Thoracic outlet syndrome is relatively frequent and often overlooked (5-10% of patients with upper extremity pain). Diagnosis is difficult and requires direct correlation between a clinically confirmed compression syndrome and an anatomical cause for narrowing of the thoracic outlet, a naturally narrow and non-stretchable conduit that is widely variable in the general population. In other words, morphological and anatomical abnormalities observed at clinical evaluation and complementary work-up are only relevant when symptomatic. Multiple maneuvers have been described in the literature: Adson, Wright or Eden maneuvers, Roos test or Tinel sign. These are non-specific and not sufficient by themselves for diagnosis. Each clinical maneuver has an average sensitivity of 72% and specificity of 53%, but the combination of two maneuvers (Adson and Wright maneuvers for example) improves sensitivity (79%) and specificity (76%). As a result, indications for surgical management are difficult to confirm, and dedicated work-up with reliable complementary techniques is needed. The purpose of this paper
is to review the imaging work-up of thoracic outlet syndrome and demonstrate the value of evaluation in the sitting position, corresponding to the typical symptomatic position, at the time of conventional angiography.

Materials and methods

Patient population

Retrospective study of 81 surgical interventions performed in 56 patients with thoracic outlet syndrome between 1997 and 2005. The patient population included 45 females and 11 males (sex-ratio of 4.5), aged 17-57 years (mean age of 37.7 years). Twenty-six patients underwent bilateral surgery, in two settings for 25 patients and in a single setting for 1 patient. Inclusion criteria were the presence of vascular or neurological symptoms or signs of thoracic outlet syndrome. Surgery was indicated for patients with persistent disabling symptoms in spite of optimal conservative management (NSAIDS, physical therapy, and local injections for a few patients). All patients underwent surgery using the transaxillary first rib resection procedure described by Ross, including transection of the subclavian, anterior and middle scalene and clavicular fracture (2 patients) and brachial plexus stretch injury (1 patient).

Clinical features

Symptoms were most frequently mixed (with neurological component) in 41 patients (73.2%), arterial only in 8 patients (14.3%), and venous only in 6 patients (10.7%). Pain was generally the main symptom, considered severe when refractory to pain medication, daily or permanent, or nocturnal and causing insomnia. Pain was considered important when it evolved by recurring flare-ups and, while non-disabling, interfered with daily activities. Arterial symptoms were characterized by stress related ischemia (pain, cramps, upper extremity fatigue during daily activities). One patient presented with acute upper extremity ischemia requiring bypass surgery. Neurological symptoms included paresthesia, dysesthesia and hypesthesia, typically C7 and C8 in distribution, often worsened by positional maneuvers. Numbness was described by patients as a dead hand sensation with clumsiness. Weakness, mainly involving the interosseous and hypothenar muscles, and rarely the biceps or triceps muscles, could cause patients to drop objects. Patients with venous symptoms complained of edema. Two patients presented with upper extremity venous thrombosis. Symptoms were right sided in 19 patients (34%), left sided in 19 patients (34%) and bilateral in 18 patients (32%). Contralateral occurrence of symptoms following surgery was recorded in 9 patients (16%) over a 6 month to 5 year period. Symptom duration ranged from 1 month to 10 years (median of 18 months), with diagnosis often delayed.

In a number of patients, alternate diagnoses had been considered, including carpal tunnel syndrome (6 patients, 11%), ulnar nerve compression (4 patients, 7%), cervicobrachial neuralgia from cervical disk herniation (2 patients), tendinitis, and arterial dissection (1 patient). Symptoms occurred following trauma in 3 patients, including clavicular fracture (2 patients) and brachial plexus stretch injury (1 patient).

