Jordan Medical Journal

ORIGINAL ARTICLE

Cross-sectional Study of the Anatomic Variation of Brachial Plexus' Nerve Roots Origin in Jordan: Prefixed and Postfixed

Osama Samara[1], Feras Al Khatib[2], Ruba Braik[1], Tariq Alsayouri[2], Abdallah Al-Qawasmeh[2], Osama Afaneh[2], Nosaiba Al Ryalat[1], Darwish Badran[3], Amjad Shatarat[4*]

[1] Department of Radiology, School of Medicine, University of Jordan, Amman, 11942, Jordan.

[2] School of Medicine, University of Jordan, Amman, 11942, Jordan.

[3] Ibn Sina University for Medical Sciences, Amman, 16197, Jordan.

[4] Aqaba Medical Sciences University, Aqaba, 77110, Jordan.

*Corresponding author:

a.shatarat@ju.edu.jo

Received: December 2, 2023

Accepted: March 14, 2024

DOI: https://doi.org/10.35516/jmj.v59i1.2033

Abstract

Background and Aims: Anatomical variations in the origin of brachial plexus and the nerve roots contributing to it exist. Based on literature review, these variations are not uncommon and may even be the rule rather than the exception. However, data regarding these variations in the Jordanian population is absent, and assessment of such variations is important in both clinical evaluation and surgical procedures. Such anatomical variations may increase the likelihood of specific pathologies, like thoracic outlet syndrome, and can influence the surgical strategies employed for the brachial plexus. This study aimed to explore the anatomy and variations of the brachial plexus's origin in normal healthy Jordanian subjects using magnetic resonance imaging (MRI), particularly prefixed and postfixed variants.

Materials and Methods: This was a cross-sectional study. Random selection of 50 subjects undergoing cervical spine MRI, for which a 3D NerveVIEW sequence of the brachial plexus nerve roots was performed in both coronal and axial planes. For each subject, identification of the nerve root levels contributing to the formation of the brachial plexus on each side was performed and prefixed/postfixed variations were identified. Other measurements, diameter and length of nerve roots, were identified, and a comparison of these measurements between males and females in the studied population was performed.

Results: Out of the 94 brachial plexuses analyzed, 25 were prefixed (26.6%) and none were postfixed. Those 25 prefixed plexuses were identified in 15 subjects; 10 subjects having the prefixed variant bilaterally (66.7% of all prefixed plexuses), 4 subjects were left prefixed plexus (26.7%) and only one was a right prefixed plexus (6.7%). Data analysis of the lengths and diameters of all nerve roots contributing to the formation of the brachial plexuses in all subjects (n=94) showed that the mean diameter and length of the left-sided roots were significantly thicker and longer than their right-sided counterparts (p-values were 0.0178 and 0.0014, respectively). In addition, nerve roots contributing to brachial plexuses formation were longer and wider in males than those in females.

Conclusions: This study concluded that anatomical variation of the nerve roots contributing to brachial plexus is common among the Jordanian population, particularly the pre-fixed variant.

Keywords: Brachial plexus, Prefixed, Postfixed, 3D NerveVIEW, Neuroanatomy, Spinal nerves.

INTRODUCTION

The brachial plexus forms a complex network of nerves responsible for supplying both motor and sensory nerves in the upper extremity.

It typically originates from the anterior rami of spinal nerves C5-T1 (the roots of the brachial plexus). These roots merge to form trunks, which then split into divisions. These divisions subsequently merge into cords and ultimately, cords give rise to the terminal branches. The terminal branches encompass musculocutaneous, axillary, radial, median, and ulnar nerves.

The complexity of the brachial plexus stems not only from the multiple roots and trunks involved but also from anatomical variations between people and even within the same subject, as right and left plexuses may demonstrate variations. MRI has many advantages in assessing the brachial plexus as it is non-invasive and can provide us with different imaging planes.

