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Computed Tomography Angiography in Thoracic Outlet Syndrome

Torasik Çıkış Sendromunda Bilgisayarlı Tomografi Anjiyografi

Atakan Küskün[1], Çetin Atasoy[2], Cemil Yağcı[3]

[1]Kırklareli University Faculty of Medicine, Department of Radiology, Kırklareli, Türkiye
[2]Koç University Faculty of Medicine, Department of Radiology, İstanbul, Türkiye
[3]Ankara University Faculty of Medicine, Department of Radiology, Ankara, Türkiye

Abstract

Objectives: To evaluate the effectiveness of computed tomography (CT) angiography (CTA) in demonstrating subclavian artery stenosis and explaining symptoms in thoracic outlet syndrome (TOS). To investigate possible compression points of the neurovascular bundle along the cervicoaxillary canal and their changes with postural maneuver.

Materials and Methods: The study group consisted of 50 patients referred from the physical therapy and rehabilitation clinic with TOS symptoms, while the control group consisted of 20 patients without symptoms of TOS who required contrast-enhanced thorax CT for other reasons. The thoracic outlet of the patients were scanned with a multidetector helical CT scanner during the postural maneuver and in the neutral position after the intravenous contrast medium was administered. The control group was scanned under the same conditions only during the postural maneuver. Axial, sagittal reformatted and volume rendering images were evaluated for bony anomalies, subclavian artery stenosis, costoclavicular distance and anterior scalene muscle thickness.

Results: Six patients had cervical rib and eleven patients had hypertrophy of the C7 transverse process. Significant subclavian artery compression was found in 32 of the 100 shoulders in the study group during the postural maneuver, while no significant artery compression was recorded in the control group. The mean minimum costoclavicular distance after postural maneuver was significantly lower and anterior scalene muscle thickness was significantly higher in the patient group.

Conclusion: CTA is a minimally invasive method that can guide the surgical planning, especially in patients with vascular TOS, as it objectively shows the arterial stenosis, its location and, possibly the cause of the compression.

Keywords: Computed tomography angiography, thoracic outlet syndrome, subclavian artery, brachial plexus, cervical rib

Öz

Amaç: Bilgisayarlı tomografi (BT) anjiyografinin (BTA) torasik outlet sendromunda (TOS) subklavyan arter stenozunu göstermede ve semptomları açıklamadaki etkinliği değerlendirildi. Subklavyan arter ve ven ile brakiyal pleksustan oluşan nörovasküler demetin servikoaksiller tünel boyunca basıya uğrayabileceği muhtemel noktalar ve bunların postüral manevra ile değişimleri araştırıldı.

Gereç ve Yöntem: Çalışma grubunu, fizik tedavi ve rehabilitasyon kliniğinden refere edilen, kliniği TOS'u düşündüren 50 hasta oluştururken kontrol grubunu başka nedenlerle kontrastlı toraks BT çektirmesi gereken, TOS semptomları göstermeyen 20 hasta oluşturmuştur. Hastaların süperiorda C6-C7 intervertebral diskinden inferiorda aortik arkusa kadar uzanan toraks çıkımı bölgesi, çok kesitli BT cihazında, intravenöz opak madde verilmesini takiben, önce postüral manevra hemen sonrasında nötr pozisyonda tarandı. Kontrol grubuna da aynı şartlar altında yalnızca postüral manevra

Address for Correspondence/Yazışma Adresi: Atakan Küskün
Kırklareli University Faculty of Medicine, Department of Radiology, Kırklareli, Türkiye
Phone: +90 533 435 19 94 **E-mail:** atakankuskun@klu.edu.tr **ORCID ID:** orcid.org/0000-0001-6559-5322

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sırasında çekim yapıldı. Aksiyel, sagital reformat ve üç boyutlu "volume rendering" görüntüleri kemik anomalileri ve arter stenozu açısından değerlendirildi. Minimum kostaklaviküler mesafe ve anterior skalen kas kalınlığı ölçümleri yapıldı.