Imaging work-up

Thoracic spine radiographs were obtained in all patients to detect the presence of accessory ribs (6 patients, 11%), apophysemegaly (1 patient), or first rib synostosis (1 patient). EMG was obtained in 22 patients with neurological deficits. This showed C7 or C8 radicular abnormality in 73% of cases. Several examinations were performed in patients with vascular symptoms. Venography was performed in patients with venous symptoms (15 patients, 27%). Bilateral injections were performed, with arms extended along the body (series 1), then with the arms elevated (series 2). Doppler US was performed in 7 patients (12%), positive in 5 patients (71%). Most patients underwent angiography (48 patients, 86%). Forty-six angiograms were performed in 56 patients with thoracic outlet syndrome and demonstrate the value of evaluation in the sitting position, corresponding to the typical symptomatic position, at the time of conventional angiography.

Results

Angiographic results are summarized in table I. In 9 patients (19%), the first angiographic series was negative and the second series was negative; in 39 patients (81%), the first series was negative and the second series was positive. Thirty three (69%) of 48 patients underwent a third angiographic series in the sitting position. This third series was not necessary for diagnosis in 15 cases (35% with stage 2+ or 3 on the first 2 series). Also, 2 patients underwent angiographic evaluation at outside facilities where evaluation in the sitting position was not performed. In the 33 patients who underwent all 3 angiographic series, none had 3 negative series. Only the third series was positive for 8 patients (24%). No patient showed stable stenoses on all three series. Worsening was demonstrated in 30 patients (91%) between series 2 and 3, including 87% of
very significant stenoses (demonstration of stage 2+ or 3). No angiogram related complication was recorded.

Venography was performed in 13 patients. Five patients underwent a single positive series, and 8 patients underwent 2 series. In 6 patients (75%), the first series was negative and the second series was positive. Stenoses were stable on both series in two patients. Worsening was demonstrated between series 1 and 2 in 75% of patients, with very significant stenoses in 33% (demonstration of stage 2+ and 3).

**Discussion**

Angiography, similar to Doppler US, venography, CT and MRI does not reproduce the conditions under which symptoms occur (1) and dynamic evaluation is necessary in patients with thoracic outlet syndrome, where compression of the brachial plexus is much more frequent than compression of the subclavian artery (2% of cases) (2).

The thoracic outlet is a narrow conduit and traversing neurovascular structures may easily be compressed by physiologic or non-physiologic changes in its size, such as during shoulder, cervical spine and rib cage movements. The interscalene triangle is involved in 49% of cases. It is bound anteriorly by the anterior scalene muscle that may compress the artery during contraction, inferiorly by the upper margin of the first rib, especially in patients with anatomical variants, and posteriorly by the middle and posterior scalene muscles. The subclavian artery and brachial plexus traverse this triangle. The subclavian vein courses in the prescalene space. In 18% of patients, compression occurs at the costoclavicular space, bound superiorly by the clavicle, anteriorly by the subclavius muscle, and posteriorly by the first and second ribs, especially in hyperabduction (3). The subclavian vein is ventral to the artery; the brachial plexus is more posterior. Finally, the subcoracoid tunnel or retropectoralis minor space is located dorsal to the pectoralis minor muscle, ventral to the subscapularis muscle, and under the coracoid process. Anatomical variants may be congenital (0.012-1% of the general population): complete or partial absence of regression of lower cervical ribs, hypertrophy of the C7 transverse processes, absence of the first rib, congenital bands and ligaments or acquired: impaired spine posture, first rib fracture or hypertrophic clavicle callus formation. Thin patients with drooping clavicles may be predisposed (4, 5).

We noted a female predominance for the arterial and neurological types, both in our

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<td>Series 1 (n=48)</td>
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<td>Supine</td>
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<td>Supine, arms up</td>
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<td>Series 3 (n=33)</td>
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Fig. 1: Upper extremity angiogram with injection of iodinated contrast material, frontal projection.

a Series 1, supine: no visible stenosis (stage 0).
b Series 2, supine, arms up: no visible stenosis (stage 0).
c Series 3, sitting, arms up, right side: stenosis >80% (stage 2+).
d Series 3, sitting, arms up, left side: complete occlusion (stage 3).
patients (45 females and 11 males) and in the literature (6). This may be explained by the more vertical orientation of the first rib in females and a more thoracic type of respiration compounded by the estrogen and progesterone impregnation causing muscular and ligamentous laxity (7). Age also plays a role, as shown in our series (mean age of 37.4 years for females and 42.5 years for male), and reports from the literature (7). This may be explained by several morphological changes of the rib cage (8, 9), narrowing of the costoclavicular space (10) and progressive drooping of the clavicles.