The standard medical description of the brachial plexus is that it arises from C5, C6, C7, C8, and T1 nerves, with occasional contribution from the fourth cervical (prefixed) or the second thoracic (postfixed) nerves. A prefixed brachial plexus is defined by a contribution from the fourth cervical nerve and a postfixed brachial plexus is defined as one with a contribution from the second thoracic nerve.

A comprehensive awareness of the probability of encountering these variations holds clinical significance in various scenarios. For instance, rhizotomy of the C4 root in the treatment of spasmodic torticollis, the increased likelihood of specific pathologies like thoracic outlet syndrome, and the achievement of effective analgesia for the brachial plexus [1-5]. The brachial plexus is also considered an injury-prone structure, with some injuries having detrimental complications [6-9].

This necessitates a thorough comprehension of the potential variations within the encountered brachial plexuses. Variations may manifest in any segment of the brachial plexus, including the roots, trunks, divisions, cords, or branches. This paper aimed to elucidate variations, specifically within the roots of the brachial plexus.

MATERIALS AND METHODS

Study design

This was a cross-sectional study, and the brachial plexus scans on which the study were based were obtained prospectively.

Study setting

This study was conducted at Jordan University Hospital. Data collection and analysis were performed between Nov 2021 and June 2022.

Study population

The population was selected randomly and additional brachial plexus sequences were obtained in patients who were undergoing cervical spine MR for complaints such as neck pain.

Sampling procedure and sample size calculation

The Raosoft sample size online calculator (http://www.raosoft.com/samplesize.html), an automated software program, was used for sample size calculation, using an 8.2% margin of error at a 90% confidence level; the required sample size was calculated to be 101.

Inclusion and exclusion criteria

Subjects were excluded if there was any previous neck surgery, trauma, or accident that may have affected the upper limbs' function. Also, subjects with any masses/lesions close in location to the brachial plexus or along its pathway were excluded (e.g. tumors). The inclusion criterion was the subject's agreement to obtain additional sequences for brachial plexus during their cervical spine MRI. Three subjects were excluded as each met at least one exclusion criterion.

Data collection

The MR system used in this research to obtain images is Ingenia 1.5T System-Philips (Netherlands), through which a 3D NerveVIEW sequence for the brachial plexus was obtained in both coronal and axial planes. Images obtained of the brachial plexus were characterized by high-resolution T2W TSE acquisition with reduced remaining intra-lumen signal of the veins. The 3D isotropic imaging method allows reformatting in any plane without loss of resolution, thus enhancing assessment of spinal nerve plexuses [10].

The parameters used in the 3D NerveVIEW sequence are as follows:

- TR/TI (ms) = 2200/255.
- TE (ms) = 190.
- Acquisition matrix (m×p) 252×308
- Magnification tools were not employed.

Data collected using the images were the nerve root levels contributing to the formation of brachial plexus in each subject on both sides (right and left), paying attention to prefixed and post-fixed variants, as well as the diameter of each of these roots.

On the coronal 3D NerveVIEW images, the nerves contributing to the formation of superior, middle, and inferior trunks of the brachial plexus at each side were identified (*Figure 1*). In particular, careful scrutinization for the possible contribution of the C4 nerve to the superior trunk and/or T2 nerve to the inferior trunk was performed.

Diameters of nerve roots were measured on axial images at the level of nerve root foramina just before the nerve exits the foramen, ensuring uniform measurements *(Figures 2 and 3)*. Lengths of nerve roots contributing to the brachial plexus on each side in each subject were measured on coronal views. For C4, C5, and C6 nerves, length was measured from nerve root origin at the level of the cord proximally down to the beginning of the superior trunk distally *(Figure 4)*. For C8, T1, and T2 nerves, length was measured from nerve root origin at the level of the cord proximally down to the beginning of the inferior trunk distally. For C7 nerves *(Figure 5)*, length was measured from nerve root origin at level of the cord proximally down to level of beginning of inferior trunk as well (since the middle trunk is only a continuation of C7 nerve, and literature data was insufficient to determine at which point precisely the C7 nerve root was separated from middle trunk and merely described middle trunk as continuation of C7 nerve root, the researchers assumed both middle and inferior trunks begin at same level. When a prefixed plexus was encountered, the same measurements for its diameter and length were obtained in addition *(Figure 6)*.

