5% (n=5, np=7)**	**36% (n=6, np=9)**
	Prefixed	12.5% (n=5, np=7)	16% (n=3, np=4)
	Postfixed	0% (n=0, np=0)	20% (n=3, np=5)
Trunks	Overall	**23.2% (n=9, np=13)**	**44% (n=8, np=11)**
	Superior Trunk	10.7% (n=4, np=6)	16% (n=3, np=4)
	Middle Trunk	7.11% (n=3, np=4)	4% (n=1, np=1)
	Inferior Trunk	5.4% (n=2, np=3)	24% (n=4, np=6)
Cords	Overall	**19.6% (n=10, np=11)**	**40% (n=9, np=10)**
	Lateral Cord	5.36% (n=3, np=3)	20% (n=5, np=5)
	Medial Cord	1.79% (n=1, np=1)	20% (n=4, np=5)
	Posterior Cord	12.5% (n=6, np=7)	1: 36% (n=6, np=9) 2: 64% (9, np=16)
Terminal Nerves	Overall	**26.8% (n=15, np=15)**	**52% (n=8, np=13)**
	Musculocutaneous Nerve	14.29% (n=8, np=8)	20% (n=3, np=5)
	Median Nerve	7.27% (n=4, np=4)	4% (n=1, np=1)
	Ulnar Nerve	3.57% (n=2, np=2)	4% (n=1, np=1)
	Axillary Nerve	1.79% (n=1, np=1)	8% (n=1, np=2)
	Radial Nerve	0% (n=0, np=0)	16% (n=2, np=4)

Summary of each category variations were split into. Percentages are based on number of plexuses (np).

Most Common Variants

Communicating branches

A common variant found in all species was a communicating branch usually between two terminal nerves. The communicating branches found in this study occurred between two nerves with similar spinal nerve contributions, suggesting there would be little, if any, changes in function. A communicating branch between the lateral cord and the medial head of the median nerve occurred in 17.9% (n=8, np=10) of the *Homo sapiens* brachial plexuses but was not observed in the non-human primate species. These communicating branches were found bilaterally in four samples, unilaterally in two samples, and four of the twenty specimens in which only one side was available for dissection. Similar communicating branches were observed in previous cadaveric studies; however, these variants were reported to usually be unilateral (Fregnani, Macéa, Pereira, Barros, & Macéa, 2008; Rao & Chaudhary, 2001; Budhiraja, et al., 2011; Malukar & Rathva, 2011; Prathap, Radhika, Jyothi, Shailaja, & Poonam, 2013; Goel, Rustagi, Kumar, Mehta, & Suri, 2014).

The most common communicating branch was found between the musculocutaneous nerve and the median nerve occurring in nine *Homo sapien*s brachial plexuses (16.4%) and five non-human primate (20%) brachial plexuses. This variant was found bilaterally in two samples, unilaterally in five samples, and found in two *Homo sapiens* specimens in which only one side was available for dissection. In the non-human primate species, the musculocutaneous nerve to median nerve communicating branch was found bilaterally in four samples and unilaterally in one sample. Results of this study align with other similar studies observing variant branching patterns in the brachial plexus. A communicating branch between the musculocutaneous nerve and median nerve has been reported to occur between 1.7-11.2% with sample sizes of n=24 to n=116 (Prathap, Radhika, Jyothi, Shailaja, & Poonam, 2013; Gelmi, et al., 2018; Eglseder & Goldman, 1997; Gumusalan, Yazar, & Ozan, 1998; Le Minor, 1990; Venierotos & Anagnostopoulou, 1998). There are few studies describing communicating branches in any non-human primate species, and none that found communicating branches in the species involved in this study.

In this study, one *Homo sapiens* specimen lacked the musculocutaneous nerve. The *m. coracobrachialis*, *m. biceps brachii*, and *m. brachialis* were all innervated by branches of the median nerve. This special type of communications between the musculocutaneous nerve and median nerve is considered type V, according the Venierotos and Anagnostopoulou's five types of communications between the musculocutaneous nerve and median nerve (Venierotos & Anagnostopoulou, 1998). Type V communications are relatively rare with occurrences up to approximately 11% in a Budhiraja's study with n=116 (Fregnani, Macéa, Pereira, Barros, & Macéa, 2008; Rao & Chaudhary, 2001; Budhiraja, et al., 2011; Malukar & Rathva, 2011; Prathap, Radhika, Jyothi, Shailaja, & Poonam, 2013). Because the median nerve supplied branches to the musculature usually innervated by the musculocutaneous nerve, no clinical signs of this variant may have been apparent in this individual. However, clinicians should be aware of this potential branching pattern as the patient's medical treatment could be affected. This rare variant branching pattern may stem from the embryonic development of the lateral cord. The typical pathway of the developing lateral cord causes the nerve to split; one pathway laterally to provide innervation to brachial flexor muscles while the other centrally with the medial cord to form the median nerve (Leijnse, de Bakker, & D'Herde, 2020).

Communicating branches are thought to be the product of axon strands crossing over the central artery during embryonic development of the upper limb. When these axon strands cross over the central artery, the axon strands merge with another axon bundle which then develops into a connecting branch. The amount of axon strands crossing over determines the amount of potential impact of the communicating branch (Leijnse, de Bakker, & D'Herde, 2020). Communicating branches may also form when axon bundles meet an obstacle, like a vessel or cartilaginous mass, forcing the bundle to split and then re-converge centrally. A study performing microdissections, or a histological investigation, would provide more information on both the level of contribution and the effect of a communicating branch (Leijnse, de Bakker, & D'Herde, 2020).

Musculocutaneous nerve with relation to the m. coracobrachialis

The musculocutaneous nerve usually branches from the lateral cord, piercing its way through the *m. coracobrachialis*, then sending muscular branches to the *m. biceps brachii* and *m. brachialis* before terminating as the lateral cutaneous nerve of the forearm. Although, the musculocutaneous nerve does not pierce through the *m. coracobrachialis*, it still innervates that muscle. In *Homo sapiens*, this variant branching pattern occurred in 18% (n=7, np=7) of specimens: three samples unilaterally and in five samples in which only one side was available for dissection. In non-human primate species, this variant branching occurred in 23.1% of specimens: bilaterally in four samples, unilaterally in three samples, and one sample in which only one side was available for dissection. While not very common, this branching pattern is not considered to be rare either and has been observed in many other studies (Nasrabadi, et al., 2017; Thakur, Jethani, & Parsad, 2015; Tripathi, et al., 2018). Patil and Shishirkumar (2012) hypothesized that during embryonic development of the *m. coracobrachialis*, part of the muscle may have degenerated or not fully formed where the musculocutaneous nerve typically pierces through. This would then result in the musculocutaneous nerve not piercing *m. coracobrachialis* while still providing muscular branches for innervation to this muscle (Patil & Shishirkumar, 2012).

Prefixed and postfixed brachial plexuses

In this study, out of 56 *Homo sapiens* brachial plexuses, seven exhibited prefixed brachial plexuses: four of them were bilateral, one was unilateral, and two were from samples in which only was side was available for dissection. In the non-human primate species, there were four prefixed brachial plexuses: two were bilateral, one was unilateral, and one was from a specimen in which only one side was available for dissection. No postfixed brachial plexuses were observed in *Homo sapiens*, but five were found in non-human primate specimens. Of these five, four were bilateral and one was unilateral.

A consistent contribution from C4 spinal root is only reported in the brachial plexus of primates and has not been consistently found in other placental mammal taxa (Shearer, 2019). Miller (1934) and Harris (1939) hypothesized the contribution from C4 may correlate to the locomotive patterns of primates. Furthermore, both studies suggested contributions from C4 or T2 spinal roots could relate to increased muscle mass needed for locomotion. Contributions from C4 could be due to increased shoulder muscle mass and increased shoulder movement in non-human primate locomotion. Increased muscle mass may require more motor units and may recruit the motor units from other spinal roots like C4 or T2 (Harris, 1939; Miller, 1934; Shearer, 2019). The functional importance of contribution from T2 is less hypothesized and less clear. Using histological and surgical techniques, Pellerin et al. (2010) reported the connection of T2 to the brachial plexus carries only sensory fibers. Yokogawa et al (2014) studied 16 human patients after a total en bloc spondylectomy in which there was a bilateral transection of T2. They report no change in motor function even with total loss of T2 contribution. Patients with a lost connection to a spinal root from C5 to T1 had significant loss of function, supporting that spinal roots C5 to T1 provide the brachial plexus with both sensory and motor neurons (Yokogawa, et al., 2014).

A prefixed or postfixed brachial plexus branching pattern is well studied in both human and non-human primate literature. Human brachial plexuses are commonly not prefixed nor postfixed, but a prefixed branching pattern occurs more often than a post fixed branching pattern (Ahmet & Sait, 1999; Suruchi, Vani, & Roopa, 2007; Valeria, Adilson, & Omar, 2003; Guday, Bekele, & Muche, 2017). This study aligned with the published findings. Although the accounts of prefixed and postfixed brachial plexus branching patterns are numerous, there is little research concerning how these variations impact sensory or motor distributions (Pellerin, et al., 2010; Ahmet & Sait, 1999; Suruchi, Vani, & Roopa, 2007; Valeria, Adilson, & Omar, 2003; Guday, Bekele, & Muche, 2017). Functional studies such as those are out of the scope of this study.

Published data shows the branching patterns for the non-human primate brachial plexus is highly variable, making it difficult to determine a species' normal branching pattern. Many studies do not agree on which spinal roots are involved in the typical branching pattern of the species examined in this current study. Some of studies suggest C4 or T2 contributions are part of the typical branching pattern, while others do not (Araujo, et al., 2012; Chase & DeGaris, 1940; Howell & Straus Jr, 1947; Mizuno, 1969; Ono, 1937; Santos-Sousa, et al., 2016; Shearer, 2019; Sugiyama, 1965; Tokiyoshi, et al., 2004; Bolk, 1902). In the new world monkey *Aotus sp.*, Mizuno (1969) suggests the brachial plexus is postfixed; whereas Bolk (1902) and Shearer (2019) report the brachial plexus is formed by spinal roots C5-T1 with no contribution from C4 or T2. In new world monkey *Saimiri sp.*, Shearer (2019) and Bolk (1902) found T2 gives supplemental contributions; however, Mizuno (1969) found T2 contribution to be a rare occurrence. In old world monkey *Macaca sp.*, many studies reports that C4 or T2 contributions are normal within the brachial plexus. All these studies do agree that C5-T1 are the most common spinal roots contributing to the brachial plexus (Aversi-Ferreira, Pereira-de-Paula, Prado, Lima-e-Silva, & Mata, 2007; Santos-Sousa, et al., 2016; Brooks, 1883). The brachial plexus of the old world monkey, *Chlorocebus aethiops* was the only brachial plexus found to be postfixed in a typical branching pattern (Booth, 1991). In the current study, a postfixed brachial plexus of *Chlorocebus aethiops* was found bilaterally in one specimen, concluding a postfixed brachial plexus is the typical branching pattern.

Unilateral Versus Bilateral Variations

When available, bilateral dissections were within one specimen to collect data on unilateral and bilateral variations. Whether the variant branching patterns occur bilaterally or unilaterally suggests possible reasons for the variant to occur. If variants are found more frequently to be unilateral, an anomaly most likely occurred during embryonic development. Bilateral variants may suggest evolutionary pressures influence these variant branching patterns (Shearer, 2019).

Homo sapiens

In *Homo sapiens*, many of the variations were found unilaterally (n=27, np=27). The most common unilateral variations were found in the communicating branches (n=7, np=7). Communicating branches were found between the musculocutaneous nerve and the median nerve (n=5, np=5); the axillary nerve and radial nerve (n=1, np=1); and the superior trunk and middle trunk (n=1, np=1). Communicating branches were found bilaterally between the musculocutaneous nerve and the median nerve (n=1, np=2), but were not found between the axillary nerve and radial nerve or between the superior trunk and middle trunk. Some variant branching patterns occurred more bilaterally (n=6, np=16). The most common bilateral variation was the prefixed brachial plexus (n=2, np=4); however, this variation did occur unilaterally in one specimen (n=1, np=1).

Non-human Primates Species

Unilateral variations (n=35, np=35) occurred more often than bilateral variations (n=30, np=60) in non-human primates. The most common unilateral variation was the number of branches of the inferior subscapular nerve (n=7, np=7). This variation also occurred bilaterally in five specimens (n=5, np=10). The most common bilateral variations included a postfixed brachial plexus (n=2, np=4) and the various branching patterns of the posterior cord (n=10, np=20). Only four specimens showed bilateral asymmetry in the branching pattern of the brachial plexus (n=4, np=4).

Comparative Analysis between Homo sapiens and Non-human Primate Species

In both the human and non-human primate species, additional root contribution was the most common bilateral variation. Additional root contribution has been hypothesized to be due to increased muscle mass needed for locomotive patterns. This is supported by the observation that this variation is usually bilateral (Harris, 1939; Miller, 1934; Shearer, 2019).

Some of the bilateral variations found in the non-human primates were observed more commonly unilaterally in humans. The communicating branch between the musculocutaneous nerve and median nerve was seen as a unilateral variation in humans (n=5, np=5), but a bilateral variation in non-human primates (n=2, np=4). Communicating branches are attributed to axon bundles crossing over a blood vessel and merging with another axon bundle during embryonic development (Leijnse, de Bakker, & D'Herde, 2020). Thus, it is unclear why this variation would be bilateral in non-human primates, but unilateral in humans.

The posterior cord variations occurred more consistently bilaterally in non-human primates. Non-human primates had more bilateral variation (n=10, np=20) versus unilateral variation (n=4, np=4); whereas *Homo sapiens* had a bilateral variation in one specimen (n=1, np=1) and a unilateral variation in two specimens (n=2, np=2). In *Homo sapiens*, a split in the posterior cord typically occurs during embryonic development. An obstruction in the pathway of the developing posterior divisions causes the axillary nerve to form before the merger of the posterior division of the inferior trunk (Leijnse, de Bakker, & D'Herde, 2020). Although not studied, the two different branching patterns observed in the posterior cord of the non-human primates are likely also due to an obstacle faced during embryonic development. It could be hypothesized that non-human primates' blood vessels develop slightly different than *Homo sapiens* therefore when the brachial plexus is developing, it hits the obstacle of the blood vessel creating the two-part posterior cord more often than found in *Homo sapiens*.

Comparative Level of Variability Between Non-Human Primates and Humans

The brachial plexus of *Homo sapiens* has been well documented throughout many studies (Budhiraja, et al., 2011; Eglseder & Goldman, 1997; Gelmi, et al., 2018; Goel, Rustagi, Kumar, Mehta, & Suri, 2014; Gumusalan, Yazar, & Ozan, 1998; Malukar & Rathva, 2011; Le Minor, 1990; Prathap, Radhika, Jyothi, Shailaja, & Poonam, 2013; Rao & Chaudhary, 2001). While there are many variant branching patterns of the human brachial plexus, there is also a widely accepted typical brachial plexus branching pattern. Any deviation from this accepted typical branching pattern can be noted as variant. Unfortunately, this is not the same for the brachial plexus of non-human primates; current literature on non-human primates describes highly variable branching patterns (Bolk, 1902; Booth, 1991; Booth, 1997; Brooks, 1883; Chase, 1940;

Emura et al, 2017; Shearer, 2019). Thus, no typical branching pattern for non-human primates exists. There are consistencies such as the brachial plexus receiving contribution from roots C5-T1; formation of a medial, lateral, and posterior cord; and the terminal branches consisting of the musculocutaneous nerve, ulnar nerve, median nerve, axillary nerve, and radial nerve.

In this study, the typical branching pattern of the *Homo sapiens* brachial plexus was still found to have some variant branching patterns. 71% (n=28, np=40) of the studied specimens had a level of variability that ranged between 3.85-38.46%. Many of these variant branching patterns were not identical bilaterally, even when a bilateral variation was present.

As previously stated, the current literature regarding the non-human primate brachial plexus is highly variable (Bolk, 1902; Booth, 1991; Booth, 1997; Brooks, 1883; Chase, 1940; Emura et al, 2017; Shearer, 2019). In the current study, many areas of the brachial plexus branching pattern varied, but a few different common branching patterns emerged. The levels of spinal root contribution to the plexus varied both in previous literature and in this current study. The non-human primates displayed a prefixed brachial plexus in three specimens (n=3, np=4); two of these specimens were old world monkeys (n=2, np=3) and one was a new world monkey (n=1, np=1). Three specimens (n=3, np=5) exhibited a postfixed branching pattern, all were terrestrial old world monkeys.

Another highly variable portion of the non-human brachial plexus was the superior and inferior subscapular nerves. The superior subscapular nerve varied both in origin and the number of branches it formed. The superior subscapular nerve originated from the superior trunk (n=6, np=9) or the posterior cord (n=11, np=16) with either one (n=6, np=8), two (n=10, np=16) or three (n=1, np=1) branches. The variability of the superior subscapular nerve branching pattern occurred across all species, in both the old world monkeys and new world monkeys included in this study. The inferior subscapular nerve also varied in the number of branches it formed. The inferior subscapular nerve originated from the axillary nerve forming one (n=5, np=8), two (n=7, np=10), or three (n=5, np=7) branches. The variability of the branching pattern of the inferior subscapular nerve occurred across all non-human primate species involved in this study.

The posterior cord also showed variation. This study found two patterns of formation of the posterior cord. The formation of a single posterior cord by the posterior divisions of the superior, middle, and inferior trunks occurred in six specimens (n=6, np=9); similar to the typical human brachial plexus. The formation of a two-part posterior cord occurred in nine specimens (n=9, np=16). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.

This study originally hypothesized that the *Homo sapiens* brachial plexus would have a higher level of variability when compared to the old world monkeys and new world monkeys due to *Homo sapiens* increases manual dexterity of the forelimb. Current findings disagree with that hypothesis. The brachial plexus of non-human primates displayed a higher level of variability, making it difficult to discern a typical brachial plexus branching pattern. The level of variability between old world monkeys and new world monkeys is similar and the branching pattern displayed across all non-human primates can be placed in one of the three categories discussed.

This investigation found that there are similar variant branching patterns found in both *Homo sapiens* and non-human primate brachial plexuses. The non-human primates exhibited a higher level of variability within the brachial plexus compared to *Homo sapiens*. While there is no clear explanation for the reasoning to this, Shearer (2019) hypothesized that the rate of evolution was due to different embryonic development patterns that have not been explored in non-human primates. Shearer (2019) also suggested a stabilizing selection of the brachial plexus was present due to the general structure of the brachial plexus being relatively consistent, along with the types of variant branching patterns observed.