Bulgular: Altı hastada servikal kosta, on bir hastada C7 transvers proses hipertrofisi saptandı. Değerlendirilen 100 omuzdan 32'sinde postüral manevra sonrası anlamlı derecede subklavyan arter basısı bulunurken kontrol grubundaki hiçbir omuzda anlamlı düzeye ulaşan arter basısı kaydedilmedi. Hasta grubunda postüral manevra sonrası ortalama minimum kostaklaviküler mesafe daha düşük iken anterior skalen kas kalınlığının daha yüksek olduğu saptandı.

Sonuç: BTA'nın TOS'unda arteriyel stenozu, yerini ve eşlik eden kemik anomalilerini olduğu kadar TOS'un dinamik patofizyolojisini göstermede başarılı olduğu anlaşılmaktadır.

Anahtar Kelimeler: Bilgisayarlı tomografi anjiyografi, torasik çıkış sendromu, subklaviyan arter, brakiyal pleksus, servikal kot

Introduction

Thoracic outlet syndrome (TOS) is a dynamic neurovascular compression syndrome seen especially with arm raising and is caused by compression of the subclavian vessels and brachial plexus in the cervicoaxillary tunnel (1-3). Acquired or congenital anomalies of the bony and soft tissue structures that form the borders of the three anatomical regions composing the thoracic outlet may cause TOS. Some of the bone anomalies that can be seen in the cervicothoracic region include accessory cervical rib, bifurcation of the 1st rib, fusion of the 1st and 2nd ribs, and hypertrophy of the C7 transverse process. Soft tissue changes that can cause TOS include congenital fibrous bands and ligaments, congenital or acquired muscle changes (hypertrophy, fibrosis, etc.) and posttraumatic soft tissue changes (3,4). These soft tissue and bone abnormalities, and some commonly used physical examination maneuvers, such as the Adson test, costoclavicular (CC) test, abduction-external rotation test, and hyperabduction test, further narrow the interscalene triangle, CC distance, or subcoracoid tunnel, subsequently causing or contributing to the symptoms of TOS (4). The clinic of TOS varies according to whether the compressed structure is a vessel or a nerve. Vascular and neurogenic compression result in symptoms of TOS in 5-15% and 85-95% of cases, respectively (4-7). Vascular TOS develops with compression of the subclavian vein or artery. If the subclavian vein is compressed, edema and venous distension are observed in the affected extremity. In advanced stages, thrombosis of the axillary and subclavian veins may develop, which is called Paget-Schroetter syndrome (6,8). In the presence of subclavian artery compression, the affected extremity has a decreased pulse and claudication. As with vein compression, thrombosis and/or poststenotic aneurysmatic enlargement may be observed in the advanced stage. In TOS of neural origin, findings differ according to whether the sympathetic system is compressed or not. If the sympathetic system is not affected, pain, paresthesia and motor weakness are noted in the ipsilateral extremity. If the sympathetic nerves are compressed, Raynaud's phenomenon is observed. Sometimes the subclavian artery is compressed along with the sympathetic nerves, in which case pain, color and temperature changes, ischemia and trophic changes may be observed in the affected extremity (8).

Considering the difficulties in the diagnosis of TOS (9). the need for an objective diagnostic method that can reveal the location, severity and cause of the pathology is obvious. Nerve conduction tests are the most effective method when neural compression is involved. Doppler ultrasonography is the most commonly used radiological method in TOS of vascular origin. While Doppler ultrasonography can reliably demonstrate the presence of arterial compression, the site of compression may be obscured by bony structures. It is not possible to reveal the structure or structures causing compression with Doppler ultrasonography (4). The use of magnetic resonance (MR) imaging (MRI) has gained acceptance in the last decade in both neural and vascular TOS, especially for the soft tissue structures that might be causing compression. MR neurography and diffusion tensor imaging techniques, with the availability of high resolution 3.0 Tesla magnetic field strength MRI devices, can depict brachial plexus compression and neuropathy due to the TOS (8). Digital subtraction angiography (DSA), which can be considered as the gold standard in the diagnosis of vascular TOS, is an invasive method and has not been widely accepted among clinicians (3).