Statistical analysis

Data collected including the levels of nerve roots contributing to the formation of brachial plexus, presence or absence of prefixed/postfixed variation, lengths and diameters of these nerve roots and age and gender for each participant were entered into an Excel spreadsheet. Data were sorted based on the variables being analyzed, including gender, age, and prefixed or postfixed status. The selected data was then imported into GraphPad Prism 5 for further analysis.

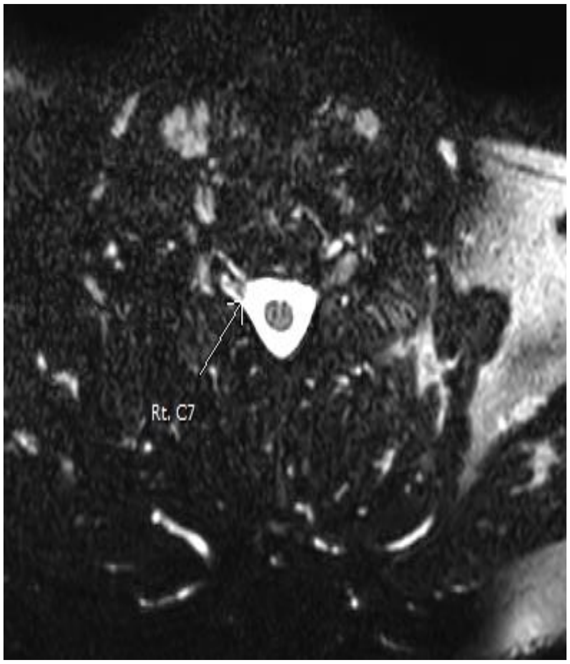

Figure 2. Axial 3D nerveVIEW of brachial plexus at the lower cervical level shows the right C7 nerve root in its exiting foramen.

Figure 1. Frontal (AP) 3D nerveVIEW of the brachial plexus shows the right C5 and C6 nerves joining to form the superior trunk. The right C7 nerve continues to form the middle trunk.

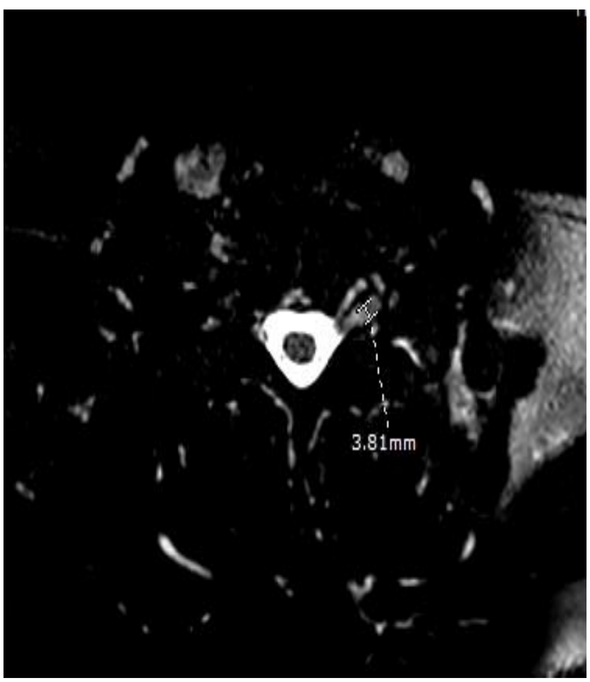

Figure 4. Axial 3D nerveVIEW of brachial plexus at the lower cervical level. The diameter of the left C8 nerve measured 3.81mm at the level of nerve root foramen.