Future Directions and Clinical Importance

Continued documentation of variant branching patterns in brachial plexuses may lead to the understanding of these variations. Although documentation of variant branching patterns is available, more research needs to be conducted to understand how these variant branching patterns may affect sensory or motor innervation. Clinicians should know the common variant branching patterns along with how these variations could alter the course of treatment. They need to be aware of the frequency and possibility of a prefixed or postfixed brachial plexus. Studies have shown that C4 electrode placement caused paresthesia in the forearm and hand of patients with a prefixed branching pattern (Pellerin, et al., 2010). The same study highlighted the potential to incorrectly diagnose a cervical disc prolapse if C4 contribution is not taken into consideration. The spinal root T2 contributes to sensory innervation and is especially important to note for those with breast cancer and needing a mastectomy and/or an axillary node clearance. Occasionally, there is loss of sensation in the arm and forearm after surgery. This could be due to damage of T2 in a postfixed brachial plexus.

The availability of non-human primate specimens for comparative studies is limited. Due to small sample sizes, a concise branching pattern for each species was not evident with a median of n=2, np=4 for the non-human primate species. Thus, a full comparison between non-human primate data (np=25) and the human data (np=55) could not be obtained.

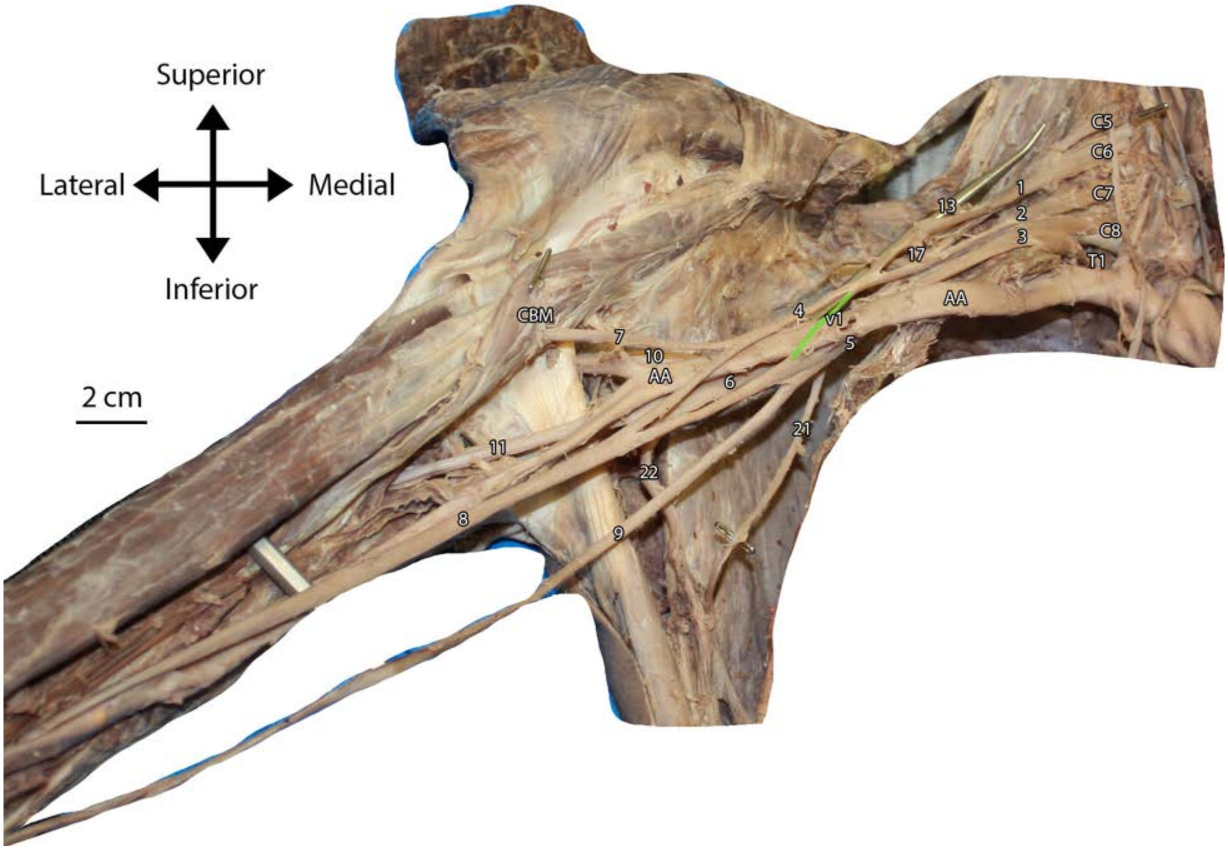
Availability limits also occurred with the human cadavers. Since the cadavers are used for various anatomy courses, the brachial plexus on only one side was able to be dissected. This eliminated the opportunity to deem if the variant branching pattern was unilateral or bilateral in 52.6% (n=20) of the specimens. In this study, a bilateral comparison of the brachial plexuses of non-human primate species achieved in 96% (n=12, np=24) of the non-human primate specimens; whereas, a bilateral comparison of the brachial plexuses of *Homo sapiens* was only achieved in 47.4% (n=18, np=36).

The more samples obtained, the stronger the evidence will be to support certain conclusions made about how these variant branching patterns affected the specimen. For future studies, more equivalent and larger sample sizes will benefit being able to draw more conclusive results and definitive branching patterns.

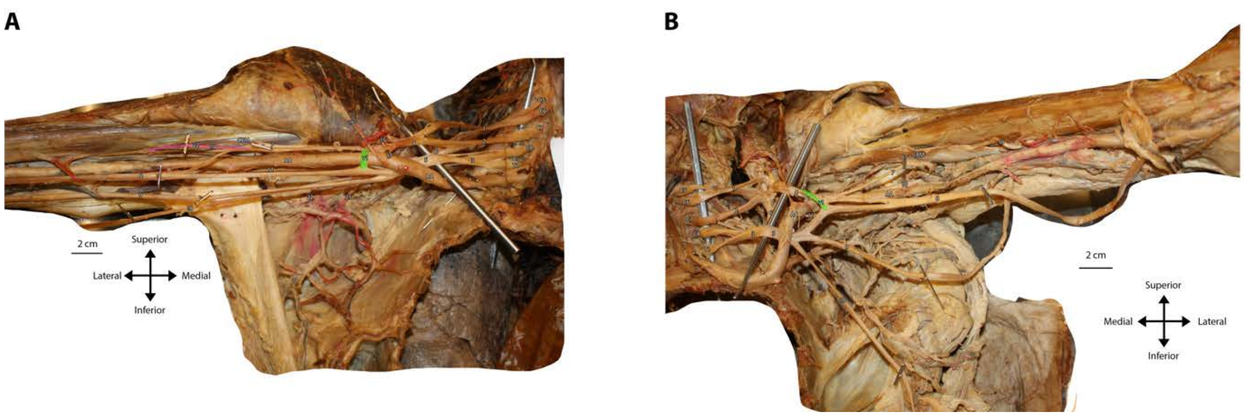
Microscopic examination of different sections of the brachial plexus may determine if variant branching patterns correlate with variant contributions from spinal nerve roots. Ideally, a sample of each spinal root, trunk, cord, and terminal branch could be analyzed for spinal root contributions. Then used to compare a normal brachial plexus to one exhibiting a variant. These discoveries could be expanded to studies investigating whether different spinal root contributions affected sensory and motor function.

The most meaningful way to investigate the potential effects of a variant brachial plexus would be to conduct a study with live human subjects. After obtaining consent, bilateral MRI images of their brachial plexuses would be analyzed for variant branching patterns. This would be followed by a series of tests to initiate muscle movement and cutaneous sensations. Data would be collected from both non-symptomatic and symptomatic subjects, male and female, and bilaterally. Imaging of the brachial plexus branching pattern and data on the functionality of the nerves would elucidate correlations between variant branching patterns of the brachial plexus and the function of the nerves.

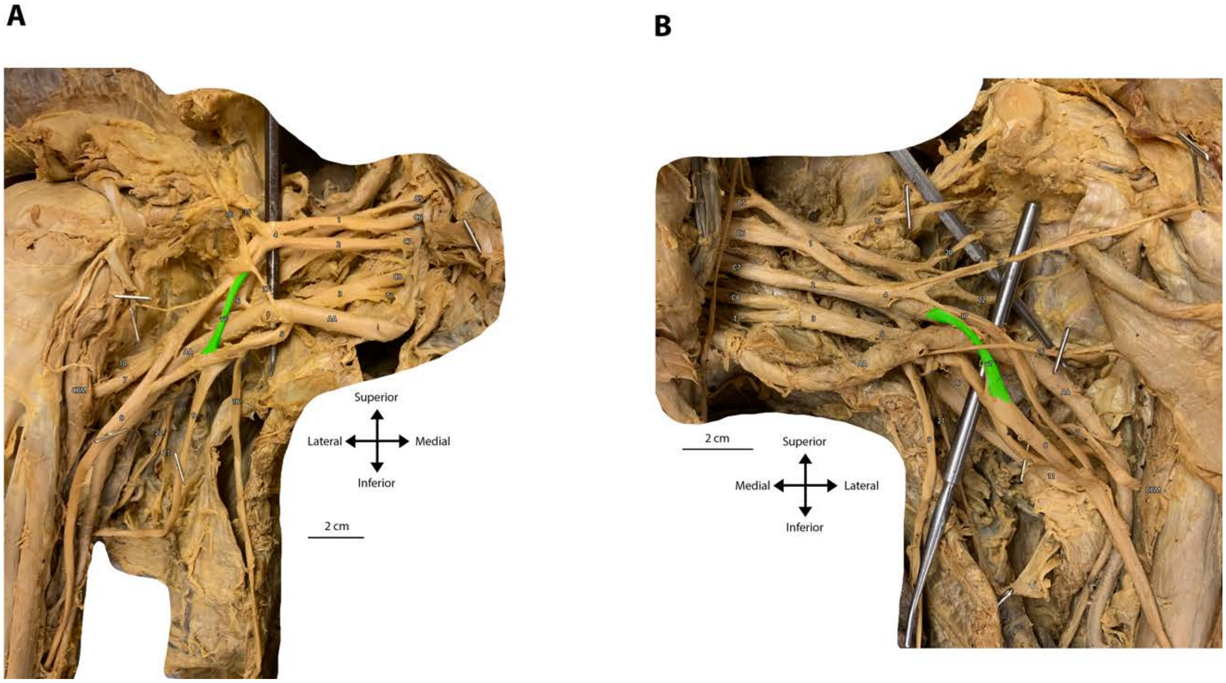
APPENDICES: TABLES AND FIGURES



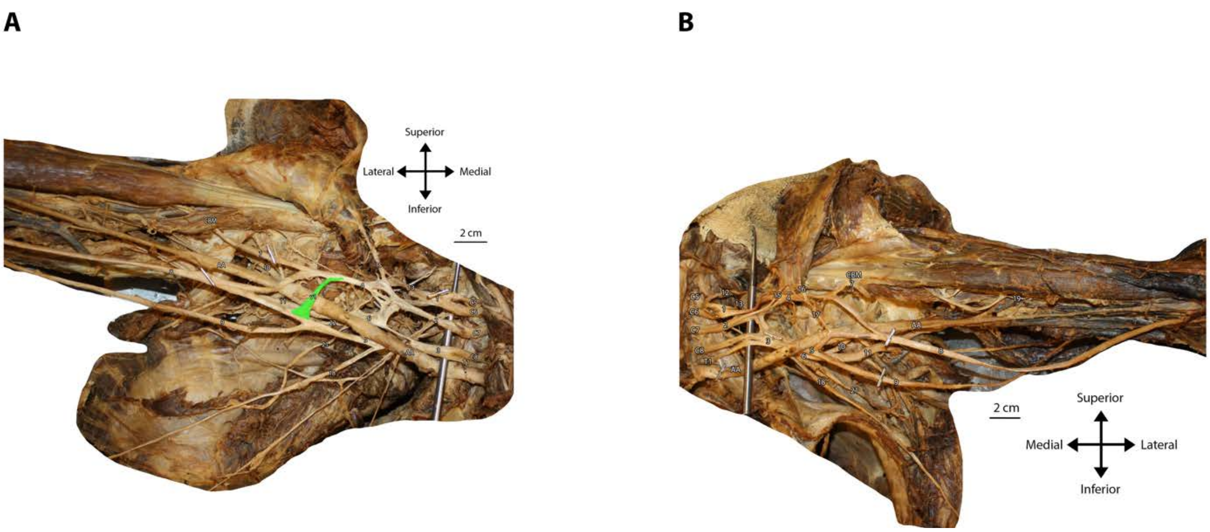
Appendix Figure 1. ***Homo sapiens*** **437-W Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch (green) between the lateral cord and the medial head of the median nerve.



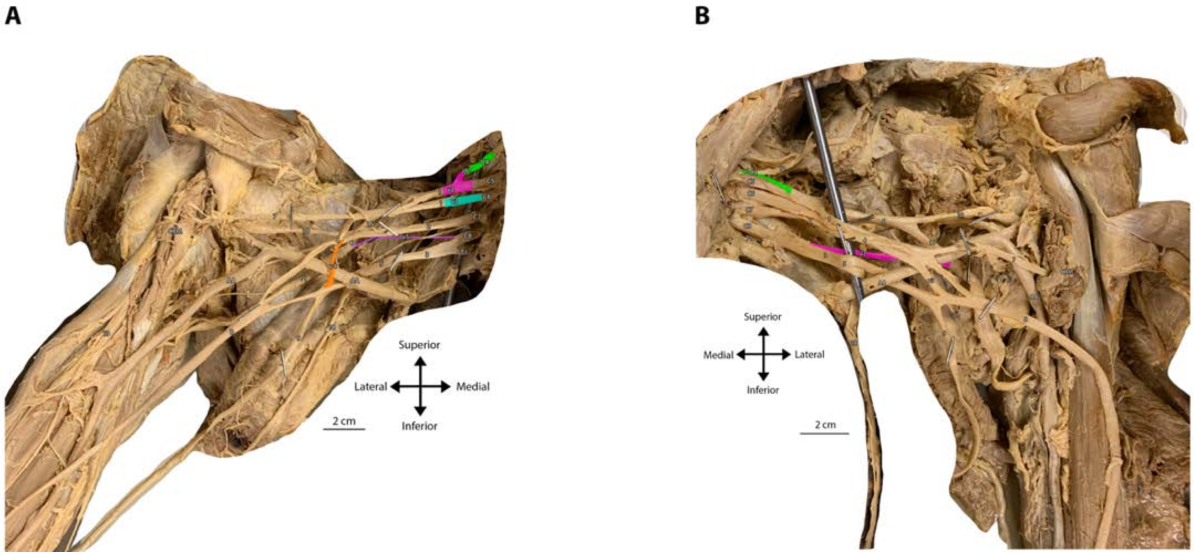
Appendix Figure 2. ***Homo sapiens*** **4049 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) The lateral cutaneous nerve of the forearm (pink) originates from the lateral head of the median nerve. There is a communicating branch (green) between the lateral cord and the medial head of the median nerve. (B) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve.



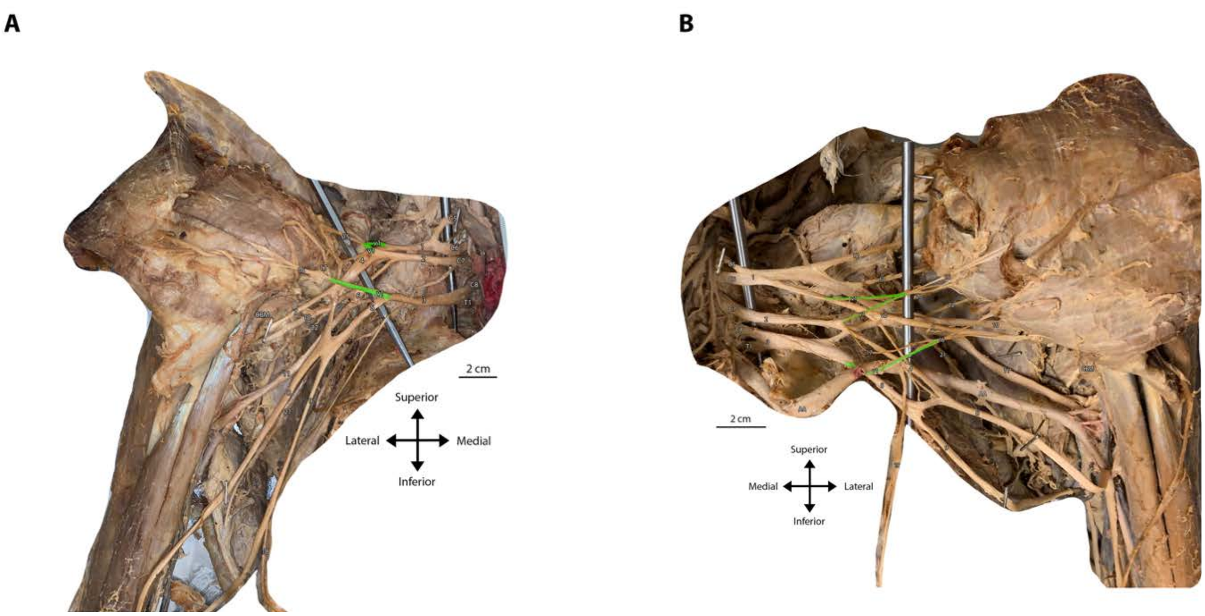
Appendix Figure 3. ***Homo sapiens*** **4055 Right and Left Brachial Plexuses.**
The right (A) and left (B) anterior view of the brachial plexus. (A-B) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve.