Studies have reported that computed tomography angiography (CTA) can show arterial and venous compression (3,5). CTA is superior to DSA because it is less invasive and superior to Doppler ultrasonography because it can reveal the site and the probable cause of compression. However, CT has some limitations in the evaluation of TOS. Fibromuscular bands cannot be shown with CT because they are thin and their X-ray attenuation is not much different from muscles and other cervical soft tissues (3,4). Although individual nerve roots can be distinguished by CT at the exit of the neural foramen, the brachial plexus is not visualized and evaluated well enough and its location can only be determined when normal anatomy is known (10).

In our study, we planned to perform CTA to a group of patients with TOS symptomatology in two postures. We tried to show the effect of postural maneuver on the cervicoaxillary tunnel and possible arterial compression site. Our aim is to find possible relations between TOS symptoms and bony anomalies, CC distance, arterial compression and anterior scalene muscle (ASM) thickness with CTA.

Materials and Methods

Selection and Description of the Cases

The study group included 50 patients who were admitted to the physical therapy and rehabilitation outpatient clinic of Ankara University İbni Sina Research and Practice Hospital in 2002-2003 and were diagnosed with TOS based on complaints, symptoms and physical examination findings. Conventional radiographic examinations of these patients were completed before CTA. There were nine male and 41 female patients. The mean age was 42.7 years, the youngest being 18 and the oldest 70 years.

The control group consisted of 20 patients who were admitted to the Department of Radiology, Ankara University İbni Sina Research and Application Hospital for contrast-enhanced thorax CT examination for another reason unrelated to TOS and who did not show symptoms and signs of TOS. Patients with bone anomalies or soft tissue patologies in the cervicothoracic region were not included in the control group.

Informed consents of all the participants in the study and control groups were obtained.

Technical Information

CTA examinations were performed with an 8-detector multislice helical device (Light Speed Ultra, General Electric, Wisconsin, USA). In all patients, 18-22s after intravenous administration of 75cc of nonionic iodinated contrast medium (370 mg/mL) at a rate of 3.5 cc/s, the region extending from the level of the C6-C7 intervertebral disc superiorly to the arch of aorta inferiorly was scanned with a slice thickness of 1.25 mm and a slice spacing of 0.7 mm. Other parameters were 140 kV and 150 mAs. The examination was performed both in the neutral position and during a postural maneuver involving hyperabduction (≥130°) and external rotation of the arms and extension of the neck. In both positions, the patient was in deep inspiration.

In the control group, CTA examinations were performed only during the postural maneuver with the same parameters as in the patient group, encompassing the whole thorax from the level of the C6-C7 intervertebral disc.

Axial raw data were reconstructed separately for each shoulder using appropriate centering and FOV of 17-21 cm. These reconstructions were used to create sagittal reformats and three-dimensional volume rendering images for the evaluation of bony structures, subclavian artery stenosis, CC distance and ASM thickness. Bony structures were examined for the presence of accessory cervical rib and apophyseal hypertrophy of the C7 vertebra. The diameter of the subclavian artery was evaluated on sagittal reformat and volume rendering images, and a decrease of more than 50% in the diameter of the artery was considered significant for stenosis. The CC distance was measured between the lower edge of the clavicle and the upper edge of the first rib (the upper edge of the accessory cervical rib was used in two patients) in both neutral position and during postural maneuver. The cross-sectional area of the ASM was measured at the level where the subclavian artery leaves the thoracic outlet between the anterior and middle scalene muscles in the both neutral and postural maneuver axial images.

Statistical Analysis

The symptomatic shoulders of the patient group were compared with the control group in terms of minimum CC distance and ASM thickness during postural maneuver. The t-test was used for statistical evaluation. In the patient group, shoulders with and without significant vascular compression during postural maneuver were compared in terms of CC distance and ASM measurements both in neutral position and during postural maneuver. Mann-Whitney U test was used for statistical evaluation. CC distance measurements during postural maneuver and in neutral position were compared in the patient group. Paired samples t-test was used for statistical analysis. Patients with and without bone anomalies were compared for significant subclavian artery stenosis. “Fisher’s exact” test was used for statistical evaluation.