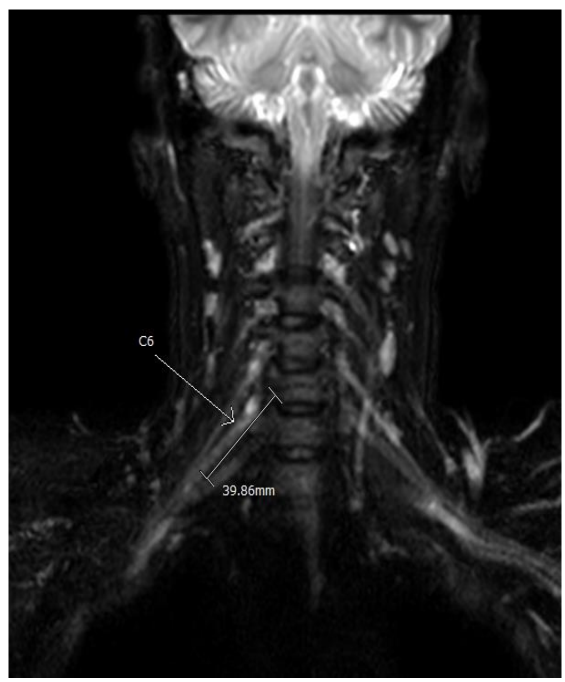

Figure 3. Frontal (AP) 3D nerveVIEW of brachial plexus. The length of the C6 nerve root was measured at 39.86mm from its origin at the cord level proximally down to the beginning of the superior trunk distally.

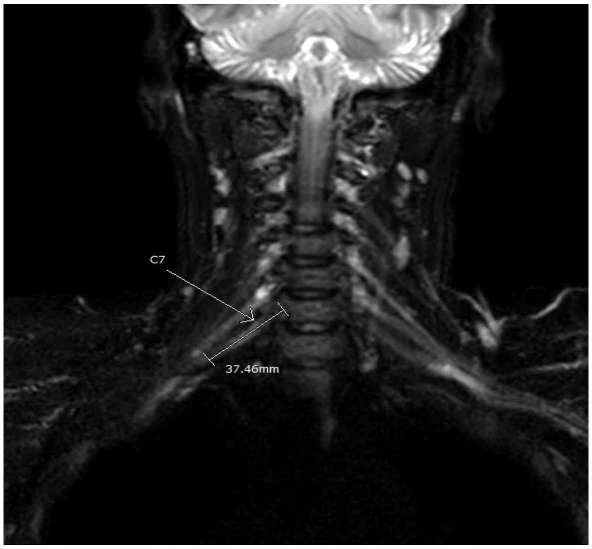

Figure 6. Frontal (AP) 3D nerveVIEW of brachial plexus. The length of the C7 nerve root was measured at 37.46mm from its origin at the cord level proximally down to the beginning of the inferior

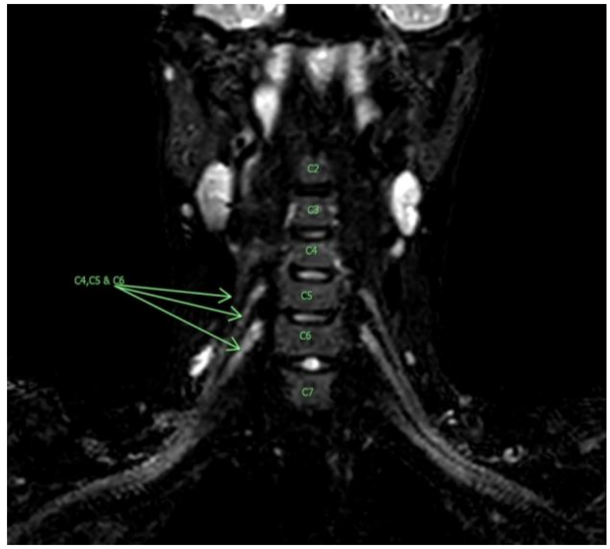

Figure 5. Frontal (AP) 3D nerveVIEW of brachial plexus. C4 contributes to formation of superior trunk on the right side (prefixed variant).