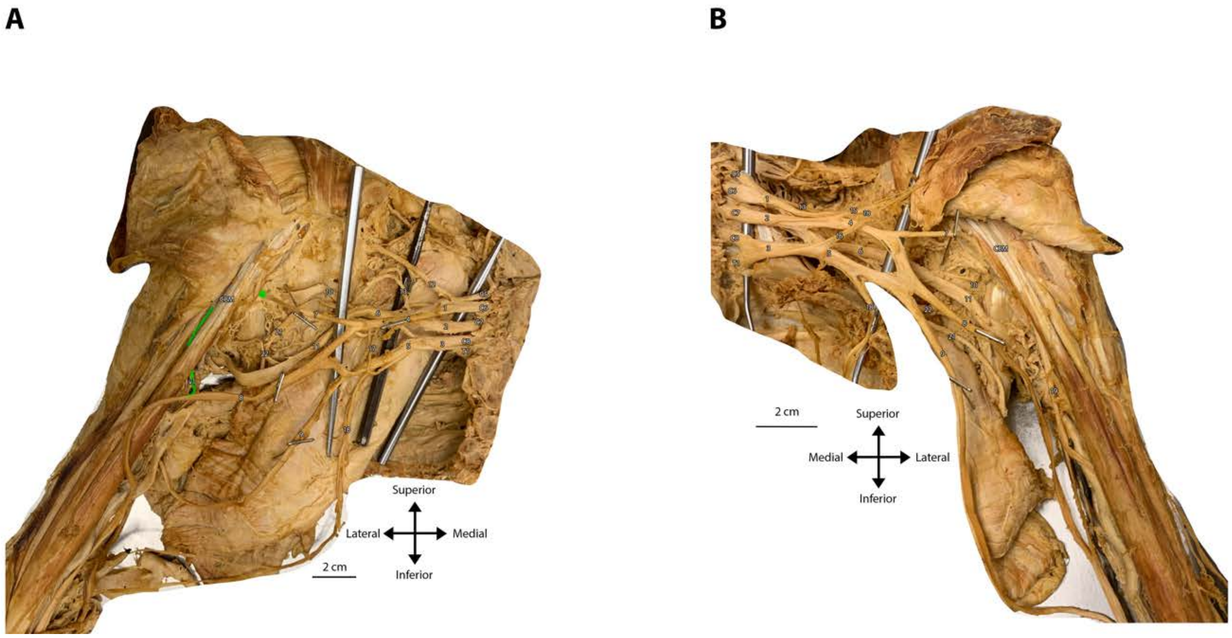
Appendix Figure 4. ***Homo sapiens*** **4060 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve. (B) Typical branching pattern of the brachial plexus.



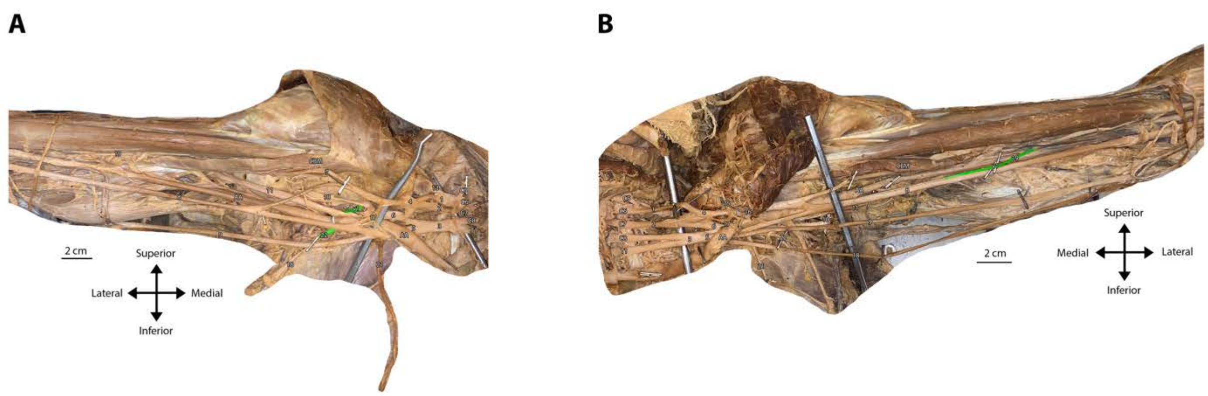
Appendix Figure 5. ***Homo sapiens*** **4063 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) The brachial plexus is prefixed (green). There are four trunks. C4 merges (pink) with C5 to create the most cranial trunk. C6 continues alone to create the second most cranial trunk (blue). The middle and inferior trunk are formed as normal. The posterior division of the inferior trunk merges (purple) directly into the radial nerve, bypassing the posterior cord. There is a communicating branch (orange) between the lateral cord and the medial head of the median nerve. (B) This brachial plexus exhibits a prefixed pattern (green). The posterior division of the inferior trunk (pink) bypasses the posterior cord and directly merges into the radial nerve.



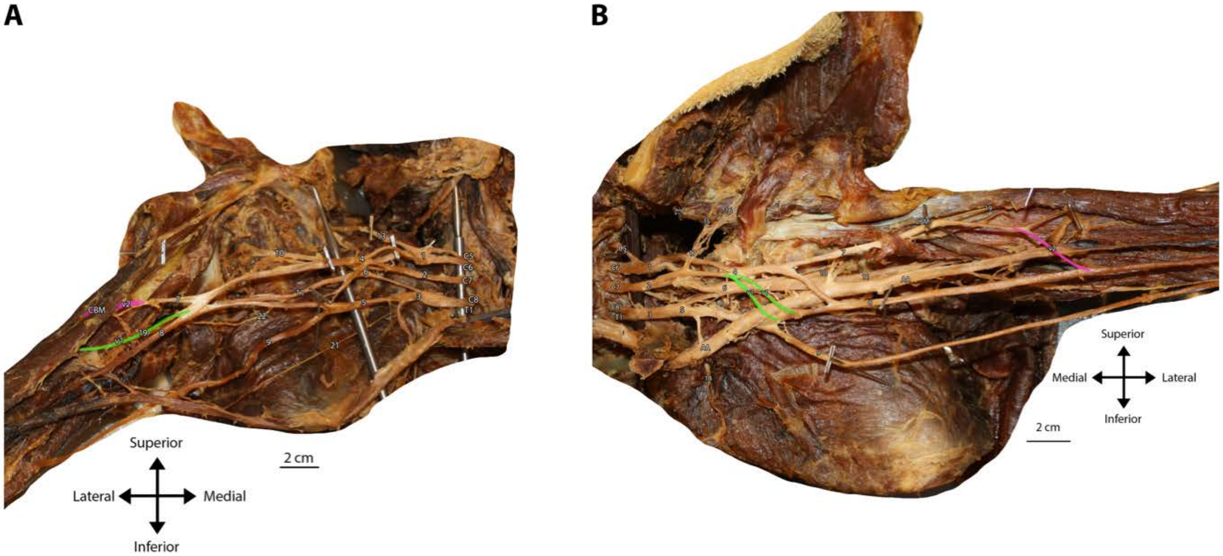
Appendix Figure 6. ***Homo sapiens*** **4064 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is no ansa pectoralis connecting the lateral and medial pectoral nerves (green). (B) The lateral pectoral nerve originates from the superior and middle trunks (green, 15). The medial pectoral nerve originates from the inferior trunk (green, 16).



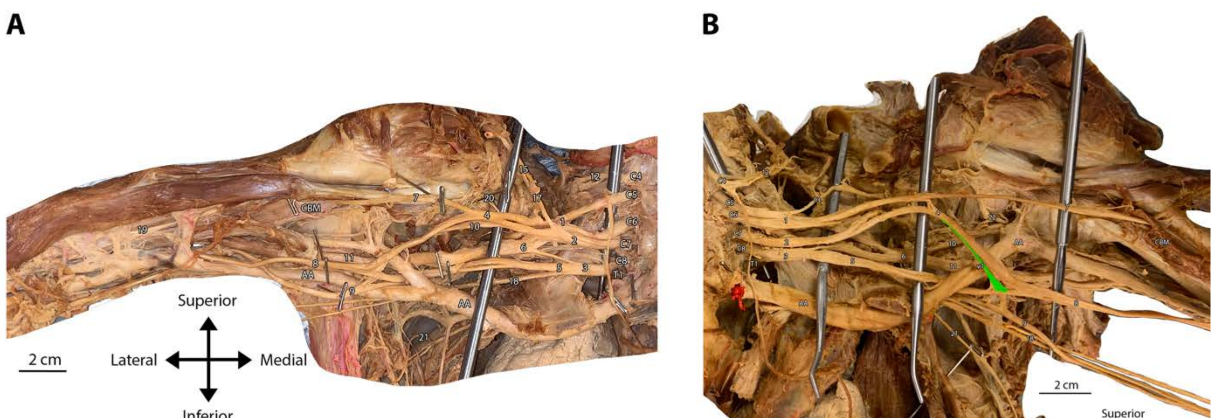
Appendix Figure 7. ***Homo sapiens*** **4065 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is a communicating branch (green) between the musculocutaneous nerve and the median nerve. (B) Typical branching pattern of the brachial plexus.



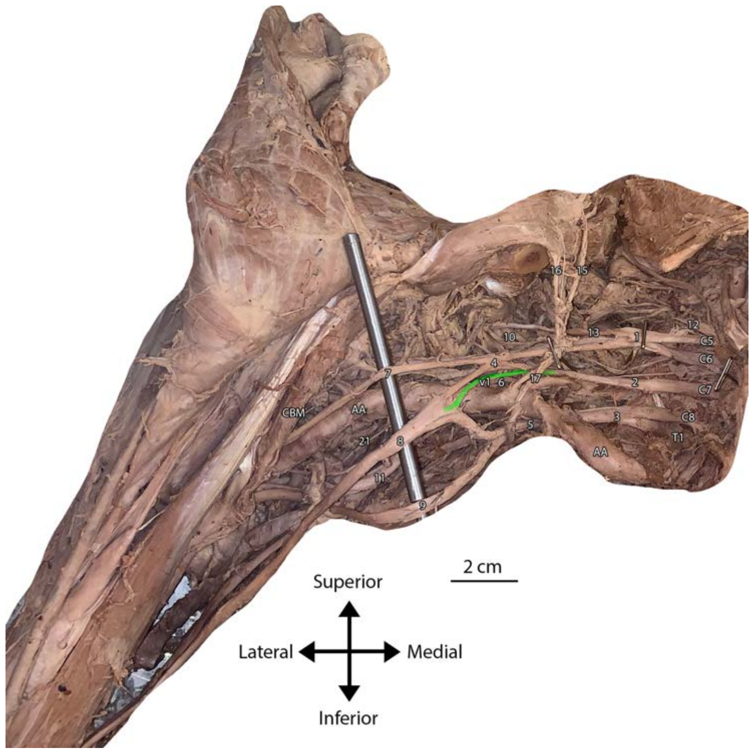
Appendix Figure 8. ***Homo sapiens*** **4067 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) The superior subscapular nerve and inferior subscapular nerve originate from the axillary nerve (green). (B) The lateral cutaneous nerve of the forearm (green) originates from the median nerve.



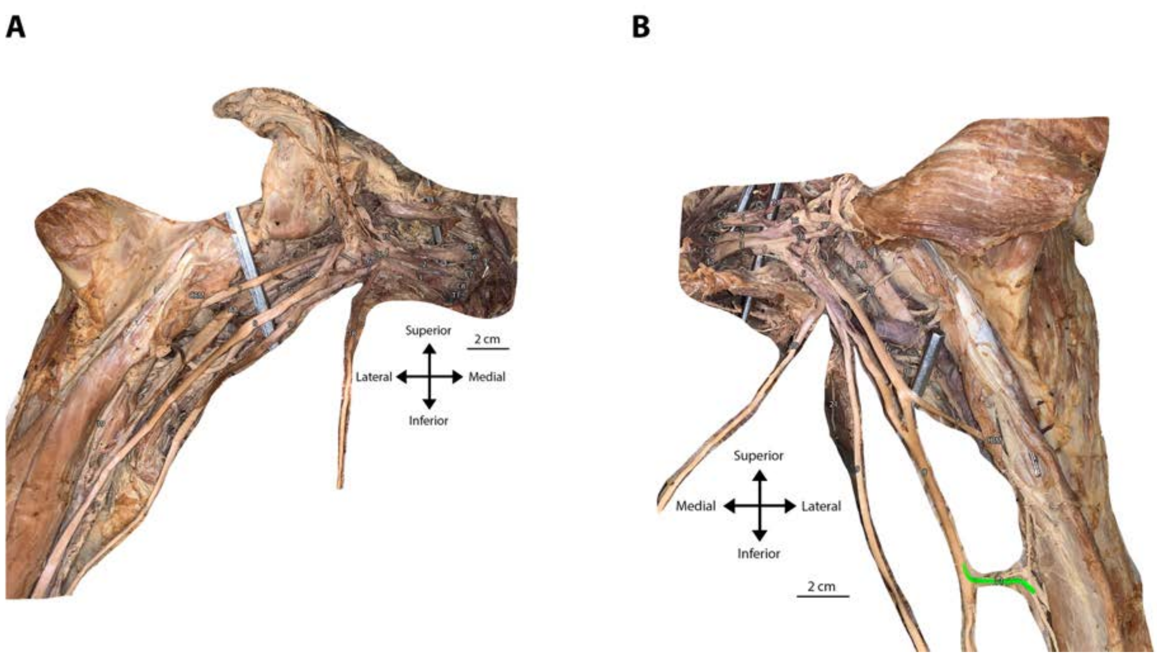
Appendix Figure 9. ***Homo sapiens*** **4069 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) The musculocutaneous nerve (pink) does not pierce *m. coracobrachialis*. There is a communicating branch (green) between the musculocutaneous nerve and the median nerve. (B) There are two communicating branches (green) between the lateral cord and the medial head of the median nerve. There is a communication branch (pink) between the musculocutaneous nerve and the median neve.



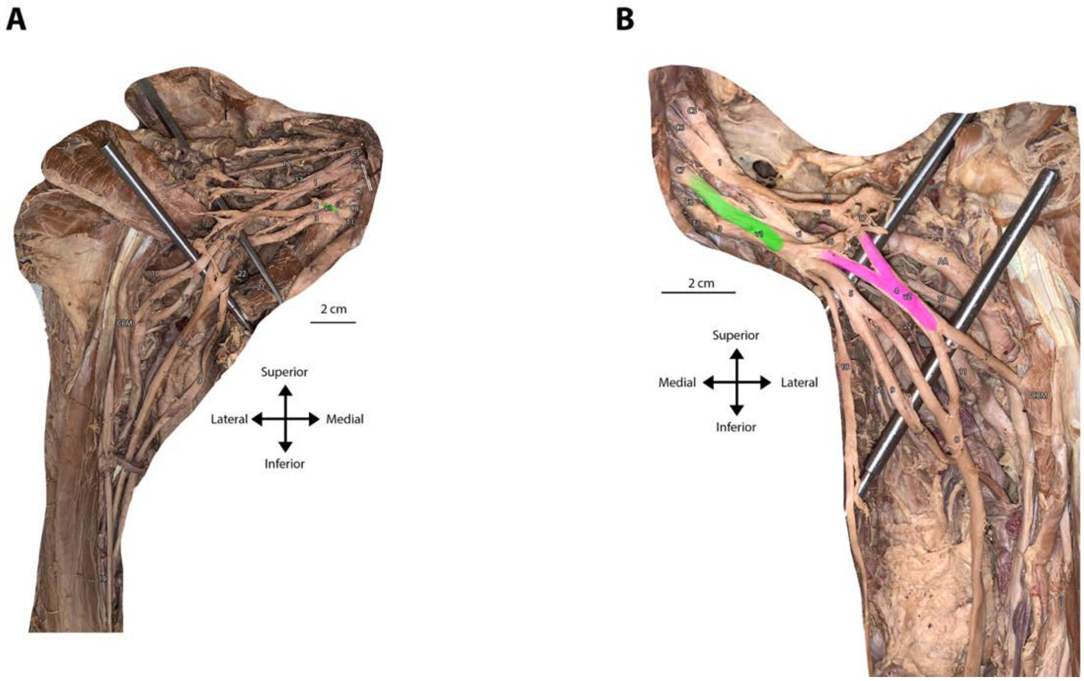
Appendix Figure 10. ***Homo sapiens*** **4070 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) Typical branching pattern of the brachial plexus. (B) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve.



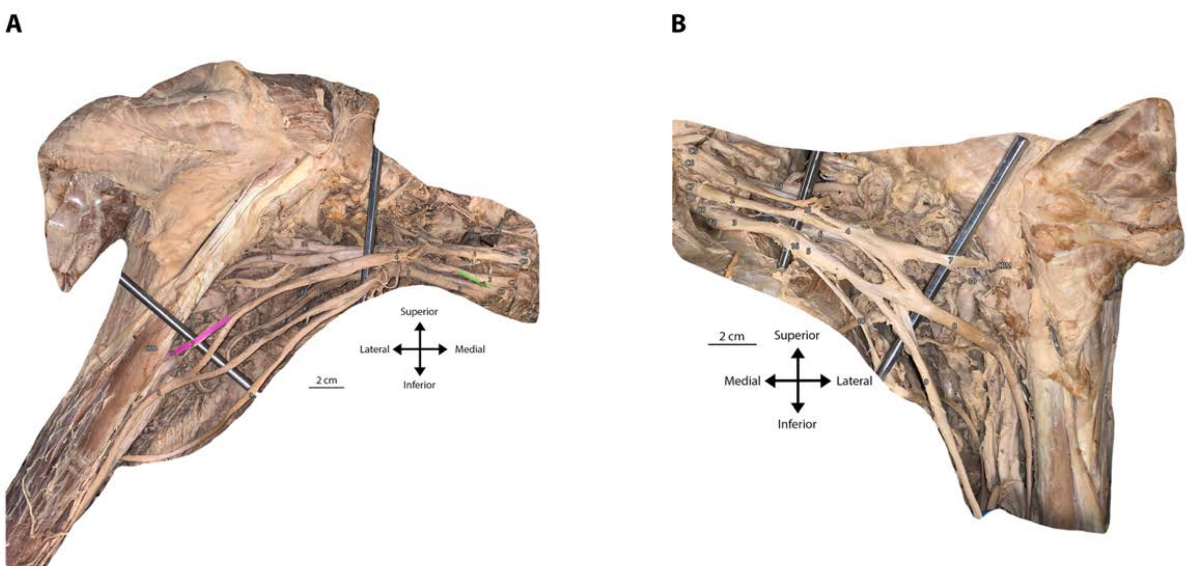
Appendix Figure 11. ***Homo sapiens*** **16-009 Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch (green) from the middle trunk to the median nerve.