Results

Of the 100 shoulders (50 patients) evaluated in the patient group, 72 were symptomatic (bilateral in 25 patients, on the left in 12 patients and on the right in ten patients). Significant subclavian artery stenosis was detected in 32 of the 100 shoulders (bilateral in ten and unilateral in 12) after postural maneuver, 23 of which were in the symptomatic shoulders. No significant arterial stenosis was found in the patient group in the neutral position. Also, there was no significant arterial stenosis in the control group.

Accessory cervical rib was present in six patients (bilateral in five patients, one on the left) (Figure 1). All patients with accessory cervical rib were symptomatic, but three of the bilateral cervical rib patients were symptomatic only in one shoulder. Apophyseal hypertrophy of the transverse processes of the C7 vertebrae was noted unilaterally in five patients (two on the right and three on the left) and bilaterally in six patients (Figure 2). Ten of the 11 patients and 11 of the 17 shoulders with the apophyseal hypertrophy were symptomatic. One patient had fusion of the 1st and 2nd ribs on the right. None of the patients in the control group had bony abnormality.

The mean minimum CC distance during postural maneuver in the control group was 14.48 mm, while the same value was 14.70 mm in the symptomatic, 14.40 mm in the non-symptomatic shoulders of the patient group. There was no statistically significant difference between the control group and the symptomatic patients (p=0.842) (Table 1).

The mean ASM cross-sectional area (thickness) during the postural maneuver was 83.91 mm^2 in the control group and 83.26 mm^2 in the symptomatic and 86.11 mm^2 in the non-symptomatic shoulders of the patient group. There was no statistically significant difference between the control group and the symptomatic patients (p=0.921) (Table 1).

In patients with arterial stenosis (Figure 3), the mean minimum CC distance values were 25.47 mm and 10.52 mm in the neutral position and during the postural maneuver, respectively. In patients without significant arterial stenosis (Figure 4), these values were 27.04 mm and 16.52 mm, respectively. There was a statistically significant difference between the mean CC distance values during the postural maneuver between patients with and without arterial stenosis, but no difference was found between the values in the neutral position ($p_{postural}$=0.0001 and $p_{neutral}$=0.074) (Table 2).

The mean ASM thickness in patients with arterial stenosis was 79.69 mm^2 and 89.63 mm^2 in the neutral position and during the postural maneuver, respectively. These values were 78.66 mm^2 and 85.68 mm^2 in patients without significant stenosis, respectively. There was no statistically significant difference in

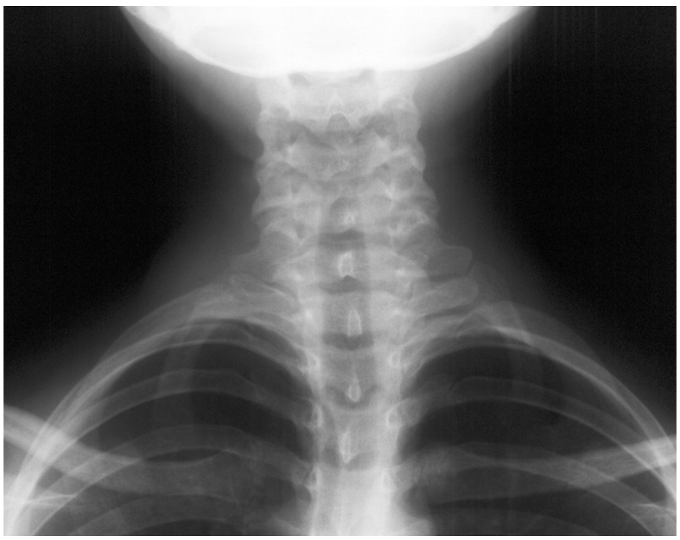

Figure 1: AP radiograph shows bilateral cervical ribs

Table 1: Comparison of control group and symptomatic shoulders of patient group in terms of CC distance and ASM thickness in the postural maneuver		
	CC distance postural maneuver	**ASM thickness postural maneuver**
Control	14.48 mm	83.91 mm^2
Symptomatic shoulders	14.70 mm	83.26 mm^2
P-value	0.842	0.921
CC: Costoclavicular, ASM: Anterior scalene muscle		