A comparison between the selected groups was performed using one-way ANOVA (Bonferroni posttest) or the t-test (two-tailed), whichever was appropriate. All statistical analyses were performed with GraphPad Prism 5, and *P* values less than 0.05 were considered to indicate statistically significant differences.

Ethical considerations

The study proposal was approved by Jordan University's Institutional Review Board (IRB) ethical committee. Informed consent was obtained from all participants. Participants' data were treated with confidentiality and no personal information about the subjects (e.g., names, emails, phone numbers) were shared.

RESULTS

Data analysis of the 47 subjects who met the inclusion criteria (3 subjects were excluded). Considering each subject has 2 (bilateral) brachial plexuses, a total of 94 plexuses were analyzed. The participants varied by age; the youngest was 22, while the oldest participant was 78, and approximately 75% of the participants were in the age range of 30-60 years old (Table I).

Prefixed and post-fixed:

Analysis of prefixed and post-fixed variants revealed that 15 participants (32%) had a prefixed BP, 10 of which were bilateral (66.7%), 4 had left prefixed brachial plexus (26.7%) and one had right prefixed brachial plexus (6.7%), thus the total number of prefixed plexuses out of 94 plexuses analyzed was 25 *(Figure 6)*. Among these 15 participants with the prefixed variant, 9 were females and 6 were males Among the 25 plexuses, 14 (56%) were found in females, and 11 (44%) were found in males.

There were no participants with a post-fixed brachial plexus. Out of the 94 brachial plexuses analyzed, 25 were prefixed (26.6%), while 69 were not prefixed (73.4%).

Mean diameters and mean lengths of the brachial plexus (Table II).

The mean diameters of the analyzed roots on the left side of the brachial plexus (n=47, mean = 3.648 mm) were significantly thicker than the mean diameters of the right side brachial plexus (n=47, mean = 3.442 mm) (p = 0.0178) *(Table II)*. The mean diameters of nerve roots in prefixed plexuses were significantly thicker than those in non-prefixed plexuses ($p = 0.0395 < 0.05$).

Table I portrays the diversity of the participants by identifying their genders and age ranges (n=47)

Gender	Participant number	Percentage (%)
Male	16	34%
Female	31	66%
Age range	Participant number	Percentage (%)
20-29	4	8.51%
30-39	9	19.14%
40-49	14	29.79%
50-59	12	25.53%
60-69	4	8.51%
70-79	4	8.51%

Table II compares the brachial plexus' mean lengths/diameters of each nerve root between left/right sides, males/females, and prefixed/non-prefixed

Roots	Mean diameters (mm)			Mean lengths (mm)			Mean diameters (mm)		Mean lengths (mm)		Mean diameters (mm)		Mean lengths (mm)	
	Right	Left	overall	Right	Left	overall	Male	Female	Male	Female	Prefixed	Non-prefixed	Prefixed	Non-prefixed
C4	3.47	3.62	3.55	37.5	44.2	41.2	3.72	3.40	40.8	41.6	3.55	-	41.2	-
C5	3.39	3.78	3.58	48.3	52.4**	50.3	4.08**	3.32	50.2	50.4	3.76	3.49	50.4	50.3
C6	3.45	3.55	3.50	40.4	43.5*	41.9	3.99**	3.25	42.6	41.6	3.70	3.40	42.0	41.9
C7	3.48	3.69	3.59	42.6	44.8	43.7	3.82	3.47	47.5*	41.7	3.74	3.52	45.1	43.0
C8	3.46	3.69	3.57	36.5	38.8	37.6	4.05**	3.33	42.6***	35.1	3.72	3.50	38.7	37.1
T1	3.44	3.53	3.49	31.8	33.9	32.8	3.70	3.38	36.3***	30.5	3.53	3.47	32.9	32.8

- $n^{Males} = 16$. $n^{Females} = 31$
- $n^{Prefixed} = 25$,
- $n^{Non\text{-}prefixed} = 22$
- $n^{Right} = 47$,
- $n^{Left} = 47$
- *All values are in millimeters (mm)*
- *Values were rounded up to three significant figures*
- *The t-test was used for the analysis of all data in this table*
- * indicates significance ($p < 0.05$)