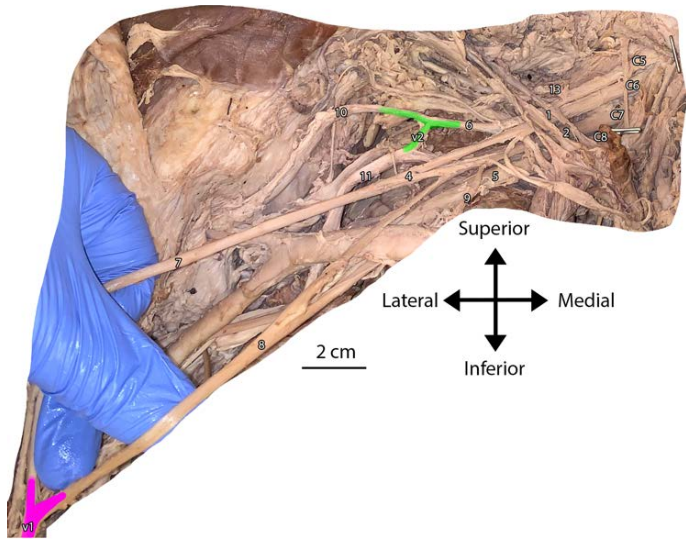
Appendix Figure 12. ***Homo sapiens*** **18-019 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) Typical brachial plexus branching pattern. (B) There is a communicating branch (green) between the musculocutaneous nerve and median nerve.



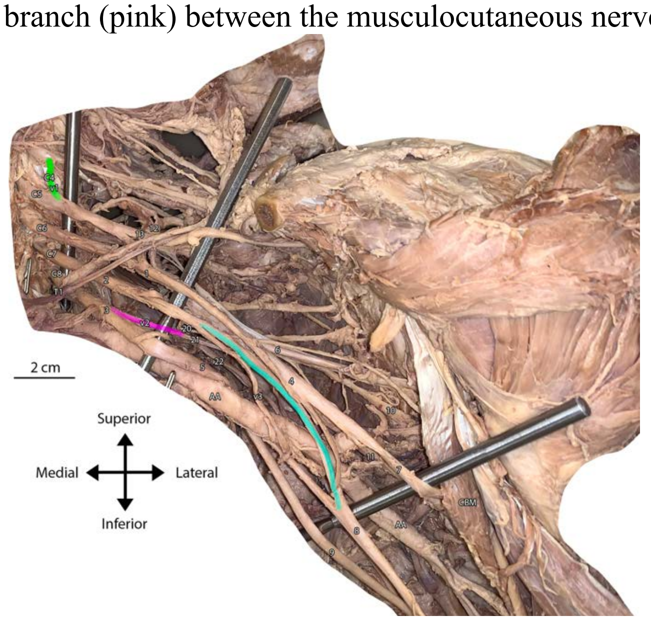
Appendix Figure 13. ***Homo sapiens*** **18-025 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is a communicating branch (green) between the C7 and C8 roots. (B) There is no true middle trunk. The C7 root (green) merges with the anterior division of C8 and T1 roots to form the inferior trunk. The anterior division of the inferior trunk merges with the anterior division of the superior trunk to form the lateral cord (pink).



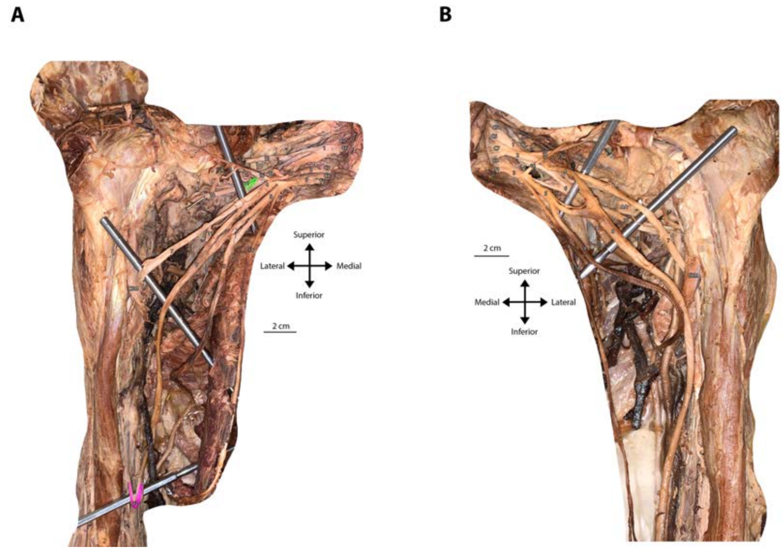
Appendix Figure 14. ***Homo sapiens*** **19-004 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is a communicating branch (green) between the C7 and C8 roots. The musculocutaneous nerve (pink) does not pierce *m. coracobrachialis*. (B) Typical branching pattern of the brachial plexus.



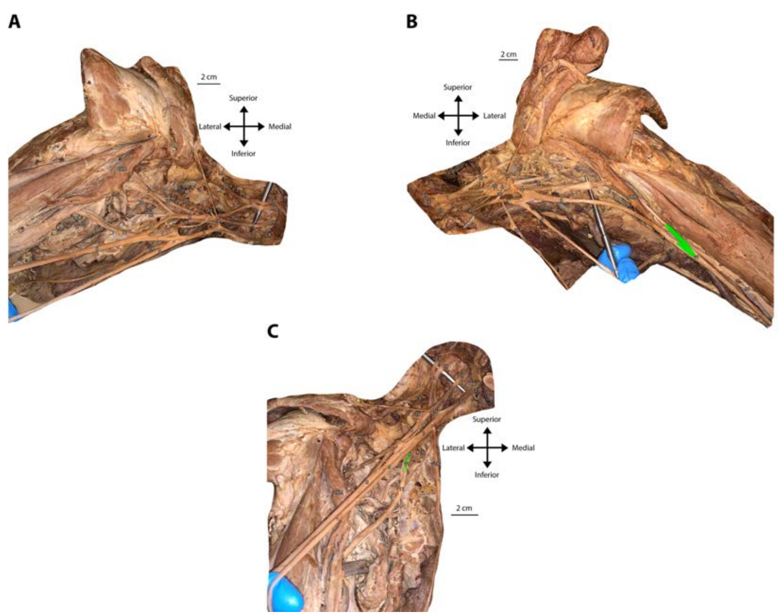
Appendix Figure 15. *Homo sapiens* 19-011 Right Brachial Plexus.
Anterior view of the right brachial plexus. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern (green). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. There is a communicating branch (pink) between the musculocutaneous nerve and median nerve.



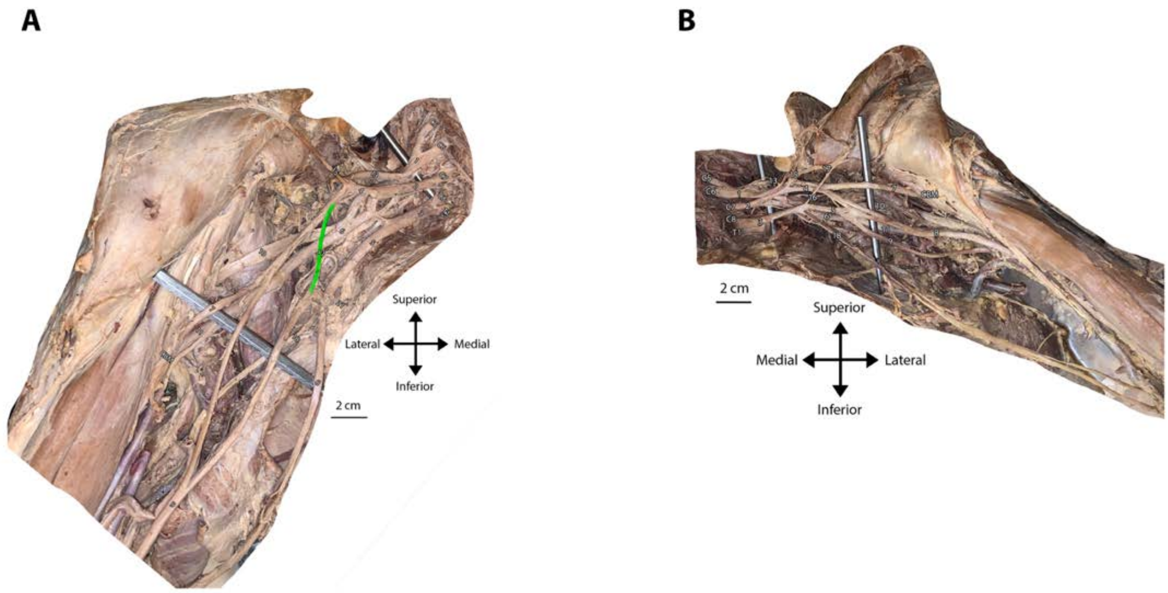
Appendix Figure 16. *Homo sapiens* 19-012 Left Brachial Plexus.
Anterior view of the left brachial plexus. This brachial plexus is prefixed (green). The middle trunk sends a communicating branch (blue) to the median nerve without merging with the superior trunk to form the lateral cord. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern (pink). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve.



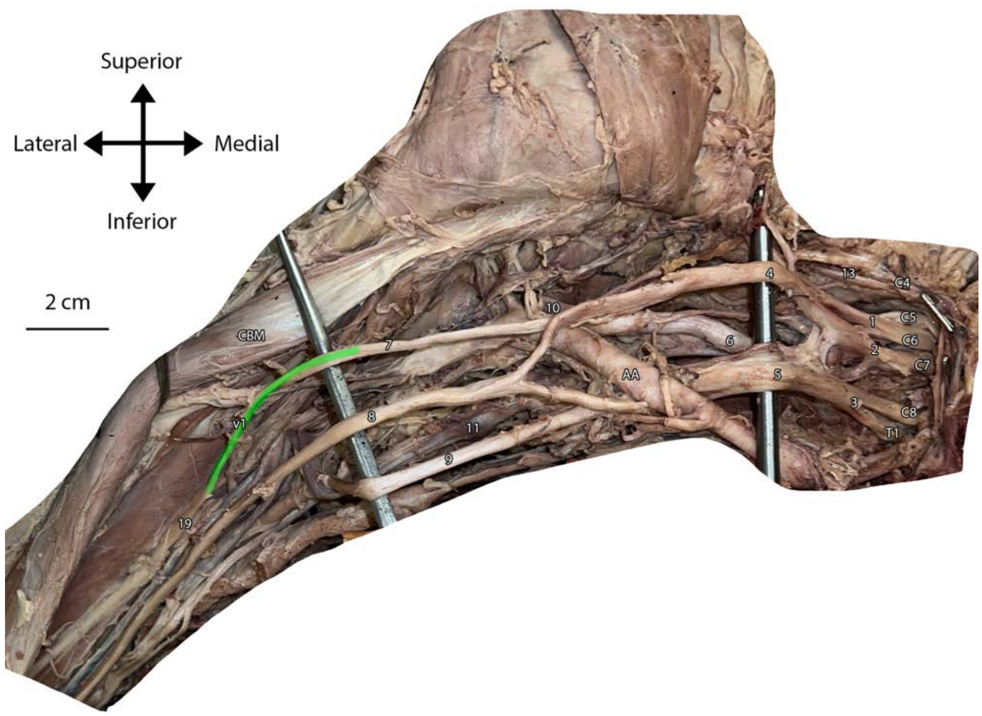
Appendix Figure 17. *Homo sapiens* 19-013 Right and Left Brachial Plexuses.
(A-B) Anterior view of the right (A) and left (B) brachial plexus. (A) There is a communicating branch (pink) between the musculocutaneous nerve and the median nerve. The posterior aspect of the brachial plexus exhibits the two-part posterior cord pattern (green). The upper posterior cord, created from the merger of the posterior divisions of the superior and middle trunks, forms the axillary nerve. The lower posterior cord, created from the merger of the posterior division of the inferior trunk with the upper posterior cord, forms the radial nerve. (B) Typical branching pattern of the brachial plexus.



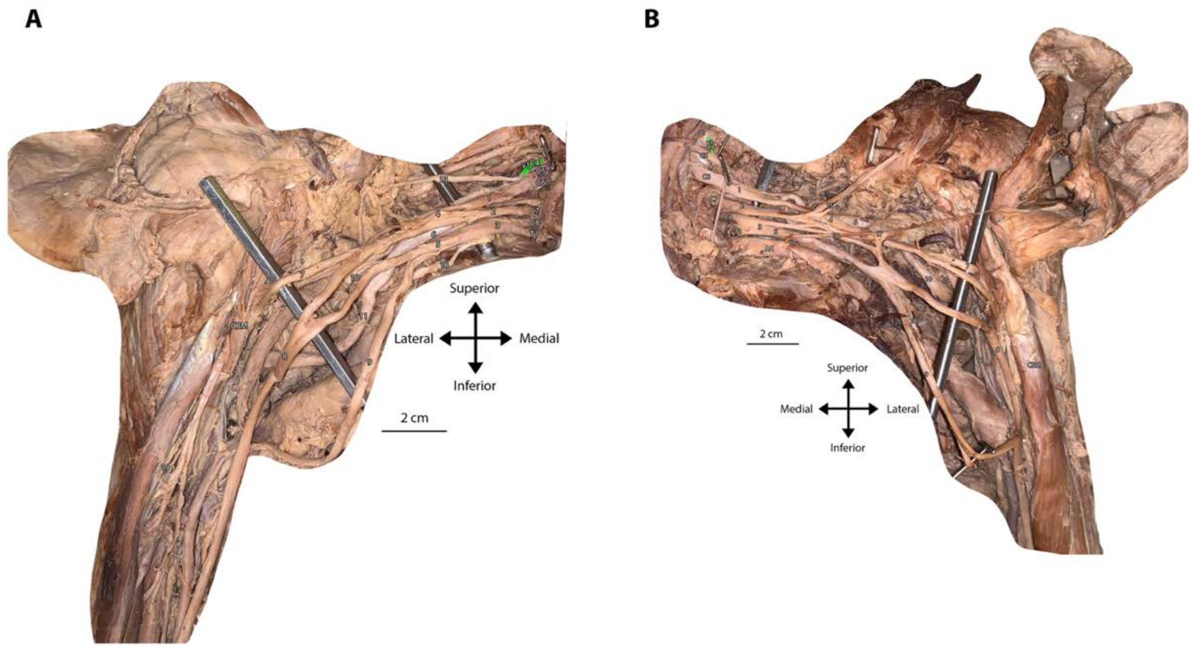
Appendix Figure 18. *Homo sapiens* 19-015 Right and Left Brachial Plexuses.
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) Typical branching pattern of the anterior cords. (B) There is communicating branch (green) between the musculocutaneous nerve and median nerve. (C) Anterior view of the posterior aspect of the brachial plexus. There is a communicating branch (green) between the ulnar nerve and radial nerve.



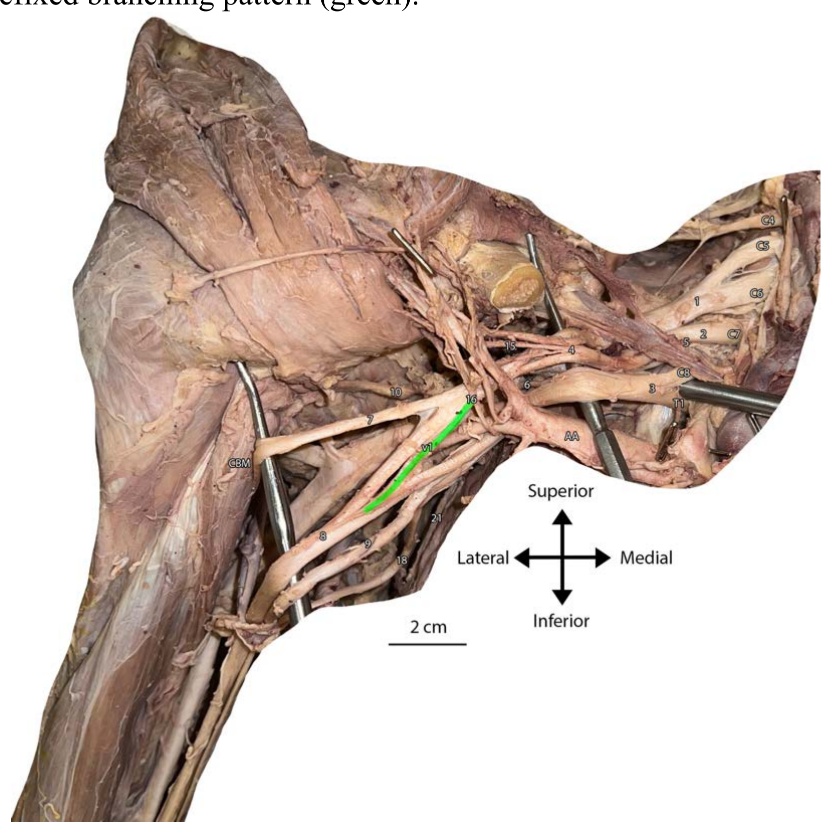
Appendix Figure 19. ***Homo sapiens*** **19-016 Right and Left Brachial Plexuses.**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. (A) There is a communicating branch (green) between the lateral cord and the medial head of the median nerve. (B) Typical branching pattern of the brachial plexus.



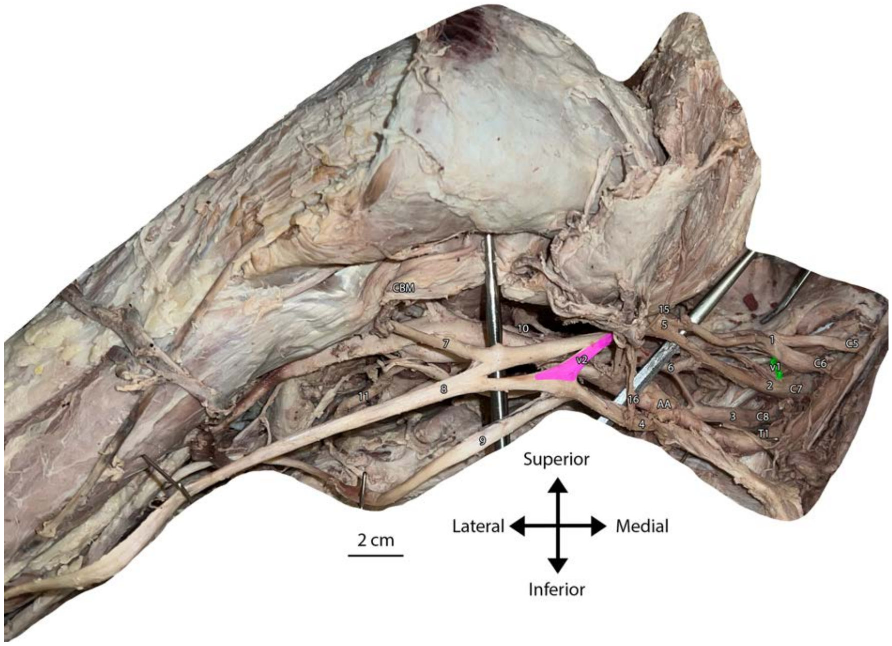
Appendix Figure 20. ***Homo sapiens*** **19-017 Right Brachial Plexus.**
Anterior view of the right brachial plexus. The musculocutaneous nerve (green) does not piece *m. coracobrachialis*.