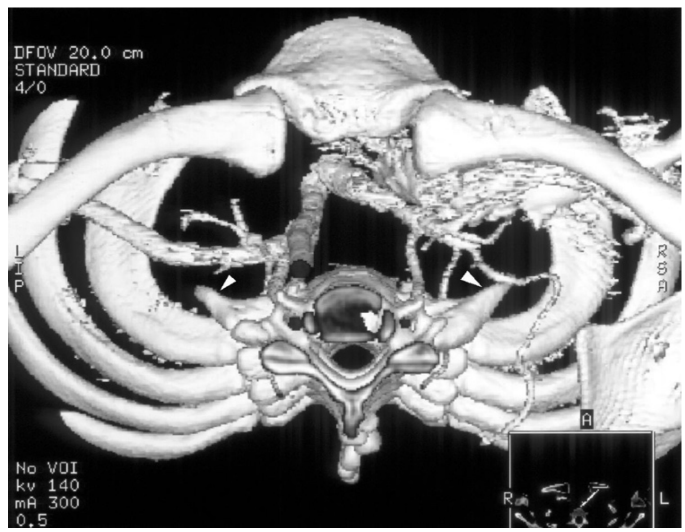

Figure 2: 3D surface shaded display (SSD) shows bilateral C7 apophyseal hypertrophy

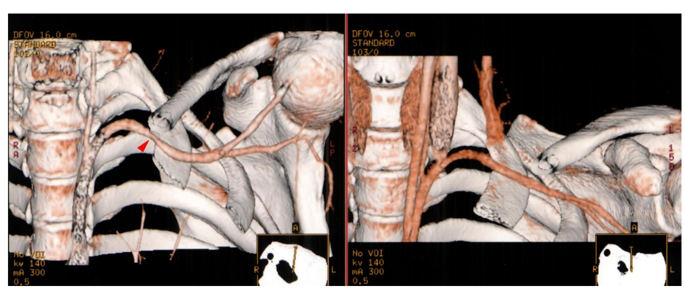

Figure 3: Volume rendering images show subclavian artery compression and stenosis with hyperabduction maneuver on the left while normal on the right with neutral position

Table 2: Comparison of patients with and without arterial stenosis in terms of CC distance and ASM thickness both in the neutral position and postural maneuver				
	CC distance neutral position	**CC distance postural**	**ASM thickness neutral position**	**ASM thickness postural**
Patients with arterial stenosis	25.47 mm	10.52 mm	79.69 mm^2	89.63 mm^2
Patients without arterial stenosis	27.04 mm	16.52 mm	78.66 mm^2	85.68 mm^2
P-value	0.074	0.0001	0.668	0.462
CC: Costoclavicular, ASM: Anterior scalene muscle				

ASM thickness between these groups. The mean minimum CC distance in the patients with arterial stenosis was significantly lower (10.52 mm) during the postural maneuver than that in the neutral position (16.52 mm) (p=0.0001) (Table 2).

The mean minimum CC distance in the patient group was significantly lower during the postural maneuver (14.60 mm) than that in the neutral position (26.54 mm) (p=0.0001). The mean ASM thickness in the patient group was significantly lower in the neutral position (78.99 mm^2) than that during the postural maneuver (84.06 mm^2) (p=0.003) (Table 3).

Patients with bone anomalies had a higher rate of arterial stenosis compared to normal patients. While arterial stenosis was found in 21.1% of patients with normal bone structure, 58.6% of patients with bone anomalies had arterial stenosis (p=0.001) (Table 4).

Discussion

In our study, there were bony anomalies in 18 of 50 cases in the patient group (36%). There were cervical rib in six patients (12%) and hypertrophy of C7 apophysis in 11 patients (22%). Our rate of cervical rib in the patient group is low compared to Henry et al. (11), who gives 29.5% cervical rib rate in the TOS patients in their meta-analysis. But some authors as Demondion et al. (3) found a lower prevalence of cervical rib (5-9%) in the TOS patients. So our results are in the range of the literature. As expected, we found that patients with bone anomalies had almost three times higher rate of arterial compression compared to patients with normal bone structure. Arterial TOS is known to be the most prevalent type in patients with bone anomalies (12), and our findings are consistent with the literature and reiterates that bone anomalies play an important role in the compression mechanism.