Most reports (7) indicate the more frequent right sided involvement as well as the presence of bilateral symptoms in 10-60% of cases. In our series, involvement was bilateral in 18 patients (32%), left sided in 19 patients (34%) and right sided in 19 patients (34%).

In the management of thoracic outlet symptoms, complementary examinations may be performed, but none provides diagnostic certainty. These examinations are mainly helpful for differential diagnosis. A frontal radiograph of the thoracic spine should always be obtained (11) to detect bone abnormalities (present in eight patients or 14% of our patients), especially cervical ribs. EMG may confirm the distribution of nerve involvement (12), frequently C7 or C8, the severity of involvement, and allows exclusion of a differential diagnosis (13, 14). In our study, EMG was not always performed, but it was helpful in 73% of cases when performed.

Doppler US is a non-invasive technique that allows differentiation between venous thrombosis and spasm in patients with venous symptoms, demonstration of a collateral circulation, and detection of arterial abnormalities, plaque or embolic genic aneurysm. US is easy to perform and its sensitivity is higher for patients with more pronounced clinical findings (15, 16), especially with the help of the Adson maneuver (arm abduction and retropulsion, hand behind neck, contralateral head rotation and deep inspiration) that mobilizes the thoracic outlet. Dynamic maneuvers may also be performed, preferably those reproducing the symptoms, at the time of scanning to demonstrate variations in vascular flow. A gradual decrease in arterial flow to complete absence of flow indicates compression of the subclavian artery. Dynamic arterial occlusion is abnormal when occurring at low to moderate amplitude movements. Dynamic arterial occlusion in hyperabduction may be physiologic and occur in 30-50% of normal subjects (17). This technique is operator dependent and requires a certain degree of expertise along with excellent knowledge of the underlying pathology, with reported sensitivity and specificity values of 84% and 89% in the literature (18). Even though US does not allow optimal evaluation of all regional anatomical structures, it can easily complement physical examination as a first line imaging study. In our study, Doppler US was performed in only 7 patients. Early on, the surgical team requested Doppler US in all patients. However, because of the discordance between results from US and combined clinical findings and dynamic maneuvers, angiography with dynamic maneuvers and sitting acquisition soon replaced Doppler US as a complementary evaluation in the work-up of patients with thoracic outlet syndrome. Other centers propose CT or MRI evaluation in all patients. This work-up is justified since surgery is invasive and surgeons require the most sensitive imaging studies available to confirm the diagnosis. The situation is similar to patients with carotid artery stenosis where the surgeon frequently requires CTA or MRA confirmation after US prior to surgical management. MRI and CT evaluation allow excellent delineation of the site and cause of symptoms and functional anatomy of the thoracic outlet while enabling acquisition of excellent angiographic images. These are usually second line imaging techniques, even though their indications are increasing. Images with the arm extended along the side of the body and elevated must be acquired. CT allows multiplanar reconstructions (MPR) and angiography with the help of iodinated contrast material injected intravenously in the arm opposite the symptomatic side (19). Sagittal reformatted images are useful to evaluate the arteries and detect the presence of post-stenotic aneurysmal dilatation. In addition, CT is optimal for bone evaluation and may provide imaging guidance for procedures in patients with radicular compression (20). Radiation exposure is reduced by the use of several techniques (tube current modulation for example) while maintaining excellent image quality (21). MRI provides improved evaluation of soft tissues, especially the brachial plexus, fibrous bands and muscle anomalies with the help of sagittal and coronal TIW acquisitions (22, 23). Time of flight or contrast material enhanced angiographic acquisitions complete the MRI evaluation (24). A limitation to MR remains the longer duration of the examination. A pitfall for both CT and MRI is the supine acquisition and impaired ability to perform dynamic maneuvers due to bore diameter (23). Supine acquisitions may lead to an increase in the rate of false negative results (23) with reduced sensitivity compared to US (22, 24). Nonetheless, the availability of open MR scanners could address some of these pitfalls.