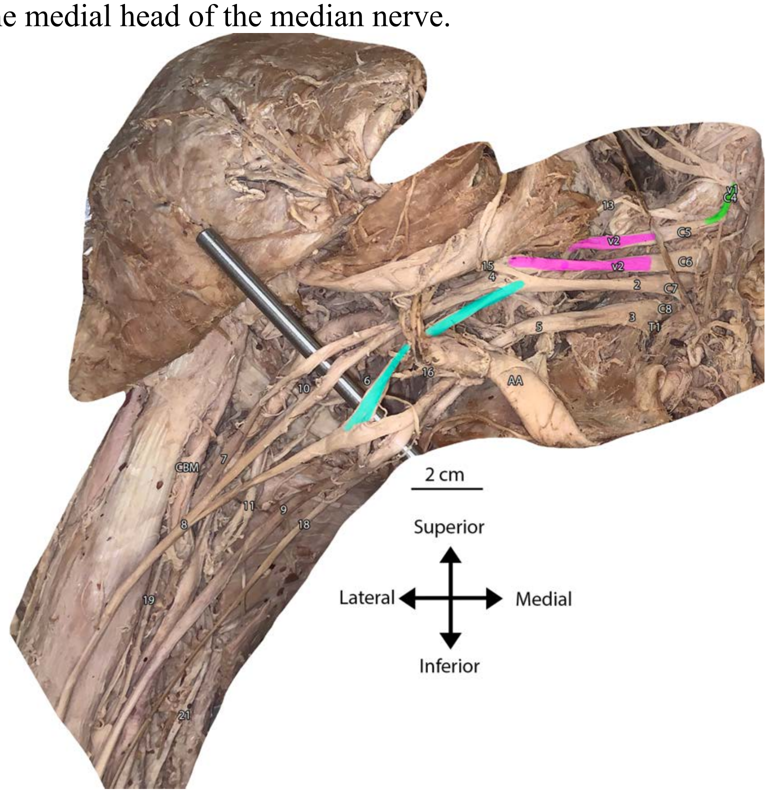
Appendix Figure 21. ***Homo sapiens*** **19-019 Right Brachial Plexus**
(A-B) The right (A) and left (B) anterior view of the brachial plexus. The brachial plexus exhibits a prefixed branching pattern (green).



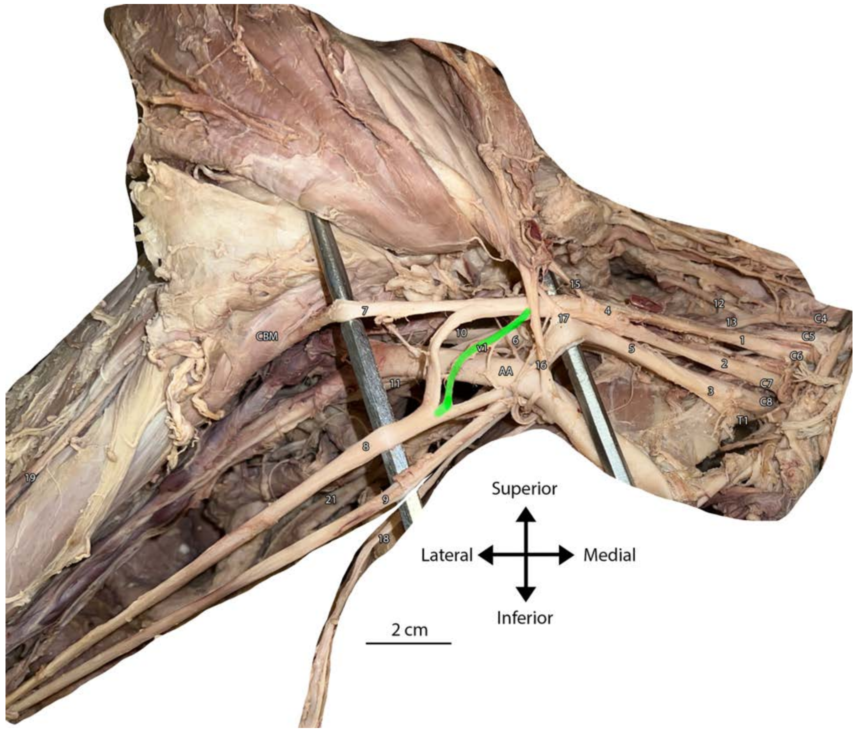
Appendix Figure 22. ***Homo sapiens*** **20-013 Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch (green) between the lateral cord and the medial head of the median nerve.



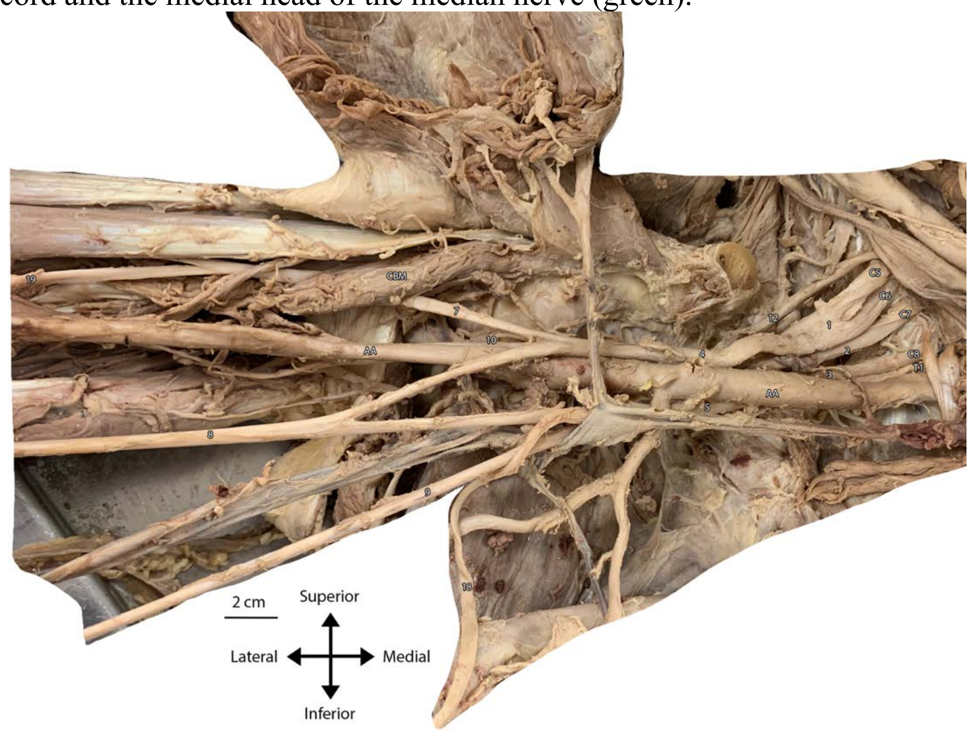
Appendix Figure 23. ***Homo sapiens*** **20-017 Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch (green) between the C6 and C7 root. There is a communicating branch (pink) between the lateral cord and the medial head of the median nerve.



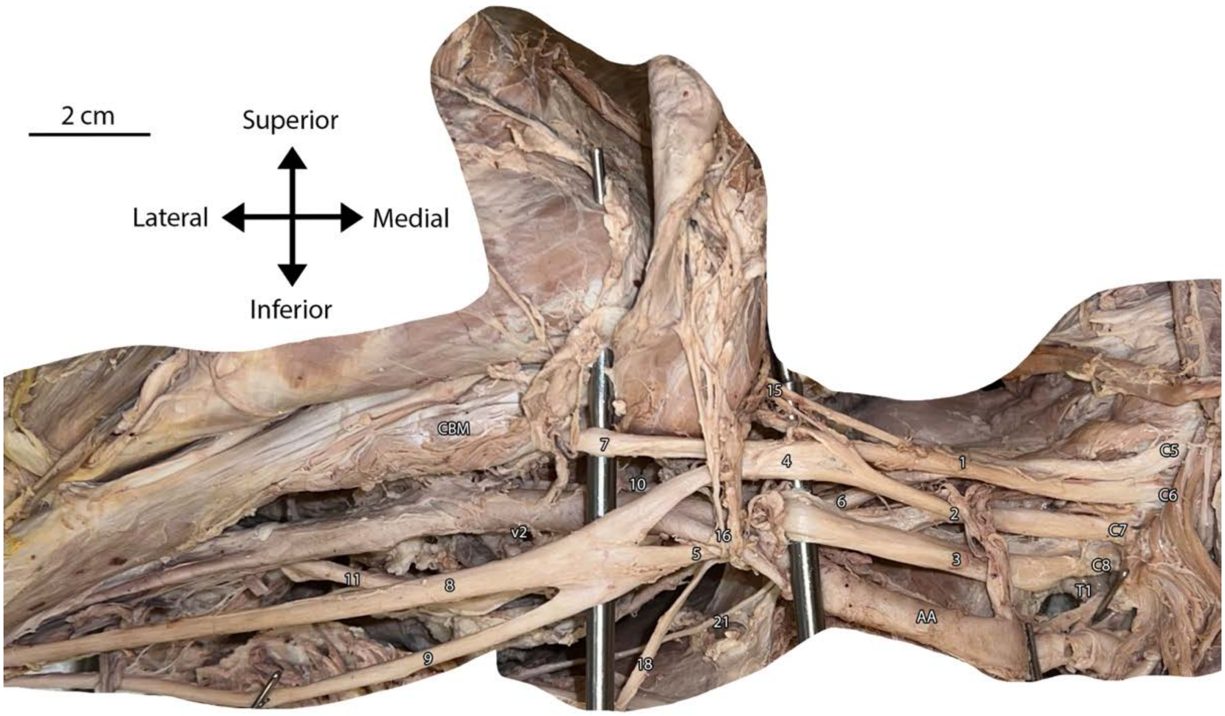
Appendix Figure 24. ***Homo sapiens*** **20-018 Right Brachial Plexus.**
Anterior view of the right brachial plexus. This brachial plexus is prefixed (green). There is no superior trunk. The C5, C6, and C7 roots all merge at one point to form the lateral cord (pink). There is a communicating branch (blue) between the middle trunk and the medial head of the median nerve.



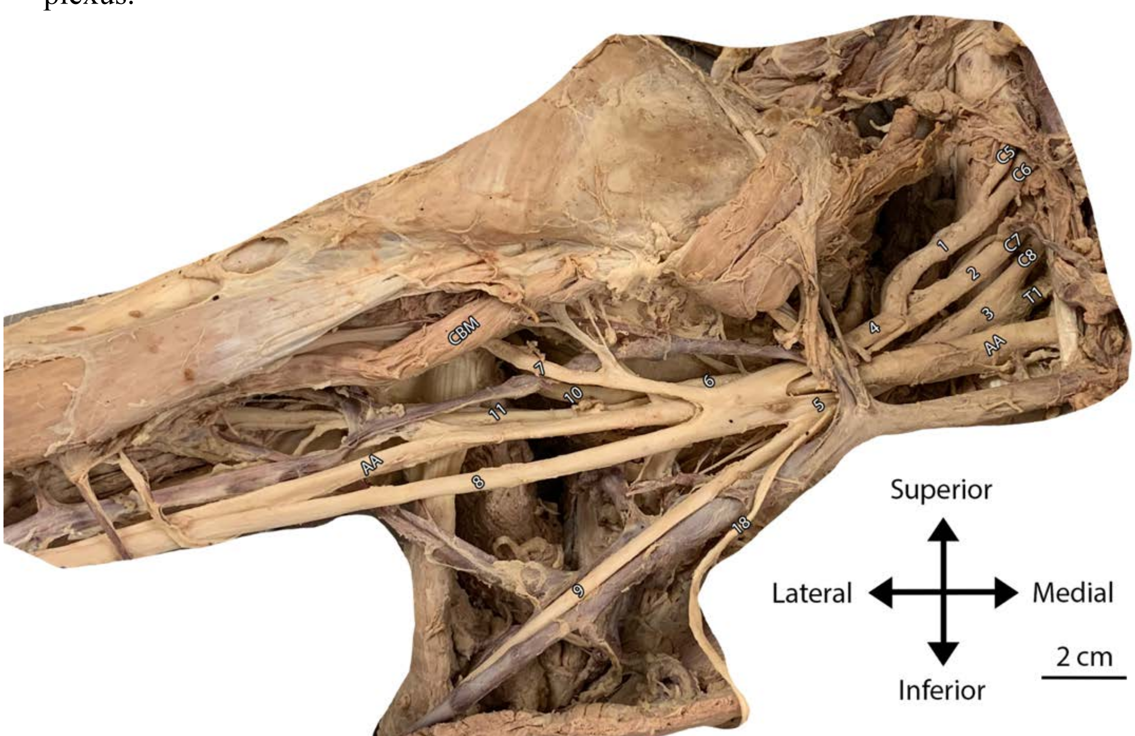
Appendix Figure 25. ***Homo sapiens*** **21-031 Right Brachial Plexus.**
Anterior view of the right brachial plexus. There is a communicating branch between the lateral cord and the medial head of the median nerve (green).



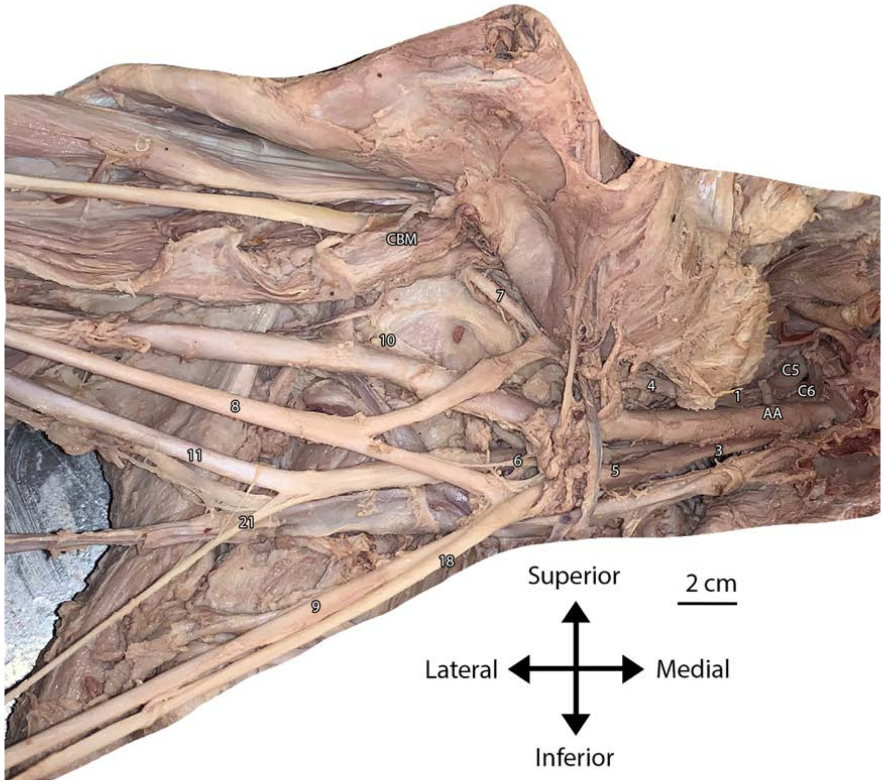
Appendix Figure 26. ***Homo sapiens*** **17-023 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



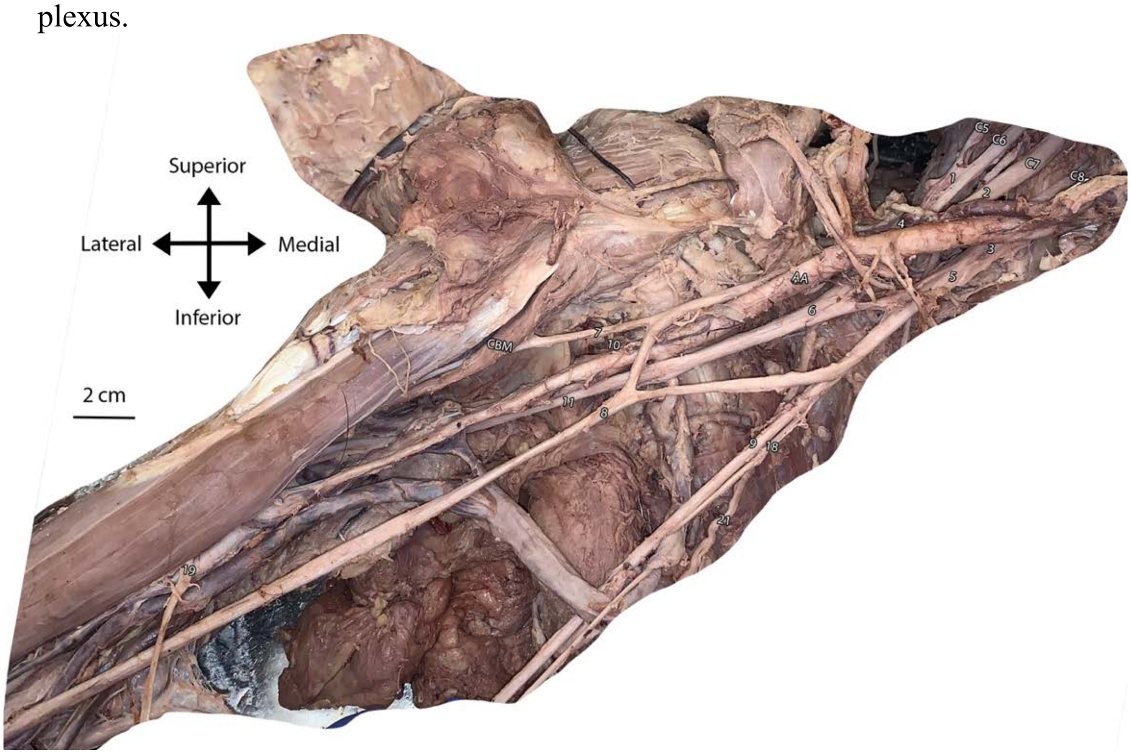
Appendix Figure 27. ***Homo sapiens*** **17-028 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