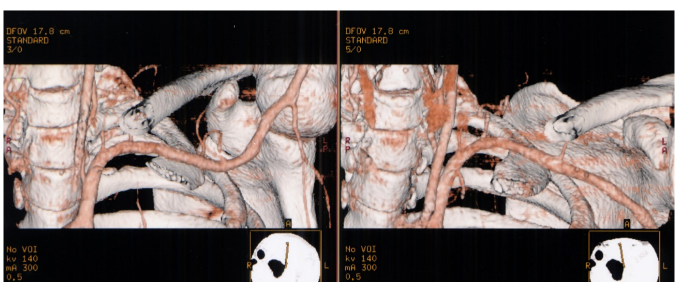

Figure 4: Volume rendering images show normal subclavian artery in neutral position on the right and with hyperabduction maneuver on the left in the control group

Table 3: Comparison of patients in the neutral position and postural maneuver in terms of CC distance and ASM thickness		
	CC distance	ASM thickness
Patients in neutral position	26.54 mm	78.99 mm^2
Patients with postural maneuver	14.60 mm	84.06 mm^2
P-value	0.0001	0.003
CC: Costoclavicular, ASM: Anterior scalene muscle		

Table 4: Distribution of the patients with arterial stenosis and bone anomaly			
	No arterial stenosis	Arterial stenosis	Total
Normal bone structure	56 (78.9%)	15 (21.1%)	71 (71%)
With bone anomaly	12 (41.4%)	17 (58.6%)	29 (29%)
Total	68 (68%)	32 (32%)	100 (100%)

Several studies investigated the functional anatomy of the thoracic outlet and showed significant narrowing of the CC space after postural maneuver (2,10,13). In our study, we found that the mean minimum CC distance decreased significantly with hyperabduction maneuver in the patient group. Although the aforementioned studies and our study seem to be compatible, two differences between them should be taken into consideration. Matsumura et al. (13) and Remy-Jardin et al. (14) used a postural maneuver in which only the arm on the examined side was in hyperabduction, the other arm was in neutral position and the head was in extension facing the examined side. This posture is not fundamentally different from the postural maneuver we used, considering the shoulder being examined, but it should be kept in mind that rotation of the head to the examined side may cause a difference in the CC distance. In addition, unlike our study, these studies included normal subjects to examine the normal dynamic anatomy of the thoracic outlet. On the other hand, Demondion et al. (10) used MRI in their study instead of CT, and they have found CC narrowing in the patient group like us which exceeded the one in the control group. We have found significant narrowing in the patient group with postural maneuver but contrary to the study of Demondion et al. (10) there was no significant difference between the symptomatic shoulders of the patient group and the control group in terms of average minimum CC distances.

As expected, the average minimum CC distance measured after postural maneuver was lower in patients with vascular stenosis than in patients without stenosis. The CC space, which is one of the three possible compression points in the cervicoaxillary canal, narrows with hyperabduction maneuver and compresses the neurovascular bundle as we showed in our study. However, we have found no significant difference between the CC distance measurements of patients with and without compression in the neutral position. In other words, patients with vascular stenosis have a normal CC distance at rest, which however narrows more than normal and causes compression of the subclavian artery when the arm is hyperabducted with provocative tests or with some daily activities. This finding emphasizes the dynamic aspect of TOS.

Demondion et al. (10) measured anteroposterior diameter in sagittal images for ASM thickness in their study on the functional anatomy of the thoracic outlet with MRI. They have found increased muscle thickness in the TOS patients compared to normal subjects in both neutral and postural maneuvers. Although their measurements during hyperabduction were slightly higher compared to the neutral position, they found no significant increase in muscle thickness with the hyperabduction maneuver (10). In our study, we used cross-sectional area measurement on axial images to represent the thickness of the ASM. As far as we know, there is no study in the literature using cross-sectional area measurement of ASM thickness on CT for this purpose. We have found that the ASM was significantly thicker during hyperabduction compared to the neutral position. And this finding confirms that area measurement may be more sensitive than diameter measurement and shows the role of the ASM in the mechanism of TOS. The ASM thickens during hyperabduction and contributes to the compression of the neurovascular bundle.