  ** indicates strong significance ($p < 0.01$)

  *** indicates very strong significance ($p < 0.0001$)

The mean lengths of the nerve roots on the left side of the brachial plexus (n=47, mean = 42.6488 mm) were significantly longer than the mean lengths of the right-side brachial plexus (n=47, mean = 39.91 mm) (p = 0.0014). When comparing individual nerve roots, in terms of length, C5 had the longest root (mean = 50.33 mm), followed by C7 (mean = 43.68 mm), C6 (mean = 41.91 mm), C4 (mean = 41.23 mm), C8 (mean = 37.63 mm), and T1 had the shortest root (mean = 32.82 mm) ($p < 0.05$, One-way ANOVA) (Figure 7). The mean lengths of nerve roots in prefixed plexuses (41.80 mm) were slightly longer than those in non-prefixed plexuses (41.02 mm), but there was no statistical significance ($p = 0.3941$) *(Table II)*.

Gender's influence on the brachial plexus (Table II).

Gender analysis revealed that males (n=16) had longer and thicker nerve roots than females (n=31). The mean diameters of the brachial plexus roots in males (3.914 mm) were significantly thicker than that in females (3.350 mm), ($p = 10^{-10}$). The mean lengths of the brachial plexus nerve roots in males (43.83 mm) were significantly longer than those in females (39.92 mm), ($p = 10^{-5}$)

Age influence on the brachial plexus.

Mean nerve root diameters were compared across three age groups: 20-39 years old (13 subjects, 3.475 mm), 40-59 years old (26 subjects, 3.485 mm), and 60-79 years old (8 subjects, 3.840 mm). The results indicated that the oldest age group had significantly thicker diameters ($p = 0.0052$, One-way ANOVA). For the above three age groups, the mean lengths of brachial plexus nerve roots were 41.09 mm, 41.62 mm, and 40.52 mm, respectively, and there was no statistical significance ($p = 0.6279$).

DISCUSSION

This study is the first in Jordan to assess variation in brachial plexus nerve roots. Data analysis of 94 brachial plexuses showed that 25 plexuses were prefixed plexuses (26%), however, none of the plexuses analyzed was postfixed. Among the 25 plexuses, 14 (56%) were found in females, and 11 (44%) in males. This percentage of prefixed plexuses is in support of data from literature which concluded that brachial plexus variations are not uncommon and when taking into consideration that this percentage of variation is only at the "roots" level [11], this further supports the notion that variations in brachial plexus anatomy may be the rule rather than the exception [12,13]. Gilcrease-Garcia et al. reported variations in the brachial plexus in approximately 50% of the population [12]. Elzawawy reported variations in 90% and 85% of cases in two different studies, respectively [13,14].

The percentage of prefixed and postfixed brachial plexuses varies widely in the literature, and this may be attributed to the fact that studies were conducted in different regions on different ethnicities. For example, Fazan et al. described that out of the 54 brachial plexuses that were examined, 13 were of prefixed origin (24%), and from those 13 plexuses, 2 were in males and 11 were in females. Only 3 of the plexuses were of postfixed origin [15].

On the other hand, another paper studied 32 cadavers and found that only 9.4% of the plexuses were prefixed and only 2 were postfixed [16]. Also, Guday et al. identified that out of 40 brachial plexuses examined, 17.5% were prefixed and 7.5% were postfixed [17]. In a meta-analysis conducted by Benes et al., which included a total of 40 studies and a total of 3,055 upper limbs, the overall prevalence of the prefixed and postfixed brachial plexus were 11% and 1%, respectively, and importantly in less than 0.1% of cases, the brachial plexus received a branch from both C4 and T2. The prevalence of a prefixed plexus is generally higher than that of a postfixed plexus [18].