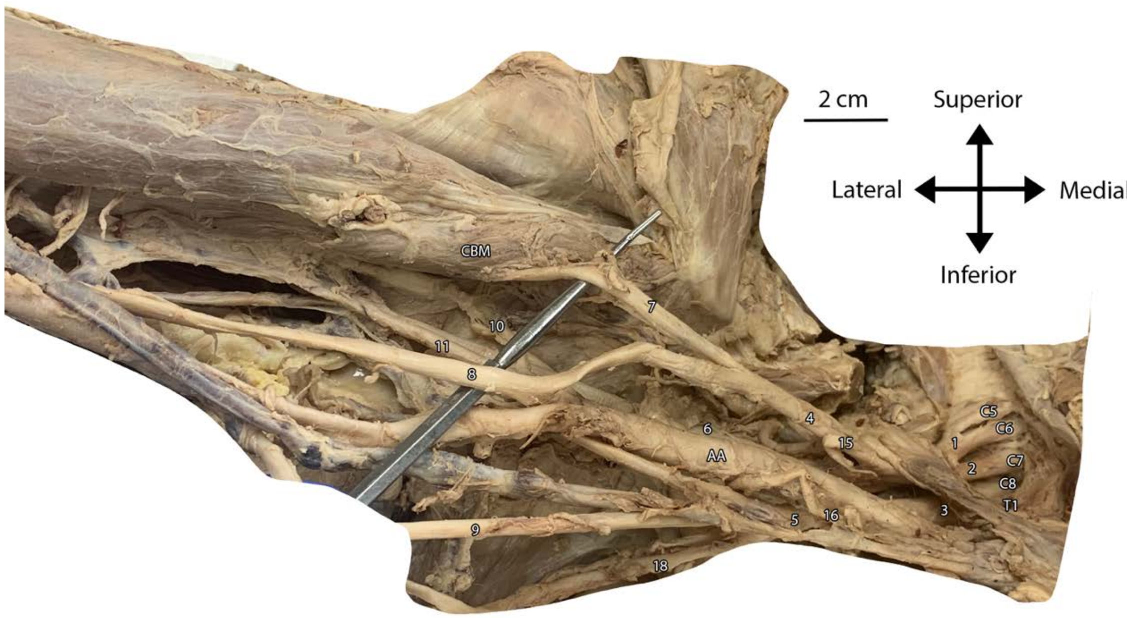
Appendix Figure 28. ***Homo sapiens*** **18-006 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



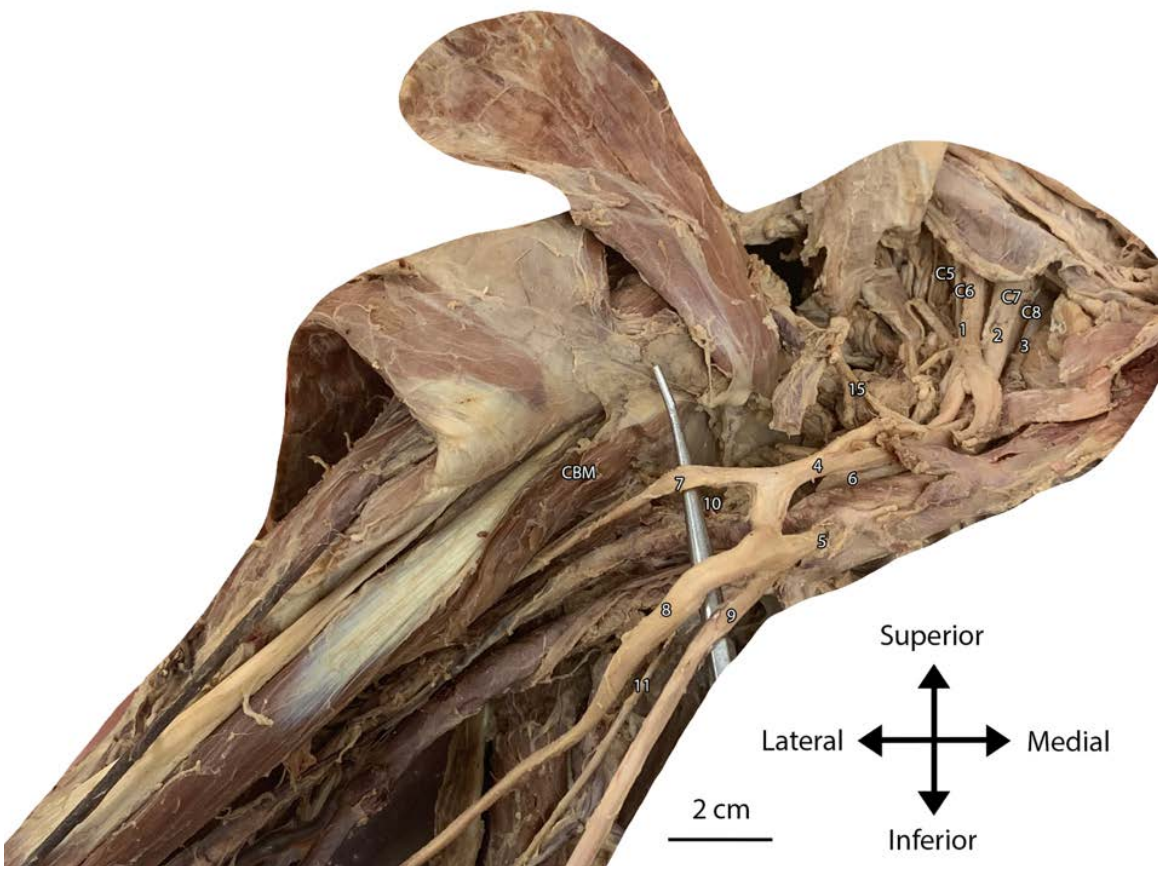
Appendix Figure 29. ***Homo sapiens*** **19-014 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



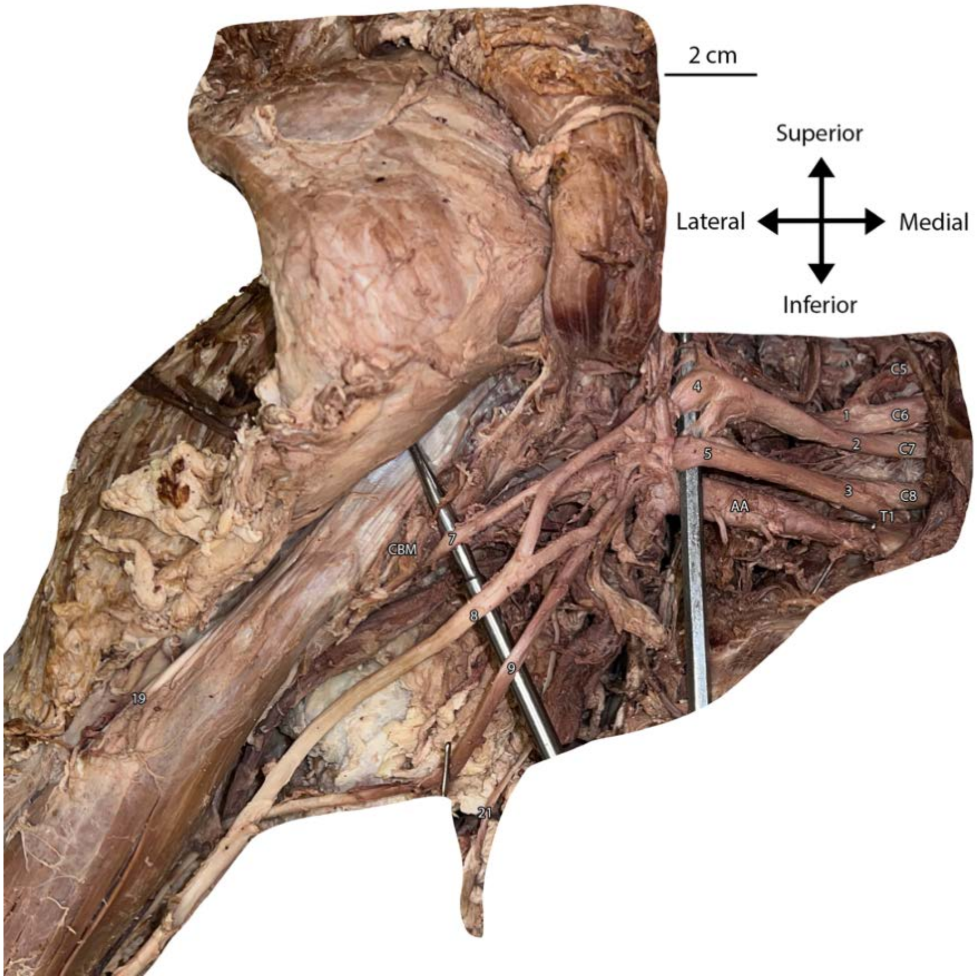
Appendix Figure 30. ***Homo sapiens*** **19-023 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



Appendix Figure 31. ***Homo sapiens*** **19-027 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



Appendix Figure 32. ***Homo sapiens*** **20-019 Right Brachial Plexus.**
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.



Appendix Figure 33. *Homo sapiens* 21-029 Right Brachial Plexus.
Anterior view of the right brachial plexus. Typical branching pattern of the brachial plexus.

Appendix Table 1. Summary of non-human primates, including age and sex when available and source of acquisition.

ID	Genus	Species	Source	Age	Sex
4982686557	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	Juvenile	Male
C1302037	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	Juvenile	UK
C1305246	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	Juvenile	Female
LC131604	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	Juvenile	Female
Y1305092	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	Adult	Female
Y1409053	*Macaca*	*fascicularis*	Charles River Laboratory; Mattawan, MI	UK	Male
12042391	*Macaca*	*mulatta*	Charles River Laboratory; Mattawan, MI	UK	Male
R1525R	*Macaca*	*mulatta*	Charles River Laboratory; Mattawan, MI	Juvenile	Male
1248	*Chlorocebus*	*aethiops*	MD Anderson Cancer Center; Houston, TX	Adult	UK
1448	*Chlorocebus*	*aethiops*	MD Anderson Cancer Center; Houston, TX	Adult	UK
86508*	*Aotus*	*sp.*	MD Anderson Cancer Center; Houston, TX	Adult	UK
2231	*Saimiri*	*sp.*	MD Anderson Cancer Center; Houston, TX	Adult	UK
2254	*Saimiri*	*sp.*	MD Anderson Cancer Center; Houston, TX	UK	UK

UK: unknown/ unavailable. Green: old world monkey species; Blue: new world monkey species
*Indicates only one side available for dissection

Appendix Table 2. Summary of where cadavers were dissected, age, biological sex, date of death, and cause of death.

Identification	Dissection Location	Body Donation Program	Age	Sex	Date of Death	Cause of Death
4049	GVSU	MSU	89	M	8/1/18	Dementia
4050	GVSU	MSU	89	F	8/2/18	Exacerbation of Congestive Heart Failure; Coronary Artery Disease
4055	GVSU	MSU	84	M	8/25/18	Aspiration Pneumonitis; Parkinson's Disease
4060	GVSU	MSU	70	M	9/16/19	Myocardial Infarction
4063	GVSU	MSU	99	F	10/9/18	Multi-organ System Failure; Arteriosclerotic Heart Failure
4064	GVSU	MSU	68	M	10/17/18	Small Cell Lung Cancer
4065	GVSU	MSU	106	F	10/19/18	Acute Respiratory Failure; Aspiration Pneumonia; Vascular Dementia
4067	GVSU	MSU	87	M	10/26/18	Cerebro-atherosclerosis
4069	GVSU	MSU	86	F	11/3/18	Congestive Heart Failure; Dementia; COPD
4070	GVSU	MSU	90	F	11/5/18	Alzheimer's Disease
437-W *	CMU	WSU	78	M	8/17/19	Non-Small Cell Lung Cancer; Esophageal Cancer
482-D *	CMU	WSU	87	M	10/23/19	GI hemorrhage
WMED-16-009 *	GVSU	WMU	72	M	2016	Septic Show, Pneumonia, Acute Respiratory Failure
WMED-17-023 *	GVSU	WMU	96	M	2017	Cardiopulmonary Arrest, Prostate Carcinoma
WMED-17-028	GVSU	WMU	94	F	2017	Complications of Right Hip Fracture
WMED-18-006 *	GVSU	WMU	81	F	2018	Unknown
WMED-18-010	GVSU	WMU	69	M	2018	Acute Respiratory Failure; COPD
WMED-18-019	GVSU	WMU	72	F	2018	Intercereral Hemorrhage
WMED-18-025	GVSU	WMU	65	F	2018	Dementia - Alzheimer's Disease
WMED-19-004	GVSU	WMU	92	M	2019	Pancreatic Cancer
WMED-19-011 *	GVSU	WMU	88	M	2019	Advanced Cancer: Tumor in Neck; Hypertension, Diabetes
WMED-19-012 *	GVSU	WMU	92	M	2019	Cardiovascular Disease

Appendix Table 2 (continued).

Identification	Dissection Location	Body Donation Program	Age	Sex	Date of Death	Cause of Death
WMED-19-013	GVSU	WMU	90	F	2019	Unspecified Protein-Calorie Malnutrition, Cerebral Atherosclerosis
WMED-19-014 *	GVSU	WMU	61	F	2019	Ischemic Bowel, Mesenteric Artery Thrombosis
WMED-19-015	GVSU	WMU	79	M	2019	Bladder Cancer
WMED-19-016	GVSU	WMU	77	M	2019	Medical Decompensation Following Subdural Fall
WMED-19-017 *	GVSU	WMU	88	F	2019	Acute Respiratory Failure; Metastatic Esophageal Cancer
WMED-19-019	GVSU	WMU	67	F	2019	Lung Cancer
WMED-19-023 *	GVSU	WMU	85	F	2019	Melanoma: Right Wrist - Metastatic
WMED-19-027 *	GVSU	WMU	86	M	2019	Non-Hodgkin's Lymphoma
WMED-20-013 *	GVSU	WMU	77	M	2020	Complications due to Metastatic Lung Cancer
WMED-20-017 *	GVSU	WMU	68	M	2020	Metastatic Esophageal Adenocarcinoma
WMED-20-018 *	GVSU	WMU	92	F	2020	Atherosclerotic Heart Disease
WMED-20-019 *	GVSU	WMU	93	F	2020	Protein Calorie Malnutrition; Uterine Cancer
WMED-20-024	GVSU	WMU	65	M	2020	Adenocarcinoma of the Lung
WMED-21-013 *	GVSU	WMU	76	M	2021	Pulmonary Fibrosis
WMED-21-029	GVSU	WMU	75	M	2021	Craniocerebral Trauma
WMED-21-031 *	GVSU	WMU	74	F	2021	Renal Failure; Failure to Thrive

* Indicates only one side available for dissection. Full death date given when available.

Appendix Table 3. Location of where variant branching patterns occur in *Homo sapiens*.

Roots	Prefixed (C4)	n=5; np=7	bilateral	n=2; np=4
			unilateral	n=1; np=1
			x	n=2; np=2
	Postfixed (T2)	n=0; np=0	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=0; np=0
Trunks	Superior Trunk	n=4; np=6	bilateral	n=2; np=4
			unilateral	n=1; np=1
			x	n=1; np=1
	Middle Trunk	n=3; np=4	bilateral	n=1; np=2
			unilateral	n=2; np=2
			x	n=0; np=0
	Inferior Trunk	n=2; np=3	bilateral	n=1; np=2
			unilateral	n=1; np=1
			x	n=0; np=0
Cords	Lateral Cord	n=3; np=3	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=2; np=2
	Medial Cord	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1
	Posterior Cord	n=6; np=7	bilateral	n=1; np=2
			unilateral	n=2; np=2
			x	n=3; np=3
Terminal Branches	Musculocutaneous Nerve	n=8; np=8	bilateral	n=0; np=0
			unilateral	n=3; np=3
			x	n=5; np=5
	Median Nerve	n=4; np=4	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=4; np=4
	Ulnar Nerve	n=2; np=2	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=1; np=1
	Axillary Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	Radial Nerve	n=0; np=0	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=0; np=0

Appendix Table 3 (continued).

Branches	Suprascapular Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1
	Medial Pectoral Nerve	n=2; np=3	bilateral	n=1; np=2
			unilateral	n=0; np=0
			x	n=1; np=1
	Lateral Pectoral Nerve	n=2; np=3	bilateral	n=1; np=2
			unilateral	n=0; np=0
			x	n=1; np=1
	Medial Antebrachial Cutaneous Nerve	n=2; np=4	bilateral	n=2; np=4
			unilateral	n=0; np=0
			x	n=0; np=0
	Lateral Antebrachial Cutaneous Nerve	n=2; np=2	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=1; np=1
	Superior Subscapular Nerve	n=5; np=5	bilateral	n=0; np=0
			unilateral	n=3; np=3
			x	n=2; np=2
	Thoracodorsal Nerve	n=3; np=3	bilateral	n=0; np=0
			unilateral	n=2; np=2
			x	n=1; np=1
	Inferior Subscapular Nerve	n=4; np=4	bilateral	n=0; np=0
			unilateral	n=3; np=3
			x	n=1; np=1

Appendix Table 3 (continued).

Connecting Branches	Lateral Cord to Medial Head of Median Nerve	n=8; np=10	bilateral	n=2; np=4
			unilateral	n=2; np=2
			x	n=4; np=4
	Musculocutaneous Nerve to Median Nerve	n=8; np=9	bilateral	n=1; np=2
			unilateral	n=5; np=5
			x	n=2; np=2
	Axillary Nerve to Radial Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	Superior Trunk to Middle Trunk	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	C6 root to C7 root	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1
	Median Nerve to Medial Antebrachial Cutaneous Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1

n= number of individual specimens, np= number of individual brachial plexuses, x= only one side of specimen was available for dissection.

Appendix Table 4. Location of where variant branching patterns occur in non-human primate species.