Only 5-15% of TOS cases are of vascular origin (4-7), and not all vascular TOS cases are arterial in nature. In this study, 32 of 100 shoulders evaluated had significant subclavian artery stenosis. Of these, eight arteries in seven patients had complete occlusion. All of the patients with occlusion had symptoms in the affected side, while the patient with bilateral occlusion only had symptoms on one side. Although bilateral complete occlusion was detected in one patient, the complaint was only on the right side. If we accepted the patients with complete occlusion as arterial TOS, our arterial TOS rate was 14%. This value is still somewhat higher than the literature, and may be due to subject allocation of our study. But cases defined as vascular/arterial TOS in the literature are those with pure vascular symptoms, whereas we cannot say that there was no neural component in our 7 patients with complete occlusion because we haven't done any electrophysiological evaluation via nerve conduction and EMG in this study. And we haven't discriminated our patients into subtypes of TOS according to symptoms.

In 24 patients with significant stenosis but not complete occlusion, we did not find a relationship between symptoms and arterial stenosis. We hypothesized that a significant arterial compression or compression of the other neurovascular bundle elements (as brachial plexus and subclavian vein) due to close location to the compressed artery would cause symptoms of TOS. However, the results do not support this hypothesis. A source of error may be the inclusion of patients with clinical symptoms suggestive of TOS instead of patients with a diagnosis of TOS. This decision can be criticized, but other studies in the literature have generally been conducted in a similar manner. Demondion et al. (10) and Remy-Jardin et al. (14) used patients who were not diagnosed with TOS but whose clinical findings suggested TOS.

Matsumura et al. (13) found a diameter reduction in the subclavian artery ranging from 6-33% during postural maneuver in normal individuals. As Gillet et al. (5) reported, 30-50% cutoff points were used in the literature for subclavian artery stenosis. We have accepted 50% or more reduction in the diameter of the subclavian artery as significant stenosis, and as expected there were no arterial stenosis cases in the control group due to postural maneuver.

Study Limitations

There are some limitations of our study. First of all, referred patients in the study had clinical symptoms of TOS, there was no definite TOS diagnosis. This may have explain why we couldn't have reached significant relationship between symptomatic and stenosis patients. Also if patients had been subgrouped in the outpatient clinic according to symptoms as arterial, venous and neurogenic TOS we may have found more meaningful results.

Conclusion

Mean minimum CC distance at hyperabduction was significantly lower in patients with subclavian artery stenosis than in those without arterial stenosis. In addition, decrease in CC distance with hyperabduction was significantly higher in patients with vascular compression compared to patients without compression. Therefore, although CC spaces of patients with subclavian artery stenosis may be normal in the neutral position, they narrow with hyperabduction, confirming the dynamic nature of TOS. Our study showed that ASM thickens with the postural maneuver, thanks to the cross-sectional area measurement, and contributes to the compression of the neurovascular bundle. Subclavian artery compression was more common in patients with bone abnormalities compared to those with normal bony structure. CTA is a minimally invasive method that can guide the surgical planning, especially in patients with vascular TOS, as it objectively shows the arterial stenosis, its location and, possibly the cause of the compression.

Ethics

Ethics Committee Approval: Institutional review board or ethics committe aproval was not required for non-interventional research during the study period 2002-2003.

Informed Consent: Written informed consents were obtained from every participant.

Authorship Contributions

Surgical and Medical Practices: A.K., Concept: A.K., Ç.A., C.Y., Design: A.K., Ç.A., C.Y., Data Collection and/or Processing: A.K., Analysis and/or Interpretation: A.K., Ç.A., C.Y., Literature Search: A.K., Ç.A., Writing: A.K.

Conflict of Interest: According to the authors, there are no conflicts of interest related to this study.

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