Concerning the lengths of nerve roots, this study initially examined differences in nerve root lengths across various levels, between the right and left sides, among males and females, and across different age groups. In terms of variations in nerve root lengths at different nerve root levels, this study identified a general trend of decreasing mean nerve root lengths from C5 to T1 (and in prefixed plexuses, from C4 to T1), except for C7, which was shorter than C5 but longer than the rest of the nerves.

The nerve roots of C4 and C5 were the longest, which might be explained by the fact that the origin of these nerve roots is furthest away from their union to form the superior trunk. For C7, the relative increase in its length might be attributed to the fact it is the only nerve that forms the middle trunk, moreover, it can be attributed to the absence of a clear-cut point indicating the origin of the middle trunk, which may have resulted in less accurate measurements of this root's length. This could be a limitation in our study.

Regarding the comparison of nerve root lengths between the right and left sides, this study revealed that the mean lengths of the left-sided brachial plexus nerve roots were significantly longer than those on the right side. This contrasts with the findings of Fetty et al., who reported longer C5, C6, and C8 root lengths on the right side in males when compared to the left, while in females only C8 root was significantly longer on the right side [19]. The differences in our results may be attributed to different factors; one factor is each study involved participants from different ethnic backgrounds. Another factor that might contribute to the differences between our study and Fetty et al. study is the approach by which measurements were performed i.e., MR images in our study and cadaveric assessment in Fetty et al study. For example, measurements on MRI can be affected by the curved tracts of the nerve roots, while the tortuous tracts of the roots of plexuses might have been manipulated during length measurements in cadavers [20].

Gender variation in nerve root lengths showed that the mean lengths of these nerve roots in males were significantly longer than those in females. This may be because males are generally taller, and it might attributed to hormonal differences between the two sexes, as it was shown that androgens have trophic effects on nerves when placed in vitro [21, 22]. Our results were similar to a cadaveric dissection study performed by Fetty et al., which found that roots in males were longer for each of the studied roots (C5-T1) [19]. Regarding different age groups, our study didn’t show any statistically significant difference.

This study assessed the mean diameter of brachial plexus nerve roots and compared measurements between the right and left sides, males and females, and among different age groups. The mean diameters of the left-sided brachial plexus roots were significantly thicker than those on the right. Gender differences in nerve root diameters showed that males’ nerve root diameters were significantly thicker compared to females. This again is likely attributed to the fact that in general, males are larger and have more muscle mass than females. Additionally, a hormonal effect might contribute to this as mentioned earlier in this discussion. A clinical implication of the wider diameters of male roots is that an increased diameter is reflected as a thicker nerve, which may require higher doses of regional anesthesia. This might explain different responses and the adverse effects of regional anesthesia [23-26]. When comparing nerve root diameters in different age groups, our study shows that the older population (60-79 years old) had significantly thicker nerve roots. However, the small sample size in this age group (8 participants) may have influenced this result.

Acknowledging certain limitations in this study is imperative. The ability to generalize the results is constrained by factors such as the small sample size, a limited number of subjects in each age group, and the exclusive inclusion of participants from a single institution. This limitation can be attributed to the time-intensive process of imaging the brachial plexus. Additionally, the absence of a clear-cut cutoff point for the root of C7 may have impacted the accuracy of measurements for this nerve root.

CONCLUSIONS

This study revealed that variation in the anatomy of brachial plexus nerve roots is not uncommon in the Jordanian population, particularly the prefixed type. Although literature data is limited, variations in BP are of significant clinical consideration when performing anesthesia or surgical procedures related to the brachial plexus. Future studies with a larger sample size are recommended to investigate the measurements and variations of the brachial plexus using advanced MRI sequences such as '3D Nerve View'. Furthermore, a study comparing the prevalence of variations in brachial plexus nerve roots in Jordan with other populations can be considered in the future.