Roots	Prefixed (C4)	n=3; np=4	bilateral	n=1; np=2
			unilateral	n=1; np=1
			x	n=1; np=1
	Postfixed (T2)	n=3; np=5	bilateral	n=2; np=4
			unilateral	n=1; np=1
			x	n=0; np=0
Trunks	Superior Trunk	n=3; np=4	bilateral	n=1; np=2
			unilateral	n=1; np=1
			x	n=1; np=1
	Middle Trunk	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	Inferior Trunk	n=4; np=6	bilateral	n=2; np=4
			unilateral	n=2; np=2
			x	n=0; np=0
Cords	Lateral Cord	n=5; np=5	bilateral	n=0; np=0
			unilateral	n=4; np=4
			x	n=1; np=1
	Medial Cord	n=4; np=5	bilateral	n=1; np=2
			unilateral	n=2; np=2
			x	n=1; np=1
	Posterior Cord 1 Section	n=6; np=9	bilateral	n=3; np=6
			unilateral	n=2; np=2
			x	n=1; np=1
	Posterior Cord 2 Sections	n=9; np=16	bilateral	n=7; np=14
			unilateral	n=2; np=2
			x	n=0; np=0

Appendix Table 4 (continued).

Terminal Branches	Musculocutaneous Nerve	n=3; np=5	bilateral	n=2; np=4
			unilateral	n=3; np=3
			x	n=1; np=1
	Median Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1
	Ulnar Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=0; np=0
			x	n=1; np=1
	Axillary Nerve	n=1; np=2	bilateral	n=1; np=2
			unilateral	n=0; np=0
			x	n=0; np=0
	Radial Nerve	n=2; np=4	bilateral	n=2; np=4
			unilateral	n=0; np=0
			x	n=0; np=0
Branches	Dorsal Scapular Nerve	n=1; np=2	bilateral	n=1; np=2
			unilateral	n=0; np=0
			x	n=0; np=0
	Medial Pectoral Nerve	n=7; np=9	bilateral	n=2; np=4
			unilateral	n=5; np=5
			x	n=0; np=0
	Lateral Pectoral Nerve	n=6; np=8	bilateral	n=2; np=4
			unilateral	n=4; np=4
			x	n=0; np=0
	Superior Subscapular Nerve Superior Trunk | 1 Branch	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	Superior Subscapular Nerve Superior Trunk | 2 Branches	n=5; np=8	bilateral	n=3; np=6
			unilateral	n=2; np=2
			x	n=0; np=0
	Superior Subscapular Nerve Posterior Cord | 1 Branches	n=5; np=7	bilateral	n=2; np=4
			unilateral	n=2; np=2
			x	n=1; np=1
	Superior Subscapular Nerve Posterior Cord | 2 Branches	n=5; np=8	bilateral	n=3; np=6
			unilateral	n=2; np=2
			x	n=0; np=0
	Superior Subscapular Nerve Posterior Cord | 3 Branches	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0

Appendix Table 4 (continued).

Branches	Thoracodorsal Nerve From Posterior Cord	n=6; np=9	bilateral	n=3; np=6
			unilateral	n=2; np=2
			x	n=1; np=1
	Thoracodorsal Nerve From Upper Posterior Cord	n=4; np=5	bilateral	n=1; np=2
			unilateral	n=3; np=3
			x	n=0; np=0
	Thoracodorsal Nerve From Lower Posterior Cord	n=2; np=2	bilateral	n=0; np=0
			unilateral	n=2; np=2
			x	n=0; np=0
	Thoracodorsal Nerve From Radial Nerve	n=5; np=9	bilateral	n=4; np=8
			unilateral	n=1; np=1
			x	n=0; np=0
	Inferior Subscapular Nerve 1 branch	n=5; np=8	bilateral	n=3; np=6
			unilateral	n=1; np=1
			x	n=1; np=1
	Inferior Subscapular Nerve 2 branches	n=7; np=10	bilateral	n=3; np=6
			unilateral	n=4; np=4
			x	n=0; np=0
	Inferior Subscapular Nerve 3 branches	n=5; np=7	bilateral	n=2; np=4
			unilateral	n=3; np=3
			x	n=0; np=0
Communicating Branches	Musculocutaneous Nerve to Median Nerve	n=3; np=5	bilateral	n=2; np=4
			unilateral	n=1; np=1
			x	n=0; np=0
	Median Nerve to Ulnar Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0
	Axillary Nerve to Radial Nerve	n=2; np=3	bilateral	n=1; np=2
			unilateral	n=1; np=1
			x	n=0; np=0
	Medial Cord to Median Nerve	n=1; np=1	bilateral	n=0; np=0
			unilateral	n=1; np=1
			x	n=0; np=0

n= number of individual specimens, np= number of individual brachial plexuses, x= only one side of specimen was available for dissection.

Appendix Table 5. Summary of variant branching patterns found in non-human primate species.

Genus + Species	Identification	Side	Roots		Trunks			Cords		
			Prefixed (C4)	Postfixed (T2)	Superior Trunk	Middle Trunk	Inferior Trunk	Medial Cord	Lateral Cord	Posterior Cord
Macaca fascicularis	Y1305092	Left	0	0	0	1	1	1	1	1
		Right	0	0	0	0	0	0	0	1
	LC131604	Left	0	0	0	0	0	0	1	1
		Right	0	0	0	0	0	0	0	1
	Y1409053	Left	1	0	1	0	0	0	0	2
		Right	1	0	1	0	0	0	0	2
	4982686557	Left	0	0	0	0	0	0	0	1
		Right	0	0	0	0	0	0	0	1
	C1305246	Left	0	0	0	0	0	0	1	2
		Right	0	0	0	0	0	0	0	1
	C1302037	Left	0	0	0	0	0	0	0	1
		Right	0	0	0	0	0	0	0	2
Macaca mulatta	12042391	Left	0	1	0	0	1	0	0	2
		Right	0	1	0	0	1	0	0	2
	R1525R	Left	1	1	1	0	1	1	1	2
		Right	0	0	0	0	0	0	0	2
Chlorocebu s aethiops	1248	Left	0	1	0	0	1	1	0	2
		Right	0	1	0	0	1	1	0	2
	1448	Left	0	0	0	0	0	0	0	2
		Right	0	0	0	0	0	0	0	2
Aotus sp.	86508	Left	1	0	1	0	0	1	1	1
Saimiri sp.	2231	Left	0	0	0	0	0	0	0	2
		Right	0	0	0	0	0	0	0	2
	2254	Left	0	0	0	0	0	0	0	2
		Right	0	0	0	0	0	0	0	2

Appendix Table 5 (continued).

Genus + Species	Identification	Side	Major Branches				
			Musculocutaneous Nerve	Median Nerve	Ulnar Nerve	Axillary Nerve	Radial Nerve
Macaca fascicularis	Y1305092	Left	1	0	0	0	1
		Right	1	0	0	0	1
	LC131604	Left	0	0	0	1	1
		Right	0	0	0	1	1
	Y1409053	Left	0	0	0	0	0
		Right	0	0	0	0	0
	4982686557	Left	0	0	0	0	0
		Right	0	0	0	0	0
	C1305246	Left	0	0	0	0	0
		Right	0	0	0	0	0
	C1302037	Left	0	0	0	0	0
		Right	0	0	0	0	0
Macaca mulatta	12042391	Left	0	0	0	0	0
		Right	0	0	0	0	0
	R1525R	Left	0	0	0	0	0
		Right	0	0	0	0	0
Chlorocebus aethiops	1248	Left	0	0	0	0	0
		Right	0	0	0	0	0
	1448	Left	0	0	0	0	0
		Right	0	0	0	0	0
Aotus sp.	86508	Left	1	1	1	0	0
Saimiri sp.	2231	Left	0	0	0	0	0
		Right	0	0	0	0	0
	2254	Left	1	0	0	0	0
		Right	1	0	0	0	0

Appendix Table 5 (continued).

Genus + Species	Identification	Side	Other Branches					
			Dorsal Scapular Nerve	Medial Pectoral Nerve	Lateral Pectoral Nerve	Superior subscapular	Thoracodorsal Nerve	Inferior Subscapular
Macaca fascicularis	Y1305092	Left	0	0	0	2; ST	PC	2
		Right	0	0	0	2; ST	PC	3
	LC131604	Left	0	1	1	2; PC	PC	1
		Right	0	0	0	2; PC	PC	2
	Y1409053	Left	0	0	0	1; ST	upper PC	2
		Right	0	0	0	2; upper PC	upper PC	3
	4982686557	Left	1	0	0	1; PC	PC	2
		Right	1	0	0	1; PC	PC	2
	C1305246	Left	0	1	0	1; upper PC	upper PC	3
		Right	0	0	0	2; ST	PC	3
	C1302037	Left	0	1	1	1; PC	PC	3
		Right	0	0	0	2; ST	upper PC	3
Macaca mulatta	12042391	Left	0	0	0	2; ST	radial nerve	2
		Right	0	1	1	2; ST	radial nerve	2
	R1525R	Left	0	0	0	2; ST	upper PC	2
		Right	0	0	0	2; ST	lower PC	2
Chlorocebus aethiops	1248	Left	0	1	1	2; upper PC	radial nerve	1
		Right	0	0	0	2; upper PC	lower PC	1
	1448	Left	0	1	1	1; upper PC	radial nerve	1
		Right	0	1	1	1; upper PC	radial nerve	1
Aotus sp.	86508	Left	0	cut/ absent	cut/ absent	1; PC	posterior cord	1
Saimiri sp.	2231	Left	0	cut/absent	cut/absent	2; upper PC	radial nerve	1
		Right	0	cut/absent	cut/absent	3; upper PC	radial nerve	1
	2254	Left	0	1	1	2; upper PC	radial nerve	3
		Right	0	1	1	2; upper PC	radial nerve	2

Appendix Table 5 (continued).

Genus + Species	Identification	Side	Communicating Branches			
			MCN to MN	MN to UN	AN to RN	MC to MN
Macaca fascicularis	Y1305092	Left	0	0	0	0
		Right	0	0	0	0
	LC131604	Left	0	1	0	0
		Right	0	0	0	0
	Y1409053	Left	0	0	0	0
		Right	1	0	0	0
	4982686557	Left	1	0	0	0
		Right	1	0	0	0
	C1305246	Left	0	0	1	0
		Right	0	0	1	0
	C1302037	Left	0	0	0	0
		Right	0	0	0	0
Macaca mulatta	12042391	Left	0	0	0	0
		Right	0	0	0	0
	R1525R	Left	1	0	0	0
		Right	1	0	0	0
Chlorocebus aethiops	1248	Left	0	0	0	0
		Right	0	0	1	0
	1448	Left	0	0	0	0
		Right	0	0	0	0

Appendix Table 5 (continued).

Genus + Species	Identification	Side	Communicating Branches			
			MCN to MN	MN to UN	AN to RN	MC to MN
Aotus sp.	86508	Left	0	0	0	0
Saimiri sp.	2231	Left	0	0	0	0
		Right	0	0	0	0
	2254	Left	0	0	0	0
		Right	0	0	0	1

Blue: New world monkeys; Green: Old world monkeys. PC: Posterior cord; MCN: Musculocutaneous nerve; MN: Median nerve; UN: Ulnar nerve; AN: Axillary nerve; RN: Radial nerve; MC: Medial cord; 0: No variation found; 1: variation found. For "Superior Subscapular Nerve" and "Inferior Subscapular Nerve" 1, 2, and 3 indicate the number of branches found.

Appendix Table 6. Summary of variant branching patterns found in *Homo sapiens*.

Biological Sex	Cadaver Identification	Variant Side	Roots Prefixed (C4)	Roots Postfixed (T2)	Trunks Superior Trunk	Trunks Middle Trunk	Trunks Inferior Trunk	Cords Medial Cord	Cords Lateral Cord	Cords Posterior Cord
M	437-W	Right*	0	0	0	0	0	1	0	0
M	482-D	Left*	0	0	0	0	0	0	0	0
F	4070	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	4050	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4067	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4060	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	4063	Left	1	0	1	0	1	0	0	1
		Right	1	0	1	1	1	0	0	1
M	4055	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4064	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	4065	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4049	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	4069	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-18-010	Left	0	0	0	0	0	0	0	0
		Right	1	0	1	0	0	0	0	1
F	WMED-20-018	Right*	1	0	1	0	0	0	1	1
M	WMED-16-009	Right*	0	0	0	0	0	0	0	0
F	WMED-18-006	Right*	0	0	0	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex	Cadaver Identification	Variant Side	Roots		Trunks			Cords		
			Prefixed (C4)	Postfixed (T2)	Superior Trunk	Middle Trunk	Inferior Trunk	Lateral Cord	Medial Cord	Posterior Cord
M	WMED-19-012	Left*	1	0	0	0	0	0	1	1
M	WMED-17-023	Right*	0	0	0	0	0	0	0	0
F	WMED-19-014	Right*	0	0	0	0	0	0	0	0
M	WMED-19-011	Right*	0	0	0	0	0	0	0	1
M	WMED-19-015	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-19-016	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	WMED-19-013	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	1
F	WMED-18-019	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-19-004	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	1	0	0	0	0
F	WMED-18-025	Left	0	0	0	1	1	0	1	0
		Right	0	0	0	1	0	0	0	0
F	WMED-19-019	Left	1	0	1	0	0	0	0	0
		Right	1	0	1	0	0	0	0	0
M	WMED-19-027	Right*	0	0	0	0	0	0	0	0
F	WMED-19-023	Right*	0	0	0	0	0	0	0	0
F	WMED-20-019	Right*	0	0	0	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex		Variant	Roots		Trunks			Cords		
	Cadaver Identification	Side	Prefixed (C4)	Postfixed (T2)	Superior Trunk	Middle Trunk	Inferior Trunk	Lateral Cord	Medial Cord	Posterior Cord
M	WMED-20-017	Right*	0	0	0	0	0	0	0	0
M	WMED-21-013	Right*	0	0	0	0	0	0	0	0
M	WMED-20-024	Right*	0	0	0	0	0	0	0	0
F	WMED-17-028	Right*	0	0	0	0	0	0	0	0
M	WMED-21-029	Right*	0	0	0	0	0	0	0	0
M	WMED-20-013	Right*	0	0	0	0	0	0	0	0
F	WMED-19-017	Right*	0	0	0	0	0	0	0	0
M	WMED-19-031	Right*	0	0	0	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex	Cadaver Identification	Variant Side	Major Branches: Musculocutaneous Nerve	Median Nerve	Ulnar Nerve	Axillary Nerve	Radial Nerve
M	437-W	Right*	0	0	0	0	0
M	482-D	Left*	1	0	0	0	0
F	4070	Left	0	0	0	1	0
		Right	0	0	1	0	0
F	4050	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	4067	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	4060	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	4063	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	4055	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	4064	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	4065	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	4049	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	4069	Left	0	0	0	0	0
		Right	1	0	0	0	0
M	WMED-18-010	Left	1	0	0	0	0
		Right	0	0	0	0	0
F	WMED-20-018	Right*	1	0	1	0	0
M	WMED-16-009	Right*	0	1	0	0	0
F	WMED-18-006	Right*	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex	Cadaver Identification	Variant Side	Major Branches: Musculocutaneous Nerve	Median Nerve	Ulnar Nerve	Axillary Nerve	Radial Nerve
M	WMED-19-012	Left*	0	1	0	0	0
M	WMED-17-023	Right*	0	0	0	0	0
F	WMED-19-014	Right*	0	0	0	0	0
M	WMED-19-011	Right*	1	1	0	0	0
M	WMED-19-015	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	WMED-19-016	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	WMED-19-013	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	WMED-18-019	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	WMED-19-004	Left	0	0	0	0	0
		Right	1	0	0	0	0
F	WMED-18-025	Left	0	0	0	0	0
		Right	0	0	0	0	0
F	WMED-19-019	Left	0	0	0	0	0
		Right	0	0	0	0	0
M	WMED-19-027	Right*	0	0	0	0	0
F	WMED-19-023	Right*	0	0	0	0	0
F	WMED-20-019	Right*	0	0	0	0	0
M	WMED-20-017	Right*	0	0	0	0	0
M	WMED-21-013	Right*	1	1	0	0	0
M	WMED-20-024	Right*	0	0	0	0	0
F	WMED-17-028	Right*	0	0	0	0	0
M	WMED-21-029	Right*	0	0	0	0	0
M	WMED-20-013	Right*	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex		Variant	Major Branches				
	Cadaver Identification	Side	Musculocutaneous Nerve	Median Nerve	Ulnar Nerve	Axillary Nerve	Radial Nerve
F	WMED-19-017	Right*	1	0	0	0	0
M	WMED-19-031	Right*	0	0	0	0	0

Appendix Table 6 (continued).

Bio-logical Sex	Cadaver Identification	Variant Side	Branches: Supra-scapular Nerve	Medial Pectoral Nerve	Lateral Pectoral Nerve	Medial ante-brachial cutaneous nerve	Lateral ante-brachial cutaneous nerve	Superior sub-scapular nerve	Thoraco dorsal Nerve	Inferior Sub-scapular nerve
M	437-W	Right*	0	0	0	0	0	0	0	0
M	482-D	Left*	0	0	0	0	0	0	0	0
F	4070	Left	0	0	0	0	0	1	1	1
		Right	0	0	0	0	0	0	0	0
F	4050	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4067	Left	0	0	0	1	0	0	0	0
		Right	0	0	0	1	0	1	0	1
M	4060	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	4063	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4055	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4064	Left	0	1	1	0	0	0	0	0
		Right	0	1	1	0	0	0	0	0
F	4065	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	4049	Left	0	0	0	1	0	0	0	0
		Right	0	0	0	1	1	0	0	0
F	4069	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-18-010	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	1	1	1

Appendix Table 6 (continued).

Bio-logical Sex	Cadaver Identification	Variant Side	Branches: Supra-scapular Nerve	Medial Pectoral Nerve	Lateral Pectoral Nerve	Medial ante-brachial cutaneous nerve	Lateral ante-brachial cutaneous nerve	Superior sub-scapular nerve	Thoraco dorsal Nerve	Inferior Sub-scapular nerve
F	WMED-20-018	Right*	1	1	1	0	0	1	0	0
M	WMED-16-009	Right*	0	0	0	0	0	0	0	0
F	WMED-18-006	Right*	0	0	0	0	0	0	0	0
M	WMED-19-012	Left*	0	0	0	0	0	1	1	1
M	WMED-17-023	Right*	0	0	0	0	0	0	0	0
F	WMED-19-014	Right*	0	0	0	0	0	0	0	0
M	WMED-19-011	Right*	0	0	0	0	1	0	0	0
M	WMED-19-015	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-19-016	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	WMED-19-013	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	WMED-18-019	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-19-004	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	WMED-18-025	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
F	WMED-19-019	Left	0	0	0	0	0	0	0	0
		Right	0	0	0	0	0	0	0	0
M	WMED-19-027	Right*	0	0	0	0	0	0	0	0
F	WMED-19-023	Right*	0	0	0	0	0	0	0	0
F	WMED-20-019	Right*	0	0	0	0	0	0	0	0

Appendix Table 6 (continued).