Venography is excellent in the evaluation of patients with venous symptoms because of its high sensitivity (93% in our series) and ease of performing dynamic maneuvers. On the other hand, it cannot characterize the nature of the compression. In addition, venous compression has been described in asymptomatic patients, requiring that results be interpreted with caution (22).

In our series, 91% of patients who underwent angiography in the sitting position showed worsening of stenosis (87% with very significant stenosis). In addition, 8 patients (24%) with stenosis had negative angiograms in the supine position, illustrating the improved sensitivity of the sitting acquisition. Angiography is not routinely performed in patients with thoracic outlet syndrome without specific vascular symptoms, and it should preferably be performed in patients with obvious arterial involvement such as aneurysm or occlusion (19). However, angiography may be helpful in patients with negative results at non-invasive imaging and positive clinical findings or when the surgical team requires confirmation of findings by this sensitive examination prior to invasive surgery. The acquisition of angiography in the sitting position was proposed based on the results of angiography in the supine position. Results from supine angiography were well below those obtained at clinical examination in the sitting position with dynamic maneuvers. Because the only difference was the sitting position, angiography in the sitting position with use of similar maneuvers was attempted. The variation in the degree of stenosis between supine and sitting positions on angiography and other imaging studies (US for example) suggests that gravity during arm abduction in the sitting position plays a substantial role in the pathophysiology of arterial stenosis. As...
such, the weight of the shoulder presumably contributes to compression of the neurovascular bundle at the thoracic outlet. Nonetheless, angiography is not without limitations. Angiography does not allow diagnosis of the cause of compression, a fact that probably is of little clinical significance since it does not affect surgical management of patients with positive clinical findings. Angiography is invasive, exposes patients to ionizing radiation, and requires the administration of iodinated contrast material. In addition, the potential morbidity of angiography in the sitting position using a transfemoral approach and the Seldinger technique is probably superior to that of angiography in the supine position. Finally, it should be noted that 10 patients (18%) referred for unilateral symptoms had bilateral positive findings on angiogram. Nine (16%) of these patients presented with contralateral recurrence of symptoms between 6 months and 5 years after surgery. This result does not raise questions about the role of angiography because, in our study, the goal was not to demonstrate the presence of positional arterial variations at the thoracic outlet (the prevalence of positive results at invasive positional examination in the general asymptomatic population is unknown) but to identify symptomatic patients that would benefit from surgery. These are biases in our study, typical of retrospective studies, but also patient selection biases, since all underwent surgery.

Conclusion

Angiography, in patients with thoracic outlet syndrome, allows demonstration of intrinsic lesions responsible for symptoms, which is important in the presurgical period, with the use of dynamic maneuvers and acquisitions in the sitting position that increase the sensitivity of the examination, as shown by our results. Angiography is more sensitive than Doppler US and other cross-sectional imaging modalities (CT or MRI) to demonstrate some vascular abnormalities though the latter allow improved evaluation of the regional anatomy of the thoracic outlet. However, the purpose of our study was not to promote angiography in the routine work-up of patients with thoracic outlet syndrome. Angiography is indicated in patients with diagnostic difficulties unresolvable by non-invasive imaging modalities. It is reasonable to propose that all patients with possible thoracic outlet syndrome first undergo clinical evaluation with dynamic maneuvers performed in the sitting position, complemented by Doppler US and thoracic spine radiographs. If US and radiographs are sufficient and the surgeon does not require additional imaging because of the correlation with clinical findings, surgical management could then be entertained. If US is negative (discordant with clinical findings) and/or the surgeon wishes to obtain additional imaging to determine the site and cause of symptoms, visualize the functional anatomy of the thoracic outlet syndrome to finally ascertain the indication for surgical management, CT or MRI including angiography would be performed. If CTA or MRA examinations are negative and the clinical suspicion remains, angiography with dynamic maneuvers in the sitting position should then be performed.

References