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دراسة مقطعية للتغير التشريحي في أصل جذور الأعصاب في الحزمة العصبية العضديّة في الأردن: التغيرات المسبقة والمرحّلة

أسامة سمارة[1]، فراس الخطيب[2]، ربى بريك[1]، طارق السيوري[2]، عبد الله القواسمة[2]، أسامة عفانة[2]، نسيبة الريالات[1]، درويش بدران[3]، أمجد شطرات[4]

[1] قسم الأشعة التشخيصية، كلية الطب، الجامعة الأردنية، عمان، 11942، الأردن

[2] كلية الطب، الجامعة الأردنية، عمان، 11942، الأردن

[3] جامعة ابن سينا للعلوم الطبية، عمان، 16197، الأردن

[4] جامعة العلوم الطبية في العقبة، العقبة، 77110، الأردن

Received: December 2, 2023

Accepted: March 14, 2024

DOI: https://doi.org/10.35516/jmj.v59i1.2033

الملخص

الخلفية والأهداف: توجد تغيرات تشريحية في أصل الضفيرة العصبية العضديّة والجذور العصبية التي تسهم في تكوينها. بناءً على استعراض الأدبيات، تبدو هذه التغيرات شائعة وقد تكون حتى القاعدة بدلاً من الاستثناء. ومع ذلك، تفتقر البيانات المتعلقة بهذه التغيرات في السكان الأردنيين، وتقييم مثل هذه التغيرات مهم في التقييم السريري والإجراءات الجراحية، على سبيل المثال، قد تزيد مثل هذه التغيرات من احتمالية حدوث مرض معين، مثل متلازمة مخرج الصدر ، ويمكن أن تؤثر على الاستراتيجيات الجراحية المستخدمة للضفيرة العصبية العضديّة. يهدف هذا البحث إلى استكشاف تشريح وتغيرات أصل الضفيرة العصبية العضديّة في الأفراد الأردنيين الأصحاء باستخدام التصوير بالرنين المغناطيسي، خاصة الأشكال المسبقة prefixed والمُرحَّلة postfixed.

منهجية الدراسة: هذه الدراسة مقطعية. تم اختيار عشوائي لـ 50 فردًا يخضعون لتصوير العمود الفقري الرقبي بالرنين المغناطيسي، حيث تم إجراء تسلسل NerveVIEW ثلاثي الأبعاد لجذور الأعصاب في الضفيرة العصبية العضديّة في كل من الأوضاع المحوري والإكليلي. تم تحديد مستويات الجذور العصبية التي تسهم في تكوين الحزمة العصبية العضديّة على كل جانب لكل فرد، وتم التعرف على التغيرات المسبقة/المرحّلة. تم تحديد قياسات أخرى، مثل قطر وطول جذور الأعصاب، وتمت مقارنة هذه القياسات بين الذكور والإناث في السكان المدروسين.

النتائج: من بين الحزم العصبية العضديّة التي تم تحليلها والبالغ عددها 94، كانت 25 مسبقة (26.6%) ولم تكن هناك أي مرحّلة. تم التعرف على هذه الحزم المسبقة في 15 فردًا؛ 10 منهم كانت لديهم الشكل المسبق على الجانبين (66.7% من جميع الحزم المسبقة)، وكانت 4 حزم على الجانب الأيسر (26.7%) وكانت حزمة واحدة فقط على الجانب الأيمن (6.7%). أظهر تحليل البيانات للأطوال والأقطار لجميع جذور الأعصاب التي تسهم في تكوين الحزم العصبية العضديّة في جميع الأفراد (عددهم 94) أن قطر وطول الجذور اليسرى كانا أكبر بشكل ملحوظ من نظرائهم في الجهة اليمنى. بالإضافة إلى ذلك، كانت جذور الأعصاب التي تسهم في تكوين الحزم العصبية العضديّة أطول وأوسع في الذكور من تلك في الإناث.

الاستنتاجات: توصلت هذه الدراسة إلى أن التغير التشريحي لجذور الأعصاب التي تسهم في تكوين الحزمة العصبية العضديّة شائع بين السكان الأردنيين، خاصة الشكل المسبق.

الكلمات الدالة: الحزمة العصبية العضديّة، مسبقة، مرحّلة، NerveVIEW ثلاثي الأبعاد، علم الأعصاب، الأعصاب الشوكية.