Bio-logical Sex	Cadaver Identification	Variant Side	Branches Supra-scapular Nerve	Medial Pectoral Nerve	Lateral Pectoral Nerve	Medial ante-brachial cutaneous nerve	Lateral ante-brachial cutaneous nerve	Superior sub-scapular nerve	Thoraco dorsal Nerve	Inferior Sub-scapular nerve
M	WMED-20-017	Right*	0	0	0	0	0	0	0	0
M	WMED-21-013	Right*	0	0	0	0	0	0	0	0
M	WMED-20-024	Right*	0	0	0	0	0	0	0	0
F	WMED-17-028	Right*	0	0	0	0	0	0	0	0
M	WMED-21-029	Right*	0	0	0	0	0	0	0	0
M	WMED-20-013	Right*	0	0	0	0	0	0	0	0
F	WMED-19-017	Right*	0	0	0	0	0	0	0	0
M	WMED-19-031	Right*	0	0	0	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex	Cadaver Identification	Variant Side	Connecting Branches: LC to Medial head of MN	MCN to MN	RN to UN	ST to MT	C6 to C7	MN to MACN
M	437-W	Right*	0	0	0	0	0	0
M	482-D	Left*	0	1	0	0	0	0
F	4070	Left	1	0	0	0	0	0
		Right	0	0	0	0	0	0
F	4050	Left	0	0	0	1	0	0
		Right	0	0	0	0	0	0
M	4067	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
M	4060	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	4063	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
M	4055	Left	1	0	0	0	0	0
		Right	1	0	0	0	0	0
M	4064	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	4065	Left	0	0	0	0	0	0
		Right	0	1	0	0	0	0
M	4049	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	4069	Left	1	1	0	0	0	0
		Right	0	1	0	0	0	0
M	WMED-18-010	Left	1	0	0	0	0	0
		Right	1	1	0	0	0	0
F	WMED-20-018	Right*	0	0	0	0	0	0
M	WMED-16-009	Right*	0	0	0	0	0	0
F	WMED-18-006	Right*	0	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex	Cadaver Identification	Variant Side	Communicating Branches: LC to Medial head of MN	MCN to MN	RN to UN	ST to MT	C6 to C7	MN to MACN
M	WMED-19-012	Left*	0	0	0	0	0	0
M	WMED-17-023	Right*	0	0	0	0	0	0
F	WMED-19-014	Right*	0	0	0	0	0	0
M	WMED-19-011	Right*	0	1	0	0	0	0
M	WMED-19-015	Left	0	1	0	0	0	0
		Right	0	0	1	0	0	0
M	WMED-19-016	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	WMED-19-013	Left	0	0	0	0	0	0
		Right	0	1	0	0	0	0
F	WMED-18-019	Left	0	1	0	0	0	0
		Right	0	0	0	0	0	0
M	WMED-19-004	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	WMED-18-025	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
F	WMED-19-019	Left	0	0	0	0	0	0
		Right	0	0	0	0	0	0
M	WMED-19-027	Right*	0	0	0	0	0	0
F	WMED-19-023	Right*	0	0	0	0	0	0
F	WMED-20-019	Right*	0	0	0	0	0	0
M	WMED-20-017	Right*	1	0	0	0	1	0
M	WMED-21-013	Right*	0	0	0	0	0	1
M	WMED-20-024	Right*	1	0	0	0	0	0
F	WMED-17-028	Right*	0	0	0	0	0	0
M	WMED-21-029	Right*	0	0	0	0	0	0
M	WMED-20-013	Right*	1	0	0	0	0	0

Appendix Table 6 (continued).

Biological Sex		Variant	Communicating Branches					
	Cadaver Identification	Side	LC to Medial head of MN	MCN to MN	RN to UN	ST to MT	C6 to C7	MN to MACN
F	WMED-19-017	Right*	0	0	0	0	0	0
M	WMED-19-031	Right*	1	0	0	0	0	0

Table shows if there were specific variations in the branching pattern in the brachial plexus. *Homo sapiens* shown in orange. 0 indicates no variation; 1 indicates variation found. * Indicates only one side available for dissection. MCN: Musculocutaneous nerve; MN: Median nerve; UN: Ulnar nerve; RN: Radial nerve; LC: Lateral cord; ST: Superior trunk; MT: Middle trunk; MACN: Medial antebrachial cutaneous nerve

Bibliography

Agur, A. M., Dalley, A. F., & Grant, J. C. (2017). *Grant's Atlas of Anatomy 14th edition.* Lippincott Williams & Wilkins.

Ahmet, U., & Sait, B. (1999). Some variations in the formation of the brachial plexus in infants. *Turk J Med Sci, 29*, 573-577.

Aktan, A., Oztunk, L., Bilge, O., Ozer, M., & Pinar, Y. (2001). A cadaveric study of the anatomical variations of the brachial plexus nerves in the axillary region and arm. *Turk J Med Sci, 2*, 146-150.

Araujo, E. B., Lima, A. R., Pinheiro, L. L., Muniz, J. A., Imbeloni, A., & Branco, E. (2012). Origem e distribuicao do plexo braquail de Saimirir sciureus. *Pesquisa Veterinaria Brasileira, 32*, 1351-1354.

Aversi-Ferreira, T. A., Pereira-de-Paula, J., Prado, Y. C., Lima-e-Silva, M. S., & Mata, J. R. (2007). Anatomy of the Shoulder and Arm Muscles of Cebus libidinosus. *Brazilian Journal of Morphology, 24*(2), 63-74.

Beller, J. A., & Snow, D. M. (2014). Proteoglycans: road signs for neurite outgrowth. *Neural Regen Res, 9*, 343-355.

Bolk, L. (1902). Der Plexus Cervico-Brachialis der Primaten. *Petrus Camper, 1*, 371-566.

Booth, K. K. (1991). The Brachial Plexus in the Vervet Monkey (Cercopithecus pygerythrus). *J Med Primatol, 20*(1), 23-28.

Booth, K. K., Baloyi, F. M., & Lukhele, O. M. (1997). The Brachial Plexus in the Chacma Baboon (Papio ursinus). *J Med Primatol, 26*, 196-203.

Boyle, E. K., Mahon, V., & Diogo, R. (2020). Muscles Lost in Our Adult Primate Ancestors Still Imprint in Us: on Muscle Evolution, Development, Variations, and Pathologies. *Current Molecular Biology Reports, 6*, 32-50.

Brooks, W. T. (1883). The brachial plexus of the Macaque monkey and its analogy with that of man. *Journal of anatomy and physiology, 17*, 329.

Budhiraja, V., Rastogi, R., Asthana, A. K., Sinha, P., Krishna, A., & Trivedi, V. (2011). Concurrent variations of median and musculocutaneous nerves and their clinical correlation - a cadaveric study. *IJAE, 116*(2), 67-72.

Chase, R. E., & DeGaris, C. F. (1940). The brachial plexus in Macacus rhesus, compared with man. *American Journal of Physical Anthropology, 27*, 223-254.

Del Rio, J. A., & Soriano, E. (2007). Overcoming chondroitin sulphate proteoglycan inhibition of axon growth in the injured brain: lessons from chondroitinase ABC. *Curr Pharm Des, 13*, 2485-2492.

Diogo, R., & Molnar, J. (2016). Links between Evolution, Development, Human Anatomy, Pathology, and Medicine with a Proposition of A Re-defined Anatomyical Position and Notes on Constraints and Morphological "Imperfections". *J. Exp. Zool. (Mol. Dev. Evol.), 326*(4), 215-224.

Diogo, R., & Wood, B. (2012). *Comparative Anatomy and Phylogeny of Primate Muscles and Human Evolution.* CRC Press.

Diogo, R., Richmond, B. G., & Wood, B. (2012). Evolution and homologies of primate and modern human hand and forearm muscles, with notes on thumb movements and tool use. *Journal of Human Evolution, 63*(1), 64-78.

Dongoghue, M. J., & Cracraft, J. (2004). *Assembling the Tree of Life.* Oxford University Press.

Dunn, J. C., & Cristóbal-Azkarate, J. (2016). New World monkeys. *Nature Education Knowledge, 7*(6), 1.

Eglseder, W. A., & Goldman, M. (1997). Anatomic variations of the musculocutaneous nerve in the arm. *Am J Orthop, 26*(11), 777-780.

Emamhadi, M., Chabok, S. Y., Samini, F., Alijani, B., Behzadnia, H., Firozabadi, F. A., & Reiganian, Z. (2016). Anatomical Variations of Brachial Plexus in Adult Cadavers; A Descriptive Study. *The archives of bone and joint surgery, 4*(3), 253-258.

Emura, K., Arakawa, T., & Terashima, T. (2017). Anatomical Study of the Brachial Plexus in the Common Marmoset (Callithrix Jacchus). *The Anatomical Record, 300*, 1299-1306.

Figuerdo-da-Silva, S., Vasconcelos-da-Silva, E., Abreu, T., & Aversi-Ferreira, T. A. (2020). Comparative Anatomy of the Brachial Plexus and Shoulder Nerves of the Sapajus. *J Med Primatol, 50*, 9-20.

Fregnani, J. H., Macéa, M. I., Pereira, C. S., Barros, M. D., & Macéa, J. R. (2008). Absence of the musculocutaneous nerve: a rare anatomical variation with possible clinical-surgical implications. *Sao Paulo Med J, 126*(5), 288-290.

Gebo, D. L. (2014). *Primate Comparative Anatomy.* Johns Hopkins University Press.

Gelmi, C. E., Pedrini, F. A., Fermi, M., Mariani, G. A., Cocco, L. I., & Billi, A. M. (2018). Communication between median and musculocutaneous nerve at the level of cubital fossa - A case report. *Translational Research in Anatomy, 11*, 1-4.

Goel, S., Rustagi, S. M., Kumar, A., Mehta, V., & Suri, R. K. (2014). Multiple unilateral variations in medial and lateral cords of brachial plexus and their branches. *Anat Cell Biol., 47*(1), 77-80.

Guday, E., Bekele, A., & Muche, A. (2017). Anatomical study of prefixed versus postfixed brachial plexuses in adult human cadaver. *ANZ J Surg, 87*(5), 399-403.

Gumusalan, Y., Yazar, F., & Ozan, H. (1998). Variant innervation of the coracobrachialis muscle and unusual course of the musculocutaneous nerve in man. *Kaibogaku Zasshi, 73*(3), 269-272.

Harris, E. E. (2015). *Ancestors in Our Genome: The New Science of Human Evolution.* Oxford University Press.

Harris, W. (1939). *The morphology of the brachial plexus.* Oxford University Press.

Howell, A., & Straus Jr, W. L. (1947). The anatomy of the Rhesus monkey. *Hafner, New York*, 153.

Landmesser, L. (1978). The development of motor projection patterns in the chick hind limb. *J Physiol, 284*, 391-414.

Lawrence, J. M., & Cords, M. (2012). Old World monkeys. *Nature Education Knowledge, 3*(7), 13.

Le Minor, J. M. (1990). A rare variation of the median and musculocutaneous nerves in man. *Arch Anat Histol Embryol, 73*, 33-42.

Leijnse, J. N., de Bakker, B. S., & D'Herde, K. (2020). The brachial plexus - explain its morphology and variability by a generic developmental model. *Journal of Anatomy, 236*, pp862-882.

Malukar, O., & Rathva, A. (2011). A study of 100 cases of brachial plexus. *National Journal of Community Medicine, 2*(1), 166-170.

Miller, R. (1934). Comparative studies upon the morphology and distribution of the brachial plexus. *American Journal of Anatomy, 54*, 143-175.

Mizuno, N. (1966). The brachial, lumbar, and sacral plexuses in an owl-monkey (Aotes trivirgatus Humboldt, 1911), with special reference to comparison with other primates. *Primates, 7*, 449-470.

Mizuno, N. (1969). The brachial plexus in the squirrel monkey (Saimiri sciureus). *Primates, 10*, 19-35.

Moore, K. L., Agur, A. M., Dalley, A. F., & Moore, K. L. (2015). *Essential Clinical Anatomy.* Philadelphia: Wolters Kluwer Health.

Naldaiz-Gastesi, N., Bahri, O. A., Munain, A. L., McCullagh, K. J., & Izeta, A. (2018). The panniculus carnosus muscle: an evolutionary enigma at the intersection of distinct research fields. *Journal of Anatomy, 233*(3), 275-288.

Nasrabadi, H. T., Abedelahi, A., Shoorei, H., Shokoohi, M., Salimnejad, R., Dolatkhah, M. A., & Seghinsara, A. M. (2017). A variation of musculocutaneous nerve without piercing the coracobrachialis muscle while communicating to the median nerve: a case report and literature review. *Int J Surg Case Rep, 41*, 453-455.

Natsis, K., Apostolidis, S., Nikolaidou, E., Noussios, G., Trifon, T., & Lazaridis, N. (2009). Levator claviculae muscle: A case report. *2*, 6712.

Ono, M. (1937). On the short branches of the brachial plexus in macaques. *J. Hokuetsu Med. Assoc., 52*, 163-177.

Pellerin, M., Kimball, Z., Tubbs, R. S., Nguyen, S., Matusz, P., Cohen-Gadol, A. A., & Loukas, M. (2010). The prefixed and postfixed brachial plexus: a review with surgical implications. *Surgical and Radiologic Anatomy, 32*, 251-260.

Pellerin, M., Kimball, Z., Tubbs, R. S., Nguyen, S., Matusz, P., Cohen-Gadol, A. A., & Loukas, M. (2010). The prefixed and postfixed brachial plexus: a review with surgical implications. *Surg Radiol Anat, 32*(3), 251-260.

Perelman, P., Johnson, W. E., Roos, C., Seuánez, H. N., & Horvath, J. E. (2011). A Molecular Phylogeny of Living Primates. *PLoS Genetics, 7*(3), e1001342.

Prathap, K. J., Radhika, P. M., Jyothi, K. C., Shailaja, S., & Poonam, D. N. (2013). A study of branching pattern of the lateral cord of the brachial plexus. *Int J Cur Res Rev, 5*(11), 116-124.

Rao, P. V., & Chaudhary, S. C. (2001). Absence of musculocutaneous nerves: Two case reports. *Clin Anat, 14*, 31-35.

Rodriguez-Niedenfuhr, M., Burton, G. J., Deu, J., & Sañudo, J. R. (2001). Development of the arterial pattern in the upper limb of staged human embryos: normal development and anatomic variations. *J Anat, 4*, 407-417.

Rogawski, K. M. (1990). The rhomboideus capitis in man - correctly named rare muscular variation. *Okajimas Folia Anat. Jpn., 67*(2-3), 161-163.

Safran, M. R. (2004). Nerve injury about the shoulder in athletes, part 1: suprascapular nerve and axillary nerve. *Am J Sports Med, 32*, 803-819.

Santos-Sousa, C. A., Gomes, M. S., Carvalho, N. C., Souza-Junior, P., Santos, C. M., & Abidu-Figueirdo, M. (2016). Origin and antimeric distribution of brachial plexus nerves in Macaca mulatta (Zimmermann 1780) (Primates: Cercopithecidae). *Italian Journal of Zoology, 83*(4), 469-481.

Shearer, B. M. (2019). *The morphology and evolution of the primate brachial plexus.* CUNY Academic Works.

Shearer, B. M. (2019). *The Morphology and Evolution of the Primate Brachial Plexus.* CUNY Academic Works.

Singhal, S., Rao, V. V., & Ravindranath, R. (2007). Variations in brachial plexus and the relationship of median nerve with the axillary artery: a case report. *Journal of brachial plexus and peripheral nerve injury, 2*, 21.

Souza-Junior, P., Carvalho, N. C., Dowich, G., Nogeuria, D. M., Anjos, B. L., Santas-Sousa, C. A., & Abidu-Figueiredo, M. (2018). Origin and Antimeric Distribution of Brachial Plexus Nerves in Alouatta guaria clamitans Cabrera, 1940 (Primates: Atelidae). *The European Zoological Journal, 85*(1), 362-371.

Sugiyama, T. (1965). On the plexus brachialis of Macacus cyclopsis. *Acta Medica Nagasakiensia, 9*, 65-88.

Sultan, H. E., & El-Tantawi, G. A. (2013). Role of dorsal scapular nerve entrapment in unilateral interscapular pain. *Arch Phys Med Rehabil, 94*, 1118-1125.

Suruchi, S., Vani, V., & Roopa, R. (2007). Variations in brachial plexus and the relationship of median nerve with the axillary artery: a case report. *J Brachial Plex Peripher. Nerve Inj, 2*, 21.

Tank, P. W., & Grant, J. C. (2013). *Grant's Dissector (15th ed.).* Philadelphia: Wolters Kluwer Health/ Lippincott Williams & Wilkins.

Thakur, K. C., Jethani, S. L., & Parsad, V. (2015). Non piercing variation of musculocutaneous nerve. *Journal of Evolution of Medical and Dental Sciences, 4*(90), 15515-15517.

Tokiyoshi, A., Koizumi, M., Kawai, K., Honma, S., Takgi, K., & Kodama, K. (2004). Scalenus muscles in the macaque monkeys. *Anatomical science international*(79), 32-42.

Tripathi, A., Kausar, H., Arora, S., Khare, S., Jain, S., Kaushik, R. K., & Kumar, A. (2018). A cadaveric study on the anatomical variations of the musculocutaneous nerve in relation with median nerve and coracobrachialis muscle. *Journal of Anatomical Sciences, 26*(2), 58-61.

Valeria, P. S., Adilson, L. C., & Omar, A. R. (2003). Brachial plexus variations in its formation and main branches. *Acta Cir Bras, 18*.

Venierotos, D., & Anagnostopoulou, S. (1998). Classification of communications between the musculocutaneous and median nerves. *Clin Anat, 11*(5), 327-331.

Yamamoto, C., Murakami, T., & Ohtsuka, A. (1988). Homology of the adductor pollicis and contrahentes muscles: a study of monkey hands. *Acta Medica Okayama, 42*(4), 215-226.

Yokogawa, N., Murakami, H., Demura, S., Kato, S., Yoshioka, K., Hayashi, H., . . . Tsuchiya, H. (2014). Motor function of the upper-extremity after transection of the second thoracic nerve root during total en bloc spondylectomy. *PLOS ONE, 9*, e109838.